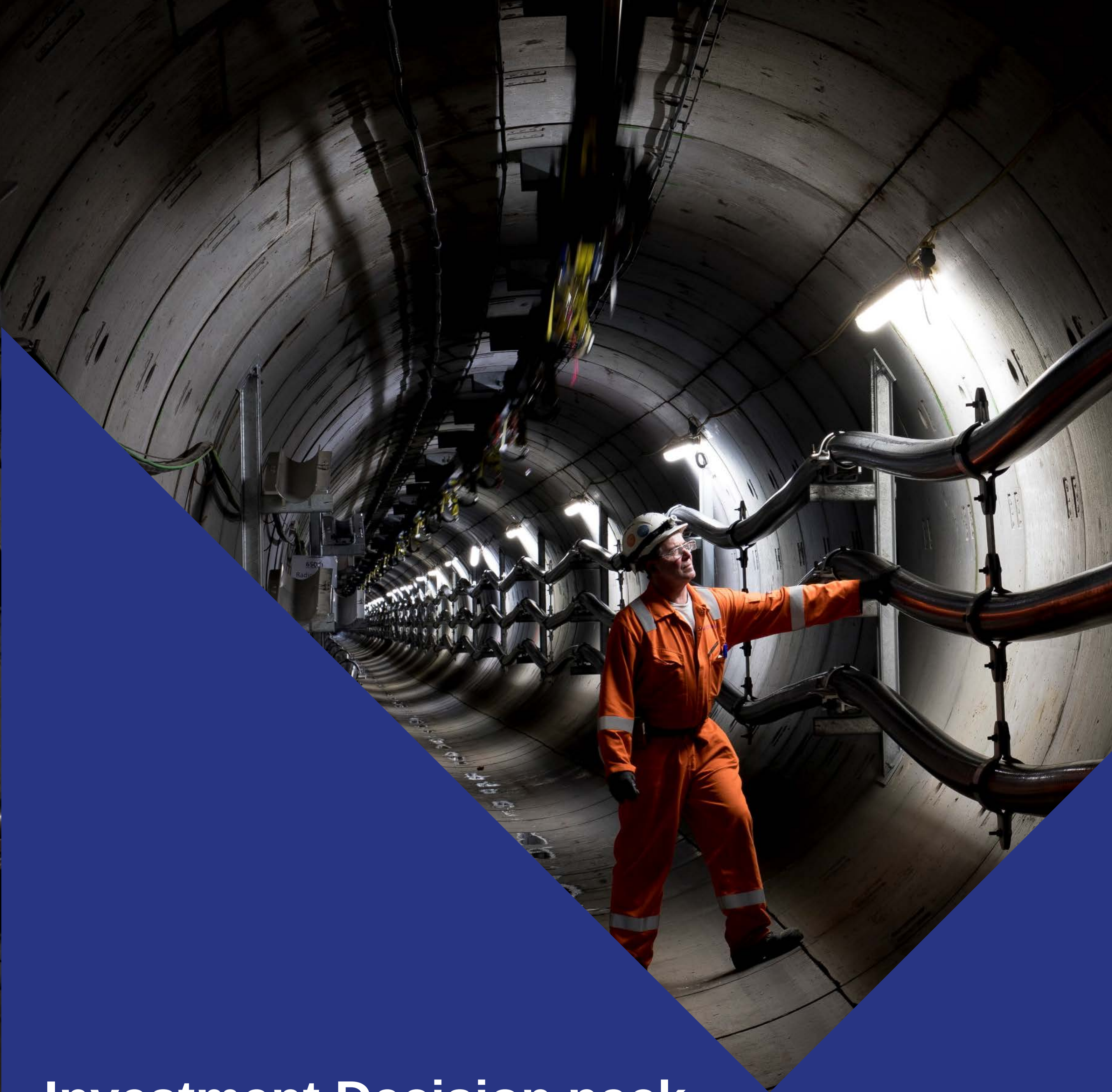

Investment Decision pack NGET_A9.19 – London Power Tunnels Phase 2 December 2019

As a part of the NGET Business Plan Submission

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Engineering Justification Paper; Non-Load Related London Power Tunnels 2				
Name of Scheme	London Power Tunnels 2			
Primary Investment Driver	Asset Health/Environmental			
Reference	A9.19			
Output Asset Types	Non-Load Asset Replacements Cables			
Cost	£852m (2018/19 Price Base)			
Delivery Year(s)	RIIO-T2 • Circuit 1: Wimbledon to New Cross – 2025, £345.5m • Circuit 2: New Cross to Hurst – 2026, £413.2m • Circuit 3: Hurst to Littlebrook – 2024, £93.2m			
Reporting Table	C2.2A			
Outputs included in RIIO T1 Business Plan	Yes LPT2 was included in the RIIO-T1 proposals and is part funded across the Switchgear, Transformer, Cables, and Tunnels non-load asset categories. Elements of the T1 spend proposals were deferred during T1 and details of this are covered in the report narrative.			
Spend Apportionment	**Pre T1**	**T1**	**T2**	**T3+**
	£13.6m	**£162.7m**	**£645.8m**	**£29.9m**

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Table of Abbreviations

Abbreviation:	Prose:
ACL	Available for Commercial Load
BENR	Bengeworth Road Substation
CBA	Cost Benefit Analysis
CPO	Compulsory Purchase Order
DCO	Development Consent Order
DoRM	Division of Responsibility Matrix
EoL	End of Life
ESO	Electricity System Operator
ETIC	Electricity Transmission Investment Committee
FES	Future Energy Scenarios
FIDIC	The International Federation of Consulting Engineers
GBR	Ground Baseline Report
GFR	Generic Family Reliability
GIS	Gas Insulated Switchgear
GSP	Grid Supply Point
HURS	Hurst Substation
ICG	Infrastructure Client Group
iCHEME	Institute of Chemical Engineers
JCOP	Joint Code of Practice
LITT	Littlebrook Substation
LoS	Line of Sight
LPT	London Power Tunnels
NARM	Network Assessment Risk Methodology
NEC	New Engineering Contract
NEWX	New Cross Substation
ECC	Engineering and Construction Contract
NPV	Net Present Value
OHL	Overhead Line
P13	Project 13
PMO	Project Management Office
PROIL	Pro-Rata Oil Leaves
SGT	Super Grid Transformer
SQSS	Security and Quality of Supply Standard
WHAM	West Ham Substation
WIMB	Wimbledon Substation
XLPE	Crosslinked polyethylene

1.0 Executive Summary

London Power Tunnels Phase 2 (LPT2) is a non-load related cable replacement project in South London, between Wimbledon, New Cross, Hurst and Littlebrook substations.

The LPT2 programme spans RIIO-T1, T2 and T3, and will deliver a total of 6 new circuits to the value of £852m (in 2018/19 prices). The RIIO-T2 spend is £645.8m and includes delivery of a majority of the LPT2 works, including the commissioning of 2 out of 3 twin circuits, within the RIIO-T2 period.

The project replaces assets at the end of their anticipated asset life cycle and so removes risk from the system to maintain an overall secure system. 275kV oil-filled cables, which are now obsolete, are replaced with 400kV & 275kV XLPE cable circuits housed in a deep-bore cable tunnels. The project also includes the associated substation works.

Commissioning of the new circuits will be phased from 2024 with works completing in 2028. The offline solution ensures the overall deliverability of critical assets in an acceptable timeframe. This also minimises system risk during construction.

National Grid has worked closely with UKPN to ensure the solution not only delivers a secure Transmission system, but also provides an option to meet Distribution requirements including asset replacement and growth. The project has been considered in the following context:

Investment Need: What are the key investment drivers and current scope?

The principle investment driver for LPT2 is an ongoing need for a transmission connection between Wimbledon, New Cross, Hurst and Littlebrook substations. The existing oil-filled cables connecting and supplying these substations were installed in 1967 and are reaching the end of their asset lives. The cables are suffering from tape corrosion, resulting in excessive oil leaks and cable faults, and have now been assigned as the highest priority cable circuits for intervention. The three key decision drivers for replacing the existing circuits are: 1) deteriorating asset health; 2) the unacceptable level of risk from the ‘do nothing’ option; and 3) projected growth in demand for the London region. System design studies have confirmed there is a continuing need for a transmission network in this area. This is to maintain ongoing compliance with the Security and Quality of Supply Standards, which is a standard licence condition. This transmission route is critical for securing demand at these substations and the local distribution network (724MW at peak in 2018/19). It also provides an important route through the London network for flows to and from the south east and to and from the south coast.

Optioneering: What process was implemented to select the preferred solution and are future variances anticipated?

For each system solution identified, varying construction techniques (i.e. cable tunnel; direct buried underground cables; overhead lines) were analysed together with the cost and risk associated with the routes. This determined the construction of a tunnel to house new circuits as the only viable solution. After considering the feasibility of a wide set of solutions, two main options were identified. These options connect New Cross substation to either 1) Wimbledon substation or 2) West Ham substation. The direct replacement of the New Cross to Hurst and Hurst to Littlebrook cable circuits is common to both solutions. A Cost Benefit Analysis using a Net Present Value (NPV) methodology considered these two system and tunnel routing options to achieve system risk reduction. The connection to Wimbledon (option 1) is the preferred option as it offered the lowest capital cost (£838m vs. £866m at the time of analysis) and the best net present value (£709m vs. £714m). Furthermore, it is the least risky route in terms of a feasible solution, option 2 involves a tunnel underneath London’s Canary Wharf and many high-rise structures with deep piled foundations.

Innovation through the development process drawing on lessons from the tunnel industry and LPT1 has seen savings on the programme of over £50m across civil, mechanical and electrical work packages.

A new Grid Supply Point (GSP) at Bengeworth Road is considered a possible variant to the preferred solution, creating options 1a) and 2a). This variant is subject to an ongoing connection request from UKPN, thus it is out of firm scope at present, subject to final agreement with UKPN. A solution including Bengeworth Road provides optimal value for consumers and addresses the needs of both Transmission and Distribution networks in terms of; asset replacement, demand capacity and diversity of supply within South London at lowest cost. These works would be funded by customer connection and demand charges, and the associated costs are therefore not included in this submission.

Delivery Strategy: What is the current project status?

Following extensive early engagement with the market, spot procurement processes are underway for four of five key work packages, with tendering and negotiations continuing into 2020. The Tunnels Contract, which represents over half the capital investment, is expected to be awarded by the end of 2019. National Grid will award 5 common NEC4 Contracts (using Options C 'target cost' and A 'lump sum'). We will use a special condition X12 as a collaboration clause, and a division of responsibilities schedule, to ensure common understanding across all contract partners, a key lesson learnt from LPT1. We will form an Enterprise with key contractors, managing the works and interfaces as an integrator, following the Project 13 principles created by the Infrastructure Client Group (ICG). The ICG was established under Institute of Civil Engineers guidance. The Group helps to support the implementation of the Government's Infrastructure Cost Review Report 2010. This delivery approach has been chosen following learnings from other major infrastructure projects and aligns with feedback from our market engagement. The Enterprise will incentivise cross-package collaboration delivering a common focus on achieving the project outcomes.

To secure the 165 below ground easements and land rights associated with the programme, Compulsory Purchase Orders (CPOs) have been submitted for two of the three circuits and the third will be issued late in 2019. Above ground land rights have now all been secured or at heads of terms stage. Five planning approvals have been received of the six required. The final planning approval is under consideration with Bexley Borough Council before Christmas 2019. Enabling works have started at New Cross as part of wider ground investigation works which has also included deep boreholes to inform our tunnelling contracts and tunnel design as to the ground conditions that can be reasonably anticipated. Key risks to the project include challenging ground conditions in South London, consents and approvals from third parties and the uncertainties for both National Grid and our supply chain around Brexit.

Conclusion: LPT2 delivers best value to end consumers, considers the requirements of both distribution and transmission networks and will successfully re-wire South London, removing significant risk on the network. The cost estimation and delivery strategy has been developed using market engagement and industry best practice. The programme seeks to establish a collaborative and innovative approach focussed on rewarding delivery of key outcomes. Following lessons learnt from recent National Grid projects, there has been extensive engagement with Ofgem on the LPT2 programme to date on the needs case and delivery programm

2.0 Baseline Assumptions

This report is based on a number of assumptions:

- Costs are in 2018/19 price base unless otherwise specified.
- A new GSP at Bengeworth Road has been considered in the optioneering process but will not be included in the firm project scope until the connection agreement is agreed early 2020.
- Total project costs do not include consideration of either the Bengeworth Road GSP unless specifically stated.
- Total project costs do not account for ongoing maintenance of the existing cables.
- Project costs to not account for decommissioning of the existing circuits.
- The current programme sees the LPT2 circuits commissioned from 2024 to 2028, Available for Commercial Load (ACL) programme dates of 2024 (Circuit 3) and 2025 (Circuit 1) are stretch target dates and are aspirational at this stage; the justification of such stretch targets is discussed in Section 10.

3.0 Background Information

LPT2 is the second phase of a major asset replacement project within London and follows the successful delivery of National Grid's London Power Tunnels Phase 1 (LPT1) constructed between 2010 and 2018. LPT1 delivered ten new 400kV circuits across north London in 32km of 3 and 4m diameter tunnels between existing substations at Wimbledon, Willesden and Hackney. The last asset was fully commissioned in 2018.

Phase 2 (LPT2) will deliver three circuits (operating at 275 and 400kV) across south London in 32km of 3 & 3.5m diameter tunnel accommodating twin cable circuits across south London (from Wimbledon to New Cross and on to Littlebrook via Hurst). LPT2 will meet LPT1 at Wimbledon substation connecting into the existing LPT1 shaft.

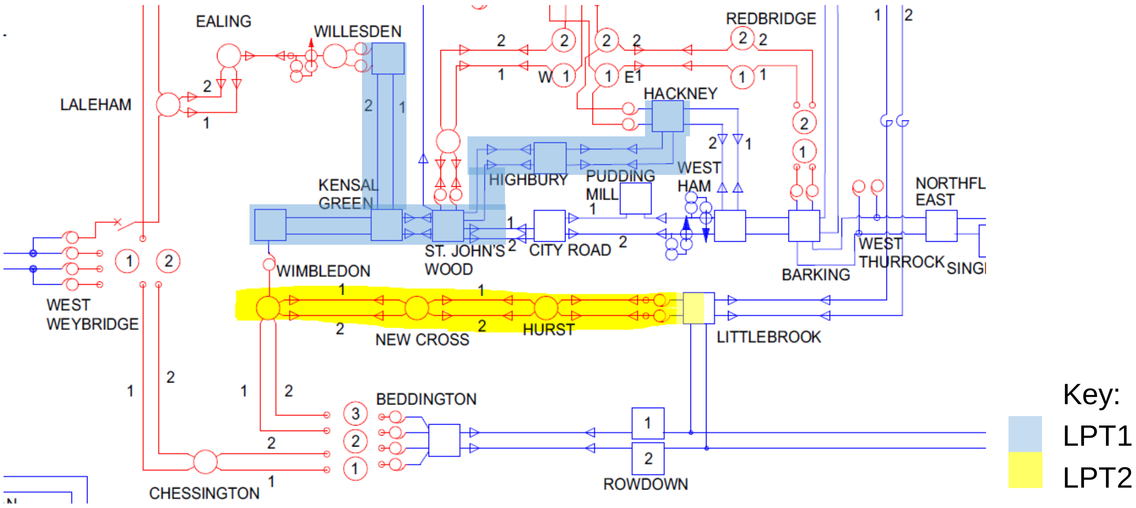


Figure 1 – London Transmission Network

The project is funded across the Switchgear, Transformer, Cables & Tunnels non-load asset categories, ultimately delivering the replacement of the following circuits:

Table 1 – LPT2 circuits for delivery in RIIO-T2 and beyond

Asset Type	Asset Sub-Type	Asset Designation	Length. For Intervention (km)	Age	Planned Replacement Year
Oil-filled Cables	Circuit 1	NEWX – WIMB 1	13.5	52	2025 (Stretch*)
		NEWX – WIMB 2	13.5	52	2025 (Stretch*)
	Circuit 2	HURS – NEWX 1	21	52	2028
		HURS – NEWX 2	21.2	52	2028
	Circuit 3	HURS – LITT 1	2.6	52	2024 (Stretch*)
		HURS – LITT 2	2.6	52	2024 (Stretch*)

**for further discussion of stretch targets see Section 9*

3.1 Ofgem Engagement

Throughout the LPT2 programme we have engaged frequently with Ofgem. This engagement is summarised in the schematic below and described in the below timeline:

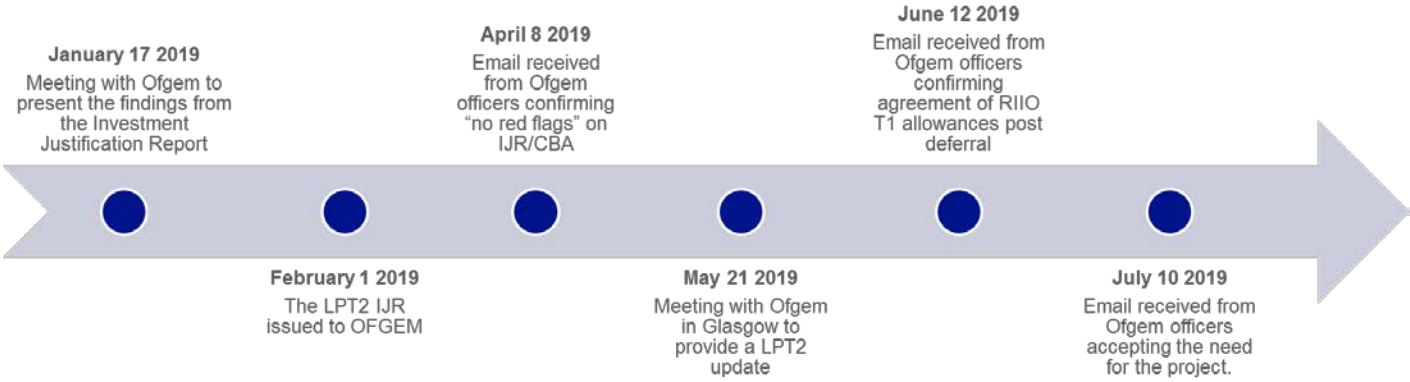


Figure 2 – Timetable of Engagement with Ofgem

The project team have engaged with Ofgem throughout the development and initial delivery of LPT2. Submitting an investment justification report in February 2019 and providing updates on the procurement strategies and decisions taken in May.

In June agreement was reached with Ofgem as to how £166m of the LPT2 allowances should be deferred from the RIIO-T1 to T2 period. For cables and tunnels RIIO-T1 allowances contained £276m (in 2009/10 prices) and a forecast further £410m (in 2009/10 prices) for RIIO-T2. The revised allowances for cables and tunnel was £110m in RIIO-T1 and £576m in RIIO-T2. The decision to reprofile LPT1 between RIIO-T1 and RIIO-T2 was taken to ensure sufficient time to develop a robust programme of works, reformulate the procurement strategy and secure the majority of the land rights and consents, progressing the Compulsory Purchase Order(s), ahead of entering into contract. This reflects the learning gained from the successful completion and review of LPT1 project. The latest forecast of RIIO-T1 spend is £162.7m (in 2018/19 prices) which mainly consists of Development, Land, Enabling Works and Tunnels and Shafts Contractor spend. The overall forecast cost for the project has reduced by 13% (£127m in 2018/19 prices), reflecting embedded RIIO-T1 innovations, changes to ways of working across all our functions, and learning from major projects such as LPT1.

4.0 Needs Case

The decision to replace the existing cables was based on a number of factors. In particular, the three key decision drivers were:

- Deteriorating asset health;
- Unacceptable levels of risk from the 'do nothing' option; and
- Projected growth in demand for the London region.

The needs case presented here effectively summarises the extensive engagement undertaken with Ofgem over the period 2018 – 2019 during which Ofgem accepted the needs case for the LPT2 programme (documented in Appendix 1). The need was also accepted in setting the original T1 allowances and forecast future spend in RIIO-T2.

4.1 Investment Need

Feedback from our programme of stakeholder engagement we have undertaken to build or RIIO T2 Plan indicates that consumers and customers want us to maintain network risk at current levels. If we do not intervene on these assets in RIIO-T2, network (or asset) risk will rise, which could increase Energy Not Supplied for consumers. The rate at which this risk rises, informs the volumes required to be replaced in any given period. Risk is informed by the probability of failure (PoF) and the consequences of failure (CoF), as set out in the Network Asset Risk Metric (NARM).

The section below sets out the need for undertaking the plan intervention strategy for LPT2 Wimbledon-New Cross-Hurst-Littlebrook cable circuits in RIIO T2 to maintain network risk.

4.2 Cable Circuits

The existing Wimbledon-New Cross-Hurst-Littlebrook circuits form the sole transmission supply to the New Cross and Hurst Grid Supply Points (GSPs), supporting a peak demand of 724MW and providing system interconnection between East and West London.

At New Cross, there are both 132kV and 66kV substations which supply UK Power Networks (UKPN) distribution network as well as traction supplies for Network Rail. Hurst 275kV substation feeds the UKPN distribution network at Eltham 132kV and Bromley 33kV. Strategic development plans forecast that demand will increase London (e.g. due to electrical vehicles uptake, bus fleet electrification and electrification of heat). Current peak demand fed from Wimbledon, New Cross and Hurst GSPs is given within table 2 below.

Table 2 – Summary of Peak Demand on LPT2 circuits

Circuit	2017/18 Peak Demand (MW)
Wimbledon South	601
New Cross (132kV & 66kV)	427
Wimbledon North and Bengeworth Road	260
Hurst (including Eltham)	297

The existing cables were originally commissioned in 1967 with an anticipated asset life of 45 years. The circuits were identified in the RIIO-T1 business plan for development within the T1 period owing to the long lead times associated with cables and tunnels. The decline in condition of these circuits in recent years serves to validate the earlier planning decision.

In the last 10 years, the Wimbledon-New Cross-Hurst-Littlebrook circuits have had a high number of repairs and defects when compared with other circuits on the network. The circuits are known to be prone to tape corrosion. The use of Perfluorocarbon Tracing has enabled the retention of these circuits and enable defects to be managed, extending their asset life. However, the condition of the cable circuits is continuing to decline. The primary concerns for these routes are to the security of supply and the environmental consequences of a loss of oil containment; particularly where the cable crosses aquifers. A summary of the known route condition issues is outlined below:

- In November 2018, a loss of water pressure occurred in the cooling system on the Hurst-Littlebrook cable circuits. An additional fault would have placed significant volumes of demand at risk in Central London.
- The Hurst- New Cross circuit has suffered multiple oil losses in the last 10 years. The increase in leaks in the most recent years reveals that the cable cannot continue to run indefinitely.
- Collectively (Circuits 1,2 & 3) have leaked in excess of 15,000 litres of oil during the last 10 years.

Failure to maintain reliable transmission connections between the substations in south London increases the likelihood of concurrent failure events occurring which, at worst case, could lead to a repeat of the loss of supply seen in the 2003 blackout. This was the result of a combination of events: the need to disconnect a transformer at Hurst following a fault and the automatic protection relay disconnecting the Wimbledon – New Cross circuit. These events, in parallel with a planned outage at Wimbledon, resulted in the loss of supply. This underlines the need to ensure reliable transmission connection in south London.

4.3 Approach to Establishing Intervention Need

We assess the need for intervention on an asset-by-asset basis. The decision to replace these cable circuits was based on a number of factors, the three key decision drivers were:

- Asset Condition, leading to an increasing probability of failure;
- Unacceptable levels of risk from the 'do nothing' option; and
- Forecast growth in demand for London.

The key asset condition considerations feeding into our assessment are set out below.

4.3.1 Overview of Methodology

To identify and prioritise assets in need of intervention we apply an assessment of failure *likelihood* and then the impact that any failure may have on the electricity system, the safety of people and the environment. This impact is described as the *criticality* or *consequence* of an asset, should it fail in service. Failure likelihood may simply be expressed as a probability up to 100% (or 1). This scoring system, which places assets into discrete bands of '1' to '4' was used for all lead assets in RIIO-T1. It was combined in a matrix with an asset criticality score, again banded from 1 to 4 to arrive at 'Replacement Priorities'. The management of the volumes of assets in each replacement priority band was the basis for the capital plan submitted for RIIO-T1 and one of the Network Output Measures in Special Licence Condition 2C.

The new approach developed for lead assets is the Network Asset Risk Metric (NARM). This achieves a greater level of maturity than the health and criticality approach that preceded it. It does this in several ways:

1. A probability of failure (PoF) for each asset provides a greater resolution of asset risk of failure. The low number of discrete bands employed by the criticality approach produces a lower resolution measure and doesn't allow for prioritisation within those bands.
2. By monetising the consequences of asset failures, it is possible to measure whole network risk and enable decision making between different asset classes. The criticality approach does not define a monetised impact of this risk and there is no equivalency between asset types (e.g. several transformers in Replacement Priority '1' is equal to some volume of overhead line

conductor in the same or different replacement priority bands). This prevents any network-wide measure of risk and prioritisation between asset classes.

Our approach is summarised in the Table 3:

Table 3 – Summary of NARMs approach for identifying interventions

Principle	Likelihood of Asset Failure	Consequence of Asset Failure	Risk is a function of Likelihood of an event and its consequence
Monetised Risk	Each asset has a probability of failure. This probability is arrived at by use of an 'End of Life Modifier'. This is a score that maps an asset to a place on a probability of failure plot, specific to each asset class.	For each asset failure event, there may be safety, system and environmental consequences-these are monetised.	The probability of failure of an asset multiplied by the probability of an event with a monetised consequence produces the monetised risk of asset failure. The monetised risk of asset failure can be aggregated to give us a whole network measure of risk and allows us to make prioritisation decisions between different assets.

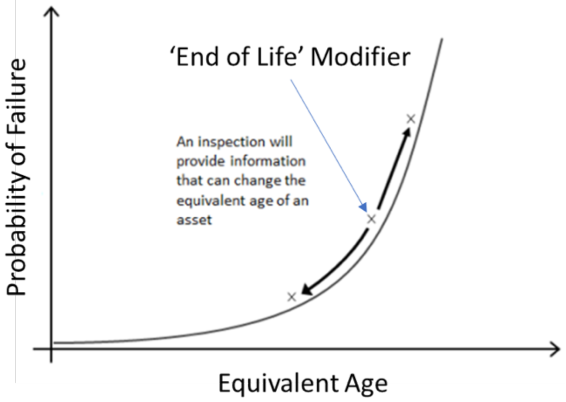


Figure 3 – End of Life Modifier Principle

Figure 3 illustrates the principle of the End of Life Modifier. The rise in monetised risk is governed by an asset's probability of failure plot, the magnitude of the risk at any given point in time is a function of the probability of failure (variable) and the probability of an event with a monetised consequence (fixed).

Our monetised risk calculations are underpinned by detailed condition information for our assets.

4.3.2 Approach for LPT2 Circuits

The key factors considered when determining the need to replace cables are the asset age, the risks associated with known failure modes, historical performance, environmental and safety factors, and forensic evidence.

Cables are typically made up of a small number of high-value assets with high criticality and location-specific installation and environmental concerns. These cable circuits are one such route, heavily affected by tape corrosion and geological conditions. Optimal replacement of these assets requires careful consideration of aspects such as replacement timescales and deliverability in addition to the more technical considerations around asset condition and performance.

Condition and fault data are used to generate an End of Life (EOL) modifier score between 0 and 100 which is related to the probability of failure (PoF). The probability of failure is combined with the consequence of failure (expressed in £) to give a risk score (also expressed in £) for each asset. The sum of all these asset risks is equal to the network risk associated with the end of life failure modes. These existing cable circuits were originally commissioned in 1967 and 5 out of 6 of these have an EoL score of 100.

4.4 Cable Monetised Risk During RIIO-T2

Stakeholders want us to maintain the current level of risk across our network. The assets detailed in this report directly influence the reliability and security of supply of the network. If no action is taken on these cables there would be an increased risk of condition related failure potentially leading to an energy not supplied event.

Figure 4 shows how non-intervention on underground cables in T2 increases network risk.

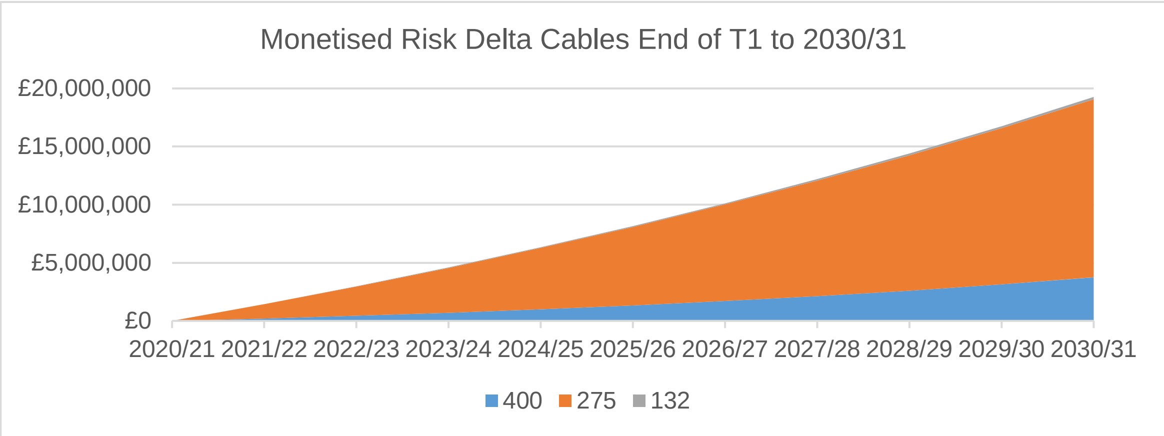


Figure 4 – Monetised Risk position for underground cables with no T2 Interventions

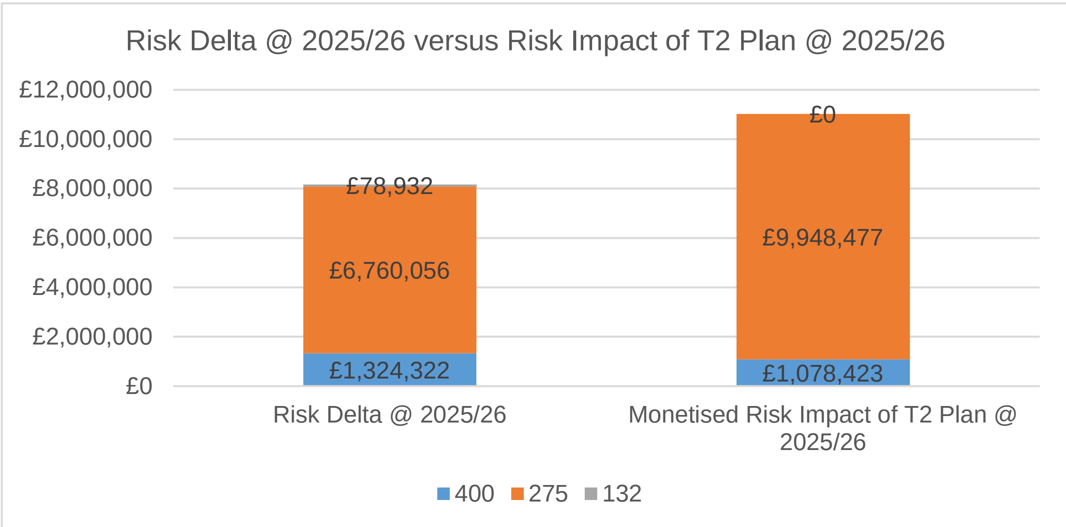


Figure 5 – Monetised Risk position for cables planned in T2

Figure 5 above shows that the monetised risk impact of our RIIO-T2 plan will reduce residual network risk below the RIIO-T1 close out position by £2m. This is expected, given the significant impact a small number of interventions will have on a relatively small volume of large assets. LPT2 cables circuits deliver an £8.3m risk reduction against an overall risk delta of £8.2m Table 4 below.

Table 4 – Monetised Risk Values for Circuits 1 and 3

Circuit*	Overall EoL Score	PoF at End of T2 (2025)	CoF (£)	End of Life Monetised Risk at Start of T2 (£)	End of Life Monetised Risk at End of T2 (£)
Wimbledon – New Cross 1	100	0.13042	26,994,942	2,820,201	3,520,763
Wimbledon – New Cross 2	100	0.13042	26,994,942	2,820,201	3,520,763
Hurst - Littlebrook 1	100	0.10447	5,262,942	549,827	686,409
Hurst - Littlebrook 2	90	0.08408	5,39,6942	453,769	576,984

**As Circuit 2 (Hurst to New Cross) is due to be completed in the T3 period it has not been included here.*

Without intervention, the monetised risk position of Wimbledon - New Cross and Littlebrook - Hurst will increase by £1.66m over the RIIO T2 period. To maintain a stable monetised risk position over the RIIO T2 period these circuits need to be replaced as they hold a high monetised risk position alongside the New Cross - Hurst circuit (planned for RIIO T3 delivery) in the cables portfolio.

4.3 Demand Growth

The UK's energy system is undergoing an unprecedented period of change as both the energy system, and the economy more widely, decarbonise to meet Net Zero legislation. While there is currently some uncertainty regarding the rate of electricity demand growth, all four of the National Grid ESO Future Energy Scenarios (FES), indicate peak demand increase of at least 25GW by 2050 (from 60GW presently to 85GW). The impact on electricity transmission infrastructure to meet these future capacity increases will be influenced by the speed of adoption of emerging technologies, electric vehicles, battery storage increases in distributed and renewable generation capacity and changes in energy usage including electrification of heat.

Greater London Authority issued the draft New London Plan in December 2017, which has recently been consulted upon. This outlines long-term vision for London until 2041 covering steady growth and key aspects such as jobs, housing, transport and communities.

Impacts on infrastructure will include:

- Population growth to 10.8 million in 2041, increase of approximately 70,000 people per year
- Construction of 66,000 new homes per year
- Smart solutions and promoting energy efficiency
- Decarbonisation of transport:
  - 8 out of 10 journeys within City to be via walking, cycling or public transport
  - Decarbonising and capacity increase of public transport
  - Decarbonised freight
  - Electric vehicles (although perceived need for fast-charging out of town)

Growth of such scale will require consideration of headroom/additional capacity of cable systems to accommodate future demand increase. To meet this future requirement 400kV cables will be installed and operated at 275kV on two sections of the route until the need to operate at maximum capacity (400kV) arises as a result of increased demand. This avoids early retirement of lower rated cables (275kV) before their full economic life has been met when demand surpasses the system capacity.

In the case of LPT2, it is important to also consider the requirements of the DNO (UKPN) and its expectations for the growth in demand at a distribution level. Table 5 below gives the Week 24 UKPN demand forecast figures for the LPT2 sites.

Table 5 – UKPN Week 24 Demand Forecast for LPT2 GSPs

Site	**Forecast Winter Peak Demand (MW)**						
Year	2020	2021	2022	2023	2024	2025	2026
Bengeworth Road	0	0	0	0	0	0	228
New Cross	229	236	230	233	270	279	559
Wimbledon	1022	1034	1062	1027	1069	1106	650
Hurst	270	273	276	293	298	303	309
Littlebrook	139	141	143	139	142	145	149

The demand growth expected in the New London Plan is shown in these UKPN figures. It can also be seen that the inclusion of Bengeworth Road in 2026, as well as the commissioning of LPT2 Circuits, sees New Cross and Bengeworth Road take some of the demand from Wimbledon.

The preferred solution must provide both the transmission and distribution networks with a satisfactory level of capability and security to continue the reliable supply of electricity, considering short to medium term network requirements (i.e. demand growth based on the Electricity Ten Year Statement).

4.4 Needs Case Summary

Indefinite extension of the current assets is clearly not viable. At the most recent asset health challenge and review, 5 of 6 existing assets under the remit of LPT2 were classified against the highest asset replacement priority due to their already extended operable life and declining asset health. The EoL equation applied in the review process reflects the accumulated knowledge of defects, oil leaks, and circuit availability statistics. These circuits jointly hold the highest monetised risk potion in the cables portfolio. These factors, along with projected future levels of demand indicate the immediate need to replace the circuits.

5.0 Optioneering Considerations

The existing circuits are approaching obsolescence. A range of asset replacement options have been explored and shortlisted to fulfil the investment drivers identified in Section 4 and summarised below:

- Asset Health: the need to replace assets at end of life;
- Asset Risk: the need to reduce network risk by replacing circuits;
- Demand Growth: the need to uprate circuit one to 400kV to facilitate network demand growth and increased system flows.

Five design considerations were examined to establish viable solutions:

1. Transmission System Requirements
2. 400kV Design Strategy
3. Cable Technology
4. Replacement Methodology
5. DNO Coordination

The analysis is summarised below. Further detail on the decisions outlined in this section can be found in Appendix 3A-3J.

5.1 Transmission System Requirements

The existing Wimbledon-New Cross-Hurst-Littlebrook route and associated circuit lengths are given in Figure 6 below, alongside a geographical map of south London, Figure 7, showing existing GSP substations.

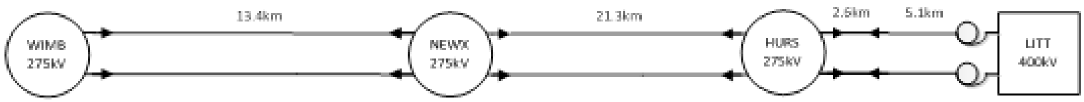
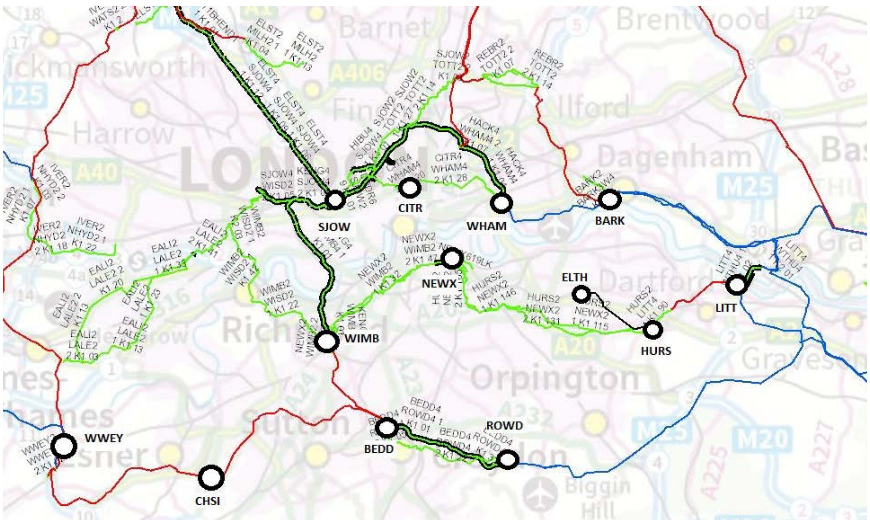


Figure 6 – Existing Circuit Route and Lengths



Key:

	400kv or 275kv voltage cable route	SJOW, CITR, WHAM, BARK and WIMB, LITT are 400kV substations
	400kv voltage OHL route	NEWX and HURS are 275kV substations
	275kv voltage OHL route	ELTH is a 132kV substation
	132kv voltage OHL route	

Figure 7 – Map of Existing Circuits to be replaced by LPT2

The Wimbledon-New Cross, New Cross-Hurst, Hurst-Littlebrook circuits provide the only transmission connections to the GSPs at New Cross and Hurst, and therefore, to continue to supply consumers within Central and South London, it is essential for the solution to maintain connections to these sites in some form.

Removing connections to any of these GSPs would reduce network resilience and require unprecedented levels of reinforcement on the distribution networks. The circuits are essential in providing a continuous through route and provide an extra flow path both into and out of London.

Consideration was given to remove the South London through route. However, in order to maintain SQSS compliance in that scenario, a third radial circuit would need to be installed between New Cross and Littlebrook. This would require a separate route or physical separation applied to avoid a loss of supply for a single event within the tunnel (i.e. fire within tunnel). The construction of a third circuit required to maintain SQSS compliance would be significantly more expensive than a like-for-like replacement of the existing circuit route, and thus has been discounted. Additionally, this continuous through route will be essential in the future, with the construction of Eleclink, NEMO and other new interconnectors, to avoid overloading existing circuit route corridors.

At the eastern end of the circuit route, alternative system routes to connect circuits to Hurst substation included consideration of both Littlebrook 400 and 275kV substations and the Longfield Tee-Rowdown circuit. The cost associated with connecting to the Longfield Tee-Rowdown circuit were prohibitively higher and led to the conclusion that the optimal solution should remain a connection to Hurst via Littlebrook.

Considering the western end of the existing circuit route, the connection of New Cross to the wider network presents several options with West Ham, City Road, St John's Wood and Wimbledon existing in close proximity. City Road is located in central London, underground space constraints limit the potential for the creation of new assets without prohibitive further investment and the compulsory purchase of land. Establishing new circuits into St John's Wood would also result in fault level complications and result in transmission system security dependence on a single site.

Following consideration of all available options, the transmission requirements were concluded to be best met by a routing solution that maintains the continuous South London through route, connecting Littlebrook via Hurst and New Cross via either Wimbledon or West Ham. These two were therefore taken forward in to more detailed optioneering.

5.2 Replacement Methodology

Three technology options are available for the construction and installation methodology for maintaining the through route by either of the two options as follows:

- New overhead line (OHL) route: an overhead line through South or Central London would not be feasible due to the densely populated urban landscape.
- Direct Burial: Stakeholder engagement and feasibility studies concluded that cable replacement by direct burial would cause unacceptable levels of disruption to road networks, as detailed in Appendix 3J, and have significant environmental implications. This methodology fails to achieve our programme and introduces significant delivery risk due to the number of existing third-party assets.
- Cable Tunnel: cable replacement by tunnel mitigates the risks identified above and provides many benefits both during installation and for the full asset life of the new circuit. For example, tunnel works require fewer above ground sites and the capability to carry out maintenance with less disruption to communities. Further details on these options are outlined in Appendix 3J- Replacement Methodology.

5.3 400kV Design Strategy

A like-for-like 275kV cable replacement would not offer sufficient headroom to accommodate prospective demand growth within London discussed in Section 4. To eliminate early asset retirement costs which would occur when these cables require uprating (after LPT2 the planned asset replacement circuit commissioning), the following two strategic issues were considered:

1. Cable Selection – Install 275kV cables and replace when uprating is required or Install 400kV cables, operate circuits 2 & 3 at 275kV until uprating occurs.
2. Circuit Voltage Rating – all circuits and equipment operate at 275 kV or all circuits and substation equipment are upgraded to 400 kV or upgrade Circuit 1 (cable and substation equipment) to 400kV and conduct substation equipment upgrades to 400kV for Circuits 2 & 3 when demand requires.

The details of the options, analysis and NPV data can be found in half of Appendix 3E.

5.3.1 Cable Selection Outcome

Install 400kV XLPE cables across all circuits & operate circuits 2 & 3 at 275kV until uprating occurs. (Increasing cost by approximately £5m in the immediate term, eliminating costs in the event of premature 275kV circuit removal/replacement)

To ensure the capability to uprate the Hurst-New Cross and Hurst-Littlebrook circuits to 400kV in the future, 400kV XLPE cable will be installed on all circuits at an additional cost of ~£5m. This will avoid the need to replace these cable assets in the future when an uprating is triggered. NPV analysis determines if these circuits require uprating and replaced at any point 40 years post-commissioning, this is the most economical solution as it will maintain system flexibility and avoid significant early asset right-off costs. Under winter loading, System Design studies indicate 400kV trigger year for Hurst –New Cross in 2036 and Hurst-Littlebrook in 2031.

5.3.2 Circuit Voltage Rating Outcome

Upgrade Wimbledon-New Cross (cable and substation equipment) to 400kV and conduct substation equipment upgrades to 400kV for Hurst-New Cross and Hurst-Littlebrook circuits when demand requires (Increasing cost by £9.5m in the immediate term, eliminating costs in the risk of premature circuit removal/retirement - anticipated 6 years post commissioning).

Due to reduced headroom on Wimbledon-New Cross, this circuit route will be installed and operated at 400kV with 2 x 400/275kV SGTs installed at New Cross. This option will require an additional investment of £9.5m compared to the prospective 275kV solution; however, provide sufficient headroom to accommodate future demand growth. NPV analysis determines economic efficiency if uprating is required 10 years post-commissioning. System forecasts based on projected demand growth, predict demand would exceeding existing circuit ratings 6 years post-commissioning of LPT2 if a 275kV option were pursued.

A 400kV solution on Wimbledon-New Cross also reduces technical complexity and programme risk as a 275kV cable connection relies upon completion of UKPN 132kV AIS decommissioning works and subsequent NGET Phase 2 works in the area, where the works are already delayed in excess of 2 years.

The options to uprate Hurst-New Cross and Hurst-Littlebrook circuits were also considered but were discounted due to the major investment required and complexities surrounding uprating Hurst and New Cross 275kV substations to 400kV and no immediate driver. So, whilst analysis indicates it is economic to uprate the cables, given the much-increased cost and risk involved it would not be economic to uprate the substations at this time.

Further detail of the analysis around these decisions can be found in Appendix 4.

5.4 Cable Technology

There are two viable cable technology choices which vary by their insulation medium; oil-filled (e.g. existing circuits) or Cross-Linked Polyethylene (XLPE). XLPE cables require less maintenance, with no ancillary fluid equipment to monitor and maintain. The absence of fluid in the cable insulation enables a more mechanically robust overall cable construction. Therefore, the XLPE cables will be used in the LPT2 Project, further detail can be found in Appendix 3I- Cable Technology.

5.5 DNO Works – Coordination with UKPN

During the development of LPT2, National Grid and UKPN have jointly assessed the need of both the Transmission and Distribution Network to ensure asset replacement plans are aligned and demand capacity issues within South London are resolved. This has resulted in UKPN submitting a customer connection application for a new GSP substation located on the existing UKPN Operational Bengeworth Road site with 2 x 240MVA SGTs providing capacity. This solution provides best value to end consumers as it addresses asset replacement needs, resolves demand capacity issues and provides diversity of supply within Central / South London at lowest cost. The site is close to the tunnel route of the Wimbledon-New Cross option. Appendix 3K details the options which were considered alongside the accompanying NPV analysis.

NGET's engagement with UKPN has resulted in an option that meets the requirements of the whole network and that both parties agree provides the best value for end consumers. As such, it has been included as an additional criteria to analyse options against for the LPT2 project. It should be noted that at the time of writing, the connection agreement has not yet been signed by UKPN and so this is not included in the current scope of works. It is anticipated that it is likely to be signed in the coming few months and then will be integrated into the engineering design work. In the unlikely event this offer is not signed, the option analysis in Section 6 holds true for both scenarios and the needs case described in Section 4 is totally unaffected by this offer.

6.0 Shortlisted Options

The consideration and evaluation of system design requirements discussed in Section 5 enable the optioneering to focus on 2 key solutions with the inclusion of Bengeworth GSP considered as a flexed variable. As discussed in Section 5, the initial design decisions taken were:

1. Maintain a continuous route through South London, connecting Littlebrook via Hurst and New Cross via either Wimbledon or West Ham
2. Replace existing direct buried cables in housed tunnel
3. Install 400kV cable throughout entire route, to be operated at 275kV providing future capability for uprating to 400kV; except for Circuit One (Wimbledon to New Cross) which is to be uprated to and operated at 400kV
4. Deploy XPLE cable technology vs traditional oil filled cable
5. Fulfil UKPN customer requirements with Bengeworth Road GSP solution.

6.1 Options Considered

Following initial assessments of the system design requirements, an NPV analysis and detailed system studies have been undertaken on two viable options, with a variant of the Bengeworth Road GSP. These options are outlined below.

Option 1 – WIMB-NEWX-HURS-LITT at 400kV (PREFERRED OPTION)

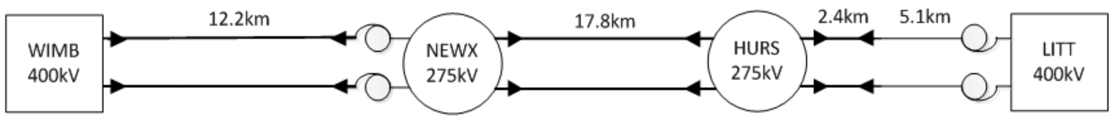


Figure 8 – Option 1 Layout

- 32.5km Tunnelling, 190km XLPE Cables
- No Additional GSP
- Non-Load substation works of low complexity as maintaining existing transmission connections

Option 1a – Option 1 + Bengeworth Road GSP (WIMB-BENG-NEWX-HURS-LITT)

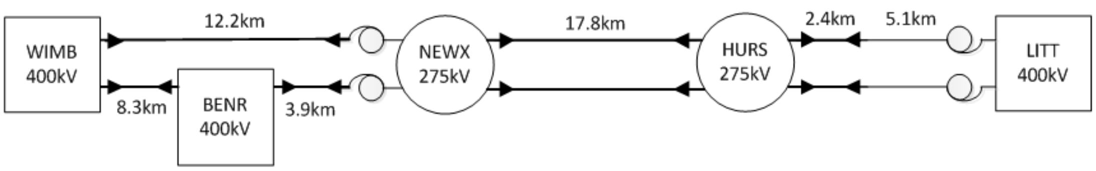


Figure 9 – Option 1a Layout

- 32.5km Tunnelling, 190km XLPE Cables
- Addition of GSP at Bengeworth Road which is located approximately 200m off the main tunnel alignment.
- Non-Load substation works of low complexity as maintaining existing transmission connections
- Effectively a variant of option 1 with added optionality due to Bengeworth Road

Option 2 - Alternative replacement with connection to West Ham (WHAM-NEWX-HURS-LITT)

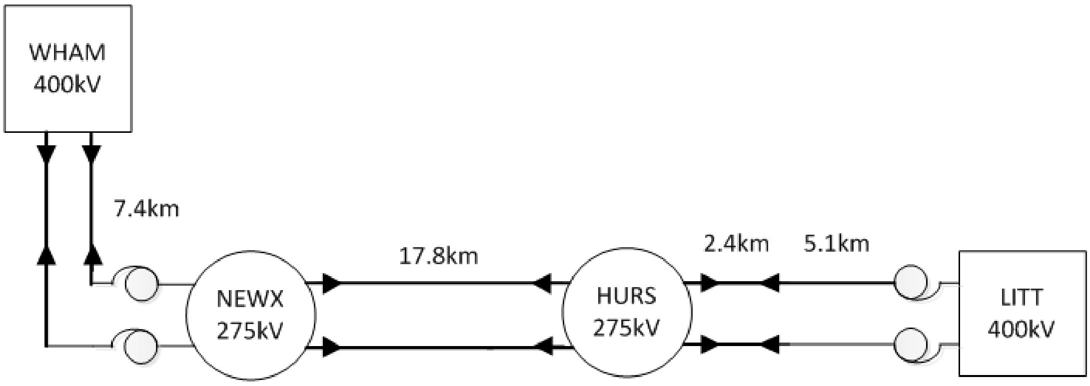


Figure 10 – Option 2 Layout

- 27.6km Tunnelling, 165km XLPE Cables
- No Additional GSP
- Non-Load substation works of high complexity due to need for a new connection into West Ham

Option 2a – Option 2 + Bengeworth Road GSP (WHAM-BENG-NEWX-HURS-LITT)

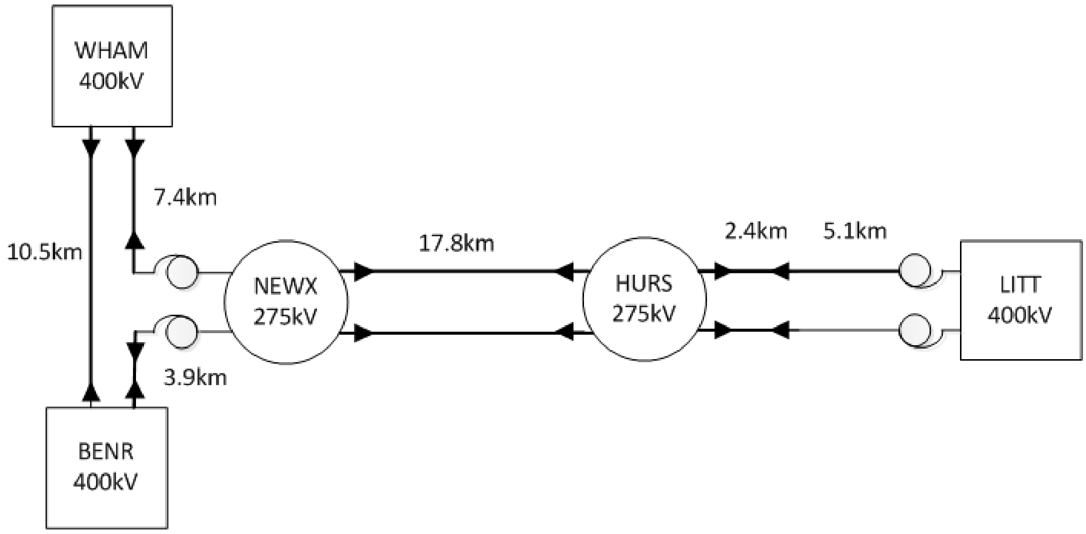


Figure 11 – Option 2a Layout

- 34.5km Tunnelling, 207km XLPE Cables
- Addition of GSP at Bengeworth Road
- Non-Load substation works of high complexity due to need for a new connection into West Ham
- Effectively a variant of option 2 with added optionality due to Bengeworth Road

Overall, inclusive of Bengeworth Road, connection to Wimbledon eliminates the need for an additional 2.5km of cable tunnel, 17km of cable and extensive substation works. Excluding Bengeworth Road, West Ham requires a shorter extent of tunnel and cable. However, as highlighted in Section 7.1 below, the overall project costs remain lower when connecting via Wimbledon due to simplified substation work requirements.

6.2 Stakeholder Engagement on Options

Throughout all aspects of development and delivery we have consulted widely with individuals, groups and markets in and outside our industry to inform the LPT2 programme complimenting the lessons learnt from LPT1 including highlighting the importance of regular engagement with Ofgem.

During the development of LPT2 the project team have undertaken extensive stakeholder engagement with the Greater London Authority, all affected Local Authorities, TfL, Environment Agency, Thames Water, several third-party developers and members of the public via a number of consultation events. A number of non-statutory stakeholders, such as London Chamber of Commerce and London Taxi Drivers Association, have also been consulted in order to obtain views from an even broader set of stakeholders.

Feedback on our proposals have also helped to shape changes to our proposal. To give just two examples of stakeholder influence on scope:

- the Environment Agency expressed its preference for a deep bored tunnel between Hurst – Crayford (to replace the buried cable of the Hurst-Littlebrook Circuit, Circuit 3) rather than a direct buried route to protect the flood protection zone through the Crayford rough.
- Members of the public also provided feedback at the 2018 summer consultation event, expressing a preference to divert HGVs away from Bexley, therefore the decision was made to create a temporary haul road, alleviating traffic from Bexley centre. We have also received positive feedback from the Local Authorities in support of our construction methodology which seeks to minimise disruption to the road network.

7.0 Cost Benefit Analysis

All options satisfy the transmission requirements presented in Section 5. Therefore, the outputs of the cost-benefit analysis (CBA) and the qualitative assessment ultimately informed the final solution.

7.1 Quantitative assessment

Both CBA and NPV analysis have been undertaken to ensure a consistent approach to financial assessment of multiple options. The Cost Benefit Analysis is in Table 6 below. Cost assumptions used in this assessment can be found in Section 9.

Table 6 – Capital Expenditure Breakdowns

	Initial Capital Expenditure for each Identified Option (£m)			
	Option 1: WIMB-NEWX-HURS-LITT	**Option 1a: WIMB-NEWX-HURS-LITT with BENR**	**Option 2: Disconnect WIMB, Connect at WHAM**	**Option 2a: Disconnect WIMB, Connect at WHAM with BENR**
Civils and Land (Tunnels, Shafts, Headhouses)	520	520	590	590
Cable Works	283	283	222	222
Non-load Substation Works	35	35	54	54
Load related costs for BENR (Infrastructure and connection)	0	68	0	148
Total (£m)	**838***	**906**	**866**	**1,014**

**the variance between £838m and the finalised value of £852m is due to pre T1 costs being negated in the initial estimates, this is consistent across both options.*

The CBA has been developed in accordance with Ofgem requirements, ensuring the NPV of the investment discounts the real cash flows to present values, using a 2.9% discount rate. Annualised NPV is not considered given the expected asset life under each option remains a constant variable (68 years).

Table 7 – NPV Results (£m)

	Option 1: WIMB-NEWX-HURS-LITT	**Option 1a: WIMB-NEWX-HURS-LITT with BENR**	**Option 2: Disconnect WIMB, Connect at WHAM**	**Option 2a: Disconnect WIMB, Connect at WHAM with BENR**
Forecast Capital Expenditure (£m)	**838**	**906**	**866**	**1,014**
Discount Rate	2.9%	2.9%	2.9%	2.9%
NPV (£m)	709	764	714	856

Given the similarity in spend profile across the options, the NPV analysis largely restates the ordinal cost ranking, with option 1 being the lowest cost option (albeit without the optionality provided by including the Bengeworth Road GSP). Including Bengeworth Road GSP, option 1a is significantly lower cost than option 2a.

7.2 Qualitative assessment

In addition to the quantitative assessment, there are a number of variable criteria that can, at this point, only be considered qualitatively:

- Land availability and consent constraints
- Bengeworth Road GSP UKPN work.
- Tunnel Design / Construction Constraints
- Substation Design / Construction Constraints
- Customer Requirements
- Programme (ACL dates)
- System Resilience

These factors are assessed in the following section.

7.2.1 Analysis supporting the Qualitative Assessment

Land availability and consent constraints: Land availability for the West Ham option (Option 2) is limited due to its location approximately 1 mile from Canary Wharf. If suitable land could be identified for a headhouse, market rates are substantial in the Canary Wharf area. There are also a considerable number of very tall, multi-storey buildings in these areas with deep piles, making obtaining land rights very challenging.

UKPN Works both options 1a and 2a facilitate the new GSP at Bengeworth Road, until a connection agreement is signed by UKPN, development of the scope and cost is limited.

Tunnel Design / Construction Constraints – the direct route between West Ham and New Cross, required for options 2 and 2a, is characterised primarily by modern multi-storey developments with very little open space for tunnel construction or intermediate shaft sites. The route would also require crossing the River Thames. Canary Wharf and Canada Wharf are large multi-story developments lining the river and any West Ham-New Cross route would need to divert around both estates. This also increases the risk and impacts of tunnelling significantly. The route is crossed by the A13 Limehouse link road which is constructed in a pile cut and cover box and London Underground Jubilee Line tunnels. A cable tunnel route in this area would need to consider of both these assets. The Jubilee Line is a deep tunnel in this area as it passes beneath the River Thames twice. The path of the future Thames Tideway Tunnel passes at a deep level from east to west through this area and consideration of a spur to Greenwich would also need to be made. Southwark Park is the only area of undeveloped land on a potential route to West Ham – this is a Grade 2 listed park and plans for shaft construction for other cable tunnels in this park have previously been rejected. These factors drive the higher civils and land cost despite the shorter routing.

The route to the North of New Cross also presents challenges. A UKPN tunnel recently constructed from New Cross to the City of London follows a route to the north of the site and has taken the only available route away from the site without the requirement for multiple third-party permissions. This tunnel could not be shared, both due to space restrictions and the divergence of the routes required by the substation connections.

Substation Design / Construction Constraints – The detailed studies concluded that both connection options at Wimbledon (Options 1 and 1a) and West Ham (Options 2 and 2a) are credible with the following points to note:

- Wimbledon 400kV hybrid design leads to slightly less balanced flows under import conditions due to additional interbus transformers (400 to 275kV), however, does lead to a reduction in flows on non-LPT2 route corridors compared to West Ham 400kV hybrid which offers wider system benefit.
- West Ham 400kV hybrid design has more balanced flows with lower rating of Wimbledon–New Cross–Hurst–Littlebrook circuits, however this option will trigger reconductoring of the Barking-West Ham OHL due to increased flows into West Ham from Barking.

- For a future 400kV upgrade, the Wimbledon connection option results in significantly higher load flows through London corridor circuits, however this could be mitigated through active power control at Littlebrook (i.e. Quadrature Boosters to replace existing SGTs if 400kV upgrade was triggered).
- The West Ham option does not readily enable construction of a new GSP at Bengeworth Road due to an increase in circuit lengths based on geographic location of the sites.

Customer Requirements – both options 1a and 2a fulfil the requirements of UKPN and provide a new GSP at Bengeworth Road, whereas options 1 and 2 fail to facilitate a new GSP. UKPN would, therefore, have to undertake asset replacement of its 132kV cables independently.

Programme (ACL) – both option 1 and 1a which connect into Wimbledon achieve our programme ACL dates, whereas option 2 and 2a fail to meet our ACL date due to the need to develop and deliver a complex tunnel solution to West Ham.

Consents – Permitted Development Rights have been secured for options 1 and 1a, whereas a tunnel drive to West Ham would likely result in additional spoil being excavated from New Cross due to the difficulty in obtaining sufficient land for an intermediate drive site to West Ham.

System Resilience – creating a new GSP at Bengeworth Road provides additional system resilience as it increases the diversity of supply to South London by allowing transfer of demand from Wimbledon.

Table 8 provides a qualitative comparison of the discussion along with a Harvey ball assessment.

Table 8 – Qualitative Assessment

	Option 1	Option 1a	Option 2	Option 2a
NPV	●	●	◑	◑
• **Land Availability**	●	●	◔	◔
• **UKPN Work**	◔	●	◔	●
• **Tunnel Design / Construction Constraints**	●	●	◔	○
• **Substation Design / Construction Constraints**	●	●	◔	◔
Customer Requirements	○	●	○	●
Programme (ACL)	●	●	○	○
Consent	●	●	◔	◔
System Resilience	◑	●	◑	●
Overall Score	◕	●	◔	◔

7.3 Optioneering Outcome

The Optioneering process reviews the validity of the project drivers and appraises the option selection process to ensure that the most economical solution is progressed. To conclude, option 1 was shown to be the preferred solution to meet LPT2's drivers.

The CBA demonstrates that option 1 is the most economic investment, and it meets all of the project drivers. Furthermore, the qualitative assessment shows it reduces the overall risk to a programme of works when compared with option 2 and 2a. The connection into Wimbledon substation carries a lower risk due to the comparatively lower environmental constraints and simplified process for obtaining planning and consents.

The option 1a solution will be triggered by the connection an agreement with UKPN to construct a GSP at Bengeworth Road.

Option 1a, Wimbledon–New Cross–Hurst–Littlebrook, including a new GSP at Bengeworth Road, provides the lowest cost solution for both the transmission and distribution system, maximising consumer value.

To reiterate, the connection offer with UKPN will be determined in January 2020 and as such it is not possible for the elements of scope to be fully progressed until an offer is confirmed. These works would be funded by customer connection and demand charges, and the associated costs are therefore not included in this submission. Option 1 uses the same route and connections as option 1a, enabling the project to proceed with planning, designs and site establishment without conducting undertaking, unnecessary work or spend. Additional deep tunnel/civil assets are required for option 1a, which may be constructed entirely from the future GSP site without a significant impact on the option 1 scope.

8.0 Solution Scope, Innovation and Establishing a Contract Strategy

This section provides a detailed description of the preferred solution scope, innovation to date, and contract strategy, setting the context for the detailed cost estimates and forecast in Section 9. Throughout the development process, drawing on lessons learnt from LPT1 and industry best practice allowed for innovation and value in design.

To inform our contract strategy, we completed extensive market engagement to identify suitable delivery models given the current market capability. The outputs from this consultation process resulted in the consideration of four contracting strategies. The contracting strategies were reviewed against market feedback and an opportunity/risk assessment completed. The chosen Contract Strategy option for LPT2 is to establish a common suite of NEC4 contracts with Key Contract Partners. These will form a 'Project 13' enterprise using the X12 collaboration clause and a common understanding of scope via a division of responsibilities. This will result in the most efficient and economical outcome for consumers for the reasons discussed in detail below.

8.1 Solution Scope

Section 7.3 (Optioneering Outcome) determined the LPT2 scope as new twin 400kV ready XLPE circuits in deep-bored cable tunnels between Wimbledon and New Cross, New Cross and Hurst and Hurst and Crayford* (*replacement of the 275kV cable section of the Hurst Littlebrook circuits). The project includes the substation equipment required to facilitate the uprating and operation of Wimbledon - New Cross circuit at 400kV and connections at other sites. New Cross - Hurst and Hurst - Littlebrook (Crayford) will be operated at 275kV with the capability to be uprated to 400kV as forecast demand increase. The route and construction components that will comprise the LPT2 project are shown and explained below in both Figure 12 and Table 9.

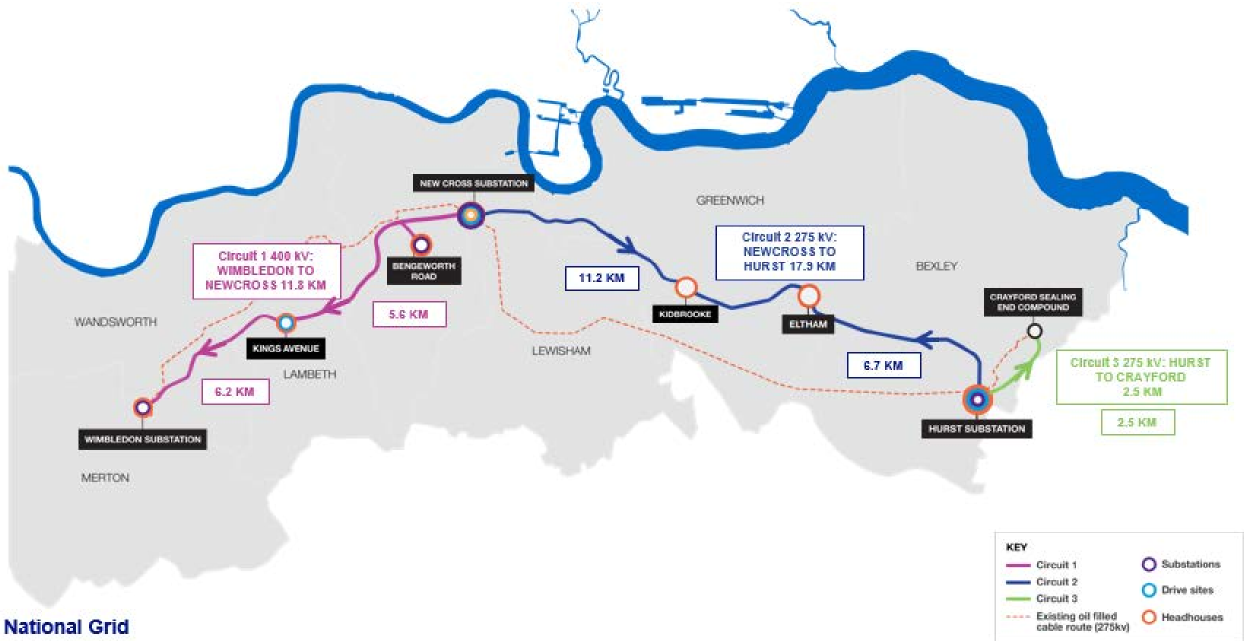


Figure 12 – Map of LPT2 Route

Table 9 – LPT2 Components

Component	Number / distance	Description
Headhouses	7	Seven above ground headhouse sites are required to ventilate the tunnel. They will be located at Wimbledon (existing headhouse), Kings Avenue, 2 at New Cross, Kidbrooke, Eltham, Hurst and Crayford. There are existing National Grid substations at Wimbledon, New Cross and Hurst into which the new circuits will connect.
Shafts	6	Permanent shafts will be constructed at all the sites detailed above except for Wimbledon, as the shaft and head house were constructed as part of the phase 1 works (LPT1). The Wimbledon shaft was designed to receive a future tunnel drive and circuits at minimal cost; space constraints at Wimbledon would have otherwise led to a complex, time consuming land negotiation, which would have been poorly received by our neighbours (from whom we would have required significant rights).
Drive Sites	3	The shafts at Kings Avenue, New Cross and Hurst are likely to be drive sites, meaning Tunnel Boring Machines (TBMs) will be launched from these shaft locations to start the tunnelling process and excavated material will be removed via heavy goods vehicle. The spacing between drive sites is designed to allow safe exit in the event of an emergency, whilst keeping the number of shafts to a minimum. The drive sites will also provide ventilation during construction and operation.
Reception Sites	4	Reception sites are likely to be located at Wimbledon, Kings Avenue, Eltham and Crayford to receive the TBMs. The proposal is to use the Kings Avenue site as both a drive and reception site. An 'intermediate site' is located at Kidbrooke to provide access, maintenance to the TBM and ventilation system mid-way between New Cross and Eltham.
Tunnel Drives	5	Every tunnel project must have a drive strategy which determines how the tunnel will be constructed. LPT2 will likely be constructed by undertaking 5 separate tunnel drives. The delivery strategy (i.e. number of concurrent drives) will be subject to the Contractor's tender returns.
Cable	190km	Approximately 190km of XLPE cables will be installed within the newly constructed 32.5km tunnels and jointed at intervals between 800m -1100m. When the shaft and tunnel construction is complete, the tunnel will be cleaned and prepared for cable installation. Cable brackets will be installed along the walls of the tunnel ready for cable installation.
Substation Works	3 locations	At Wimbledon 2 new Gas Insulated Switchgear (GIS) bays are required to terminate the new circuits and at New Cross two new 400kV/275kV Super Grid Transformers (SGTs) will be installed with connections onto existing 400kV GIS bays. At Hurst, new cables are to be installed between the newly constructed headhouse and the existing cable sealing ends including associated civil works and cable containment. At Crayford, the existing platform mounted cable sealing ends on the existing OHL tower are to be replaced in-situ and direct buried cables will run from a headhouse at Crayford to the existing OHL tower (the circuit then continues via overhead lines to Littlebrook.

8.2 Innovation in Development

A number of design innovations have been embedded into the LPT2 from LPT1 lessons, saving of approximately £47m comparative to LPT1. These are outlined in Table 10 below. Where relevant, we have outlined the saving for each innovation. In some cases, the savings cannot be quantified.

Table 10 – Lessons Learnt from LPT1

Lesson Learnt Subject Area	Description
Forced Air Ventilation	A lean and efficient Tunnel Ventilation scope has been specified and facilitates the increase in shaft separation. System design requirements were reviewed during development and a number of simulations were completed using intact, N-1 and short-term N-2 cable loads equating to savings of approximately **£8.5m**.
Access Staircases	Access Staircases for LPT2 will be open tread galvanised staircases, rather than separately ventilated precast concrete staircases due to a reduced tunnel access frequency. Supply and installation cost savings for the staircase, are in the order of **£2.8m**.
Shaft Separation (increased tunnel drive lengths)	Increased Shaft Separation has been enabled through a review of fire risk, understanding realistic cable loads and challenging the access frequency for maintenance. This has resulted in the removal of 3 shafts from the project scope, avoiding significant land acquisition costs alongside construction savings equating to approximately **£35m**.
Tunnel Diameter	Original tunnel diameter was based on a 4m ID. The Tunnel Life Safety report for LPT2 justifies that a 3m ID tunnel safely satisfies the projects requirements from a construction and operational perspective.
Contract Packages / Scope Interfaces	Following market engagement and feedback the scope has been split into six contract packages to align with market capabilities and the delivery programme (Further detail can be found in Section 10). A Division of Responsibility Matrix (DoRM) has been prepared for inclusion in all contract packages to avoid confusion between packages and clarify information exchanges and interdependencies. A delivery model aimed to incentivise collaboration with a drive to proactively manage risks and outperform project outcomes has been developed to bring the individual contract packages together (a ‘Project 13 Enterprise’ a delivery model based on effective collaboration between client organisations, contractors and other delivery partners).
Gas Detection	The need for permanent gas detection in the tunnel has been removed from scope, reducing the need/frequency to access the tunnel to undertake maintenance.
Maintenance of Sump Pumps for water management during operation	A solution has been developed which allows for the sump pumps to be raised to ground level for routine maintenance, reducing the need/frequency to access the tunnel.
Fixed Lifting Equipment	Removal of the need for fixed lifting equipment in the headhouses as the orientation and location of the buildings allow access from the outside the building footprint.
Tunnel Vehicle for use during operations	Tunnel Vehicle testing of an electric trike has successfully resulted in the de-scoping of the tunnel vehicle installed on phase 1. Testing has proven the electric trike alternative to be capable of completing the required distances and achieving speeds of up to 28km/h to transporting any injured parties to safety (should it be required during maintenance works). Replacement of the traditional tunnel vehicle with an electric trike equated to approx. £180k of savings per vehicle equating to a total project saving of **£720k**.
Tunnel Maintenance	As a result of some of the items above tunnel maintenance can be extended to once every 3 years rather than every 6 months.

The above innovations have been developed out of the lessons learnt from LPT1, the Feeder 9 gas pipeline and those from external projects, and have played a significant role in the development of the LPT2 scheme. They have been considered in the procurement strategy, the land and consents strategy, the project delivery framework (P13) and the engineering design work, to ensure that LPT2 is in a robust position at the point of contract awards and delivery stages of the project.

8.3 Contract Strategy: internal and external learning

LPT1 contracts were awarded using a range of different contract mechanisms (FIDIC – The International Federation of Consulting Engineers, NEC – New Engineering Contracts and iCHEME – Institute of Chemical Engineering contract forms were used). A key lesson from LPT1 is the importance of incentivising the right contractual behaviours between parties.

Furthermore, ground conditions in South London are significantly more challenging for the LPT2 programme (this is considered and detailed further in Section 9). A key programme driver is to award the tunnel contract as soon as land rights are secured (ahead of other areas such as cables and substations where programme float is available and development is ongoing). For other recent National Grid major projects, 'lump sum' and 'turn-key' contracts have been used. Western Link used a full turnkey contract. The Hinkley-Seabank project is using a suite of NEC Option A lump sum contracts for multiple asset types (OHL/cable/substation). These approaches were considered as part of the LPT2 strategy review. Early market engagement indicated a repeat of such approaches may be inappropriate due to the significantly divergent technologies and interfaces, the number of partners, project constraints and increased ground risk.

The British Tunnelling Society's Joint Code of Practice for the Risk Management of Tunnel works in the UK (JCOP)[1] is a key document in the industry. The objective of the Code is *to promote and secure best practice for the minimisation and management of risks associated with the design and construction of tunnels*. The code sets out:

- Common practice for the identification of risk.
- Common practice and the allocation of risk between contract parties and contract insurers.
- Practice for the management and control of risks through the use of Risk Assessments and Risk Registers.

Typically, both contractors and insurers consider the JCOP as crucial for the management of works. Furthermore, many associate its principles on the sharing of ground risk better suited and aligned to a Target Cost contract mechanism, where risk may be clearly identified and shared fairly between client and contracting organisations through the use of a Geotechnical Baseline Report (GBR). The GBR for LPT2 is based on thorough deep bore ground investigations and sets the levels of ground risk the contractor should anticipate, mitigate and price within their target price. The GBR is a key means of managing and mitigating ground risk.

8.3.1 Interface complexity and contractor relationships

Interfaces are a practical necessity for a project of this complexity and size. No single entity would have the competence to be able to deliver all of the technical specialities required for the whole project. The resultant project size and risk to a single entity would also be a deterrent for commercial procurement. Given interfaces will be required, they should be managed in the most efficient way, taking into account recent learning from the industry.

The Infrastructure Client Group (ICG) recently considered this issue. The ICG, of which National Grid is a member, was established under Institute of Civil Engineers guidance. The Group helps to support the implementation of the Government's *Infrastructure Cost Review Report 2010*, which proposed new business models and integrated supply chains.

[1] https://www.britishtunnelling.org.uk/?sitecontentid=881C32EC-21C8-41A9-8B7A-F8D530E7987E%20

The purpose of the ICG is to identify, share and disseminate best practice in the development and delivery of infrastructure, and to provide a single voice to government and industry. The ICG conducted a series of workshops and concluded that the industry needs a new approach for contracting large scale infrastructure.

One of the key recommendations in the ICG's From *Transactions to Enterprises* was to promote collaboration and integration between interfaces using the 'Project 13' approach. Traditional transactional interface management was found by the ICG to have inherent waste in the management of contracts as a series of individual projects, each procured independently in the market.

"The root causes of this poor performance lie in disintegration and disaggregation. By separating design from construction and breaking projects down into hundreds of sub-contracts we impede the flow of knowledge from the supply chain to the front end of the project where value is created, adding cost and uncertainty at every step along the way.

In its place, Project 13 is proposing to create organisations that integrate the core functions of infrastructure owners with the capabilities of their advisors and suppliers. The new approach to delivering infrastructure relies on getting the most out of all the parties involved through collaboration and integration. Collaboration works by softening the boundaries between the parties to an infrastructure programme and then integrating their capabilities, functions and activities to produce a better outcome for all."

8.3.2 The Project 13 Enterprise

We are adopting a Project 13 Enterprise model to incentivise true collaboration with a drive to proactively manage risks and outperform project outcomes.

The ICG Report set out the rationale for the Project 13 concept. The ICG landed on a new approach and a shift in thinking which resulted in the following key principles:

- A focus on client outcomes and long-term asset performance and value;
- A single Enterprise based on collaboration and early engagement to develop optimal solutions; and
- Aligned incentives against outcomes that allow sustainable rate of return for the supply chain.

The findings were followed by the development of the Project 13 Blueprint[2] and Commercial Handbook[3] to test the application of Project 13 in practice. The Project 13 Enterprise approach aligns with many of the lessons learnt and findings in the Department for Transport's (DfT) *Lessons from transport for the sponsorship of major projects*[4]. The DfT document states that programme is rarely recovered after an event – so scenario plan and change the plan. It encourages an ambition to foster a culture of transparency and early warning supported by progress reporting with a focus on most and schedule variance.

The LPT2 phased commissioning programme will accommodate this approach, taking lessons learnt from LPT1, whilst noting that the tunneling medium in South London is more challenging and will lead to lower tunnel production rates than executed on LPT1.

8.3.3 Major Project Comparisons

Broadly, major infrastructure projects today are classed by size (approx. £1bn+), duration (several years), complexity (interfaces, technology, stakeholders etc.) and importance (critical infrastructure, social-economic-political-environmental sensitivity). LPT1 falls within this group, and so becomes subject to the 'big is fragile'

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[2] http://www.p13.org.uk/wp-content/uploads/2018/06/P13-Blueprint-Web.pdf

[3] http://www.p13.org.uk/wp-content/uploads/2018/06/P13-Commercial-Handbook-Web.pdf

[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/796294/dft-review-of-lessons.pdf

aspects of scale (Ansar et al, 2017). Within this definition, tunnel projects fare particularly badly, partly due to the inherent challenges of unforeseeable ground conditions. Table 11 below is a summary of cost overruns for global tunnel projects in recent decades:

Table 11 – Global Tunnel Project Performance
(Tunnel projects, projects with tunnel elements)
Adapted from Flyvbjerg et al. (2017), Oxford Handbook of Megaproject Management

Tunnel Project	Cost overrun (%)
Furka Base Tunnel, Switzerland	**300**
Boston Artery/Big Dig Tunnel, US	**220**
Dublin Port Tunnel, Ireland	**160**
Montreal Metro extension, Canada	160
Copenhagen Metro, Denmark	150
Great Belt Tunnel, Denmark	**120**
London Limehouse Tunnel, UK	**110**
Joetsu High Speed, Japan	100
Thames Tideway, UK	**80**
Channel Tunnel, UK/France	**80**
London Jubilee Line Extension, UK	**80**
Bangkok Metro, Thailand	70
Mexico City Metro, Mexico	60
Northern Line Extension, UK	**40**
LPT1 Tunnels & Shafts, UK (tunnel only)	**30**
Crossrail, UK	**20**
Seattle Alaskan Way Tunnel, US	**20**
Channel Tunnel Rail Link HS1, UK	**Under budget est.**

The data above displays chronically poor performance against initial estimates. If we extend the sample data to include mid-size projects, recent research demonstrates an average 31% cost overrun for tunnel projects in Europe[5].

More broadly, big projects endure consistent poor performance in both cost and schedule overruns. This trajectory of overspend has remained consistent due to improved project control systems being counter-balanced by increasing complexity and fragility in big projects.

Whilst success is achievable, the prudent approach is to assess the project characteristics against benchmarked standards and recognise an appropriate level of risk contingency behind a collaborative, enterprise model approach.

Current thinking at the forefront of major project research focuses on Reference Class Forecasting – analysing where the market has performed to date, and where your project sits in relation. This reverses the traditional approach of justifying why a project will achieve its time, cost and benefits realisation targets in isolation, instead asking why (in the case of LPT2) the project is forecasted to outperform market trends.

The common causes of big project failure (Flyvbjerg, 2017) are:

- **Underestimation of Uncertainty**
  LPT2 - significant uncertainty is intrinsic to tunnelling projects.
- **Stakeholder Neglect or Mismanagement**
  LPT2 - there is an extensive and evolving set of stakeholders for LPT2 to manage
- **Inflexible Contractor Management**
  LPT2 - need to focus on value and outcomes as well as cost

[5] Cantarelli et al. (2012, Geographical Variation in Project Cost Performance, p15)

We can then state uncertainties around specific elements of the project:

- **Grounds risk** (see Sections 4, 9 and 10)
- **Lands and consents** (see Sections 4 and 10)
- **Contractor performance**
- **Global supply chain** (see Section 9)
- **Forecast macro political and economic volatility**

To remedy this potential overrun, our approach to achieve an on-time and on-budget result will be to deploy:

- Collaborative enterprise project model
- Prudent allocation of project management funding
- Prudent allocation of risk funding

8.3.4 Contract Options Analysed Using Market Engagement

Contract Options: The following contract packages were formulated in consideration of the internal and external learning:

1. Single Contract – 'turn-key' Model

2. a Mix of NEC, iCHEME and FIDIC contract models – including, lump sum, target and (smaller) cost plus arrangements as per LPT1, contract awards were staggered over 4 years.

3. Four main packages (exc. enabling works) – Tunnels and Shafts; Headhouse and M&E with Cable Installation; Cable Supply; Substations

4. Five main packages (inc. enabling works) – Tunnels and Shafts; Headhouse and M&E; Cable Supply and Installation; Enabling Works; Substations.

Leverage existing frameworks vs. spot tendering to introduce competition was considered. Enabling works, substation works, cable supply, jointing & installation all have their own defined delivery strategy.

We decided during formation of the strategy to award the enabling works through the minor civils framework in advance of the Tunnels and Shafts contract to remove large obstructions and contaminated ground at New Cross to de-risk the critical path. Tunnels and Shafts and Headhouses and M&E do not have an existing route to market and required spot tender.

The risks and opportunities of each option are outlined in a 'Harvey Ball' comparison (Table 12 and Table 13) below:

Table 12 – Risks and Opportunities for Option 1-4 Contracting Strategies

	Options			
	1	2	3	4
Supply Chain Holds Risk	◑	●	●	●
Client Holds interface Risk	●	◑	○	○
Initial Contract Price is flexed	◑	◑	●	●
Post contract changes offer value for money	○	◑	●	●
Likelihood of programme completion is compromised	●	◑	○	○
Contractor specialism is utilised	○	◑	●	●
Client has control of Design	○	○	●	●

Key: ● positive ○ negative ◑ indifferent

Table 13 – Evaluation of Contracting Options

<table>
<tr><th>Option</th><th>Benefits/ Opportunities</th><th>Drawbacks / Risks</th></tr>
<tr><td>Option 1: Single Contract Package Model – 1 Package</td><td>Single stage procurement activity.
Single point of interface for Client.
Contractor manages all interfaces with other packages,
Contractor develops understanding of NG requirements over the duration of the project.</td><td>Increased risk of contractor insolvency.
Initial contract price may be higher due to increased risk placed on the contractor being built into the tender returns.
Post contract changes reduce value for money as no competition exists.
Early contract letting reduces design optimisation between packages.
Civils contractor fails to engage with subcontractors which could impact system functionality.
Additional fee may be applied for cable procured by the principle contractor.</td></tr>
<tr><td>Option 2: LPT1 Packaging Model - 5 Packages</td><td>NG have previous experience in delivering this packaging strategy.
Evokes broader market engagement than a single package.
Increases in the number of suppliers increases competition during programme of works.
Flexibility exists to alter the quality or timing of the works (at cost).
‘Fee on Fee’ eliminated from NG procuring the cable directly with supplier.</td><td>Civils contractor fails to engage with other package suppliers which could impact system functionality.
Civils (incl. M&E) contractor resources not utilised productively during cable installation periods resulting in poor delivery performance.
Interfaces and handovers between packages need to be managed to drive right contractor behaviours.
Early letting of contracts for head houses and M&E means there is a reduced opportunity to develop the designs alongside NG assurance.</td></tr>
<tr><td>Option 3: Civils split from Building, M&E and Cable Install – 5 Packages</td><td rowspan="2">Increased diversity in supply chain allows for materials to be sourced at best cost.
Post contract changes are likely to increase value for money as competition exists.
Increased client design durations for head houses, M&E & cable install could increase design optimisation between package and influence of NG assurance.
‘Fee on Fee’ eliminated from NG procuring the cable directly with supplier.
Potential for lower initial contract prices if scope is well defined and risks already negated/reduced.</td><td rowspan="2">Increased interfaces and handovers between packages need to be manage to drive right contractor behaviours.
Duplication of resources between contractors in each package.
Technical interfaces between civils construction and the building and M&E elements that interact between the two.
‘Fee on Fee’ for cable supply (Option 4)
Additional procurement activities to be undertaken by NG.</td></tr>
<tr><td>Option 4: Civils split from Building and M&E with Cable Supply and Install – 5 Packages</td></tr>
</table>

Figure 13 below depicts the end-end procurement process and scale of the market engagement undertaken. 155 potential suppliers were shortlisted to an engagement forum of 46 suppliers. Typically, 5 or fewer suppliers then qualify to a to a tender process before entering into preferred bidder negotiations (as is currently the stage for Tunnel and Shafts, package 2).

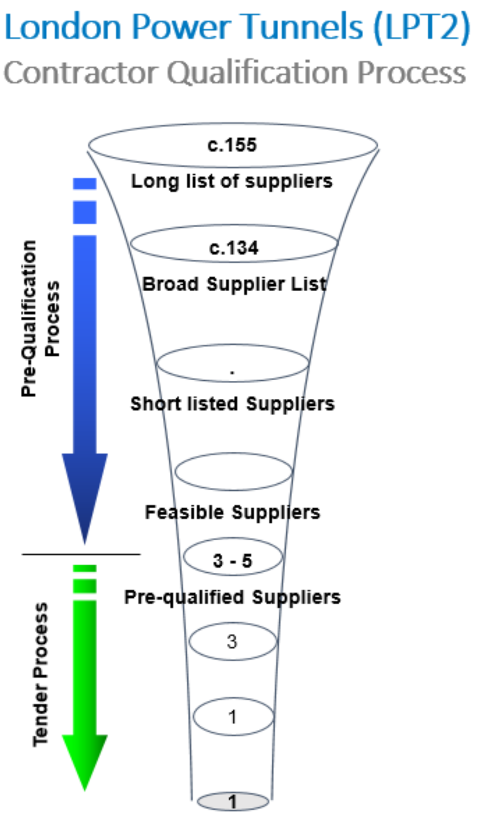

Figure 13 – Market Engagement for Tunnels and Shafts (Package 2)

The contracting strategy was informed by early market engagement with 46 suppliers from the market as well as project specific risks, constraints and interfaces. Feedback from the early market engagement shows greatest appetite for NEC Target Cost contracts to deliver LPT2 works. There is limited appetite for FIDIC and no single supplier preferred ICC or iCHEME. Further consultation with the market, indicated if options 2 and 2a were to be pursued, cable supply and installation should be awarded as independent packages, creating 5 main contracts (excluding enabling works).

The preferred packaging strategy, option 4, consists of the following 5 main packages: Tunnels and Shafts; Cable Supply; Cable Installation; Headhouses and M&E; and Substations. This strategy aligns to market segmentation and mitigates design interface issues encountered on previous project. Furthermore, the approach also aligns with the Department for Transport's *Lessons from transport for the sponsorship of major projects*. Furthermore, splitting the works as defined, enables logical programming of design and construction activities thus de-risking the critical path and avoiding premature design freezes, enabling innovation and collaboration across contract boundaries.

8.3.5 Implementation of the Contract Strategy

The chosen strategy (option 4) will be implemented via spot tender of five main packages of work as outlined in Figure 14 below. Spot tender will introduce competition, delivering value for money to consumers. Each package will require an element of Design, Supply and Construction. The scope of each work package aligns with the market feedback, market capabilities and resource available to drive value through the procurement process whilst not eliminating the possibility of a contractor being awarded more than one package.

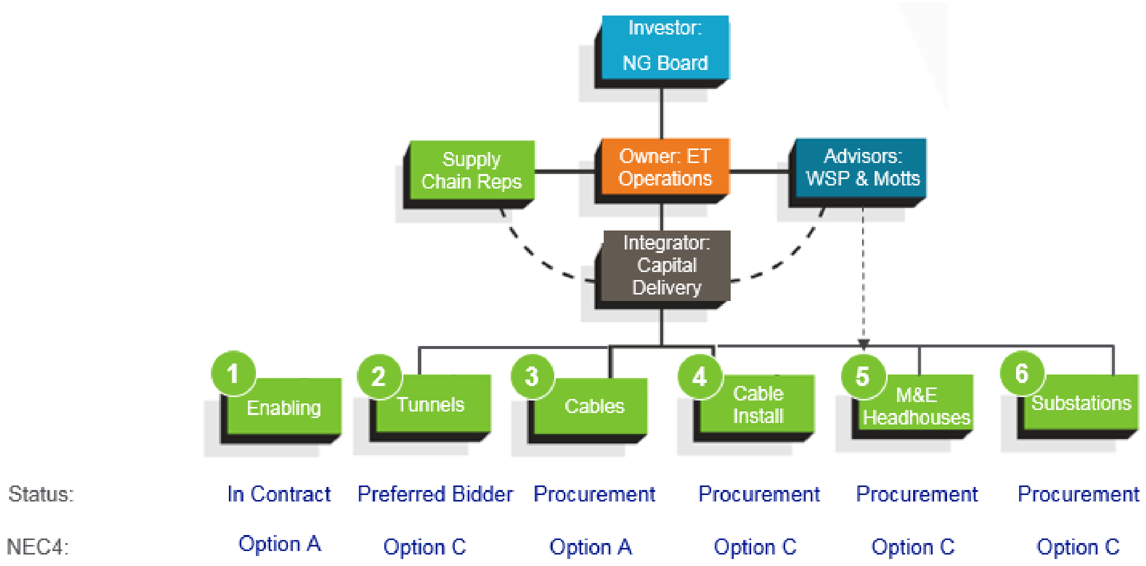

Figure 144 – Enterprise Package Strategy

Package 1 Enabling works is being delivered via an existing Minor Civils Framework, using a mini tender event approach to ensure best price across the three framework contractors. This was awarded in advance of the Tunnel and Shafts contract in June 2018 to remediate land contamination and de-risk the Tunnel and Shaft programme by giving early warning of deviations from anticipated ground conditions.

Although the chosen contracting strategy will mitigate design interface risks, interfaces will nevertheless remain between each contracted party, and these will need to be carefully managed. This strategy aligns to market segmentation. These interfaces will be managed by the emerging Project 13 Enterprise that will be formed prior to the award of all packages.

LPT2 will let Option C (Target Cost) and Option A (Lump Sum) contracts as per Figure 14 above, to deliver the portfolio with the addition of the Secondary Option X12 Multi-Party Collaboration clause to formalise the P13 Enterprise arrangement and adjoining financial incentive model. The financial incentives are designed to encourage collaborative delivery against project outcomes and drive behaviours.

The Tunnels and Shafts, Headhouses and Substations work packages will be contracted as Option C (Target Cost), based on a culmination of feedback from the market engagement forums which highlighted consideration of the following:

- Uncertainty in ground conditions south of the river Thames mean that risk sharing is appropriate to avoid uneconomical risk premiums in tender return prices.
- Uncertainty associated with contractors developing the reference design therefore providing an initial fixed price would attract significant risk premiums.
- Contractor and Client share jointly in savings and overspend through a ‘pain/gain’ mechanism, incentivising performance and collaborative working to deliver against a broader set of project outcomes.

The Option C (Target Cost) contract require more involved contract management from National Grid, However, the addition of the Secondary Option X12 Multi-Party Collaboration clause drives the P13 ways of working to deliver value for all parties in the Enterprise and consumers.

The scope of the Cable Supply package (package 3) is well defined, providing risk levels that are tolerable for contractors. It offers very limited opportunity for the Contractor to identify efficiencies during delivery and minimal opportunity for National Grid to mitigate the Contractor's risks. As such this package, will be contracted as an Option A (Lump Sum).

We are currently engaging with the market to establish the optimal position (Option A or Option C) for the Cable Install package (package 4).

9.0 Capital Cost Estimates

Chapter 9.0 sets out the costs for the preferred solution (Option 1), in accordance with the delivery and procurement strategy discussed in Section 8.0. The chapter outlines the following:

1) Main cost drivers;
2) Assurance of cost, including internal and external project benchmarking;
3) Quantification of risk; and
4) Forecast capital cost.

The estimated project costs are summarised in Table 14 below.

Table 14 – Estimated Project Costs for LPT2

Cost category	**£m (18/19 prices)**
Contractor costs	£636.93
Support functions (design, commissioning, procurement etc.)	£30.25
Land acquisition, land rights and third party approvals	£37.33
NG PM	£70.25
Contingency	£77.09
TOTAL	**£851.84**

9.1 Main Cost Drivers

The costs of tunnel project are heavily influenced by the scale and complexity of the technical parameters, including:

- Ground Conditions
- Tunnel Size (length and cross section)
- Location and Logistics
- Safety, regulatory and industry requirements
- Interfaces with other technologies

9.1.1 Ground Conditions

Chalk is a notoriously difficult material to tunnel through as outlined by the case studies in Appendix 5. Currently, only 2 tunnels exist within the chalk stratum (the DLR and Bakerloo Extension line). By contrast, most of the tunnels through London are situated north of the river in clay, a favourable geology for tunnelling. Approximately 42% of the LPT2 tunnel will run through Chalk (indicated by the green areas in Figure 15 below).

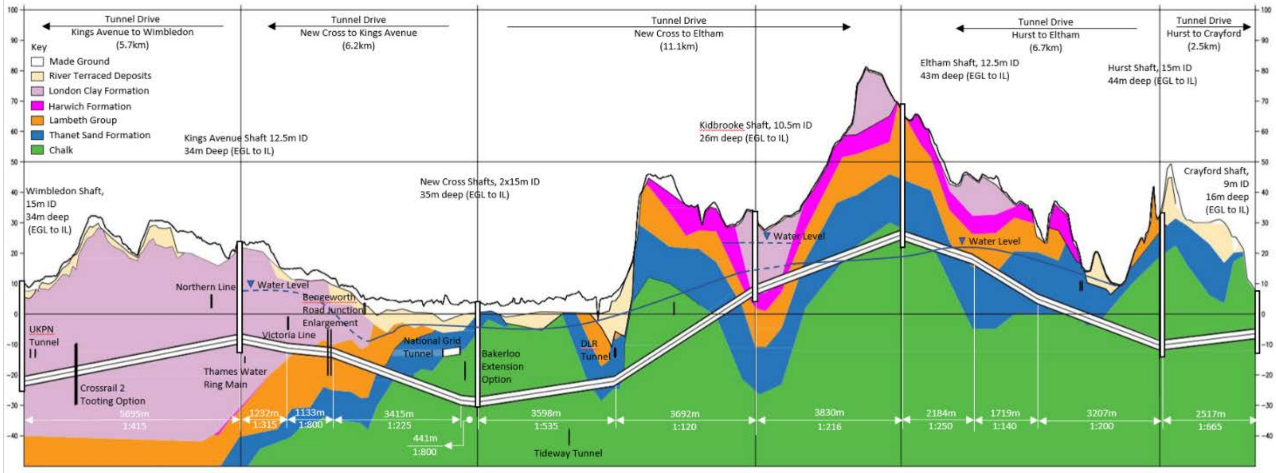

Figure 15 – Strata Map of Geology Expected on LPT2

The mixed chalk geology will therefore create difficult tunnelling conditions and have an impact on estimated cost, chosen construction method and contingencies allocated to risk. Mitigation actions have been put in place to reduce the impact of this event by the production of Geotechnical Baseline Report (GBR) which clearly stipulates the sharing of risk appropriately between contractor and client. We expect the appointed contractor to manage and mitigate this to some extent in the design and delivery phases through appropriate selection of tunnel-boring machines (TBM) and the subsequent maintenance regime. Nevertheless, significant risk will remain throughout construction as changing ground conditions are encountered, along with varying groundwater pressure and several flint bands present.

In the development phase extensive ground investigation works have been carried out to better understand and inform of possible risks and challenges. This has supported the ongoing tendering process.

9.1.2 Tunnel Size

Tunnel size is determined by two factors: length and cross section. Both impact the volume of material excavated, the scale of material removal process, and cost. Cross section is determined by the excavation cross-section and the clear section:

- The excavation cross section is the entire section excavated, designed on the basis of the clear section, the space required for a safe execution of the work.
- The clear cross section is free space of the tunnel, within the final lining, designed to accommodate the cables and associated equipment.

Excavation cross section and clear section influence the method of construction, volume of excavated material, concrete volumes, number of support structures and contingencies values allocated to risk.

9.1.3 Location and Logistics

Above ground logistical constraints as well as the macroeconomic environment of the project location (e.g. tunnelling in urban areas) have an influence on project cost. The transport, treatment and disposal of the earth removed will also vary by project location and have a significant impact upon cost.

9.1.4 Safety, Regulatory and Industry Requirements

Specific safety requirements apply to the construction of a tunnel, including:

- Construction regulations on types and performance of the construction materials, equipment and plant.
- Safety measures during tunnelling and for users of the tunnel during the operational phase (e.g. escape measures, detection systems, ventilation systems etc.)

Furthermore, the British Tunnelling Society JCOP, discussed in section 8, stipulates the following requirements on a client on a tunnelling scheme.

"The Client shall have demonstrable technical and contract management competence appropriate to the type, scope and extent of the project to be planned, designed and procured for construction in:

a) Project Development Stage studies;
b) Design Stages;
c) Construction Contract Procurement Stage procedures including selection of a Form of Contract;
d) Construction Stage and management."

Adequate provision to ensure these formal requirements are met will impacted on overall project costs.

9.2 Assurance of Cost

9.2.1 Detailed estimation to establish project cost assurance targets

Estimation methods can be found in Annex A14.09 - 'Internal Benchmarking of Capital Unit Costs'. Multiple estimating techniques were applied to test figures, including a 'top down', 'bottom up', extrapolation from actuals, analogy (adjustment using a metric via ratio – e.g. LPT1 comparison) and parametric (e.g.tunnel cost per km vs tunnel external diameter). Where relevant, the input of subject matter experts has been sought and costs have been benchmarked against external industry standards.

Costs are quantified per package, in line with the packaging strategy outlined in Section 8:

- Enabling works
- Tunnel and Shaft Construction
- Cable Supply
- Cable install
- M&E and headhouses
- Substations

9.2.2 Comparison to LPT1

Due to the unique challenges and infrequency of major cable tunnel projects, there are limited sources of reliable normalised data. We have therefore focused primarily on LPT1 costs to inform the LPT2 estimate. When comparing LPT1 and LPT2 costs it is important to consider the key project variables:

Table 15 - Important Cost Driving High Level Properties for LPT1 and LPT2

Property	Units	LPT1 Quantity	LPT2 Quantity
Overall Tunnel Length	km	32.81	32.24
Mean External Tunnel Diameter	m	3.95	3.46
Total Number of Shafts (New)	Nr	14	7
Number of Head House (Built)	Nr	11	7
Number of Fan Sites (Built)	Nr	6	4
Number of TBM Drives	Nr	5	5
Cable Voltage	kV	400	400
Cable Cross Sectional Area	mm^2	2500	2500
Cable Conductor Material	Material	Copper	Copper
Number of 400kV Cable Circuits	Nr	9	6
CCT-km of Cable Installed	Cct-km	64.18	64.48

The overall £/km for LPT2 is £26.4m, compared with £24.2m in LPT1, an increase of 9% per km (i.e. per km total non-load with land). 2% of the increase is attributed to greater land costs. The most significant factor is geology, as discussed in the following section. The differences in construction unit rates are shown in Table 16 below.

Table 16 – LPT1 & LPT2 Tunnel Construction Unit Rates (2018/19 prices)

Construction Activity	Units	LPT1 Rate Total	LPT2 Rate Total	Difference (%)
Tunnel and Shaft Works	km	£10,200,229.63	£16,613,395.09	63%
Head House, Ventilation and M&E	Per HH	£6,448,970.31	£8,387,748.38	30%
Cable Works	cct-km	£2,526,339.73	£2,883,995.57	14%
Lands for Infrastructure	Sum	£20,450,101.55	£37,001,127.22	81%
Total non-load with Land	**km**	**£24,196,372.94**	**£26,421,801.08**	**9%**

9.2.3 Strata type and composition

Strata type and composition varies considerably between LPT1 and LPT2: This can be summarised as follows:

- LPT1 - 89% London clay geology with no meaningful level of chalk.
- LPT2 – 42% chalk, 23% Thanet Sand, 25% London clay

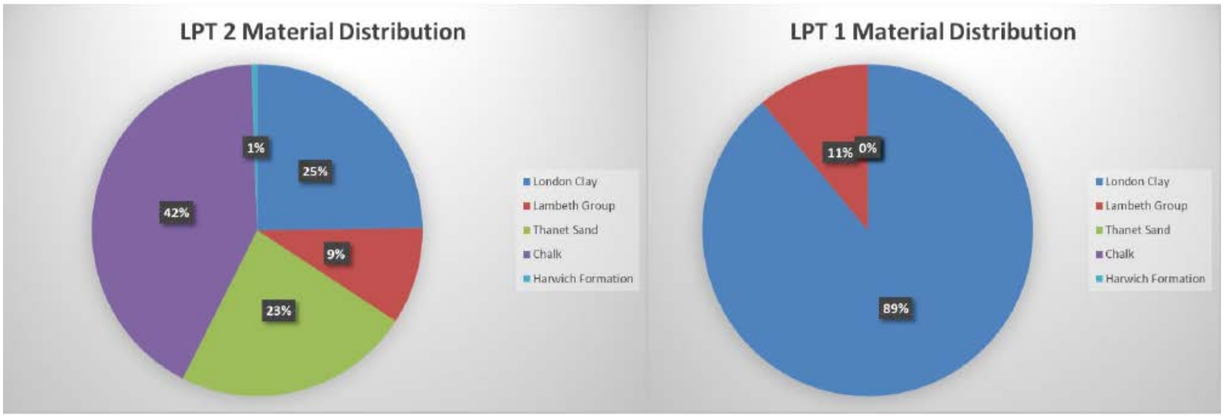

Figure 16 – Geology Distribution in LPT1 and LPT2 Tunnel Alignment

LPT2 will utilise smaller diameter TBMs and require fewer shaft sites. Therefore, the arising costs due to the challenging ground conditions expected during LPT2 is offset to some extent by smaller quantities of excavation and reduced scope of shaft construction.

9.2.4 Shaft construction

Shafts dimensions vary considerably in depth and diameter subject to ground conditions, among other factors. Therefore, supporting mechanism (e.g. Caisson, Diaphragm Wall, Secant Piles), ground treatment works pre-sinking and sinking rate will also differ.

Analysis of our current LPT2 estimate against LPT1 costs showed the independent / dependent variable combinations, shown in Figures 17 and 18 overleaf, had a significant statistical significance for estimating civil shaft construction costs.

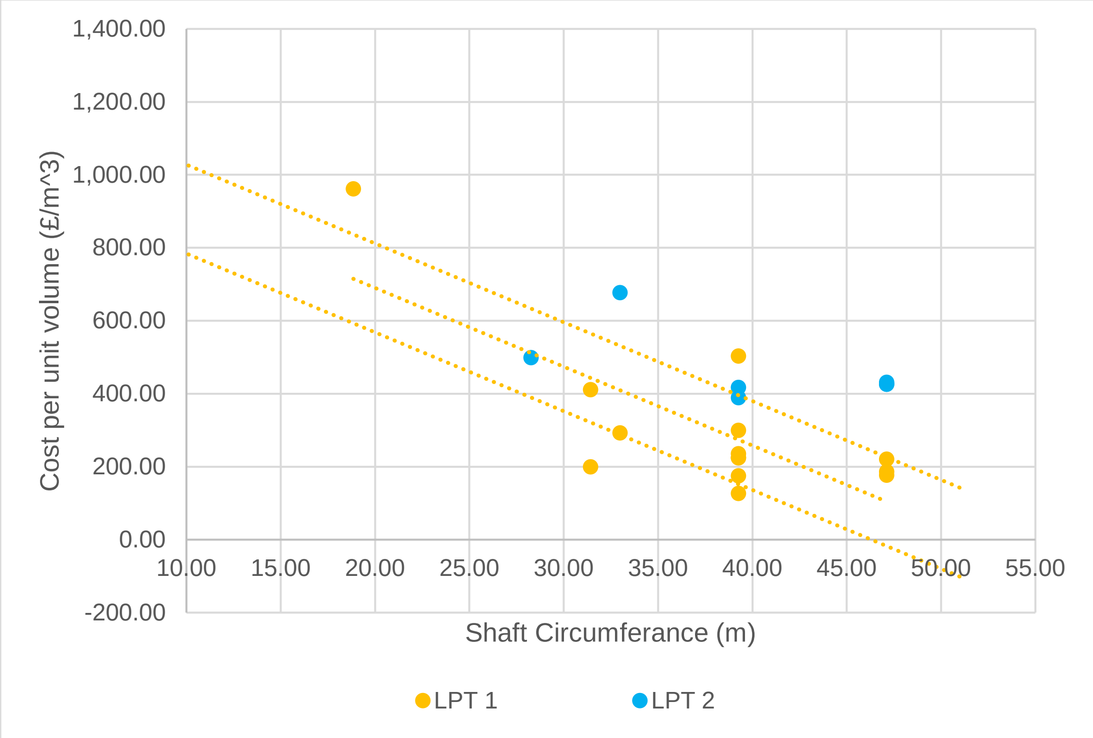

Figure 17 – Cost per Unit Volume for shaft sinking vs. shaft circumference

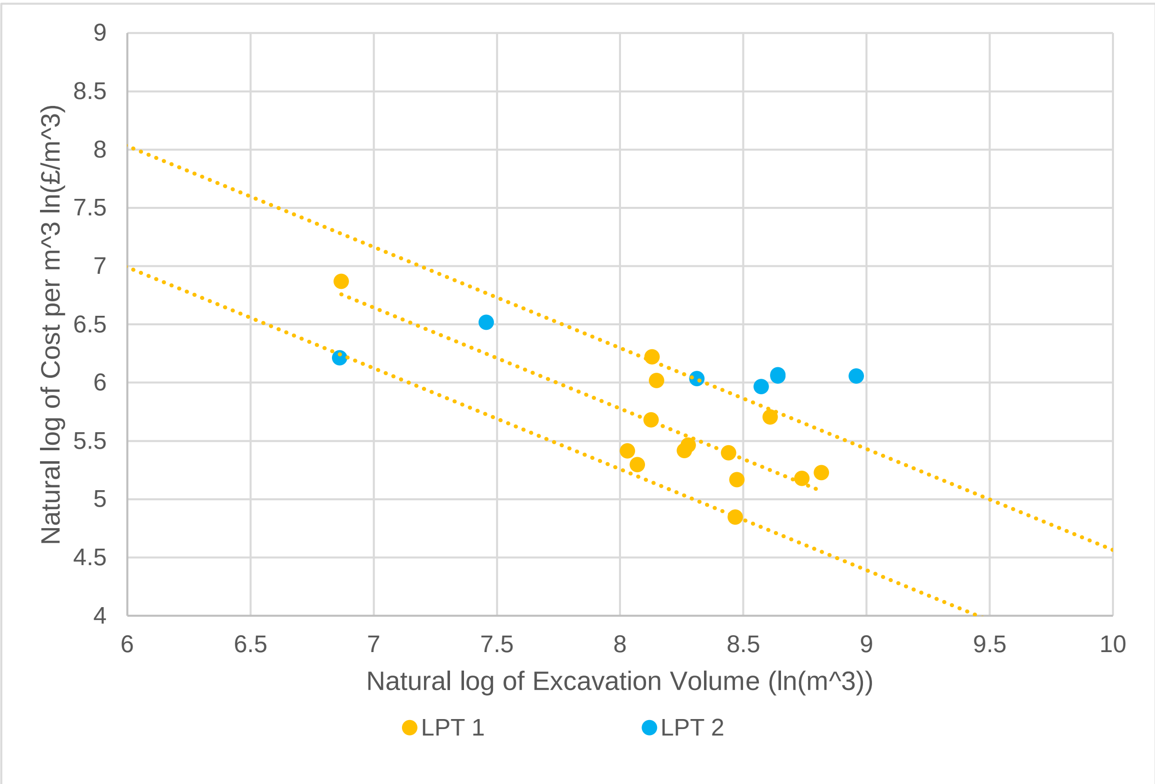

Figure 188 – Correlation of Cost per Unit Volume for shaft sinking vs. shaft circumference

This analysis shows that the engineering parameters, driven by the ground conditions, in turn drive the higher costs and unit rate of LPT2 compared to LPT1.

9.2.5 External benchmarking

External benchmarking prior to capital investment is vital to ensure cost competitiveness and alignment with the wider industry.

To secure sufficient normalised cost data, National Grid engaged with the UK Government's Infrastructure and Projects Authority (IPA) tunnelling forum, in collaboration with the British Tunnelling Society (BTS). Multiple client organisations provided tunnelling cost data for benchmarking as part of the forum, giving National Grid access to market rates for tunnel construction. Rates were used to compare against 'bottom-up' estimating. The benchmarking activities focused on gathered cost data for package 2, tunnels and shafts. The data has informed the costs of package 2, a major part of the total project costs. Outputs from the forum are shown below in Figure 19.

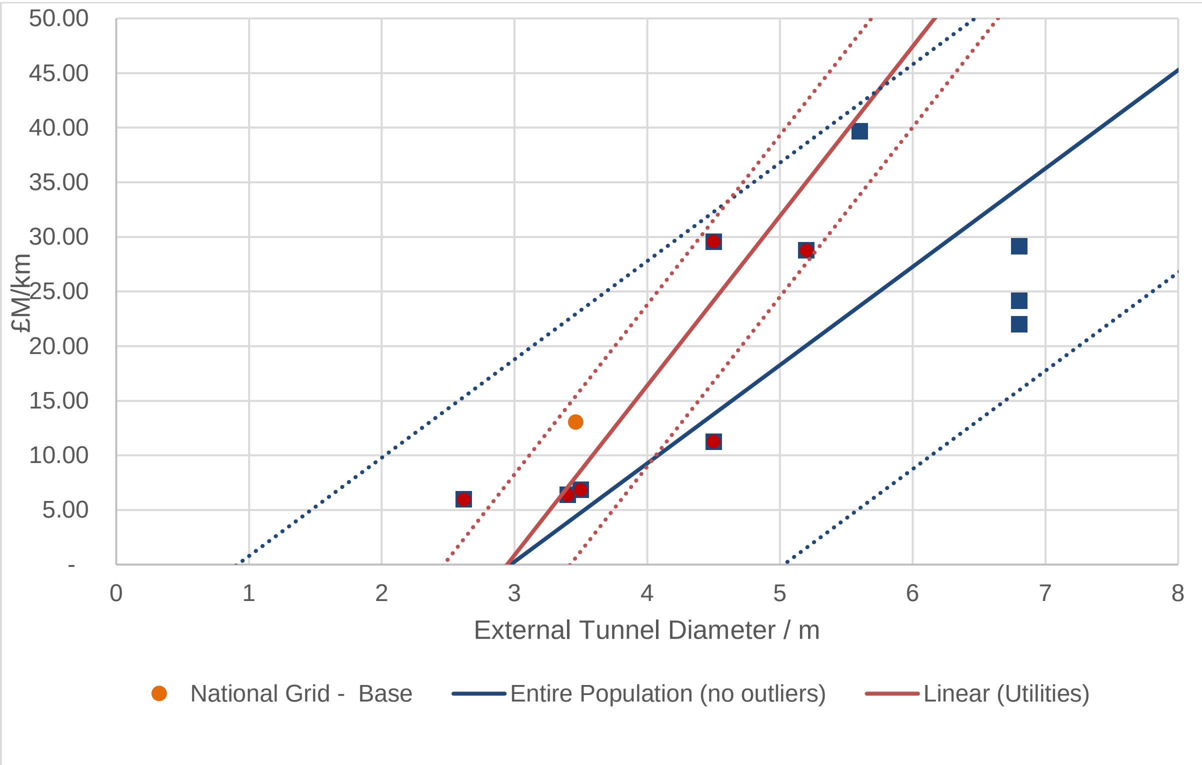

Figure 19 – Benchmarking of tunnel diameter NGET estimate vs. IPA data set

Figure 19 shows contract cost in £m/km versus external tunnel diameter as the independent variable. Trendlines are shown for the entire population of tunnels (blue) and Utilities (red). P20 and P80 predictability limits are the dotted lines.

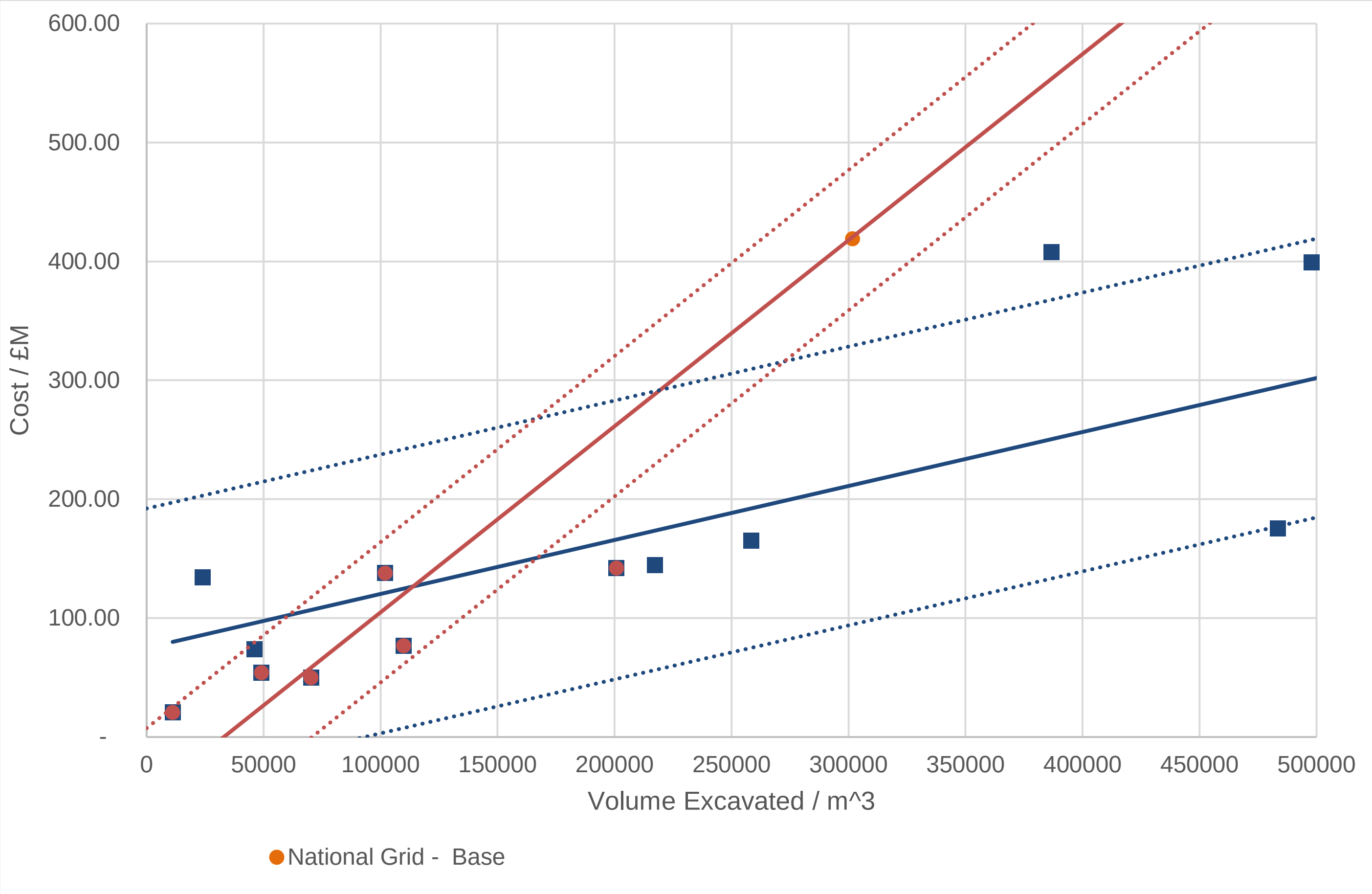

Figure 20 – Benchmarking of volume excavated NGET estimate vs. IPA Data Set

In Figure 20, the plot shows contract cost in £m versus the volume of excavated material for the tunnel as the independent variable. Trendlines are shown for the entire population of tunnels (blue) and Utilities (red). P20 and P80 predictability limits are the dotted lines. The data indicates that our estimated costs were aligned to the expected industry figures, confirming our cost forecasts are realistic and consistent with the market. In addition, our correlation of cost to the volume of earth excavated was aligned to the trend shown by other utility projects.

9.3 Quantification of Risk

As discussed in Section 8, careful consideration of site-specific factors and a full understanding of risk and uncertainty are required to mitigate the risk of significant underperformance.

9.3.1 Project Risks and Opportunities

Risks are uncertain events that effect the project objectives. These are classified as threats or opportunities. Both positive and negative events can have a major influence on the outcome of the project and therefore need to be managed. The events need to be managed not only at a project level but also programme and strategic level. This will ensure the management of risk is integrated between all contract packages and enterprise partners, which is vital for effective risk management and identification.

To manage and mitigate risk the LPT2 project has a defined risk management process, to identify, assess and manage risk throughout the project lifecycle. These are split into 3 tiers of risk – Strategic, Programme and Project risk.

Strategic risks are those with the potential to affect the overall LPT2 programme of works. Strategic risks are managed at the highest level, with scenario planning developed where appropriate, mitigation and actions developed, assigned and being actively managed to reduce the impact. Strategic risks include but are not limited to, Brexit, Land and consents agreements, Power supplies and mixed London Geology.

Figure 21 – LPT2 Risk Hierarchy

Programme risks effect multiple projects and/or packages and/or assets within LPT2. The overall impact will be managed at the Enterprise level, with actions assigned to the appropriate risk owner (Contractor or Client). The programme risks will impact each project and / or package differently and will therefore be identified within the Package risk registers.

Project risks affect an individual project outcome and/ or package and can be managed at package level and will be categorised as either Client or contractor depending upon who will own the risk management / mitigation."

Risk registers have been developed to align with the package structure mentioned previously and consider the influence on each ACL date.

The following is an illustrative extract from one of these registers.

nationalgrid

Table 17 – Summary of Key Risks

Title	Description	Cause	Impact	Probability	Impact
Mixed South London Geology	The LPT2 Tunnel route passes through mixed london Geology, the conditions could be more adverse than originally anticipated	Mixed London Geology, LPT2 Route is approximatly 42% Chalk which is harder to tunnel through	Increase in project cost Programme increase in duration	High	Very High
Power Supplies for Tunnel Boring Machines	LV supplies may not be available at the programmed dates for TBM start.	TBM drive sites will require LV supplies to power tunnel construction plant.	Procuring alternative power (generators) and/or delay to tunnelling programme.	High	Very High
Easements/Permissions & CPO Programme(s)	Additional constraints with regards to first site access dates if CPO programmes don't align, especially if Special Parliamentary Procedure is required.	Unable to secure voluntary agreements in a timely manner.	Delays to programme	Meduim	Very High
Brexit	Adverse trade conditions post-Brexit including high trade tariffs and adverse exchange rates affecting major equipment and cable system purchase. Potential labour issues.	Uncertain post-Brexit market conditions including trade tariffs, import duties and exchange rates.	Additional costs incurred in purchase of major equipment's from overseas suppliers. Import taxes imposed which are not covered through contractual arrangements.	High	High
Bengeworth Road Connection Offer	There is risk of delay to signing of connection offer and/or non-acceptance. Therefore this has the potentiatl to lead to wasted design	Lack of communication internally. UKPN has not been made aware of the criticality of Bengeworth Road connection to overall NG works on LPT2.	Impact on construction programme and additional costs associated with change to contractor's scope. Possibility of connection would become programme critical. Potential impact on size of Package 6 scope.	Very High	Meduim
Political Environment	Current politcal enviroment leading to a snap election and could lead to a new government.	Snap election called by government causing delay to planning and or change in national government could lead to a delay or review of major National Grid projects including LPT2.	Potential cost exposure and programme impact.	Low	Very High
Southwark Borough Council - Section 106	Unable to relieve current s.106 HGV number constraint.	Increase in HGV numbers above s.106 agreement.	Delays to programme and inefficiencies.	Low	Very High
AIP - Third party consents	Approvals will be required for crossing or construction near 3rd party assets - TW, LUL, NG Gas	Tunnelling near Existing assests of third parties	Payment may need to be made for surveys, remedial works and the approval process in addition to the delays caused by any additional works.	Meduim	High
Procurement Legal Challenge	Legal challenge could be raised by unsuccessful tenders	Contractors raising legal challenge to the procurement of contracts	LPT 2 Standstill/ Stop whilst legal challenge resolved	Meduim	High

Details of the significant risks are outlined as follows:

Mixed South London Geology – As discussed earlier in the report, South London Geology differs from the geology experienced on LPT1. This is by far the biggest risk to the LPT2 programme of works. Mitigation actions have been put in place to reduce the impact of this event by the production of a Geotechnical Baseline Report (GBR) which clearly stipulates the sharing of risk appropriately between Contractor and Client. The Residual risk remains with NGET, as conditions could be more adverse than investigations suggest. However, acceptance an overly conservative GBR or passing all risk to the Contractor would lead to an uneconomical higher tender cost returns.

Power supplies – There is a programme risk associated with securing low voltage supplies at the drive sites for tunnel boring machines. A number to solutions are being developed with UKPN and National Grid operation to mitigate this risk ahead of contract award and subsequent launch of the tunnel boring machines.

Easements/Permissions & CPO Programme – Three Compulsory Purchase Orders (CPO) are being progressed to obtain all necessary subterranean land rights. The success of the CPO will be determined on the number of appeals received following the three-week public consultation period. 2 Circuits will go to public inquiry in January 2020, with the third likely to follow in spring.

Brexit – Adverse trade conditions post-Brexit may result in higher exchange rates, a constrained supply of foreign labour, complications in importing foreign materials such as cables and will have an adverse impact on the supply chain capacity. This is being monitored and we will look to mitigate any potential impacts with our future contract partners, by putting provision within the contract. Within the contracts this is likely to be dealt with by way of a specific compensation event provisions. This allows the focus of any impacts relating to Brexit to be captured within one compensation event and gives the ability to mitigate any cost or time issues arising from Brexit.

Bengeworth Road Connection – The Bengeworth Road connection has the risk of delaying LPT2. The delay to the signing of connection offer and/or non-acceptance, could lead to unnecessary design. To mitigate this risk, planning collaboration sessions have been held with UKPN, with the current offer being extended until January 2020.

Political Environment – The current political climate has the potential to affect LPT2 programme of works. A change in government could cause delay to progression of the CPO's. This is being mitigated by managing the planning process.

Southwark Borough Council Section 106 – HGV vehicle movements at New Cross are limited by the Southwark Borough Council section 106 planning agreement. We believe this may result in programme inefficiencies and are working with the preferred bidder to optimise delivery given such constraint. We continue to engage with the Southwark Borough Council.

Approvals in Principle, Third Party consents – Approvals will be required for crossing or construction near 3rd party assets, work to engage with third parties to gain AIP to mitigate this risk.

Procurement Legal Challenge – Unsuccessful tenderers may raise a legal challenge following issue of tender standstill letters. In the event of appeal, progression of the contract and design must be held until the legal challenge is resolved. To mitigate this risk, a robust procurement process has been put in place with thorough moderation of the tender evaluation process.

9.4 Cost Breakdown

The following tables provide the estimated costs associated with the delivery of the engineering output of LPT2 from the point of establishing an initial business driver through to commissioning of the electrical assets and eventual completion of the project (internal close out by NGET). The estimated costs include all internal, third party, main works contractor and other costs e.g. consultant or legal fees.

As noted earlier in the report, the incremental costs of Option 1a (the Bengeworth Road GSP) works are not included. No costs are included for the operation or maintenance of the electrical assets once they are in service. The costs for operating and maintaining the asset will form part of the ongoing operational plan.

9.4.1 Overall Cost by Circuit

Table 18 – Comparison showing current National Grid Estimates by Circuit

All 18/19 Prices. All Capital Cost Included, NG, MWC, Contingency	**Wimbledon to New Cross**	**New Cross to Hurst**	**Hurst to Crayford**
Estimated total cost	£345,493,519.22	£413,171,864.57	£93,173,483.04

9.4.2 Overall Cost by Contract Package and Circuit

Table 19 – Cost breakdown by Package and Circuit

Contract / Works Package	**Wimbledon to New Cross**	**New Cross to Hurst**	**Hurst to Crayford**	**Total Non-Load**
Enabling	£925,513	£925,513	£0	£1,851,026
T&S	£200,587,110	£267,635,015	£65,542,706	£533,764,832
Cable Purchase	£42,732,812	£60,694,245	£10,486,374	£113,913,430
Cable Install	£49,555,169	£31,461,322	£6,429,367	£87,445,857
Substation	£29,144,194	£4,263,377	£1,140,037	£34,547,608
HH and M&E	£19,900,942	£29,885,870	£8,927,427	£58,714,239
Lands	£2,647,780	£18,306,523	£647,573	£21,601,875
Total	**£345,493,519**	**£413,171,865**	**£93,173,483**	**£851,838,867**

9.4.3 Cost Categorisation

For ease of assessment, we have applied a similar cost categorisation methodology to LPT2 as the one used for the recent Hinkley-Seabank SWW submission.

Table 20 – Cost Breakdown by Category

Category	**Wimbledon to New Cross Cost (£)**	**New Cross to Hurst Cost (£)**	**Hurst to Crayford Cost (£)**	**Total Non -Load**
Contractor Costs	£240,704,549	£302,683,109	£70,271,866	£613,659,525
Contract Purchases	£7,087,379	£0	£0	£7,087,379
Planting and landscaping	£1,443,713	£2,887,426	£721,857	£5,052,996
Other Procurement	£4,719,819	£5,123,298	£1,282,589	£11,125,706
Support functions (Design Assurance, Commissioning, Procurement, ET Ops Network Planning, External Affairs, Communications)	£6,477,169	£9,965,957	£917,576	£17,360,702
Consents (inc. Local authority payments)	£638,879	£851,839	£212,960	£1,703,678
Community relations	£55,672	£55,672	£0	£111,344
Project Services / Consultancy (Legal, tunnel assurance and inspection - JCOP)	£4,429,562	£4,429,562	£2,214,781	£11,073,905
Land Acquisition	£16,665,747	£7,974,587	£687,135	£25,327,469
Land Rights	£41,575	£5,624,977	£0	£5,666,552
Third Party Approvals & Asset mitigation	£2,849,975	£2,849,975	£633,328	£6,333,278
NG PM	£27,736,315	£34,671,999	£7,840,908	£70,249,222
Contingency	£32,643,164	£36,053,463	£8,390,484	£77,087,112
TOTAL	**£345,493,519**	**£413,171,865**	**£93,173,483**	**£851,838,866**

Table 21 – Comparison of National Grid PM Costs LPT1 vs LPT2

Category	**LPT1**	**LPT2**
National Grid PM	£78,576,870.3	£70,249,222
Total Project Cost 18/19FY	£926,090,382.7	£851,838,867
NG PM %	**8%**	**8%**

10.0 Delivery Strategy and Progress Update

Project delivery will be a key factor in the successful achievement of project outcomes. Section 10 outlines the progress to date, our overall programme of works, implementation of lessons learnt from LPT1 and next steps.

10.1 Land and Consents

A key lesson learnt from LPT1 was the benefits of using securing easements and permissions at the earliest opportunity (i.e. tunnel routing design freeze) ensuring land rights and planning consent are obtained well in advance of tunnel construction.

Following extensive consultation with 8 London Borough Authorities, the land and consents work stream confirmed that neither a Development Consent Order (DCO) or Environmental Impact Assessments (EIAs) would be required for the programme, allowing the project team to maximise the use of our Permitted Development rights for the tunnels.

10.2 Above Ground Rights and planning approval

Securing land rights for the above ground sites and easements for the deep tunnel happened in parallel throughout the development of the scheme. Planning permissions where progressed once land had been secured. The required above ground land rights have now all been secured or are at heads of terms stage with landowners. 5 of 6 planning approvals have been received for the above ground sites with the remaining consent with Bexley Council for consideration in December 2019.

10.3 Subterranean Land Rights and Third-Party Permissions

An easement is required where the tunnel passes under private property. 165 easements are required for the preferred solution representing a significant risk to the overall programme. Without an easement, the tunnel boring machine would be considered trespassing were it to enter the boundary of a private land where we had not secured an easement. A strategy was agreed early in the delivery programme that after a period of negotiation, outstanding easements would be pursued using National Grid's compulsory purchase powers. A public inquiry is scheduled for early January 2020 where an inspector will hear our case for securing the required land rights associated with the Wimbledon to New Cross and the New Cross to Hurst tunnel routes and circuits. The Hurst to Crayford tunnel permission CPO will follow in the Spring of 2020 negotiations for these land rights commenced later than the other routes. We are confident that many of the remaining easements will reach heads of terms and be agreed by negotiation in the reaming time before the inquiry and expect only a few objectors at the inquiry if any.

Where our proposed tunnel route crosses other deep tunnels or shallow buried assets we require permission from asset owners for our activities, in all cases monitoring of these assets will be undertaken, in some cases mitigation measures may be required on the asset prior to our tunnelling activities. These approvals are progressing but key to obtaining fully consent are the methods deployed by our future tunnelling contract partner.

10.4 Community Relations and Public Engagement

A community relations strategy has been produced and followed for number of years, including a consultation on our tunnel routes and above ground site activities. This is further detailed in Section 6.2 and has influenced design and delivery decisions on the programme (influencing the Hurst and Crayford temporary Haul road solutions to name two).

10.5 Front End Engineering and Design (FEED) and Ground Investigation Works

A front-end engineering design has been completed for the tunnel route to facilitate the land permission programme and the tender events. This will be worked up into a detailed design by our chosen contract partner and has been informed by extensive ground investigation work (deep boreholes). Early excavation works are underway at New Cross (20x50m area at 7m depth) to determine ground conditions ahead of mobilising the Tunnel and Shafts Contractor, as shown below in Figure 22. This has led to the discovery and removal of several obstructions all of which would have put the tunnel contractors programme at risk and potentially cost the programme time and money.

Figure 22 - Progress of Enabling Works at New Cross, October 2019

10.6 Spend to date

Spend to date on the scheme is £40m. £21m of this is associated with lands rights and permissions, £14m relates to ground works, development costs and engineering.

10.7 Delivery Plan and Next Steps

Development of the scheme, securing land rights and the procurement processes will continue to be the focus for 2019. National Grid's delivery team have entered into preferred bidder stage for the Shaft and Tunnel package (package 2) entering into negotiations through November 2019. The remaining packages (cable supply, cable install, M&E/Headhouses) are in the procurement process and will receive returns for all bidders in 2019. Contractors will be invited to tender for the package 6 (substation package) in early 2020.

Whilst the programme will evolve based on construction progress and onsite materialisation of risk, the below figure depicts the high-level timelines for the delivery of each package and subsequent commissioning:

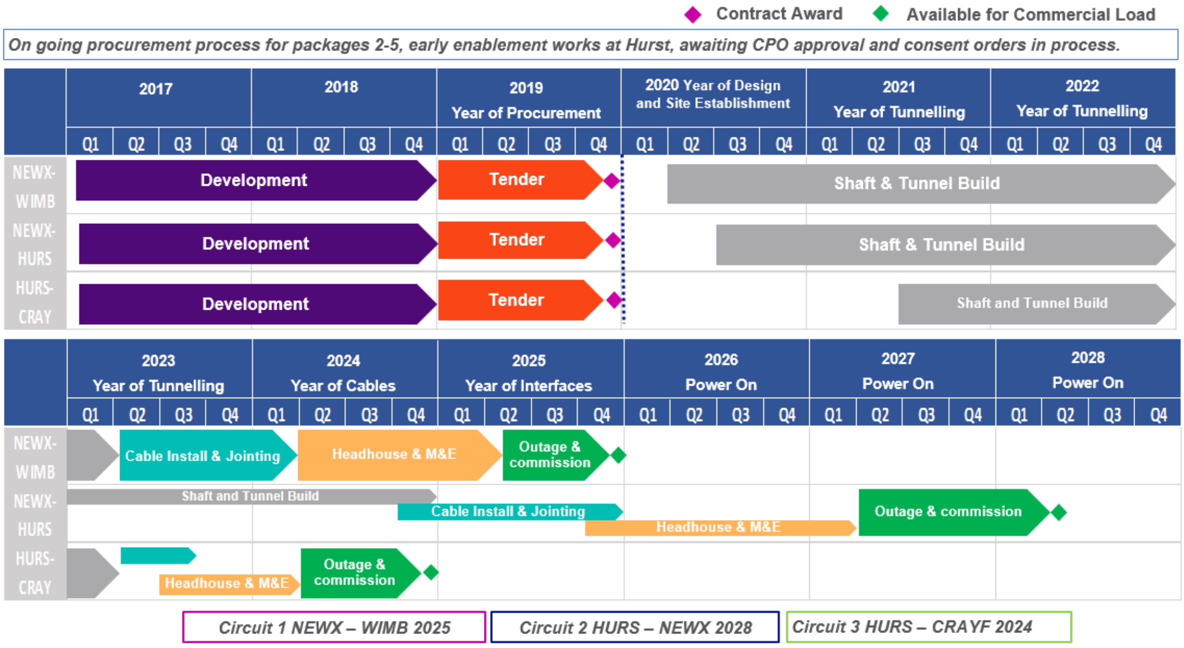

Figure 23 - High Level Project Programme (as of November 2019)

The programme shows the staged commissioning of the three circuits starting in 2024 with all works including decommissioning of the old circuits completing in 2028. The current tunnel drive strategy is likely to include the operation of 4 tunnel boring machines to deliver against our stretch target dates for the Hurst - Littlebrook Circuits and Wimbledon - New Cross of 2024 and 2025 respectively. This approach was validated through our market engagement.

10.8 Governance including Enterprise formation

It is proposed that the LPT2 project team will continue with the quarterly engagement meetings with Ofgem to maintain regular communications providing progress updates, forthcoming plans and raise any potential queries or concerns.

The overall programme of works for LPT2 has been approved by National Grid's Group Executive Committee. The programme comprises of several distinct investments all of which were sanctioned at Electricity Transmission Investment Committee (ETIC) and will receive ongoing governance to maximise scrutiny during the delivery of each investment. The sum of financing totals is more than the NGET board's financial delegated authority, so approval was sought from the Group Executive Committee for the continued delegation of authority to ETIC for each individual investment.

Since January 2018 a monthly LPT2 Project Board governance meeting has been held. The terms of reference for this states; the overall purpose of the LPT2 Project Board is to ensure that the correct investment, contracting and delivery strategies are deployed for works required by the project. In addition, the LPT2 Project Board shall provide strategic direction to the LPT2 delivery, commercial and project management office (PMO) teams.

The LPT2 Project Board acts as a forum for Heads of Function within National Grid to review and agree key decisions for the LPT2 project and other associated programmes. The Project Board will provide an escalation route for the project team and ratification/approval for key decisions made.

The initial Enterprise management model and governance plan between National Grid and our contract partners is shown in Figure 24 below. Contract review meetings will occur on a weekly basis during delivery for each contract package and will include monthly reviews with the Project Director and Contract Delivery Manager. Core Group Enterprise level meetings will occur on a quarterly basis, where each contractor will assess one another's performance against the enterprise project outcomes and the Enterprise Performance Measures. National Grid senior leadership will be meeting with senior executives from the Enterprise partners on a regular basis at Advisory Board Steering Committees to informally review and discuss the overall health of the Scheme and assess the Key Result Areas for the project.

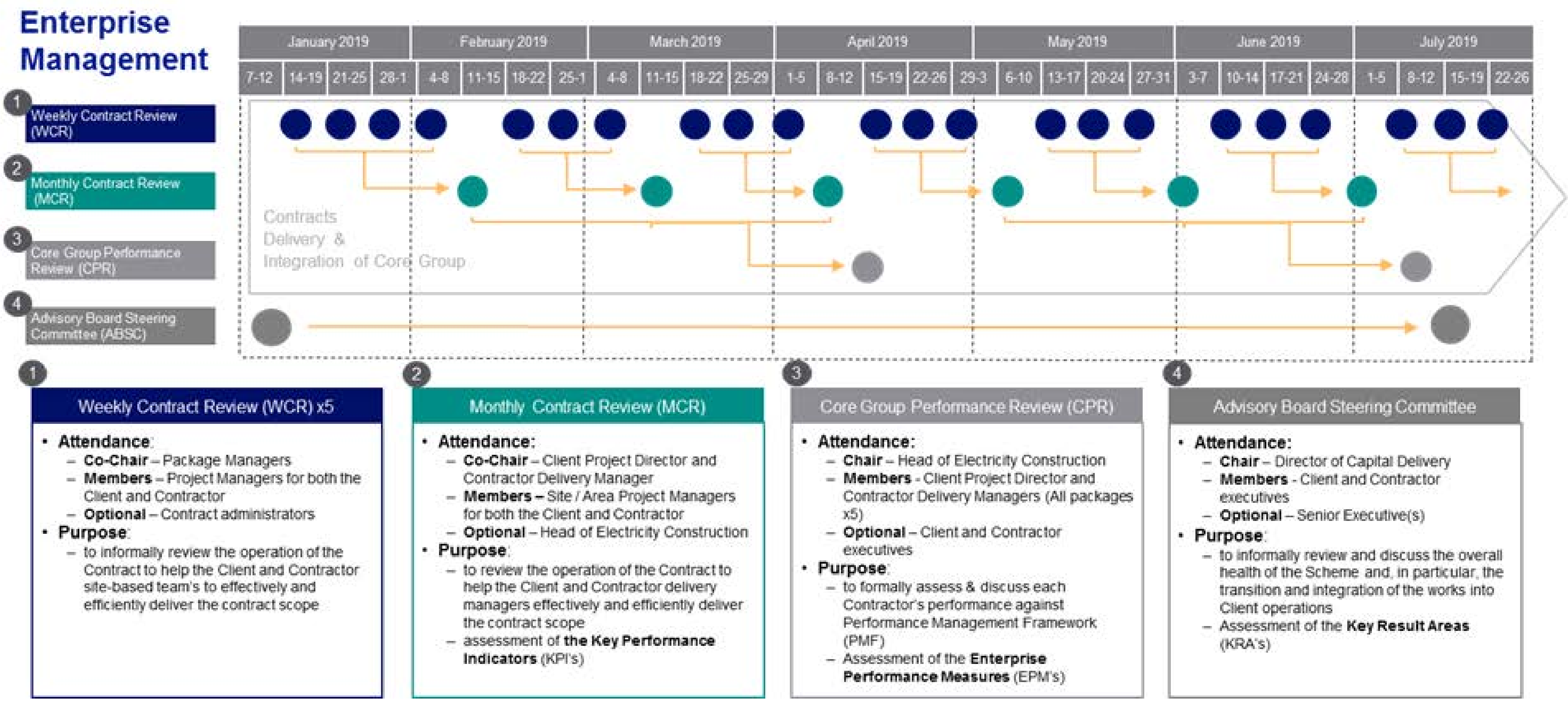

Figure 24 - Enterprise Management Plan

11.0 Conclusion

In conclusion, the project needs case is evident: the existing oil filled cables between Wimbledon – New Cross – Hurst – Littlebrook have reached the end of asset life. System Design studies have confirmed that there is a need to maintain transmission connections between the substations, to continue to supply consumers in South London and consideration has been made of the expected increase in demand of at least 25GW by 2050. The needs case has a received written approval from Ofgem as documented in Appendix 1.

Initial optioneering considered a range of technologies and deployment solutions to satisfy the need. These were narrowed down and a detailed CBA compared two viable options, with the option of a whole system solution of a future GSP at Bengeworth Road to supply UKPN also considered. As a result, the following decisions have been taken:

1) Maintain a continuous route through South London, connecting between Littlebrook, Hurst, New Cross and Wimbledon.
2) Replace existing direct buried circuits with cable circuits housed in 32km of tunnel.
3) Install 400kV cable across the whole route to avoid future early replacement costs. Circuit 2 & 3 will operate at 275kV providing capability for future uprating (to 400kV) as required; Circuit 1 (Wimbledon-New Cross) is to be uprated to and operated at 400kV.
4) Deploy XPLE cable technology, replacing the existing oil filled cable.
5) A GSP at Bengeworth Road will fulfil customer requirements for UKPN (modification in progress).

The solution:

- Delivers the lowest cost for end consumers, demonstrated by the Cost Benefit Analysis.
- Solves demand capacity issues and maintains diversity of supply within Central/South London at lowest cost.
- Achieves programme ACL dates and satisfies environmental impact constraints.
- Satisfies the requirements of key stakeholders with regards to impacts on the London Boroughs.
- Minimises operational and delivery risk during construction.

The Bengeworth Road GSP is pending in project scope until a connection agreement is signed by the customer (UKPN). A decision on target to be confirmed in early 2020. The GSP fulfils the asset replacement needs for both the Transmission and Distribution networks in South London and provides highest value for both networks. Should the connection offer not be accepted, the LPT2 needs case and programme of works remain unaffected and will proceed in line with option assessment 1.

Lessons learnt from LPT1 and other National Grid projects have been taken into consideration. Market and industry engagement has also informed the procurement and contracting strategies. The P13 Enterprise will incentivise collaborative behaviours and deliver the key outcomes of re-wiring South London, removing significant risk off the network and deliver value for end consumers. The project costs are robust when appraised against:

- External benchmarking (IPA benchmarks)
- Internal Benchmarking (appropriate comparison to LPT1)

National Grid have provided Ofgem visibility of the project during the development phase including forecast costs and delivery strategy.

Investment in the RIIO-T2 period of £645.8m is therefore economical, efficient and justified.

Appendix 1: Ofgem Needs Case acceptance email

From: Akshay Kaul
Sent: 10 July 2019 12:12
To: Chris.Bennett@nationalgrid.com
Cc: Paul O'Donovan <Paul.O'Donovan@ofgem.gov.uk>
Subject: London Power Tunnels 2 [OFFICIAL]

NGET has been actively engaging with Ofgem on the LPT2 project. You have provided us with an Investment Justification Report which presents the needs case for replacing the existing underground cables between Wimbledon – New Cross – Hurst – Crayford Cable Sealing End. The IJR proposes underground tunnels as the most economic and efficient means of implementing this replacement work.

Based solely on the evidence presented in the IJR, we accept that the cables need to be replaced and that the tunnel option seems to be the best option amongst those considered in the IJR. This view is consistent with the need case accepted by Ofgem which established existing T1 allowances for the LPT2 project.

While we did not note any obvious shortcomings in the report during our initial review, we would expect this work to be subject to more rigorous scrutiny during the assessment of your T2 business plan. This will inform our more considered view of the RIIO2 allowances in respect of the proposal, not the need for the work.

We would expect that your proposed spend within RIIO-T1 period is covered off by your existing T1 allowances. Confirmation of RIIO2 allowances will be based on our assessment of your full submission as part of T2 business plan assessment and the following consultations.

I welcome the arrangements that have been put in place for regular updates on the progress of the project at working level.

Jenny Rose, PA on behalf of
Akshay Kaul
Director of Networks Price Controls
10 South Colonnade
Canary Wharf
London
E14 4PU
Tel: 020 7901 7162
[www.ofgem.gov.uk]www.ofgem.gov.uk

Appendix 2: Monetised Risk and End of Life Modifiers

The RIIO-T2 asset replacement plan for cables is based on the Monetised Risk methodology and has been optimised to enable the most cost-efficient plan. Full details of which can be found within the "*National Grid Electricity Transmission Network Output Measures Methodology Network Asset Risk Annex*".

We have used the monetised risk (NARMs) methodology for the lead assets. The risk associated with end of life (EOL) failure modes is determined by generating an EOL modifier score for every lead asset. The EOL modifier is different for each of the lead asset types to cater for the information that needs to be considered to establish the end of life risk. In general, an end of life modifier will consider relevant condition data for the asset.

The factors to be considered when determining an EoL score for a cable asset are:

1. Historical environmental performance.
2. Historical unreliability.
3. Risk of tape corrosion or sheath failure.
4. Results of condition assessment and other forensic evidence.
5. Service experience of cable systems of similar design.
6. Number of defect repairs.
7. Number of cable faults.
8. Duty in terms of how much time annually a cable is running at or above its designed rating.

These metrics only include a few condition-related components since there is limited information that can be obtained on how deteriorated a cable is. Further condition information could be obtained by digging up and taking samples of a cable, but this is not practical, would be costly and could also cause further failures.

When determining EoL it is important to consider at which point it is no longer reasonably practicable to maintain SQSS compliance whilst maintaining a sustainable level of circuit availability. In general, the cable circuit will only meet the criteria for replacement where refurbishment will not address condition and performance issues and guarantee compliance with statutory requirements.

EoL will generally be supported by evidence of deterioration of the main cable system; this may be associated with either mechanical or electrical integrity or withstand capability. However, if a cable is known to suffer from a condition problem where the transition from reliable performance to unacceptable performance is likely to give insufficient time to plan replacement (<10 years), predicted performance of that cable system is used to prioritise investment.

Table A2.1 below defines the condition criteria across the range of possible EoL scores:

Table A2.1 – EoL Categories Probability of Failure specific to Oil-filled Cables

>=98	Definite evidence exists of a serious problem with the cable which covers a significant portion of the cable or is distributed along the route.
<98	Evidence exists of a problem with the cable, possibly with a specific section that is particularly problematic. The cable system would be expected to deteriorate to Priority 1 within 5 years.
<55	Cable known to have faults or defects – some of which could cause failure. May be a known issue with the cable family.
<20	Good condition – no known specific or general life limiting problems with the cable.

Refer to Appendix 4 for the calculations driving the EoL score in Table A.2.2 for the LPT2 existing cable circuits.

Table A2.2, below, provides a summary of the Asset Health position for the LPT2 cable circuits.

Table A2.2 – LPT2 Existing Asset Health Position

Asset	16/17 RP with RAT date	17/18 RP with RAT date	18/19 RP with RAT date	2018/19 Evidence (Faults over the previous 10 years)
HURS – NEWX 1 21.0km	5-10 (2020)	0-2 (2020)	0-2 (2020)	**EOL Score = 100** >90 defects, >2350 hours out of service, oil leaks >6000l
HURS – NEWX 2 21.2km	5-10 (2020)	0-2 (2020)	0-2 (2020)	**EOL Score = 100** >90 defects, >1500 hours out of service, oil leaks >4900l
NEWX – WIMB 1 13.5km	5-10 (2020)	0-2 (2020)	0-2 (2020)	**EOL Score = 100** >90 defects, >2350 hours out of service, > 50days ACU, oil leaks >2500l
NEWX – WIMB 2 13.5km	5-10 (2020)	0-2 (2020)	0-2 (2020)	**EOL Score = 100** >80 defects, >2350 hours out of service, oil leaks >900l
HURS – LITT 1 2.6km	5-10 (2020)	5-10 (2020)	0-2 (2020)	**EOL Score = 100** >10 cable defects, water cooling system failures. Oil leaks >400l, high overheads associated with SVL failures
HURS – LITT 2 2.6km	5-10 (2020)	5-10 (2020)	5-10 (2020)	**EOL Score = 90** 5 cable defects, water cooling system failures. High overheads associated with SVL failures.

Appendix 3: Transmission Network Requirements details

Appendix 3A: Do we need to retain connections to the existing GSPs?

As the existing Wimbledon-New Cross-Hurst-Littlebrook cable circuits are the only transmission connections to the existing GSP substations, it is, therefore, necessary to maintain connections to these sites in some form to continue to supply consumers within Central and South London. There is insufficient capacity existing within the Distribution Network to achieve the connected demand at these sites as they rely on transmission supplies to meet group demands. The transmission circuits are also important to managing import and export scenarios over the interconnectors in the South East and cross flows generally on the transmission network.

If the circuit connections to the existing New Cross and Hurst GSPs were not to be replaced, these demands would have to be supplied from other GSPs. New Cross currently has some interconnection to Wimbledon, and Hurst to Beddington, but this is only sufficient to supply a small amount of the connected demand. The consequence of not replacing the existing circuits would drive disproportionate costs in new transmission infrastructure and carry an unacceptable level of risk due to the inherent difficulties in securing additional land, consent and working on congested, heavily utilised sites.

Reducing the number of GSPs supplying existing consumers in Central and South London would also reduce network resilience, placing consumer supplies at increased risk. This would be alongside unprecedented levels of reinforcement that would be necessary within the DNO network due to the lower power carrying capacity of lower voltage equipment. Multiple new circuits would be required to replace the equivalent capacity of a double circuit transmission route.

In conclusion, it is not a credible option to disconnect these GSPs and supply the existing 724MW of connected demand from elsewhere based on insufficient capacity within the Distribution Network. If these circuits are not maintained, the security of the transmission system, distribution system and ultimately end consumers in London would be compromised. As the system need for these circuits is demand based, not voltage or compensation where a remote solution could be considered, there is a clear system need for these circuits to be replaced in some form to maintain continuity of supplies to London.

Appendix 3B: East Side Connection Options

On the basis that transmission circuit connections to existing GSPs are required to maintain supplies to South London, the high-level option review initially considered what connections could be made to Hurst substation to preserve connections on the east side of the existing south London circuits.

Hurst is located approximately 6.9km Line of Sight (LoS) to the south-west of Littlebrook 400/275kV substation, and includes a 2.4km cable section on both circuits. An alternative connection could potentially be made to the Longfield Tee-Rowdown circuit. Although slightly closer to Hurst (due south, just off the map) than Littlebrook at around 5.4km (LoS), this would require a new longer length circuit to be established as no existing overhead line route exists similar to the Hurst – Littlebrook circuits. The associated cost in constructing a new substation in the area of junction 3 of the M25, in addition to triggering 27km of re-conductoring of the Longfield Tee-Littlebrook circuits versus replacing the existing 2.4km section of cable, led to the conclusion that the optimal and economical solution was that Hurst should remain connected via Littlebrook.

Appendix 3C: West Side Connection Options

To the north-west, St John's Wood is located approximately 9.2km (LoS) from New Cross and is a highly-connected site, having the single largest demand of any National Grid substation. Establishing new circuits into this substation would cause fault level issues, and increase the transmission system security dependence on this single site meaning a HILP event could have wider ranging consequences to demand security for an increased area of London, with customer security adversely affected. Early optioneering highlighted that the existing substation is physically space constrained and so this option was not considered deliverable and was therefore discounted.

To the north of New Cross, both City Road and West Ham substations could be considered as potential sites for connection of new circuits. City Road is located in the heart of the London and encompasses an underground substation which is extremely space constrained with insufficient land/space to allow construction of new assets. Although the City Road site is located 5.7km (LoS) to New Cross, West Ham would present a more favourable connection option to the north, due to a reduced distance 5.5km and East London location. Like other London sites West Ham is a highly-congested with limited land availability. Further circuit connections would create fault issues. This could be mitigated through modified running arrangements, although this increases operational complexity.

The existing south-London oil-filled cable circuits currently terminate at Wimbledon 275kV on the west side of London which is located approximately 10.8km (LoS) from New Cross. Wimbledon substation is currently being re-developed with a new NGET 400kV GIS substation and a new UKPN 132kV substation. The new 400kV GIS substation is located adjacent to the existing LPT1 headhouse which was constructed to facilitate the connection via tunnel of 2 new cable circuits. The substation has space and infrastructure provision for optional connection of 4 new future cable circuits, of which 2 could be utilised for these new circuits.

From the perspective of connecting New Cross GSP to the transmission system, the West Ham option is a viable system alternative to replacing the existing circuits to Wimbledon like-for-like. It should be noted however that identifying a feasible circuit route and securing land would be complex due to the need to cross the Thames into Central London and pass through a densely-urbanised part of London.

Appendix 3D: Removal of Through Route

Due to the existing New Cross-Hurst double-circuit route forming the longest section, avoiding replacement of these circuits would offer a potential cost saving for the investment. Connecting New Cross and Hurst GSPs to remote parts of the network and removing the interconnection between these sites was evaluated including:

- Radial connection of LITT-HURS and WHAM or WIMB-NEWX (requiring independent third circuit to maintain compliance)
- Connection of LITT-HURS-BARK and WIMB-NEWX-WHAM
- Connection of LITT-HURS-BARK and CITR-NEWX-WHAM

Although the above non-radial options provide a resilient double-circuit route for the existing GSP sites, they subsequently increase demand and flows to an unacceptable level through the remaining 2 corridors (SJOW-BARK & ROWD-BEDD-WIMB). This is due to the removal of the third London corridor between the south east and London.

Maintaining a through route corridor, as per the existing arrangement, provides an extra flow path into and across London, avoiding overloading existing circuit route corridors. Benefits and observations for the need to retain a London through route include:

- During high interconnector import conditions, without this route, a fault on BEDD-ROWD would leave all system generation and imported flow in South East pointing towards Barking, overloading that corridor.
- In the event of high interconnector export conditions, there are known network reinforcements within the London area that will be required in the future, such as, a new route of SUND-ELST-SJOW-WIMB-NEWX-HURS-LITT to avoid overloading central London. Removal of the existing though-route would accelerate the need for investment / intervention that could otherwise be deferred.
- Uncertainty in projected London demand growth due to planned strategic developments (i.e. new London Plan) and electrification of both transport and heat may potentially trigger an uprating of the existing Wimbledon – New Cross – Hurst – Littlebrook circuits to 400kV.

Appendix 3E: 400kV Design Strategy and NPV

Cable Rating Options

One option for the works is to replace existing circuits at 275kV (like-for-like replacement), these cables would then later need to be replaced with 400kV cables once demand growth is sufficient. To avoid replacement of cable and enable the cables installed as part of LPT2 to be re-used in the event of a future 400kV uprating trigger, 400kV cable could be installed instead.

Cable supply and tunnel install costs based on the two options (noting sensitive to forex and material costs) are estimated as:

Table A3.1 – Cable and Tunnel Install Costs

Voltage (kV)	Conductor (Cu) Area (mm^2)	Cable Purchase and Tunnel Installation Cost per route (km/£) (2016/2017 Price Base)
275	2000	2,841,105
400	2000	3,004,171

An NPV analysis (shown in Table 25 below) has been conducted to determine the uprating trigger year at which it would be more economic to install 400kV capable cable as part of LPT2 and operate this at 275kV as opposed to replacing the new 275kV cable with 400kV when required. This analysis has been based on cable costs being applied within the currently proposed commissioning years, with any future replacement spread across 3 outage seasons due to system access requirements that would be needed for any future uprating of these circuits to undertake the cable replacement within the tunnels constructed as part of LPT2.

Table A3.2 – NPV Analysis of Cable Capacity Options

	Install 400kV XLPE Cable	Install 275kV XLPE Cable Then Replace Within 40 Years
Lifetime of Project/Decision	49 years	89 years
NPV	(62)	(68)
Annualised NPV	(3)	(3)
Discounted Payback	n/a	n/a
IRR	n/a	n/a
Annualised NPV Ranking	1	2
Discounted Payback Ranking	n/a	n/a
IRR Ranking	n/a	n/a

System studies considering projected future demand growth indicate that a single cable per phase solution is deemed sufficient and the most economical solution for this non-load scheme. Therefore, 400kV cable will be installed on all circuits to ensure the capability to uprate these circuits to 400kV in the future if/when a trigger develops. This will increase the total cable supply and install cost within the tunnel by circa 5%, however avoid the need to replace these cable assets in the future. NPV analysis determines that the most economical solution is to install 400kV capable cable, if these circuits require uprating and replaced at any point 40 years post-commissioning. This will also maintain system flexibility and avoid significant early asset right-off costs at a marginal increase in cost as part of the initial investment.

Circuit Voltage Rating Options

The options for the circuit ratings for Circuit One are to operate at 275kV cable as part of LPT2 and then carry out further works to uprate to 400kV when required; uprate all circuits to 400kV as part of LPT2 or to uprate Circuit One 1 & 2 to 400kV during the construction of LPT2.

Uprating Circuit One

An NPV analysis has been conducted to determine the uprating trigger year at which it would be more economic to uprate Circuit One to 400kV as part of LPT2. This analysis has been based on substation work costs being applied within the currently proposed commissioning year of 2025/26.

Table A3.3 - NPV Analysis of Circuit Voltage Rating Options

	Uprate Circuit One to 400kV	**Circuit One at 275kV then Up-rate in Future**
Lifetime of Project/Decision	48 years	58 years
NPV	(12)	(12)
Annualised NPV	(1)	(1)
Discounted Payback	n/a	n/a
IRR	n/a	n/a
Annualised NPV Ranking	1	2
Discounted Payback Ranking	n/a	n/a
IRR Ranking	n/a	n/a

As can be seen in the above table, the NPV analysis determines economic efficiency option to uprate Circuit One during LPT2, if uprating is required 10 years post-commissioning which is justified based on projected demand growth exceeding existing circuit ratings 6 years post-commissioning of LPT2. This option will require an additional investment of £9.5m compared to a prospective 275kV solution, however will provide sufficient headroom increase to accommodate future demand growth.

It is recognised this would offer an enduring solution for London in terms of increased capacity for demand growth given current uncertainties regarding the speed of demand increase.

Additionally, proceeding with a connection at 400kV would present a significantly lower risk option due to the complexities of achieving a technically and operably acceptable 275kV design solution and the inherent programme risk of connecting at 275kV due to site constraints and reliance of completion of work by UKPN.

Uprating Circuit Two and Three

If 400kV uprating of existing substations was undertaken to support operating Circuits Two and Three at this voltage, significant reconfigurations of the substations would be required. For example, at Hurst this would require the construction of new 400kV GIS substation to replace the existing 275kV AIS 4-switch mesh. In addition to the cost of new switchgear and associated protection and control equipment, the site comprises 3 x 275/132kV SGTs and 4 x 275kV Shunt Reactors, all of which would require to be replaced with 400kV rated wound plant if the substation was to be uprated. A cost of in excess of £40m would be expected to undertake such a reconfiguration of the site.

Circuit 2 is within centre of route between Wimbledon and Littlebrook, thus requires lower ratings than the cable circuits either side. Flows along this route will be lower than either end substations due to the demand supplied at these points, hence system studies conducted and results provided above identify the minimum headroom for Circuit One. An enhanced capacity of Circuit Three could be achieved via the installation of new 400/275kV transformers at Hurst with removal of existing SGTs at Littlebrook and interfacing circuits these circuits to the new planned 400kV GIS. However, with additional work necessary to uprate the VN route to 400kV and fact an additional 100MW of headroom exists compared to Circuit One based on N-1-1 condition, it is recommended this is considered as part of a separate scheme following further study work and determination of future demand trigger point on this circuit route.

Installing 400kV rated cables as part of LPT2 would not preclude future uprating of these sites to operate at 400kV. Due to the major investment required and complexities surrounding uprating Hurst and New Cross 275kV substations to 400kV and no medium-term driver to support this based on an increased headroom on these circuits compared to Circuit One, it is not recommended to conduct the uprating of these circuits at this time until a more robust driver develops.

Appendix 3F: Cable Technology

National Grid Electricity Transmission (NGET) network predominately operates at 400kV and 275kV. High Voltage (HV) underground power cables are used to carry electrical current from one substation to another in built-up areas such as cities. The cables carry crucial power flows that are required to balance supply and demand on the network. Power cables consist of three major components; conductors, insulation and protective jacket. The makeup of individual cables varies according to application. Power cables use copper or aluminium conductor surrounded by an insulation medium, as illustrated below.

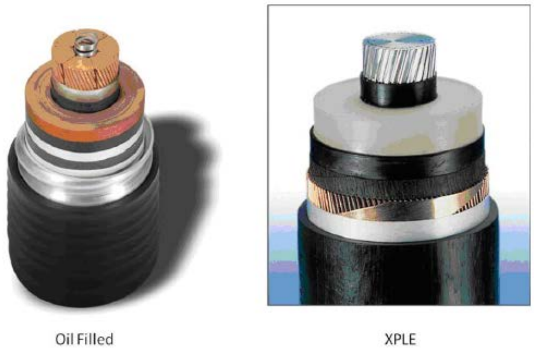

Figure A3.1 – Oil filled and XLPE Cable Technologies

Fluid-filled cable

Many of NGET’s existing cable routes were installed over 40 years ago, when cable insulation technology was based on oil-impregnated paper wrapped around a central energised conductor, with the whole assembly sealed in a rubber sheath. Over time this outer layer of insulation can degrade, leaving a risk of oil-filled cables leaking oil into cable ducts and the surrounding soil.

XLPE cable

Currently, aging cables are being replaced with modern equivalents with solid cross-linked polyethylene (XLPE) material, which is extruded around the conductor. The absence of fluid in the cable insulation enables a more mechanically robust overall cable construction. XLPE cables require less maintenance, with no ancillary fluid equipment to monitor and maintain. Due to the comparable simplicity of XLPE, this type of cable can be installed in most areas, such as tunnels, ducts and troughs.

Appendix 3G: Replacement Methodology

Overhead Line Route

The construction of a new overhead line route between the South London substations is not feasible due to the densely-populated landscape, thus an overhead line corridor does not exist.

Cable Replacement by Direct Burial

A feasibility study has been undertaken for replacing two 275kV cable circuits from Hurst Substation to Wimbledon by direct buried circuits laid along London's arterial highways. The study identified that construction works for the planned routes would require significant utility diversions, lead to extensive traffic restrictions, diversion, reduced speed limits, closures and part closures of roads. Access to homes and local shops would be restricted and may lead to temporary loss of amenity and affect local businesses.

The stakeholder engagement undertaken to date confirms that replacement via direct buried cables would cause unacceptable levels of disruption to the road network and consenting bodies would be minded to refuse any planning applications. TFL have expressed serious concerns about an in-situ replacement due to the level of disruption this would cause to the London Road Network and are, therefore, supportive of the tunnelling option. The London Borough of Lewisham have also expressed a preference for a tunnelled route over a direct highway replacement due to the potentially lengthy and disruptive road closures of some of the busiest roads and junctions in their borough. This option also fails to meet the project outcomes, such as ACL dates and the requirements of the local community, businesses & stakeholders and has therefore been rejected.

Cable Replacement by Tunnel

There are greater than 100km of cable tunnels in London owned by the DNO and ET, this is primarily due to insufficient space in the highway and the high levels of disruption an alternative would cause. Cable replacement by tunnel mitigates those risks identified above and provides many benefits both during installation and for the full asset life of the new circuits:

- The tunnel infrastructure will be designed for 120 years;
- The construction impacts associated with the removal of spoil from the tunnel are limited to a small number of Drive Sites (where a tunnel boring machine is launched and operated from), rather than across the whole of the cable route;
- There is the potential for other circuits to be accommodated within the tunnel;
- Future maintenance and repairs would be able to be carried out with ease and no disruption to the public. Access can be taken through the shafts that are put in place during the construction of the tunnel. Such maintenance would not require any excavation or heavy plant movement and the associated disruption that can ordinarily be caused on the road network when direct buried cables have to be accessed;
- At the end of the cable asset life the ease of cable removal and replacement is significantly increased through the tunnel providing access to the full cable route without the need for any excavation;
- Enclosing the new cables within a tunnel provides almost certain protection for the cable over its asset life due to the depth and protection the tunnel offers.

Tunnel installation is generally used in urban locations where direct bury installation would cause unacceptable disruption.

The advantage of housing cables in deep tunnels are that underground services such as water and sewerage are unaffected, and river or railway crossings can be made. Also, because of limited surface land take, normal development can take place at ground level and along the route of the tunnel there is minimal disruption during construction and maintenance. However, these result in significant costs associated with planning consent, land acquisition and planning and constructing a route to avoid major surface and underground structures. In addition, development at the primary construction site is likely to generate environmental impacts, such as disruption to traffic, noise, vibration and dust for the duration of the development.

Appendix 3H: DNO Works – Bengeworth Road Options

UKPN's Bengeworth Road 132/33kV substation supplies five primary substations as well as providing a 15MW supply to Thames Tideway for their construction works. The substation comprises 4 x 45MVA transformers supplied by double circuit connections to Wimbledon and Deptford.

Existing group demand exceeds Bengeworth firm capacity with the deficit forecast to reach 60 MW by 2026. P2/6 compliance is maintained by interconnection to New Cross 66kV GSP via Chadwick Road, which in turn is expected to exceed firm capacity in 2025 when it will be necessary to reinforce the south London distribution network.

The options and incremental costs associated with addressing UKPN's needs are summarised below:

- **Tunnel Share with National Grid**
    - Installing new, higher rated 132kV cables to Bengeworth Road in NGETs South London tunnel. It has been rejected due to the cost of increasing the NG tunnel bore from 3m to 4m internal diameter for the 12.2km section between Wimbledon and New Cross. Additionally, it would be necessary to reinforce Bengeworth Road 33kV to maintain P2/6 compliance.
- **UKPN Open-Cut Asset Replacement of Wimbledon-Bengeworth Road**
    - Open-cut installation of higher rated cables has been rejected by UKPN due to impracticality and delivery risk associated with extensive street excavations across high urban density South London. Even if a viable route could be identified, significant opposition is expected from local authorities due to the disruption to local communities and traffic flows. Additionally, it would be necessary to reinforce Bengeworth Road 33kV to maintain P2/6 compliance.
- **UKPN Construct Deep Cable Tunnel**
    - UKPN to construct two new tunnel sections; a new 10.5km tunnel between Wimbledon and Bengeworth Road and a new 7.8km tunnel between Bengeworth Road and Deptford equipped with high-rated 132kV cables. The route would follow the new National Grid tunnel however, due to sub-surface congestion, it is noted there is a high probability that a longer, less direct route would be required with significant delivery risk of securing intermediate shaft site locations. Additionally, it would be necessary to reinforce Bengeworth Road 33kV to maintain P2/6 compliance.
- **Constructing a new GSP at Bengeworth Road**
    - A new GSP at Bengeworth road with a 400kV cable connection, this connection is connected to the NGET system through an addition to the planned LPT2 tunnel.

Table A3.4 below provides a summary of the options considered and their incremental cost to solve UKPN's asset replacement need.

Table A3.4 – UKPN Options Summary of NPV Analysis

Option	Incremental Cost (£m)
Tunnel Share	77
UKPN Open Cut	Discounted (Not deliverable)
UKPN Deep Cable Tunnel	105
New GSP at Bengeworth	49

As is shown by the NPV Analysis a new GSP at Bengeworth Road is the most economical solution for end consumers, but it also provides qualitative benefits:

- It overcomes the identified capacity shortfall at Bengeworth Road.
- It results in a consequential increase in capacity headroom at Wimbledon and New Cross GSPs thereby deferring reinforcement at these sites. The new GSP would also facilitate demand transfer from City Road GSP (shown on the map in Figure 4) to New Cross 132kV, relieving City Road of becoming overloaded.
- It provides the minimum cost solution for reinforcement and asset replacement of UK Power Networks' south London network, including avoidance of asset replacing 10.1km of Bengeworth Road-Wimbledon and 7.8km of Bengeworth Road-Deptford circuits.
- It provides increased distribution network resilience against a High Impact Low Probability (HILP) event through GSP diversity. There are currently only a small number of GSPs supplying high levels of demand in south London.
- ‘Brown Field’ former operational land is currently available at Bengeworth Road to accommodate the new substation assets.
- Secures south London primary supplies into the medium and longer term.
- Bengeworth Road 33kV supplies five space constrained 33/11kV primary substations and Thames Tideway at Kirtling Street. Establishing a 132kV GSP would allow uprating of these downstream substations to 132/11kV thereby increasing capacity without a material increase in footprint.

Appendix 4: NGET Network Output Measures Methodology Network Asset Risk Annex

Underground Cable Parameters

SCORING PROCESS

The formula to determine the EOL modifier for cables, which is capped at a maximum of 100, is:

$$EOLmod = ACS + Sub\_ADJ$$

Equation 1

Where ACS is the main asset condition score and Sub_Adj is the sub-asset condition score adjustment.

$$ACS = (AALc * GFR) + DUTY + \max(DEFECTS,\ SEVERITY) + ACCESS + \max(OIL, PROIL) + Main\_ADJ$$

Equation 2

The factors defined in this formula are described as listed below.

CURRENT AGE VARIATION FROM ANTICIPATED ASSET LIFE AALC:

In the table below variation= age – anticipated asset life.

Table A4.1

Variation from anticipated asset life (*AALc*)	
>=Variation	Score
-100	0
-5	2
0	5
5	20
10	25
15	30

GENERIC FAMILY RELIABILITY (GFR)

This component is used to score any known generic family issues which can affect the anticipated life of the asset, that is, a design weakness may become apparent for a particular family of assets. For example, it has been determined that type 3 cables have a known generic defect. Type 3 cables are AEI and pre-1973 BICC oil filled cables with lead sheath and polyvinyl chloride (PVC) over sheath and an additional risk of tape corrosion or sheath failure. This scoring takes account of the family design issues which are a risk to the anticipated asset life.

Table A4.2

Generic Family Reliability (*GFR*)	
	Weighting
Evidence of design issue	3
Vulnerable to design issue	2
Vulnerability to design issue mitigated	1.5
Other	1

DUTY

This represents the operational stress that a cable route has undergone during the last 5 years. It is measured in terms of the hours the cable has operated at or above its maximum designed continuous rating during the last 5 years.

The England and Wales transmission owner will set this factor to zero, as cables are not operated at or even near maximum designed rating.

Table A4.3

Duty – hours at or above max rating (*DUTY*)	
>= Hours	Score
0	0
24	5
48	10
120	15

DEFECTS (DEFECTS)

This represents the total number of faults and defects raised against each asset over the last 10 complete financial years.

Table A4.4

Number of Defects (DEFECTS)	
>= Number of Defects	Score
0	0
10	15
40	35
90	40

SEVERITY (SEVERITY)

The severity of repairs to remedy faults and defects is quantified by the man-hours spent carrying out these repairs.

Table A4.5

Repair Time in Hours (SEVERITY)	
>= Time	Score
0	0
500	5
950	20
1500	30
2350	40

DAYS NOT AVAILABLE OVER LAST YEAR PERIOD APRIL/APRIL (ACCESS)

This score is determined from the total number of days out of service based on outages in the last financial year.

Table A4.6

Access (*ACCESS*)	
>= Days	Score
0	0
50	2
100	5
200	10
300	20

8.2.3.5. HISTORICAL OIL LEAKS IN LAST 10 YEARS SCORE (OIL)

This is the litres of oil leaked in the last 10 years.

Table A4.7

Oil leaks last ten years (*OIL*)	
>= Litres	Score
0	0
1000	5
1500	10
2000	15

8.2.3.6. PRO-RATA TO 1KM OIL LEAKS IN LAST 10 YEARS SCORE (PROIL)

This is the pro-rata to 1km litres of oil leaked in the last 10 years. This is quantity of oil lost over the last 10 years divided by the length of the cable.

It is important to include pro-rata oil leaks, so that significant oil leaks from short cables are not missed due their relatively low volume compared to significant oil leaks from long cables.

Table A4.8

Oil leaks last ten years (*PROIL*)	
>= Litres	Score
0	0
200	5
400	10
500	15

MAIN CABLE INFORMATION (MAIN_ADJ)

The following condition scores will be applied when determining a cable EOL score. These factors tend to be bespoke to each cable route, so need to be included in the calculation as an adjustment component.

- Known presence of tape corrosion. (Score 10)

SUB-ASSET INFORMATION (SUB_ADJ)

The cable has a number of sub-asset upon which it is reliant for operation. These sub-assets also experience deterioration.

- Risk of failure of old style link boxes. (Score 5)
- Risk of stop joint failure. (Score 5)
- Risk of sheath voltage limiter (SVL) failure. (Score 5)
- Poor Condition of joint plumbs. Information about whether they have been reinforced. (Score 5)
- Known faults with oil tanks, oil lines, pressure gauges and alarms. (Score 5)
- Condition or faults with cooling system (if present). (Score 5)
- Occurrence of sheath fault (5) Multiple faults (10)
- Known issues with the cable's laying environment (Score 5)

Appendix 5: Background Information and Case Studies

Case Study Examples and Technical Bulletins

- *National Grid, Undergrounding High Voltage Transmission Lines*. – presented to aid technical understanding.
  https://www.nationalgrid.com/sites/default/files/documents/45349-Undergrounding_high_voltage_electricity_transmission_lines_The_technical_issues_INT.pdf

- *Thames Water, Engineering Options Report, Abbey Mills Route* – confirmation of geology conditions.
  https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/WW010001/WW010001-003387-9.10.01_Engineering_Options_Report_Abbey_Mills_Route.pdf

- *The Joint Code of Practice for Risk Management of Tunnel Works in the UK, Association of British Insurers and The British Tunnelling Society* – presented to aid technical understanding
  https://www.britishtunnelling.org.uk/?sitecontentid=881C32EC-21C8-41A9-8B7A-F8D530E7987E

- *Engineering the Lee Tunnel and Shafts through Chalk at Depth – British Tunnelling Society* – presented to aid understanding of tunnelling technologies involved.
  https://www.britishtunnelling.org.uk/?sitecontentid=225A3335-5918-45A0-A141-CA8032264277