Bringing energy to your door

Celsius

A new approach to managing thermal capacity

NETWORK INNOVATION COMPETITION

ofgem

RIIO NIC NETWORK INNOVATION COMPETITION

Project Code/Version Number:
ENWEN 01/ 02

Section 1: Project Summary

1.1: Project Title	**Celsius**
1.2: Project Explanation	Celsius is an innovative, cost-effective approach to managing potentially excessive temperatures at distribution substations, which may constrain the connection of low carbon technologies. By delivering new solutions to manage these 'thermal pinch points', Celsius releases additional capacity from existing assets, reduces long-term costs for customers and avoids early asset replacement.
1.3: Funding licensee	**Electricity North West Limited**
1.4: Project description	*The Problem:* Distribution network operators have historically adopted a 'fit and forget' approach to managing electricity networks. But the predicted increase in demand resulting from the adoption of low carbon technologies (LCTs) means we need to review the way assets are managed to ensure any costs incurred are efficient. The increase in electrical load means an increase in current on the network. The greater the current, the greater the heat generated and the hotter assets become. To ensure that networks are operated safely, electricity assets have an assigned capacity rating to indicate the maximum amount of energy they can carry. If the substation load exceeds this rating assets are replaced with new, higher capacity equipment which is expensive and disruptive to customers. But these ratings can be conservative and may not take seasonal and environmental factors into account, meaning assets are not used to their full capacity. *The Method:* Celsius will be the first application of a co-ordinated approach to managing the temperature of electrical assets in distribution substations in Great Britain. A two-step structured approach will gather data to increase understanding of thermal behaviour and release capacity to customers. *The Solution:* A simple 'Thermal Ratings Tool' will accurately indicate an asset's internal operating temperature using low cost external retrofit sensors. This knowledge will enable network operators to release the maximum capacity from existing assets without degrading their health and reliability. Celsius will show when and how to intervene to enhance that capacity by using a range of retrofit cooling techniques. The Project will prove that these techniques are acceptable to customers and can be rolled out across GB. *The Benefits:* Celsius will enable network operators to release capacity at a fraction of the cost of traditional reinforcement, reducing costs for increased load for GB customers by around £0.6 billion by 2050 and releasing 13GW of capacity.

1.5: Funding			
1.5:1 NIC Funding Request (£k)	£4 744	*1.5.2: Network Licensee Compulsory Contribution (£k)*	£534
1.5.3: Network Licensee Extra Contribution (£k)	£0	*1.5.4: External Funding – excluding from NICs (£k):*	£217
1.5.5: Total Project Costs (£k)	£5 554		

1.6: List of Project Partners, External Funders and Project Supporters	*Project Partners* Ricardo-AEA Ash Wireless Electronics Impact Research UK Power Networks *Project Suppliers* University of Southampton *Project Supporters* TNEI		
1.7: Timescale			
1.7.1: Project Start Date	January 2016	*1.7.2: Project End Date*	March 2020
1.8: Project Manager Contact Details			
1.8.1: Contact Name and Job Title	Steve Cox, Head of Engineering	*1.8.2: Email and Telephone Number*	steve.cox@enwl.co.uk 07710 069573
1.8.3: Contact Address	Electricity North West Hartington Road Preston Lancashire PR1 8AF		

Section 2: Project Description

Celsius will measure and then manage the temperature of distribution substations to improve their thermal capacity and allow efficient adoption of low carbon technologies by customers.

2.1: Aims and objectives

The Problem

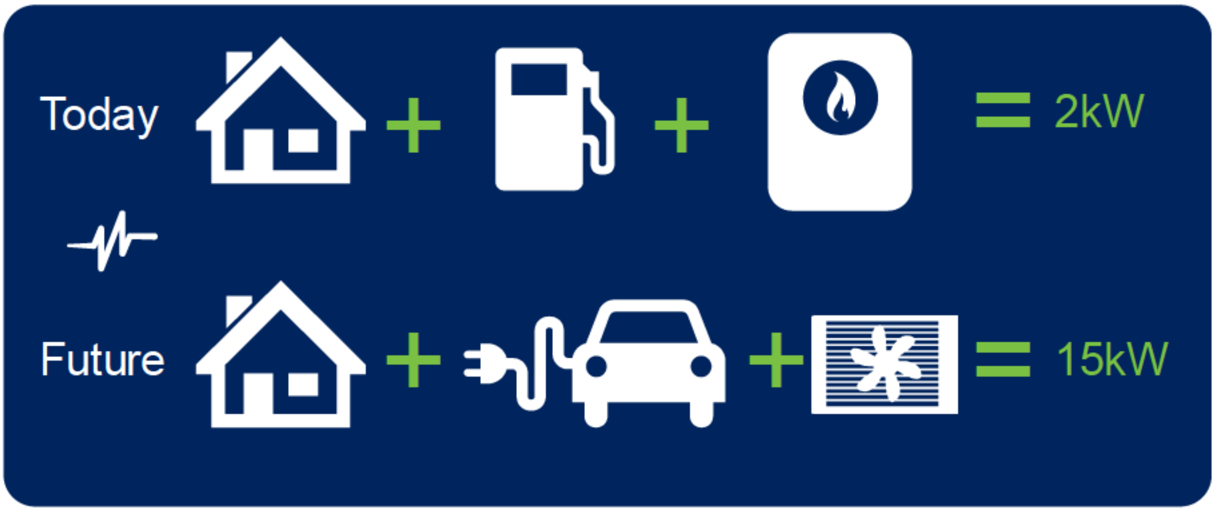
To meet the decarbonisation challenge laid down by the Government, customers will be encouraged to adopt new low carbon technologies (LCTs) such as electric vehicles (EV) and heat pumps (HP). DECC forecasts suggest that there may be up to a 60% increase in total electricity demand by 2050.

In low numbers, new LCTs can be accommodated on the existing network but when clusters of EV or HP connections arise, as anticipated in all DECC future load scenarios, this will create voltage, harmonic and thermal issues.

The chart below illustrates the scale of the challenge. On an estate of domestic properties with gas central heating, the low voltage (LV) service cables, LV mains cables and transformer (commonly referred to as secondary network assets) are scaled to supply a peak demand after diversity[1] of less than 2kW per customer. Changing the gas heating to an electric alternative such as a heat pump would add 6kW per property alone. Adding a new electric vehicle would require a further load of 3.5 to 7kW. It is not only the size of these new loads which will have a big impact. The duration of the load will also change significantly. Electric vehicles and heat pumps will draw energy for a much longer period of time than standard domestic appliances like kettles or electric showers.

The UK Government is currently incentivising low carbon technologies through the domestic renewable heat incentive[2] and plug in car and van grants[3]. Uptake of both could result in a total load per property of up to 15kW, over six times the peak demand that the network was originally designed to accommodate.

Figure 2.1: Scale of the challenge (illustrative)



Thermal constraints

This increase in load means an increase in the current flowing on the network. The greater the amount of current flowing, the greater the heat generated and the hotter an asset gets. The amount of heat generated is proportional to the square of the current that flows, meaning that a small increase in demand can lead to a relatively significant increase in the temperature of network assets.

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[1] A factor which is applied to demands to take into account that not all connected demands are operating at the same time or at their maximum rating

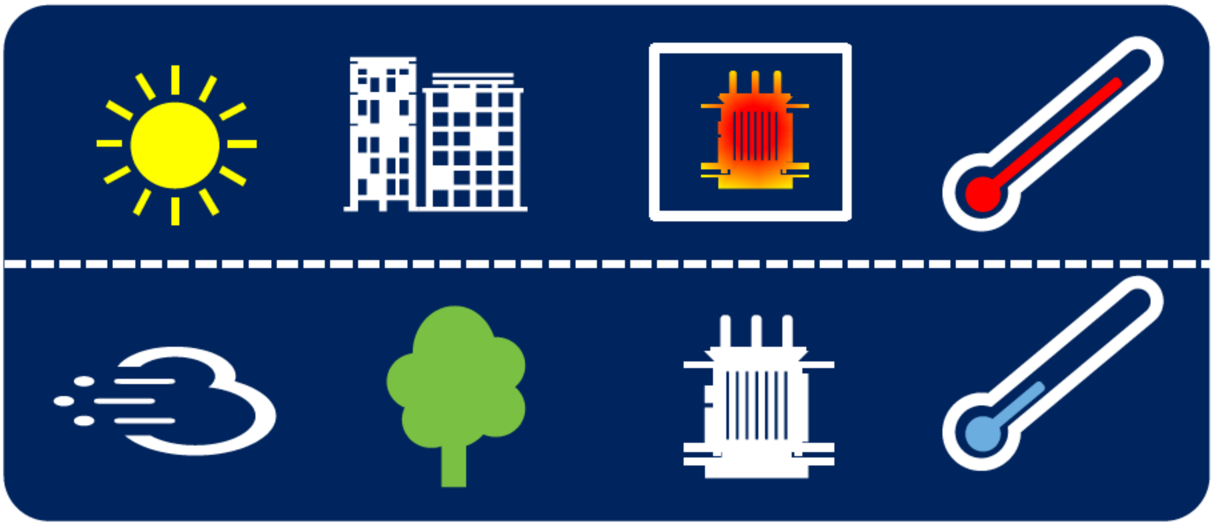
[2] https://www.gov.uk/domestic-renewable-heat-incentive

[3] https://www.gov.uk/plug-in-car-van-grants

The connection of LCTs and other electrical appliances may also lead to an increase in higher frequency currents flowing in the network, known as harmonic currents. Both load and harmonic currents cause heating within the asset, due to resistive and reactive effects. The heat generated needs to escape to the ambient surroundings which results in a temperature profile between the core of the asset, across the insulating materials and to the outside.

Many factors can affect this profile such as wind cooling, shade and sun glare. These factors can significantly affect internal operating temperature as shown in Figure 2.2.

Figure 2.2: Environment/location impact on asset temperature



To make sure that networks are operated safely, electricity assets have a manufacturer assigned capacity rating, expressed in amps, to indicate the maximum amount of energy they can carry. These static 'nameplate' ratings are a proxy for the maximum operating temperature assets are designed for.

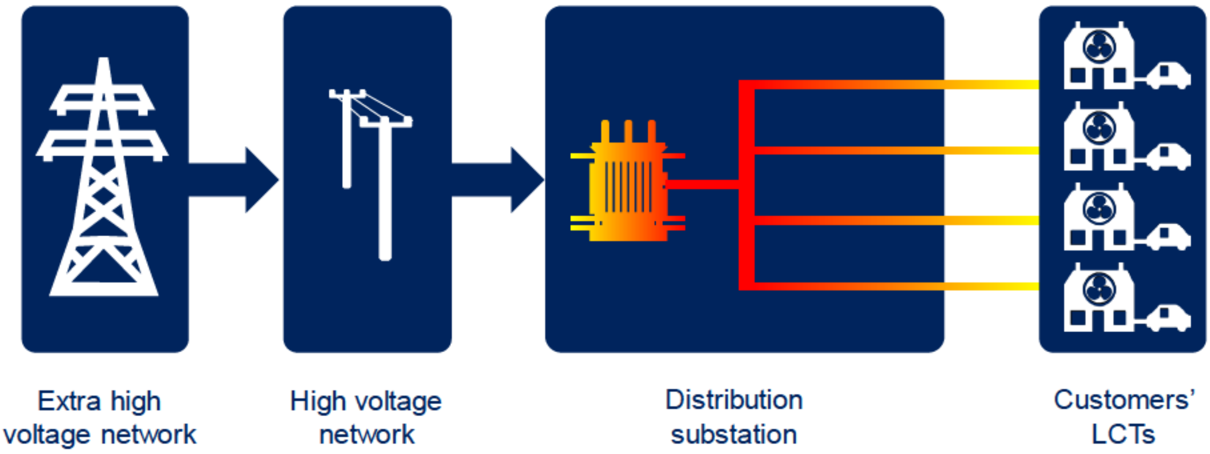
But these ratings do not take seasonal and environmental factors into account which means that the equipment may not be used to its full thermal capacity. These restrictions on an electrical asset's capacity are known as 'thermal constraints'.

If demand for electricity at a substation exceeds this static rating, the traditional approach is to replace affected assets with new, higher capacity equipment. This entails significant capital investment which customers pay for through their electricity bills.

Thermal pinch points

The expected increase in electrical load from low carbon technologies will lead to thermal 'pinch points' at distribution substations, where load is causing equipment to operate close to its maximum operating temperature.

Figure 2.3: Thermal pinch points



Our previous innovation projects such as Smart Street[4] examine ways to resolve the voltage and power quality issues associated with the expected increase in demand. C_2C[5] and other projects have delivered new solutions for thermal constraints on higher voltage networks. Now, we are turning our focus to finding solutions to the problem of thermal constraints on distribution substations.

The Celsius Method

Maximising the use of existing assets is central to Electricity North West's innovation strategy, an approach which Celsius continues. Celsius will increase understanding of the thermal behaviour of distribution substations. With greater knowledge of the behaviour of these assets, network operators can support the connection of increasing numbers of LCTs more quickly and at lower cost. This revolutionary Method will develop and demonstrate a two-step intervention approach.

Firstly, using load monitoring and improved technology to measure temperatures, Celsius will gather data across a range of environmental, load and seasonal factors on 520 distribution substations, selected to be representative of 80% of the GB substation population.

The data gathered will be analysed to:

- Explore the relationship between asset temperature, load characteristics and the surrounding environment,
- Establish a set of reliable, thermal coefficients between the measured external temperature and the internal asset hotspot temperature,
- Reveal latent capacity which can be released quickly with no further intervention.

The second intervention will release additional capacity through a range of retrofit cooling techniques. Celsius will explore a range of techniques to increase capacity and demonstrate the benefits of each. The techniques will be applied on 100 of the monitored distribution substations. This will result in a 'buy order' of cooling interventions for network operators to choose from.

The Solution

Celsius will reduce the overall costs of accommodating increased load on the distribution network. These savings will be available to all customers across GB. Our business case indicates this saving to be around **£583 million by 2050.** The Method will also enable DNOs to respond much more quickly to potential constraints arising from the connection of clusters of LCTs, releasing **13 162MW** of capacity.

Moving forward into business as usual, Celsius will maximise the value of the smart meter programme by using smart meter data, aggregated at substation level, to indicate where to deploy the Celsius Method. In this way the costs associated with step 1 of Celsius will be kept to a minimum.

Celsius will deliver:

- Reports detailing the enhanced understanding of asset temperature and its relationship with load and environmental factors,
- Recommendations and tools for the implementation of Celsius to business as usual. This is expected to include:
    - A functional specification for a reliable, low cost monitoring sensor pack for distribution substation assets, including cables and transformers,
    - A Thermal Ratings Tool that will calculate the capacity of an asset based on measured external temperature values. This will allow a network operator to better understand the operating temperature of assets and when to deploy an intervention,

[4] http://www.enwl.co.uk/smartstreet (formerly known as eta)
[5] http://www.enwl.co.uk/c2c

- A range of retrofit cooling solutions to apply when the Thermal Ratings Tool indicates an intervention is required,
- Studies to prove that the retrofit cooling techniques are acceptable to customers,
- Proposed changes to Engineering Recommendation P15 Transformer Loading Guide and Engineering Recommendation P17 Current Rating Guide for Distribution Cables.

Throughout the Celsius Project, a number of outputs will be generated. These will be shared with other network operators to encourage quick and effective implementation across GB.

2.2: Technical description of Celsius

This section provides an overview of the technical aspects of Celsius. A more detailed explanation can be found in Appendix B.1.

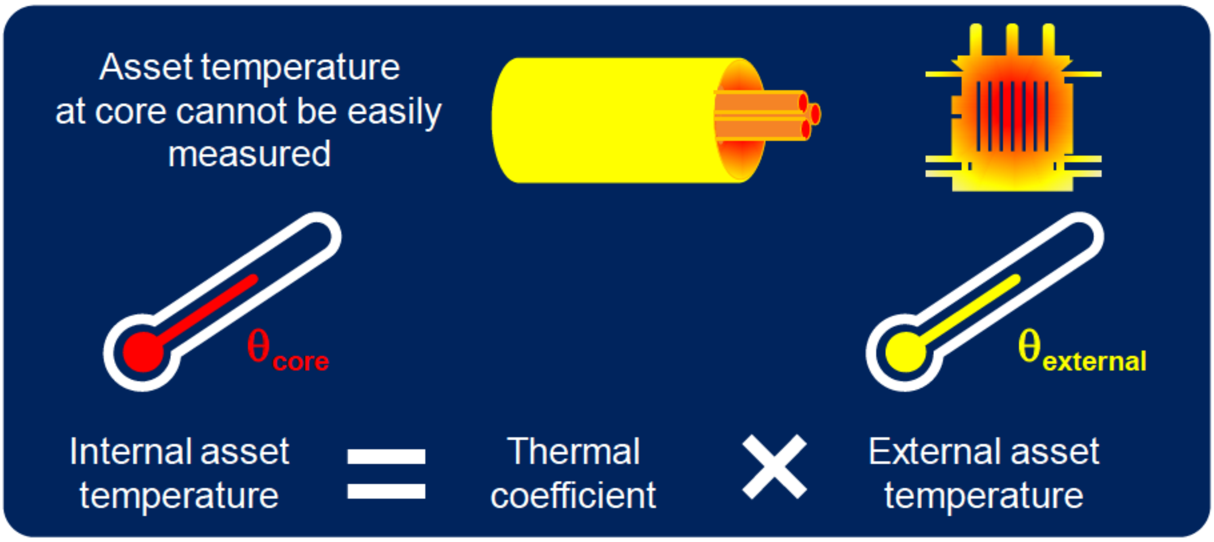
Celsius will develop an understanding of the operating temperatures of distribution substation assets, including transformers and cables, within a range of substation environments. The Project will also deliver alternative, innovative ways to optimise thermal capacity leading to faster, cheaper responses to the connection of low carbon technologies.

Retrofit thermal monitoring

Celsius will use temperature and load measurements recorded at 520 distribution substations (51 pole-mounted and 469 ground-mounted) to evaluate the available capacity margins at each site. In addition, Celsius will produce a functional specification for a low cost monitoring solution which can be deployed at scale.

To evaluate the capacity margins, we need to measure the maximum operating temperature (or hot spot) which is at the core of the asset; but it is impractical and cost prohibitive to measure directly at scale using retrofit means. To obtain these hot spot temperatures, the Celsius Project will develop a methodology to allow the internal hot spot temperatures to be calculated from the measured external temperature and other known information.

Figure 2.4: Measuring thermal hot spots



To develop this methodology for distribution transformers, more detailed measurements will be taken from 21 of the distribution substations, including internal temperature and multiple external temperatures at key locations on the outside of the transformer. This internal measurement will be taken in one of two ways:

- From a transformer with fibre optics already incorporated in the windings, purchased and installed for a previous IFI project,
- From temperature sensors deployed through drain valves and breather pipes.

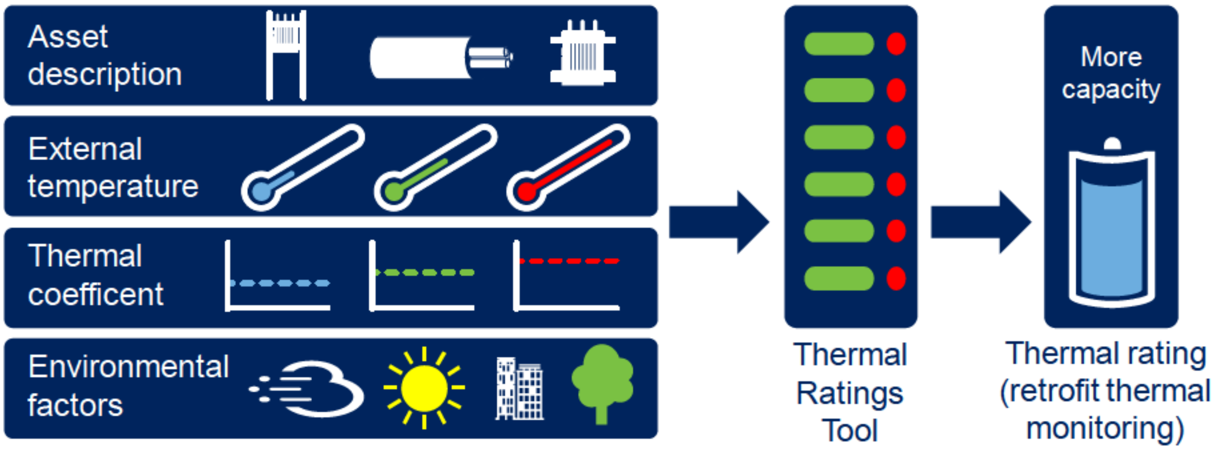
For cables, the relationship between internal and external temperatures is understood and described in ENA Engineering Recommendation P17. However, the measurement of the required external and environmental parameters in a live installation will be developed as part of the Project.

To further improve the analysis, the trials will include a wide range of load profiles and types. To facilitate this, it may be necessary to alter the load profile at some sites by adding or removing load from the cables and transformers through network switching.

These measurements will be taken for a period of 12 months to ensure all seasonal variations are captured. The data gathered will be analysed to explore the relationship between asset temperature, load and the surrounding environment. We will then undertake a Celsius capacity analysis and an evaluation of the substation capacity which can be released with no further intervention.

The output of this package of work will be a Thermal Ratings Tool, which will require minimal inputs such as temperature and environment to quantify available capacity. This tool is likely to be developed in the form of a Microsoft Excel look-up table or similar which is easily transferable and will be made available for use by other GB DNOs.

Figure 2.5: Retrofit thermal monitoring output



Retrofit cooling

To release further capacity, retrofit cooling techniques for cables and transformers will be evaluated and deployed on 100 of the initial trial sites.

Celsius will identify and evaluate a range of potential techniques and technologies which may be used to cool or thermally manage assets. For example, passive techniques such as painting transformers with reflective paint, new backfill material for cables; and active techniques such as fans on transformers. (Appendix C contains further information on these techniques.)

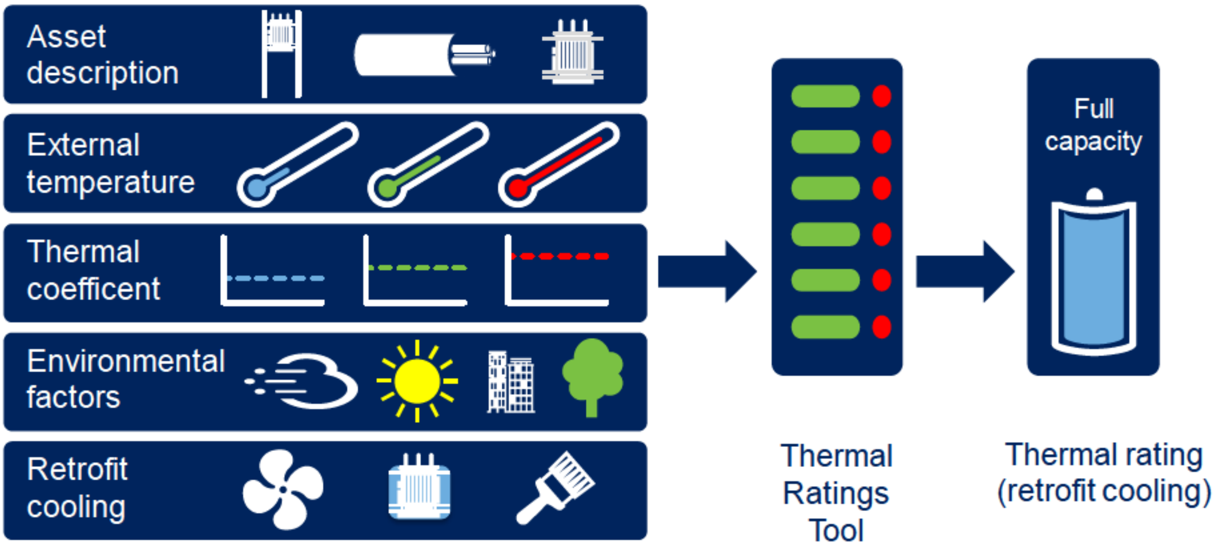
In collaboration with other distribution network operators, we will then select a number of appropriate techniques to be trialled. The selection of cooling interventions will consider the following criteria:

- Safety,
- Capacity benefit estimation,
- Cost, carbon impact and benefits,
- Operational processes,
- Substation environment limitations,
- Energy consumption,
- Ease of installation,
- In accordance with NIC governance, techniques with a TRL (technology readiness level) lower than four at the time of deployment will not be considered eligible for trial.

Once the cooling interventions are installed, the benefits will be quantified via an extended period of monitoring to allow thermal behaviour to be contrasted against the measurements taken in the initial monitoring trial.

The learning from this work will be captured as an enhancement to the Thermal Ratings Tool. This tool will automate the evaluation of the potential gain in capacity of each technique for different applications and environments.

Figure 2.6: Retrofit cooling output



Thermal flow study

As part of step 1 we will carry out detailed analysis of the heat and air flows within substations to provide evidence on the optimal configuration of indoor substations, including the location of vents and louvres. This will inform future substation design and also potentially show how air flow in existing substations can be optimised.

Asset health study

Any change in operation of network assets may impact an asset's health and subsequently an asset's operational life. Celsius aims to allow assets to carry increased load safely and without reducing asset life. To demonstrate that Celsius does not unduly affect asset life, a study will be carried out by the University of Southampton (UoS). The UoS has significant expertise in the field of electricity cables and transformers and is represented on the IEC committees on asset modelling. The outputs of this study will be reviewed in line with our standard methodology for the calculation of health indices. Any impact from Celsius on asset health will be considered in the recommendations and outputs of the wider Project.

Business as usual

Celsius will ensure that the learning generated is easily transferable to business as usual. Therefore, a key output of the Project will be a functional specification for the required low cost monitoring sensors and details on where, when and how to monitor. Additionally, Celsius will deliver the specifications and installation procedures for the various retrofit cooling techniques and propose relevant changes to the appropriate Engineering Recommendations for distribution transformers and cables.

2.3: Description of design of trials

The trials to demonstrate the Method will take place on a representative sample of distribution substations and will explore thermal management of existing network assets in the following ways:

- *Understanding thermal constraints:* development of a methodology to better understand and manage existing distribution substations to unlock latent capacity,

- *Addressing thermal constraints:* how retrofit technology can be harnessed to provide low cost alternatives to reinforcement in a manner which is acceptable to customers.

Celsius will achieve this by testing the following hypotheses (in the identified workstreams):

1. Thermal characteristics of 520 substations can be used to build a reliable Thermal Ratings Tool for distribution substation assets across GB (trials and analysis workstream),
2. Low cost sensors, attached to the exterior of an electrical asset, can be used to reliably establish the internal operating temperature and enable a Thermal Ratings Tool (trials and analysis workstream),
3. Capacity can be released quickly and cheaply by understanding the thermal performance of the distribution substation (trials and analysis workstream),
4. Further capacity gains can be achieved through low cost, retrofit cooling interventions (trials and analysis workstream),
5. Celsius does not have a detrimental impact on asset health (trials and analysis workstream),
6. Customers within the Celsius trial areas will find the implementation of innovative retrofit cooling techniques as acceptable as traditional reinforcement (customer workstream),
7. Customers who are educated on the need for and benefits of Celsius are significantly more likely to find it acceptable (customer workstream).

Site selection methodology

To ensure Celsius is applicable to the majority of GB distribution substations, a representative sample of substations will be selected from across the Electricity North West asset base. This will incorporate enough examples of each main substation type and environment so that each can be understood.

While the actual trial sites will be selected during the Project, an indicative site selection methodology, jointly developed between Ricardo-AEA and Electricity North West, is outlined below and detailed in Appendix B.2.

To maximise the use of existing equipment already funded and installed from a previous First Tier LCN Fund project, the site selection methodology begins with assessing the suitability of the substations which were part of our Low Voltage Network Solutions load monitoring trials. Where those substations are found to be unsuitable based on other criteria, the monitoring equipment will be moved, if economic, for installation at an appropriate site.

Site selection will consider the following factors:

- *Substation type, asset type (age, manufacturer etc) and surrounding environment:* this will be achieved through categorising substations, taking into account these factors, to represent the vast majority of the substation population,
- *Loading:* Feasibility work carried out by Ricardo-AEA, shows that the relationship between load and temperature is weaker where loading levels are 25% or less, as it is more heavily influenced by ambient temperatures. Therefore, only sites with loading levels greater than 25% will be selected,
- *Types of load:* for example commercial/domestic/industrial, urban/dense urban/rural, presence of certain technology (LCT clusters eg heat pumps, other innovation projects),
- *Practical considerations:* sites will be selected with the requirements of the trial in mind; for example, it is likely that the monitoring equipment will rely on mobile phone communication for data transfer. Therefore, sites with poor or no coverage will be avoided or alternative solutions found.

Retrofit thermal monitoring

The Celsius trials will capture robust load, temperature and other environmental data from 51 pole-mounted substations and 469 ground-mounted distribution substations.

(Appendix B.3 details the methodology used to quantify the number of trial sites). To ensure that the full load curve and seasonal effects are captured, this activity will continue for a period of 12 months on each of the monitored substations.

The objective of this extensive data gathering and subsequent analysis is to develop an understanding of the relationship between asset temperature, load characteristics and environment. This relationship will be validated by a selection of those assets having internal temperature sensors fitted and by the University of Southampton's peer review of the results.

Figure 2.7 below is extracted from Appendix A.1. The retrofit thermal monitoring trials are described as trial 1, trial 3 and trial 5.

Retrofit cooling

During the monitoring trial, an evaluation of retrofit cooling technologies will be carried out. A retrofit cooling workshop will be held with distribution network operators to discuss options and vote on which to take forward for trial. Selected technologies will then be installed at a total of 100 of the monitoring trial sites with monitoring data collected for analysis for a minimum period of 12 months following the retrofit cooling deployment. (Appendix B.3 details the methodology which will be used to quantify the number of trial sites). The monitoring equipment installed in the retrofit thermal monitoring step will remain in place and operational to support the cooling intervention trial.

Both active and passive cooling solutions will be evaluated. As these will be deployed at those assets closest to where our customers live and work, it is possible that they will notice audible or visual changes to those assets. To understand this fully, Celsius will carry out a programme of customer engagement and surveys in conjunction with records of when the cooling has been installed and operational. This will deliver learning on customer perception of electricity networks, Celsius and the acceptability of proposed cooling solutions versus traditional solutions.

The trials related to retrofit cooling are trial 2, trial 4 and trial 6.

Figure 2.7: Description of Celsius trials

Method	Thermal management of the distribution network
Trial 1	Retrofit thermal monitoring of pole-mounted transformers
Trial 2	Retrofit thermal monitoring and cooling intervention for pole-mounted transformers
Trial 3	Retrofit thermal monitoring of ground-mounted transformers
Trial 4	Retrofit thermal monitoring and cooling intervention for ground-mounted transformers
Trial 5	Retrofit thermal monitoring of LV cable*
Trial 6	Retrofit thermal monitoring and cooling intervention for LV cable*

* These will usually be applied at cable congestion points such as in the first few metres of LV circuits within and emerging from substations, known as the 'first leg'

2.4: Changes since Initial Screening Process (ISP)

The overall scope of Celsius has not changed since submission of the Screening Submission pro-forma. However, we have been able to confirm Partner involvement from Ricardo-AEA, Ash Wireless Electronics, Impact Research and UK Power Networks and have secured £217k of external funding. As a result the cost of Celsius is £5.55 million resulting in a reduction in NIC funding requested.

Section 3: Project Business Case

Celsius will provide additional thermal capacity to customers at lower cost and be deployable more rapidly than traditional reinforcement.

3.1: Background

Beyond 2020, a switch to low carbon transport and heating will start to increase electricity demand on the network. The timing and uptake of low carbon technologies remains uncertain but is likely to be scattered geographically and in many instances clustered. Capacity limits will be met first at the distribution substation level where load diversity is lowest and this will lead to thermal constraints. When these changes lead to levels of demand which exceed the network's capacity, DNOs need to respond quickly, cost-effectively and with minimum disruption to customers.

A thermal constraint is defined as peak load exceeding 100% of an asset rating. Once a distribution substation asset becomes thermally constrained, the traditional solution is to replace with a higher capacity asset. If this is not possible, due to space constraints, an additional distribution substation can be installed as close as possible to the centre of the load and the load split between the existing and new substations. These traditional options involve significant cost and disruption to customers.

3.2: Customer benefits

Celsius will provide additional thermal capacity to customers, more quickly and at lower cost than traditional reinforcement. Faced with increasing volumes of load-related reinforcement requirements, network operators could find that skilled resource and manufacturing constraints limit their ability to deliver network capacity at the rate required by customers. Celsius will provide a proven, alternative solution to traditional reinforcement, releasing extra capacity from existing assets, thus deferring and in some cases avoiding reinforcement until the asset reaches end of life.

Celsius consists of two steps: retrofit thermal monitoring and retrofit cooling.

Celsius step 1: Retrofit thermal monitoring

Retrofit thermal monitoring will enable capacity release by comparing actual operating temperature (affected by local conditions, wind, shade etc) against maximum operating temperature. It will also identify where local conditions have an adverse effect on the thermal performance of assets through monitoring of their behaviour. Analysis of peak loading at all Electricity North West primary substations for 2014/15 corroborates that peak loading occurs in winter in nearly all cases (94%) and this is likely to be a higher proportion at distribution substation level. Also the DECC scenarios, which are used in the business case analysis, suggest that future peak load will continue to be experienced in winter months.

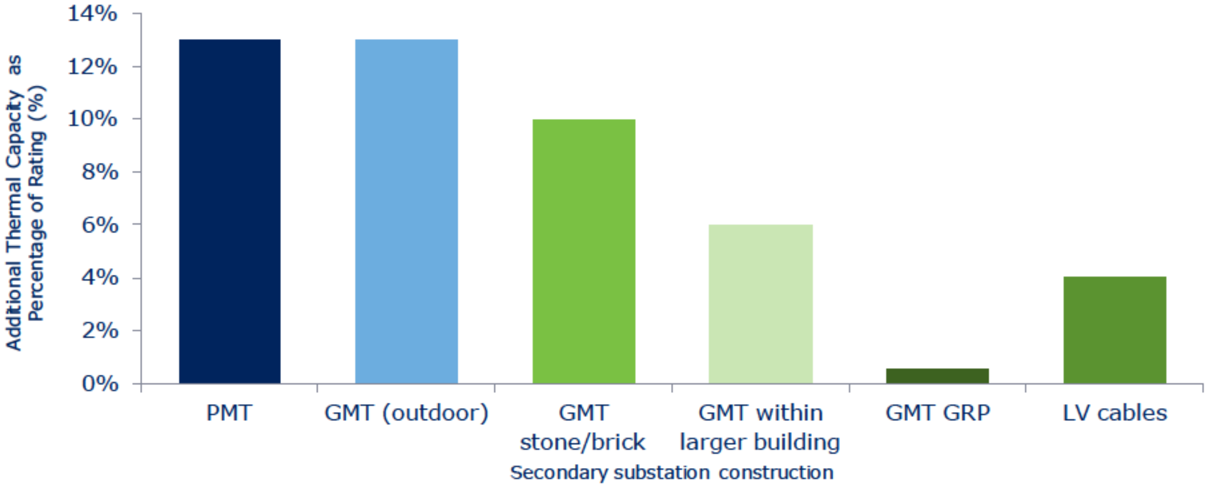
Figure 3.1 shows thermal capacity release for various representative distribution substations through application of Celsius retrofit thermal monitoring. These represent the average ratings for thermally constrained substations in the DECC 1 scenario. Capacity release has been calculated based on an average winter temperature of 5°C derived from historical UK Meteorological Office weather station records in the Electricity North West area. This takes into account recommended ambient temperature correction for various ground-mounted substation types as per IEC 60076-7[6].

Additional thermal capacity from improved understanding of environmental and asset temperature may be higher than 13% for some transformers. Standard heat testing for a subset of distribution transformers indicates that IEC standard transformer thermal model parameters[6] used in thermal capacity calculations can be conservative.

[6] International Electrotechnical Committee, IEC 60076-7:2005 Power Transformers Part 7: Loading guide for oil-immersed power transformers, 2010.

Similarly, Electricity North West LV cable ratings are based on a ground temperature of 10°C; if monitoring indicated an actual ground temperature of 5°C then an additional 4% of capacity can be realised[7].

Figure 3.1: Indicative additional thermal capacity for various representative distribution substations through application of Celsius retrofit thermal monitoring



PMT: 50kVA pole-mounted transformer
GMT: 500kVA ground-mounted transformer
GRP: Glass reinforced plastic)
LV cables assumed to be associated with 500kVA transformer

Celsius step 2: Retrofit cooling

Celsius will demonstrate a range of retrofit cooling interventions such as cooling fans, cooling fins and innovative cable backfill material. The range will cover options of varying cost/capacity released and at varying technology readiness levels. Details of indicative thermal capacity release for various cooling interventions are provided in Appendix C. To quantify the benefits of this part of Celsius, we have used retrofitted cooling fans and innovative cable backfill material which are applicable to most ground-mounted substation types in the Electricity North West area. The capacity release from these interventions is relatively well quantified in academic research and from experience of application at higher voltage levels, for example transformer fans. We have defined the additional capacity release available from a retrofitted fan to be 30%[8], and for innovative cable backfill material up to 20%[9].

For pole-mounted substations, we have assumed a generic cooling intervention is applied that provides 5% capacity release, for the purposes of calculating net benefits. Please note that this is for illustrative purposes as during the trial, a range of cooling interventions will be tested.

Celsius delivers savings for customers

The financial benefit of Celsius is achieved through increasing thermal capacity at lower cost than traditional reinforcement. This can defer and in some cases avoid reinforcement until the asset reaches end of life. Initial capital costs for traditional reinforcement and for Celsius (based on the costs of replicating Celsius once proven successful) are shown in Figure 3.2 for a 50kVA pole-mounted transformer and a 500kVA ground-mounted transformer. These sizes are representative of average pole- and ground-mounted substation ratings. Figure 3.3 shows the equivalent for cables.

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[7] The Electricity Council, Engineering Recommendation P17 Current Rating Guide for Distribution Tables Parts 1 and 2, 1978.
[8] Bayliss C, Hardy B, "Transmission and Distribution Electrical Engineering 4th Edition", Elsevier, 2012.
[9] Gouda O.E., El Dein A. Z., Amer G.M., Improving the Under-Ground Cables Ampacity by using Artificial Backfill Materials, Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, Paper ID 110.

Figure 3.2: Capital costs comparing Celsius and traditional reinforcement for representative ground-mounted and pole-mounted distribution transformers

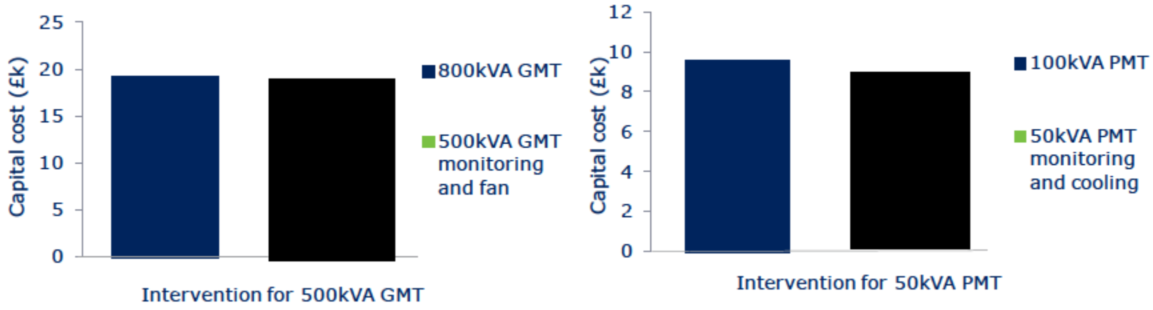
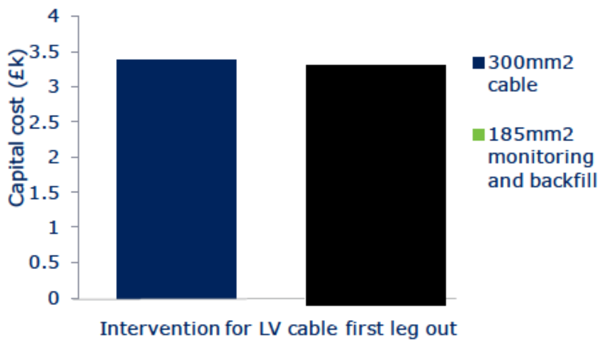


Figure 3.3: Capital costs comparing Celsius and traditional reinforcement for representative LV cable first leg out



However, to demonstrate the true benefit for Celsius, it is important to consider the timing of interventions for traditional reinforcement versus Celsius on a net present value (NPV) basis. The NPV calculation of the customer benefit replicates the approach in the RIIO-ED1 CBA template.

A case study is provided below to illustrate this for a representative substation over the period 2020 to 2050. After the case study, we present the results scaled up for a range of initial loading levels and load growth paths.

Case study – Base Case v Method Cost for a 500kVA ground-mounted substation

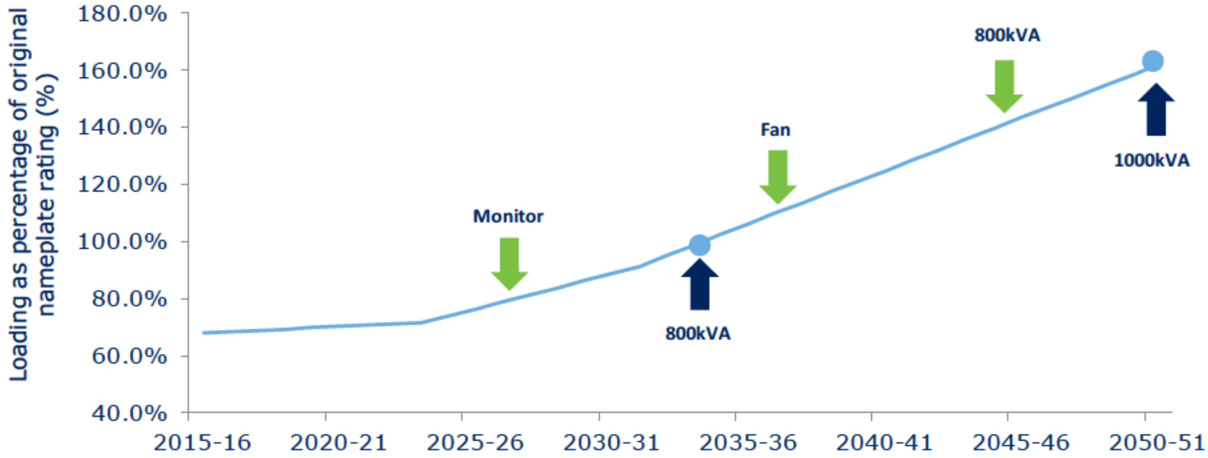
A 500kVA ground-mounted substation in a brick built enclosure is following a high load growth path derived from the DECC 1 scenario. The transformer becomes thermally constrained in 2034.

- *Traditional reinforcement:* The substation is upgraded to 800kVA[10] in 2034 then is upgraded once again to 1000kVA in 2050 following further load growth.
- *Celsius:* Monitoring is deployed in 2027 based on a nominal load trigger of 80% of rating followed by retrofitting of a fan to the transformer in 2037. In 2045, it is necessary to upgrade the substation to 800kVA, deferring reinforcement of the asset by 11 years. This deferment provides a window in which to develop greater understanding of ongoing load expectations, providing a network operator with the flexibility to target investment and resources with greater accuracy.

This is shown diagrammatically in Figure 3.4.

[10] Electricity North West three phase ground-mounted transformer ratings are: 315kVA, 500kVA, 800kVA, 1000kVA and 1500kVA.

Figure 3.4: Celsius compared to traditional reinforcement (Timing of interventions for 500kVA ground-mounted substation)



Operational costs associated with Celsius (collection of monitoring data and minor maintenance) are expected to be negligible as they would be incorporated within the scope of existing regular substation visits.

On an NPV basis to 2050, traditional reinforcement costs are **£18.0k** [redacted] Key assumptions underlying the calculation of costs are provided in Appendix A.

Monetised losses are not included in quantification of the net benefits due to the uncertainty of low carbon technology uptake on future LV network load profiles. Inclusion of monetised losses, based on a conservative linear scaling of the load profile with peak load, still results in a strongly positive net benefit for the Celsius Method in any case.

Application of Celsius here has provided a further capacity of 215kVA (approximately 13% of 500kVA from thermal monitoring and 30% of 500kVA from retrofit of a cooling fan) at much lower cost than traditional reinforcement. This provides the additional benefit of enabling a more flexible response to quickly and cost-effectively adapt the network to meet customer demand.

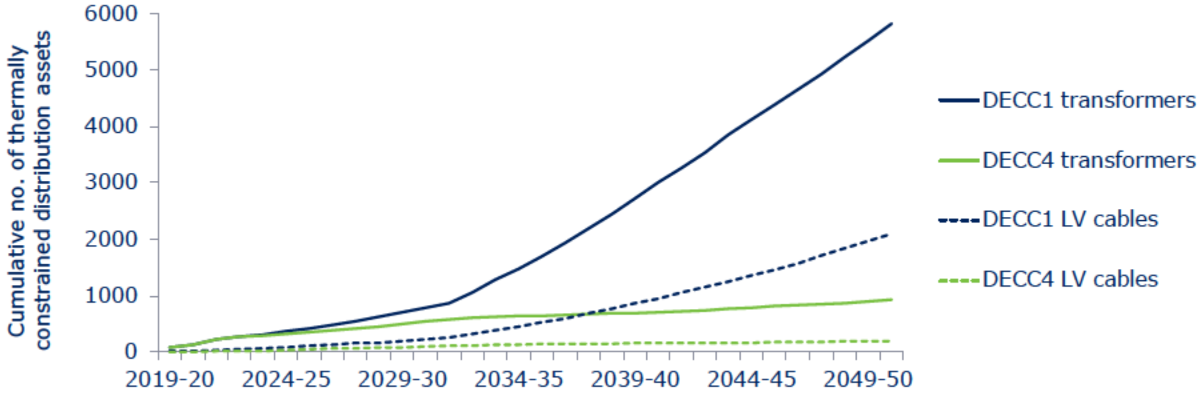
Scaling up the benefits using a disaggregated view of the DECC demand scenarios

To model the Celsius business case, we have compared traditional reinforcement and the Celsius approach to resolving thermal constraints. We have done this under a level of demand growth consistent with the 2013 DECC 1 scenario. DECC 1 represents medium uptake of electric vehicles (EV) and high uptake of heat pumps (HP). The DECC 4 scenario was used as a sensitivity case for low EV and HP uptake. These scenarios were defined for all DNOs by DECC/Ofgem in the Transform model[11] for the RIIO-ED1 Well Justified Business Plan submissions.

In a previous innovation project, Electricity North West developed a 'future capacity headroom' model. In contrast to Transform's generic network, this gives a view of peak loading and capacity for *every* distribution substation and LV cable, reflecting the real customer distribution, loading levels and network connectivity. To test the Celsius business case, we used this model to give realistic disaggregated views of how the EV and HP uptakes in DECC 1 and DECC 4 would lead to interventions in different asset types. Figure 3.5 shows the number of expected thermal constraints in each scenario from 2020 to 2050 in our disaggregated views eg in DECC 1, on 5 821 distribution substations and 1 506[12] LV cables in Electricity North West.

[11] Developed by EATL to support the development of the Well Justified Business Plans for RIIO-ED1
[12] Number of overloaded cables associated with ground-mounted distribution substations

Figure 3.5: Forecast number of thermally constrained distribution transformers and LV cables in the Electricity North West area to 2050 in the DECC 1 and DECC 4 scenarios



For consistency with our RIIO-ED1 business plan, overall intervention volumes until March 2023 are set to match DECC 4.

Thermal constraints for LV cables will emerge at the first leg out of the substation, where loading is highest. For LV cables, the majority of overloads (85% by 2050) are for a single substation LV cable rather than multiple LV cables overloaded at a substation.

The analysis for the business case then considers the net benefit of applying each of the trial methods versus the traditional solution, for assets experiencing load growth in the DECC 1 scenario. This is shown in Figure 3.6. Net benefits are presented as a percentage of traditional reinforcement costs to 2050 on a NPV basis.

Figure 3.6: Average net benefits of Celsius by 2050 per trial Method as a percentage of traditional reinforcement costs

[redacted]

To quantify the net benefits of wider rollout once proven, Celsius is scaled up to the size of the trial project, the Electricity North West area and Great Britain based on assumptions detailed in Section 4a and Appendix A, as presented in figure 3.7.

Figure 3.7: Net benefits by 2050 and capacity release for Celsius rollout

	Net benefits (£m)	Capacity released (MW)
Celsius Project	£2.7	41
Electricity North West	£42.7	1 006
Great Britain	£583	13 162

Please note that for the Celsius Project, a range of innovative cooling interventions will be applied to 100 of the initial retrofit thermal monitoring sites. For future rollout at

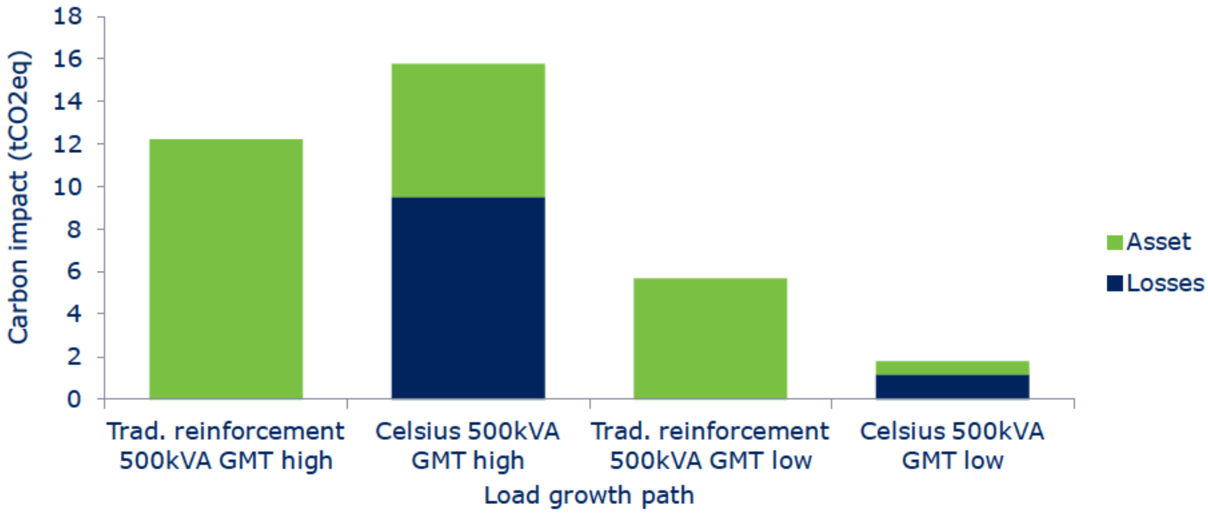
Electricity North West and Great Britain scale, a range of proven cooling interventions would be much more widely applied to thermally constrained assets.

Carbon comparison

Celsius will facilitate quicker connection of low carbon technologies. It is estimated that, at the scale of the Project, Celsius could release 30MW of capacity through retrofit thermal monitoring and an additional 11MW through applying retrofit cooling. This is equivalent to the connection of 7 800 electric vehicles or 6 800 heat pumps. The Celsius Method is less carbon intensive than reinforcing the existing assets initially compared with traditional reinforcement. Embedded carbon associated with new assets is incurred at some point in the future driven by reinforcement for continuing load growth or asset replacement due to condition. However, if load growth plateaus or falls, the asset carbon impact from an unnecessary reinforcement intervention is completely avoided.

Operational carbon associated with network losses has also been considered although the impact of low carbon technology uptake on future LV network load profiles, and thus losses, is uncertain. Losses are higher in the Celsius case. The timing of interventions for traditional reinforcement versus Celsius is key to accurately capturing network losses and their carbon impact based on how the carbon intensity of grid electricity varies over time. Figure 3.8 shows the asset and losses carbon impact of traditional reinforcement and Celsius as applied to representative distribution assets for two load growth paths derived from the DECC 1 scenarios to 2050. Carbon associated with grid losses is baselined to the traditional reinforcement scenario.

Figure 3.8: Carbon impact of traditional reinforcement and Celsius



For lower load growth paths such as in DECC 4, carbon benefits improve due to avoidance of asset carbon impact from a traditional reinforcement intervention, with the Celsius Method becoming carbon positive in comparison to traditional reinforcement.

Overall, Celsius marginally increases carbon emissions in the DECC 1 load scenario, but (valued at the cost of carbon in the RIIO-ED1 CBA template) this cost is much less than the financial benefit of reinforcement deferment, so the financial case for Celsius is still strongly positive.

As is previously described, the uncertain nature of LCT uptake may result in load reaching a plateau or falling and, as with embedded carbon, carbon emissions associated with streetworks, vehicle movements of field engineers and diesel generators deployed to support traditional reinforcement, will be avoided with Celsius.

Section 4: Benefits, Timeliness and Partners

Celsius will deliver network capacity benefits totalling a potential £583 million for GB from the application of retrofit thermal monitoring and retrofit cooling.

(a) Accelerates the development of a low carbon energy sector and/or delivers environmental benefits while having the potential to deliver net financial benefits to future and/or existing customers

Over the course of RIIO-ED1, RIIO-ED2 and beyond, greater numbers of customers will access the benefits that can be obtained through electrification of their heat and transport requirements. These new LCTs connect to the distribution network resulting in thermal constraints developing rapidly in some areas due to regional and socio-economic clustering of LCTs.

Our previous project, Smart Street, funded in 2013/14, proposed solutions to increase capacity in a timely manner through interconnection and voltage management. Celsius will develop solutions that can increase capacity rapidly when required through thermal management, specifically at pinch points on the distribution network.

Contributing to the Carbon Plan

The Carbon Plan, published by the UK Government in 2011, describes the importance of moving to a low carbon economy and sets out how the legally binding targets in the reduction of greenhouse gas emissions will be achieved. The Celsius Method can be deployed to thermally constrained areas of the network across GB, much more rapidly and cost-effectively than traditional reinforcement, as illustrated in Figure 4.1. This will help to accelerate the connection of more low carbon demand technologies.

Delivery times (comprising planning and installation time) were based on Electricity North West's operational experience of network monitoring and reinforcement requirements. It should be noted that a new ground-mounted substation will require local planning approval which can take months to obtain. Stated delivery times will be comparable with delivery times for similar traditional reinforcement measures by other distribution network operators. Celsius is able to deliver additional thermal capacity up to six times faster than traditional network reinforcement techniques.

Figure 4.1: Comparison of Celsius and traditional reinforcement installation times

Method	Description	Delivery time
Transformer thermal constraint		
Traditional reinforcement	Substation transformer replacement	12 weeks
	New ground-mounted substation	12-24 weeks
Celsius step 1: Retrofit thermal monitoring	Monitoring	4 weeks
Celsius step 2: Retrofit cooling	Retrofit solution eg install fan	2 weeks
LV cable thermal constraint		
Traditional reinforcement	LV cable first leg out replacement or cable overlay	12 weeks
Celsius step 1: Retrofit thermal monitoring	Monitoring	4 weeks
Celsius step 2: Retrofit cooling	Cable backfill	4 weeks

Reform of the electricity grid

Understanding the behaviour of network assets under a variety of load and environmental conditions will allow network operators to take timely and targeted intervention measures. This approach delivers customer benefits in the form of additional capacity headroom for LCT connections, facilitation of lower cost, faster LCT connections, and lower distribution network operating costs. This means lower bills for customers in the future by reducing the costs of network reinforcement.

Delivering significant financial and network capacity benefits

The financial and network capacity benefits that Celsius could provide are quantified in this section and Appendices A.1 (Benefits Tables) and A.2 (Method and Base Case Methodologies). These benefits are then extrapolated across Electricity North West and GB.

Celsius Project

Consistent with the site selection methodology presented in Appendix B.2, thermal monitoring will be fitted to pole-mounted and ground-mounted transformers and LV cable first legs out in ground-mounted substations (step 1: retrofit thermal monitoring). 100 of these will also be retrofitted with a cooling intervention (step 2: retrofit cooling). This could provide asset capacity release of up to **30MW** through thermal monitoring and **11MW** from retrofit cooling.

Net benefits inclusive of direct costs and the cost of network losses total **£2.0 million** for assets fitted with retrofit thermal monitoring and **£0.7 million** for retrofit cooling (including corresponding thermal monitoring on the asset) at the scale of the trial. Retrofit cooling is based on retrofitted fans and cable backfill being deployed as cooling interventions to ground-mounted transformers and LV cables respectively. A generic cooling intervention is applied to pole-mounted transformers to quantify the potential benefits (as shown in Appendix A.1). Please note that this is for illustrative purposes as a range of cooling interventions will be tested during the trial.

Electricity North West

Within the Electricity North West area, there are around 17 100 pole-mounted transformers and 16 800 ground-mounted transformers. From mid RIIO-ED1 to 2050, the DECC 1 scenario forecasts that thermal constraints will arise on 1 937 pole-mounted transformers, 3 884 ground-mounted transformers and 1 506 LV cables in the Electricity North West area. On this basis, it is expected that Celsius will provide a total net benefit of **£4 million, £37 million and £1.4 million** for the application of retrofit thermal monitoring and retrofit cooling to pole-mounted transformers, ground-mounted transformers and LV cables respectively. Celsius could release up to **19.3MW**, **828MW** and **159MW** of network thermal capacity through rollout of retrofit thermal monitoring and cooling interventions to pole-mounted transformers, ground-mounted transformers and LV cables respectively.

Great Britain

In Great Britain, there are around 351 000 pole-mounted and 232 000 ground-mounted distribution transformers. The Celsius Method can potentially be applied to any of these distribution transformers and LV cables as they approach an overload condition. A small number of London Power Network distribution substations have some differences in load profile and seasonality of peak demand and may therefore not be as suitable for the Celsius Method; but this will be further explored with our Partner UK Power Networks during Project delivery.

Based on Meteorological Office historical data on mean winter average temperature across Great Britain from 1978 to 2010[13], an average winter temperature of 5°C as used to access additional thermal capacity through retrofit thermal monitoring, is representative of, or higher than, winter conditions in most areas of the UK. Thus, it

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[13] UK Met Office, UK Climate, Mean temperature winter average across GB from 1978 to 2010, http://www.metoffice.gov.uk/public/weather/climate.

should generally be possible to achieve capacity release of a similar magnitude through retrofit thermal monitoring.

Application of the Celsius Method to Great Britain over the period from 2019/20 to 2050 should provide a net benefit of **£81 million**, **£483 million** and **£18 million** for pole-mounted transformers, ground-mounted transformers and LV cables respectively under the DECC 1 scenario. It could release up to **396MW**, **10 713MW** and **2 053MW** of network thermal capacity for pole-mounted transformers, ground-mounted transformers and LV cables respectively in response to LCT load growth, while deferring or avoiding traditional reinforcement.

(b) Provides value for money to gas/electricity distribution/ transmission customers

Potential for Direct Impact

Celsius will have a Direct Impact on the distribution network by increasing available capacity more quickly; this will enable customers to transition more quickly to new LCTs such as electric vehicles and heat pumps.

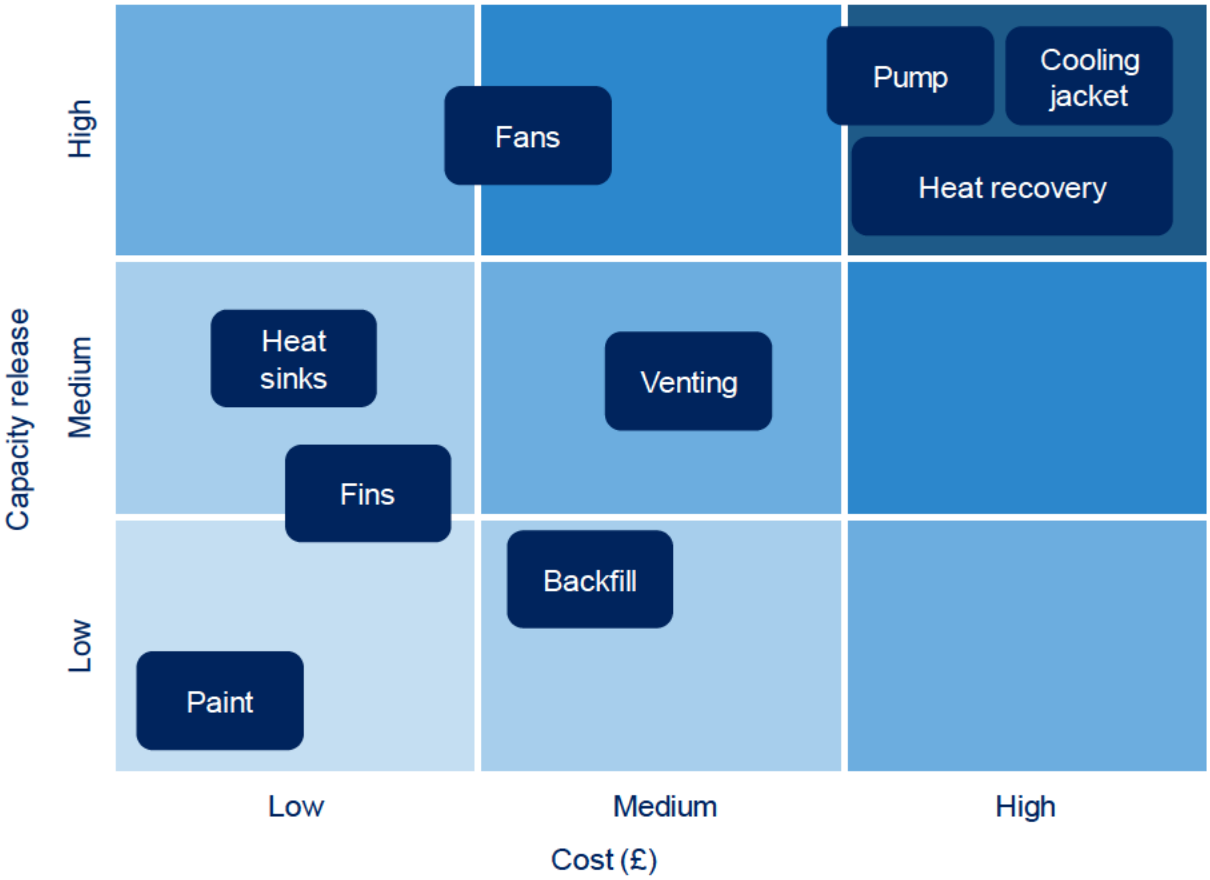
There are two steps to delivering Celsius. Firstly, Celsius will undertake studies on a wide enough proportion of distribution substations to gather enough data, through temperature, load and environmental monitoring, on which to develop a method to establish a more accurate indication of remaining thermal capacity. These sites will be selected to be representative of the distribution substation assets across GB to enable the widest possible rollout of Celsius.

Once this methodology is understood, it will be incorporated into the Thermal Ratings Tool for use by all network operators. Early studies, undertaken by TNEI as part of the preparation for this bid submission, show that capacity release of up to 13% can be expected through understanding asset temperature alone.

In addition to developing the Thermal Ratings Tool, learning from this retrofit thermal monitoring activity will also inform a functional specification for a low cost monitoring solution for use in the rollout of Celsius.

The second step of the Celsius trial involves the selection and demonstration of a range of retrofit cooling techniques for driving further capacity release. These techniques will span low cost/low capacity release to high cost/high capacity release as depicted in Figure 4.3.

Figure 4.3: Comparison of potential Celsius retrofit cooling techniques



These technologies are described more fully in Appendix C.

The retrofit cooling trial will be undertaken on 100 of the 520 substations fitted with monitoring. Several installations of each type will deliver learning about how much capacity release could be realised, and defining installation methodologies for optimal performance.

Processes to ensure competitive cost

During the bid development phase, the Project requirements were advertised on the Energy Networks Association (ENA) Smarter Networks portal. The responses were evaluated against the criteria of relevant experience and expertise, cost and Partner contribution. Impact Research and Ricardo-AEA were assessed as offering the best value for money and selected as Partners for delivering Celsius.

Following the expression of interest (EOI) process described above, Ash Wireless was identified as a preferred Partner for monitoring equipment. This preference was based on their knowledge of distribution asset temperature monitoring and successful delivery of their KlikFit sensor for supporting UKPN's Second Tier LCN Fund FUN-LV project. The costs from Ash Wireless were benchmarked against an alternative source and found to deliver a competitive solution.

Other costs have been derived from our business as usual framework agreements. These contracts are awarded based on open competitive procurement exercises compliant with EU procurement regulations and the utilities directive[14]. We will continue with competitive processes and/or benchmarking of costs during bid delivery. For instance, tender processes will be conducted to select an organisation to deliver the thermal flow study and for provision of the retrofit cooling techniques to ensure value for money is obtained for GB customers.

[14] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.094.01.0243.01.ENG

Clear roles and responsibilities for all Project participants will ensure that there is no duplication of activities. Figure 4.4 shows the expected number of person days and day rates per partner.

Figure 4.4: Partner resources

Organisation	Electricity North West	Ricardo-AEA	Impact Research	Ash Wireless	UK Power Network
No. of days	3523	1400	1209	30	20
Day rates (Avg)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Electricity North West has negotiated a contribution from each of the Partner organisations named above. This contribution, along with the DNO compulsory contribution, reduces the cost of the Project to customers by £0.751 million.

Within Celsius, we will explore all possible alternatives to planned supply interruptions during both installation and decommissioning of retrofit thermal monitoring and retrofit cooling equipment.

The Celsius team will seek to install the technologies on live assets without planned supply interruptions to customers wherever possible. However, this will not be possible for the installation of the internal monitoring sensors or installation of the retrofit thermal monitoring on pole-mounted transformers. As retrofit cooling techniques will not be selected until Project delivery, it is unclear to what extent these will require a shutdown to install. Every option available will be explored to minimise inconvenience to our customers, including generation and backfeed.

It is anticipated that the reliability and availability incentives impact could be around £99 104 and Celsius requests protection to this value.

We have sought protection based on the following assumptions:

- All external retrofit thermal monitoring on ground-mounted transformers can be installed with no shutdown due to ease of installation of the Klik-Fit sensor,
- All cable monitoring and cooling can be installed with no shutdown,
- Of the remaining Celsius installation activities, it is expected that a high proportion of trial sites can use either backfeed from another transformer or temporary generation for the duration of any installation or decommissioning activities,
- Where a planned interruption (PI) is anticipated the expected duration anticipated has been advised by our operational engineers. The table below shows these assumptions.

Equipment	Quantity	PI (hours)	% backfeed or generation	Cost of PI penalties
Internal monitoring	20	5	80	£50,466
Monitoring (PMT)	51	1	50	£9,606
Retrofit cooling (PMT)	15	4	50	£7,832
Retrofit cooling (GMT)	30	4	90	£31,201

Note: Cost of PI penalties has been established using [redacted] (2015/2016 prices) and average number of customers connected to pole-mounted and ground-mounted transformers.

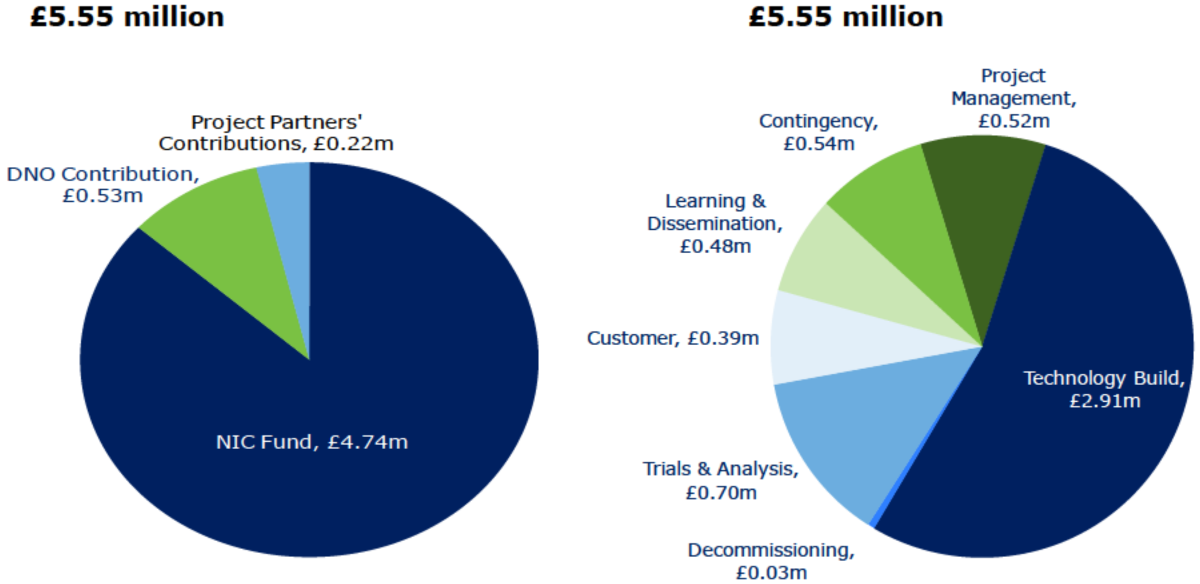
[redacted]

All potential benefits accrue to the electricity distribution networks across GB and these benefits will extend to all customers.

Project funding and costs

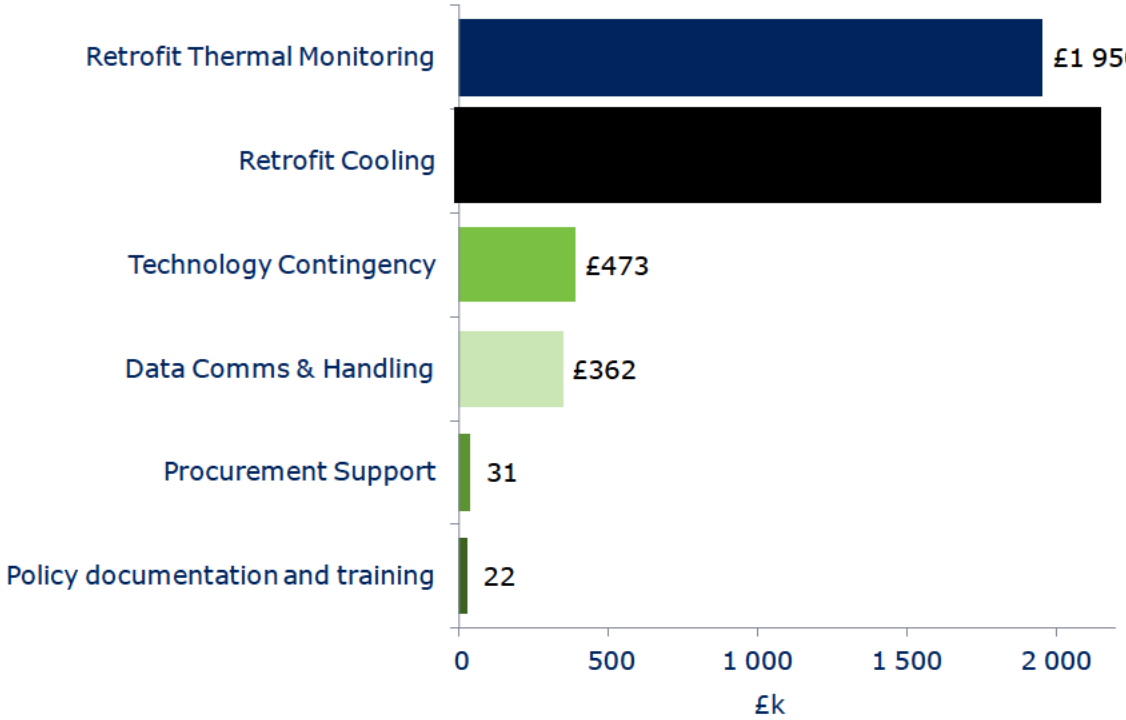
Figure 4.5 shows the cost of delivering Celsius is £5.55 million with £0.751 million funded by Electricity North West and the Project Partners. Figure 4.5 also shows the breakdown of costs across the Celsius delivery workstreams.

Figure 4.5: Celsius funding proposal and high level cost overview



The individual workstream costs have been broken down over figures 4.6 to 4.9.

Figure 4.6: Technology workstream costs overview including contingency



The two main costs in the technology workstream are the purchase and installation of the retrofit thermal monitors at 520 distribution substations and the purchase and installation of the retrofit cooling techniques. The retrofit cooling trials will be conducted on 100 of the substations initially fitted with thermal monitoring. This workstream benefits from equipment deployed and funded under previous IFI projects, such as 113 load monitors and a transformer fitted with fibre optic sensors in the transformer windings. Making use of this previously funded equipment reduces the overall cost of delivering Celsius by **£114 939.**

The cost breakdown for customer engagement activities is shown in figure 4.7 below. This workstream will include development and delivery of the Customer Engagement Plan and will undertake customer engagement activities and customer surveys to prove/disprove *1)* that customers find the innovative retrofit cooling techniques as acceptable as traditional reinforcement; and *2)* that educating customers to the need for and benefits of Celsius are significantly more likely to find those acceptable.

Figure 4.7: Customer workstream cost overview including contingency

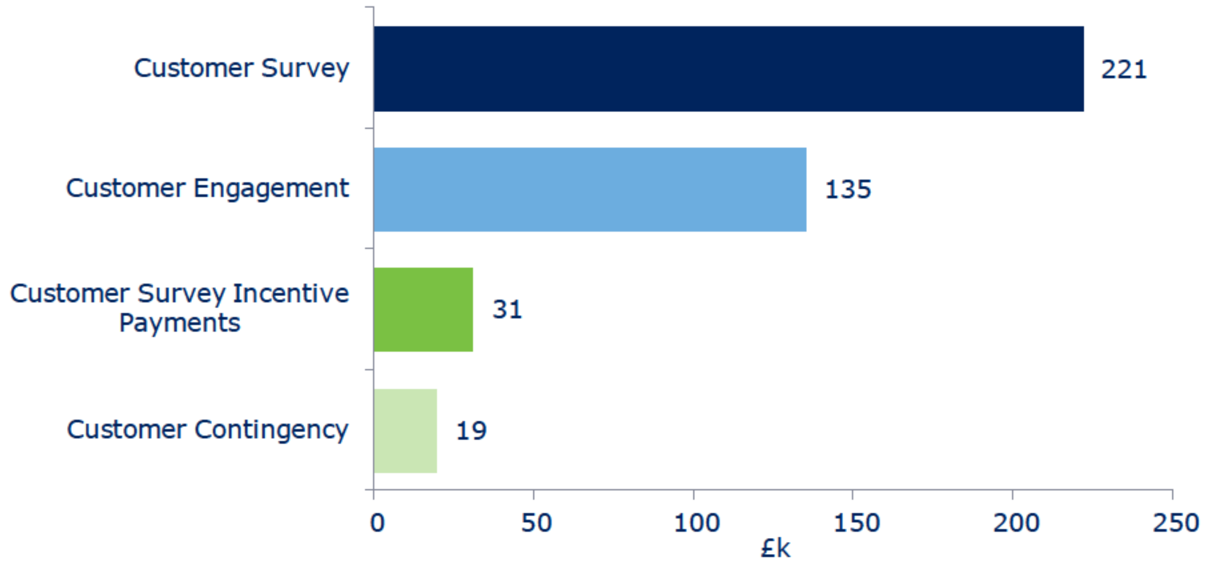
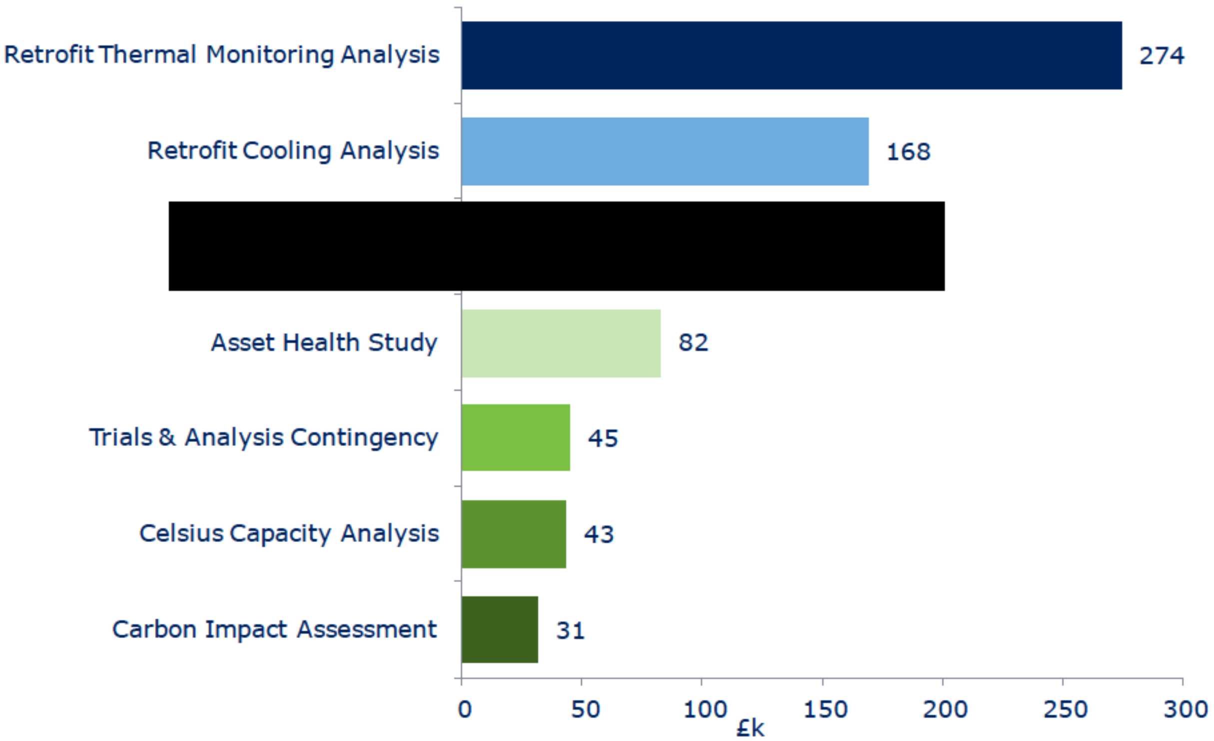
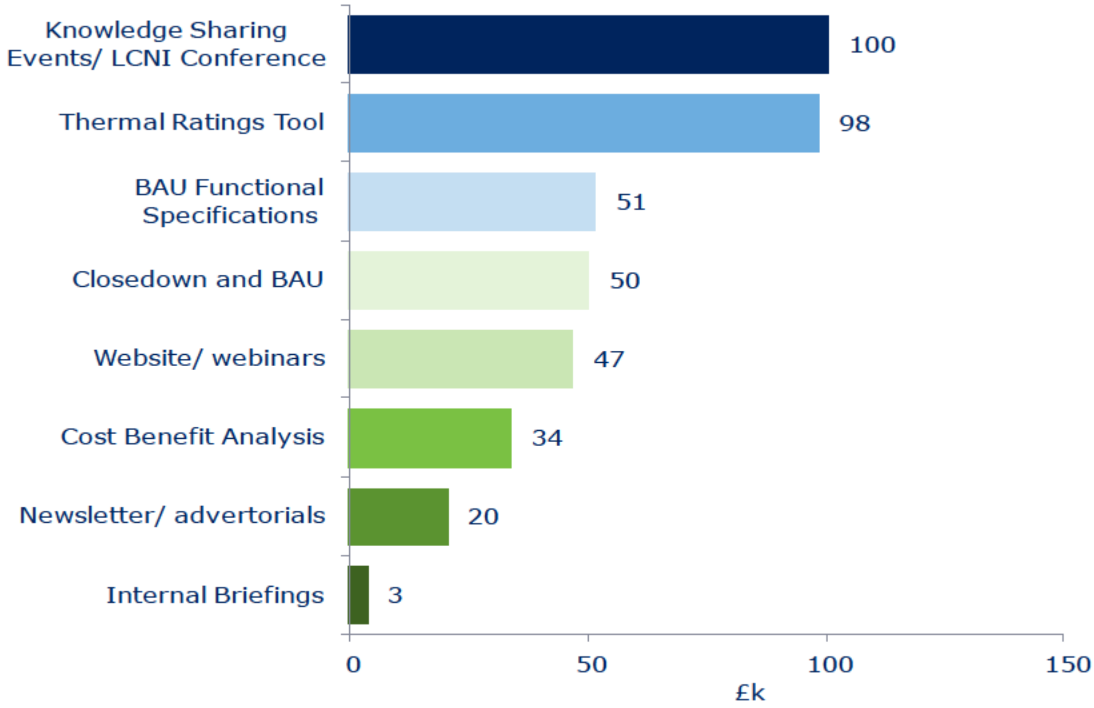


Figure 4.8: Trials and analysis workstream costs overview including contingency



The majority of cost in the trials and analysis workstream is associated with performing analysis of the raw data from the retrofit thermal monitoring and retrofit cooling trials. This will ascertain the relationship between environmental factors, external temperature and asset hotspot; and includes a peer review of coefficient calculations. Reports will be produced to describe the temperature behaviour of assets and a Celsius capacity analysis undertaken. The University of Southampton will deliver an asset health study to confirm that Celsius can be deployed with no detriment to longevity of asset life.

Figure 4.9: Learning and dissemination workstream costs overview



Celsius provides tangible outputs through the learning and dissemination workstream. These include the Thermal Ratings Tool, which will be accessible by any GB DNO, functional specifications for the retrofit thermal monitoring equipment and sets of installation methodologies for monitoring and retrofit cooling applications. Celsius will propose changes to Engineering Recommendation P15 (distribution transformers) and Engineering Recommendation P17 (underground cables). Two DNO workshops will be held to support this piece of work. Firstly, to collaborate on areas of change and secondly, to discuss the proposed changes before revised Engineering Recommendations are submitted to the Energy Networks Futures Group for consideration.

Direct Benefits

The Celsius Project will consist of two steps: retrofit thermal monitoring and retrofit cooling. These techniques will be explored as solutions to future overloads by delaying or deferring reinforcement of distribution substations.

As the Celsius techniques are not yet proven, the site selection methodology for Celsius will exclude any distribution substation with assets due for load-related reinforcement during delivery of the Celsius Project. No allowance has been sought through Electricity North West's Well Justified Business Plan for RIIO-ED1 for the purchase of retrofit thermal monitoring or retrofit cooling equipment. Therefore no expenditure included in the business plan for RIIO-ED1 will be avoided as a result of undertaking this Project and none of Electricity North West's DNO contribution, which represents a contribution of £0.534 million, will be funded by Direct Benefits.

(4c) Generates knowledge that can be shared amongst all relevant network licensees

The criterion for 4c is evaluated in Section 5: Knowledge dissemination. This is in line with Ofgem's guidance notes for completion of the full submission documents.

(4d) Is innovative (ie not business as usual) and has an unproven business case where the innovation risk warrants a limited development or demonstration project to demonstrate its effectiveness

A review of electricity utilities in the UK and internationally has been undertaken by a technical consultant, TNEI, and our future networks team. The review showed that although there has been some work in the area of thermal ratings for electricity assets it has mainly concentrated on higher voltage levels and concerned managing capacity for abnormal situations (see Appendix D for further information).

Our review concluded that Celsius is the first co-ordinated demonstration of temperature monitoring and temperature management of distribution substations for normal loading conditions as a method to unlock capacity.

Establishing asset temperature using external temperature monitoring

Although it is possible to retrofit internal temperature monitoring onto all network assets it is intrusive and very expensive. The Celsius Project aims to develop a methodology for determining the internal temperature from measured external temperatures, by measuring the internal and external temperatures on a small number of assets. The use of low cost, retrofit, external temperature sensors with a set of thermal coefficients to assess operating temperature of distribution substation assets is novel, and requires a project environment on representative assets to develop the processes required for wider scale deployment.

Understanding thermal constraints

The use of seasonal thermal ratings (ie a different rating for each season) and the application of forced cooling, is common in higher voltage assets like transformers; and the use of dynamic thermal ratings (ie real-time ratings derived from monitoring environmental conditions) for overhead lines is gaining acceptance amongst network operators. Both techniques maximise the capacity of assets but neither are routinely considered for distribution substations.

Celsius will build on this by developing a methodology to identify a more accurate site capacity or asset rating by taking into account the environment that the asset is situated in, and the characteristics of the load it experiences.

Addressing thermal constraints

The use of cooling techniques to manage asset temperature is prevalent for transmission and primary distribution assets. These techniques are designed into the operation of the network asset; for example radiators, pumps and fans on large transformers. To date, retrofit cooling techniques have not been routinely applied, either at this voltage level or (depending on the technology) on the electricity distribution network. Neither is the potential capacity release from these cooling techniques clearly understood or quantified. The testing of a set of potential retrofit techniques on a representative sample of distribution substation assets in an innovation project environment will enable a structured programme which minimises operational, commercial and technical risks.

The need for innovation funding

The development of these innovations has the potential to bring about significant cost and carbon benefits. However, as discussed above, there are many elements to explore within Celsius and the results are uncertain. Innovation funding for this Project will enable the development of the installation processes and procedures to deploy Celsius and improve understanding of the benefits.

(4e) Involvement of other partners and external funding

At Electricity North West we encourage our stakeholders to participate in innovation activity and endeavour to make it simple for them to interact with the future networks team to suggest innovation ideas.

There are various channels by which our stakeholders can make contact, including the Electricity North West contact centre which includes an interactive voice response (IVR) option for innovation, Electricity North West’s innovation website, a specific e-mail address and social media channels.

For a single licence DNO, our future networks team and senior managers are exceptionally active and accessible across the industry and within the business for example:

- Industry engagement through presenting at conferences and seminars eg IET and WEET events and chairing forums eg Distributed Generation Forum, Distribution Code Review Panel etc,
- Stakeholder engagement through engaged customer panels (both project specific and for our RIIO-ED1 business plan),
- Innovation engineers seeking new developments in technical and commercial approaches by discussing concepts with other DNOs, industry colleagues, product developers and consultants.

Our future networks steering group (FNSG) assesses project suggestions from these various sources and decides on which to take forward. The selection for the Project concept was developed from an initial list of projects, from potential Project Partners and business led ideas. The idea for Celsius was generated internally in response to DECC forecasts on LCT uptake and previous projects showing thermal constraints becoming an issue. It is important to undertake this work to develop easily deployable solutions and mitigate the risk of electricity networks becoming a constraining factor for the economic and efficient connection of customers' appliances. The Project concept has been reviewed by our technical consultancy Partner Ricardo-AEA, TNEI and the University of Southampton. The FNSG selected and approved this innovation idea as the basis for the 2015/16 submission to the Network Innovation Competition.

The decision on which Project Partners are selected is taken by the FNSG and the identification started in early 2015 through EOI and Calls for Innovation. These promote wider awareness and involvement to generate competition via the ENA Smarter Networks portal and the Energy Innovation Centre (EIC). The selection of Project Partners and suppliers is dependent on experience, skills, cost and the organisation's ability to commit resources to deliver the Celsius Project and disseminate the learning to other GB DNOs and stakeholders.

(4f) Relevance and timing

Studies undertaken as part of our First Tier LCN Fund project, Low Voltage Network Solutions, showed that the first barrier to low carbon technology uptake is voltage constraints, followed closely by thermal constraints. Our Second Tier LCN Fund project, Smart Street, and similar projects being delivered by other GB DNOs, are already demonstrating solutions to voltage problems.

The next step is to find innovative, low cost solutions for thermal constraints. Other projects, carried out under IFI and the First Tier LCN Fund, clearly show the effectiveness of managing temperature to release latent capacity for particular constraint scenarios at higher voltages. For example, Northern Powergrid's LCN Fund project, CLNR[15], carried out studies on two distribution substations and showed that additional capacity of up to 15% can be achieved by monitoring temperature. Celsius will be the first large scale application of temperature monitoring and retrofit cooling techniques on distribution substation assets; and will demonstrate a solution to the issue of thermal constraints seen at distribution substation level under normal loading conditions.

Recent developments in low cost temperature measurement make their wide scale application on distribution substations more cost-effective. So this is an opportune time to understand what level of capacity release can be achieved using these low cost measuring devices and cost-effective retrofit cooling techniques. Celsius needs to be trialled, with innovation funding support, so a business case can be established for the temperature monitoring of distribution substation assets and for each retrofit cooling technique. Only when these business cases are developed can normal business deployment be considered.

Our RIIO-ED1 Well Justified Business Plan forecasted a slow growth in the penetration of low carbon technologies onto the distribution network up to 2020 with an acceleration in the latter half of ED1 and in ED2. The RIIO-ED1 period will be used to trial the

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[15] http://www.networkrevolution.co.uk/wp-content/uploads/2015/03/CLNR-L263-LP15-P17-P27-Review-and-Recommendations-30-03-15-EW.pdf

techniques proposed in Celsius in preparation for the forecasted accelerated growth in RIIO-ED2. The timeline of the Celsius Project allows the creation of the relevant planning and installation methodologies and business case in time for the RIIO-ED2 business plans. The learning gained in Celsius will shape our approach to RIIO-ED2 as the use of electric vehicles and heat pumps increases significantly.

Section 5: Knowledge Dissemination

Celsius will deliver a series of structured interventions which can be easily adopted by other network operators to release capacity quickly and at lower cost than traditional reinforcement.

5.1: Learning generated

Celsius builds on the learning from previous IFI, First and Second Tier LCN Fund projects on thermal ratings and will generate incremental learning in a number of areas. Analysis of relevant projects can be found in Appendix D.

The Project plan incorporates early dissemination of the learning and knowledge that Celsius expects to generate.

Timely dissemination is also reflected in the Successful Delivery Reward Criteria. These provide focus on disseminating outputs as early as possible to maximise all benefits uncovered throughout Project delivery. The key knowledge outputs are shown in figure 5.1 below.

Figure 5.1: Key deliverables

Milestone	Product	Responsible
Retrofit thermal monitoring site selection and trial design finalised	Retrofit thermal monitoring site selection and trial design report	Electricity North West, UK Power Networks
Installation of retrofit thermal monitoring	Functional specification of thermal monitoring and installation methodologies including lessons learned	Electricity North West, Ricardo-AEA, Ash Wireless
Retrofit thermal monitoring installation complete	Raw data from retrofit thermal monitoring	Ricardo-AEA, Ash Wireless
Investigation of retrofit cooling techniques	Retrofit cooling technology investigation study report	Electricity North West, Ricardo-AEA
Retrofit cooling site/technology selection and trial design finalised	Report on site/technology selection, technical data and trial design	Electricity North West, Ricardo-AEA
Thermal flow study phase 1 concluded	Recommendations for best practice substation design and ventilation	Electricity North West, Ricardo-AEA
Thermal flow study phase 2 concluded	Recommendations for retrofit cooling selection and installation	Electricity North West, Ricardo-AEA
Customer survey completed	Peer-reviewed customer survey report	Electricity North West, Impact Research
Retrofit thermal monitoring data analysed and peer-reviewed	Temperature behaviour analysis report and Thermal Ratings Tool made available, Celsius capacity analysis report	Electricity North West, Ricardo-AEA, University of Southampton
Asset health study	Asset health studies and associated changes to asset health indices in CBRM	Electricity North West, University of Southampton

Milestone	Product	Responsible
Celsius business case	Cost benefit analysis and carbon impact assessment for Celsius	Electricity North West, Ricardo-AEA, University of Southampton
Processes for transition to business as usual	Report of recommendations for a business as usual process, functional specification and monitoring methodology Draft change proposals for Engineering Recommendations P15 and P17. Submit change proposal to the Energy Networks Futures Group	Electricity North West, Ricardo-AEA
Retrofit cooling data analysed and peer-reviewed	Celsius capacity release and Thermal Ratings Tool updated and user guide made available	Electricity North West, Ricardo-AEA, University of Southampton

Learning dissemination

The wealth of knowledge that the Celsius Project will generate, described above, will be of interest and benefit to various stakeholder groups. Identifying and understanding these stakeholders is important so that careful consideration can be given to their individual requirements. This will allow us to tailor knowledge sharing and information dissemination to meet the needs of each stakeholder group. With successful delivery and closedown of one LCN Fund project and a further three currently in flight, we have developed a consistent approach to capturing and sharing learning effectively.

Audiences

Our main stakeholder audiences broadly fall under the following categories:

Distribution network operators: including IDNOs, Ofgem, DECC and wider government. These will be keen to appreciate how Celsius can be employed to facilitate customer connections of LCTs. Information for this audience will focus on how Celsius will influence network reinforcement investment and reduce costs for customers while maintaining quality of supply and network reliability. This will assist in decision-making for future strategies, price control reviews and industry regulation.

Industry groups: such as the ENA and the Smart Energy Demand Coalition (SEDC), and other UK and EU industry lobbyist groups will be interested in any potential impact on network design and operation and how Celsius can obtain further benefits from the Smart Meter Implementation Programme. Manufacturers of distribution assets and/or retrofit thermal monitoring and retrofit thermal cooling equipment will be keen to ascertain any operational effects of the techniques applied and explore possible opportunities for product development and potential market opportunities.

Academic institutions: such as universities and higher education establishments who are likely to access the raw data generated in Celsius to support wider research in the area of electricity distribution networks and the thermal ratings of cables and transformers. Knowledge dissemination with this stakeholder group presents a unique opportunity to invite alternative conclusions.

Local authorities and customers: these groups will be interested in the benefits that can be gained from the rollout of Celsius, such as reduced network operation costs and lower disruption associated with reinforcement activities. It is also likely that the results from customer surveys undertaken as part of Celsius will be of particular interest in assessing planning applications or site developments.

Electricity North West: colleagues from across the organisation have been highly engaged and interested in the innovation programme and the Celsius Project team will be proactive in disseminating to this key stakeholder group. Close links with the customer contact team, those responsible for policy and standards and the commercial and procurement departments will help with successful Project delivery. The Electricity North West community as a whole have a vested interest in working together to establish how learning and knowledge will be incorporated into future business as usual.

Knowledge dissemination

As previously described, knowledge sharing and dissemination activities are designed around the Project deliverables. In addition to this planned learning, our experience shows that unplanned learning is also likely. Timely dissemination of all planned and unplanned learning is crucial to keeping stakeholders engaged. To facilitate this, Celsius will have a dedicated learning and dissemination workstream which will promote dissemination activities and identify appropriate audiences to share learning gained through the most appropriate channels, described in Figure 5.2 below.

Figure 5.2: Celsius Project dissemination activities

Dissemination method	Description	Audiences
Website	A Celsius website will provide a platform to share knowledge generated and will be easily accessible. Videos and podcasts generated from the Celsius Project can be accessed via the website and YouTube	All stakeholder groups
Seminars, conferences, workshops and exhibitions	A proportion of the dissemination activities will be delivered through a traditional format. These allow for valuable face-to-face time with stakeholders and stimulate active participation of the audience. Events may be filmed and added to the website and YouTube for a wider audience to view	All stakeholder groups
One-to-one knowledge sharing sessions	An extension of the face-to-face dissemination programme will include one-to-one knowledge sharing, particularly with network operators, to help adopt Celsius into business as usual	All stakeholder groups
Social media	Social media channels such as Twitter, Linked In and You Tube will be used as appropriate to promote learning from the Project	Customers, local authorities, DNOs, IDNOs,

Dissemination method	Description	Audiences
Press releases	Issued over the course of the Project by an in-house press officer. These articles will be designed to publicise Celsius activities and events throughout the industry in many forms including wider industry magazines	All stakeholder groups
Internal communication	Includes articles in the company magazine 'Newswire', weekly email bulletin and The Volt intranet. Making the Celsius Project's aims and objectives widely known across Electricity North West and giving up-to-date information will contribute to Project delivery and prepare for business as usual once proven a success	Electricity North West
Reports, documents and training material	Milestones and SDRCs will be agreed to govern when these documents are produced and ready to share with stakeholders	DNOs, IDNOs, Ofgem, DECC, academic institutions, equipment manufacturers, Electricity North West

The chart below shows the knowledge dissemination activities planned throughout the course of the Project.

Figure 5.3: Dissemination programme

2016	2017	2018	2019	2020
Knowledge sharing event – Introduction to Celsius, site selection, trial design and installation plan	Knowledge sharing event – Installation lessons learned (monitoring), cooling workshop outputs and initial customer engagement learning	Knowledge sharing event – Installation lessons learner (cooling), customer engagement and survey updates and Thermal Ratings Tool (monitoring inputs)	Knowledge sharing event – Customer survey results, final Thermal Ratings Tool, Celsius lessons learned and proposed engineering recommendations changes	Engineering recommendation changes
LCNI conference	LCNI conference	LCNI conference	LCNI conference	
Advertorial	Advertorial	Advertorial	Advertorial	
Internal communication	Internal communications	Internal communications	Internal communications	Internal communications
Six monthly reports	Six monthly reports	Six monthly reports	Six monthly reports	Closedown report
One-to-one briefings available for industry stakeholders	One-to-one briefings available for industry stakeholders	One-to-one briefings available for industry stakeholders	One-to-one briefings available for industry stakeholders	One-to-one briefings available for industry stakeholders
Celsius website				

5.3. IPR

Electricity North West intends to conform to the Network Innovation Competition default IPR arrangements. All Partner contracts will include the standard Network Innovation Competition default IPR clause.

Section 6: Project Readiness

Electricity North West has a proven track record of delivering innovation projects to time and budget. Together with our chosen Partners we are confident that we can deliver the Project learning and benefits.

Requested level of protection required against cost over-runs (%): 0%
Requested level of protection against Direct Benefits (%): 0%

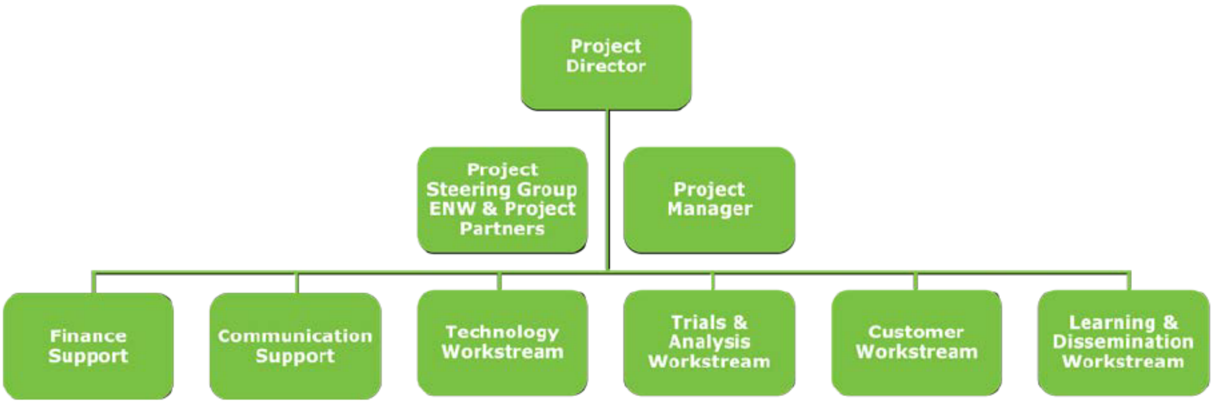
Electricity North West is confident that, if successful, the Celsius Project will be able to start in a timely manner due to the significant amount of preparatory work which has taken place prior to the Full Submission. Electricity North West already has dedicated teams set up within the future networks department who can help build on past experience from previous successful submissions.

Starting Celsius in 2016 will enable enhanced opportunities presented by the smart meter rollout by 2020 which is also when the Celsius Project is due to finish. Therefore it is vital to carry out this Project now so that electricity distribution network operators will have everything in place ready to deploy.

Project management and governance

Celsius will use the programme management and governance approach currently being employed for the delivery of the CLASS, Smart Street and Respond projects. Following the successful closedown of the C_2C project, this proven project governance methodology will ensure that Celsius delivers the defined milestones and Successful Delivery Reward Criteria. Enhancements to the methodology identified in the delivery of previous and ongoing projects can be easily transferred into the Celsius Project. The philosophy to be open and collaborative, with the commitment to get it right first time to achieve delivery success, already seen in the four project delivery teams, will be embedded in the Celsius Project team. The project management structure is shown below.

Figure 6.1: Project management organogram



Project Partners and contractual arrangements

Project Partners and suppliers are carefully selected dependent on experience, cost and the organisation's ability to commit skilled resources to deliver Celsius and disseminate the learning to other GB DNOs. The process by which Partners are selected is described in Section 4b.

Celsius has established a dedicated consortium and generated work schedules in collaboration with our Partners/suppliers that define their roles and responsibilities as well as cost and timing schedules. This will be a key success factor in enabling the Project to start in a timely manner and the schedules form the basis of our contractual arrangements with each party. Defined roles and responsibilities and their financial costing and contributions for the provision of services and/or products are included in the Full Submission workbook (See Appendix K). A key outcome of this approach is that

Electricity North West minimises time spent on agreeing contractual agreements and ensures that Celsius can be mobilised very quickly once funding has been granted.

Project costs and Direct Benefits

The costs and Direct Benefits have been compiled by a management accountant federated into the bid team. Inputs were generated by our internal and external Project Partners/suppliers and have been approved through Electricity North West's internal investment appraisal process. The cost information included in the proposal has an accuracy of between 5 and 7% and, within the overall cost calculation we have added an additional 8% as contingency against any potential changes to costs as the Celsius Project progresses.

A management accountant, responsible for managing all costs and constructing and delivering the reporting requirements will be embedded in the Project team to manage the budget. Electricity North West runs a robust financial tracking and reporting system in line with its current internal policies and frameworks. The Project finances will be held in a separate Project Bank Account required by the NIC Governance Document. This will meet the following requirements:

- Show all transactions relating to (and only to) Celsius,
- Be capable of supplying a real-time statement (of transactions and current balance) at any time,
- Accrue expenditures when a payment is authorised (and subsequently reconciled with the actual Bank Account),
- Accrue payments from the moment the receipt is advised to the bank (and then subsequently reconciled with the actual Bank Account),
- Calculate a daily total; and calculate interest on the daily total according to the rules applicable to the Bank Account within which the funds are actually held,
- Electricity North West's auditors, Deloitte, will be made aware of its responsibilities should Celsius be awarded NIC funding.

Assurance and sign off

The assurance activities of the funding request submission are underpinned by the robustness of our bid process. We assured and challenged our bid via a number of means including:

- Developing detailed internal cost models. These include evaluating the Project resources required, with proposals from third parties subject to fixed price contracts,
- All contributions by Partner organisations separately documented and challenged,
- All cost and contributions collated and reviewed by the finance team,
- Benefits estimate compiled by ourselves and bid supporter TNEI.

We have also conducted an internal process audit for the submission. This audit found no material errors or issues and will form the basis of a report to be presented to the responsible director.

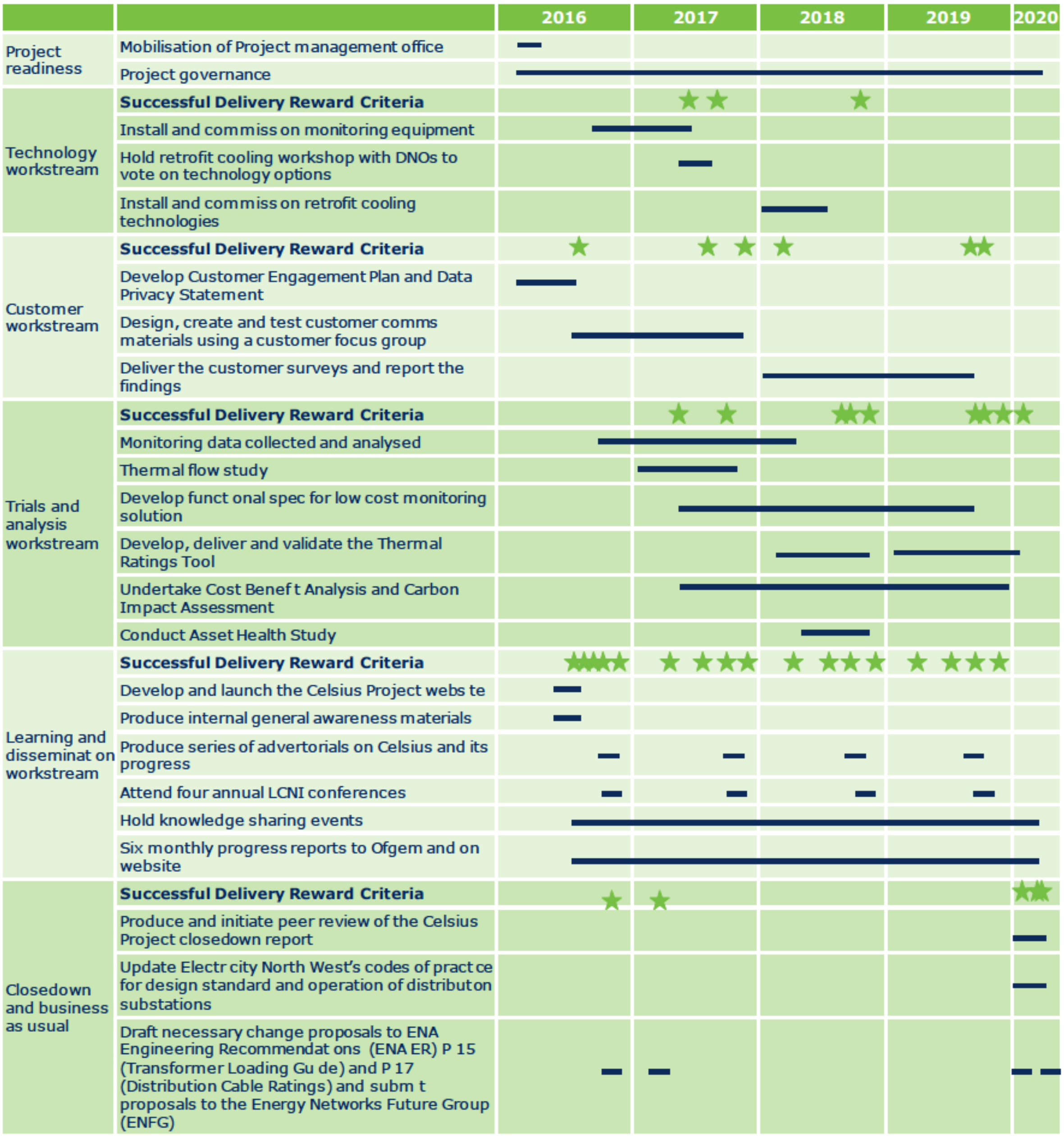
The type of review undertaken represents the most appropriate form of challenge to this type of submission.

Our submission is jointly signed off by three people: our head of engineering, Steve Cox, networks strategy and technical support director, Paul Bircham and chief executive officer, Steve Johnson.

Project plan

The Project plan sets out the approach by workstream and activities that Electricity North West and Celsius Project Partners will undertake. In addition to four workstreams, the plan includes mobilisation and closedown phases. The plan is shown in figure 6.2 and a more detailed version can be found in Appendix F.

Figure 6.2: High level project plan



Mobilisation: The mobilisation of both internal and external teams, as well as the retention of those individuals across the Project delivery lifecycle, is crucial to the successful start and continued delivery of the Celsius Project. Electricity North West has identified delegate resources to deliver Celsius, managed by a full time Electricity North West project manager. The team will also receive significant help from within the wider future networks team. Furthermore the Partners have identified resources that will be dedicated to Celsius.

Technology: The technology workstream will ensure the installation of the temperature sensors and retrofit cooling techniques. This will include their procurement and purchase. This workstream will also ensure that the data collection and communication is working on site.

Customer: The customer workstream runs in parallel with the whole Celsius Project and a more detailed Customer Engagement Plan will be issued and approved by Ofgem in early 2016. More details can be found in Section 8 of the Full Submission document.

Trials and analysis: During the trials and analysis workstream, the Celsius Project team will finalise the site selection which will be peer-reviewed by our technical consultants for the temperature monitoring and retrofit cooling steps of the Project. Once the data has been gathered it will be analysed and the results generated will provide a thermal coefficient to share with other DNOs.

Learning and dissemination: The learning and dissemination workstream will incorporate all dissemination activities and make use of real and virtual media channels to ensure maximum reach. Virtual media channels may include website, podcast, social media, webinars and blogs; while real channels include knowledge sharing events, advertorials and presenting our learning at conferences. These activities are defined in more detail and tailored for the audience in section 5.

Closedown: During this phase the new equipment will be removed and decommissioned. The closedown report will be drafted, approved and published and change proposals for ER P15 and ER P17 submitted to the ENFG.

The Project plan provides a clear roadmap to steer and support the Celsius Project delivery team in achieving the relevant milestones and SDRCs on time and within budget.

Uptake of low carbon technologies in the trial area

The Celsius scope is designed to deliver learning and develop the outputs without the need for further low carbon or renewable energy uptake on the trial networks. However, our site selection methodology does include this criterion and we are aware that Wigan and Leigh Housing, a social landlord in the North West, are currently installing a number of heat pumps in their housing stock. We will look to include this area in the deployment of Celsius to understand how heat pump loads affect the operating temperature of assets.

The methodology for determining the internal temperature from measured external temperatures can be produced based on the load curves experienced today. If it is necessary to alter this loading we can do this by using parallel feeders and linkboxes to add or remove loads as necessary. The capacity available today can be assessed using this methodology, along with the static site data and loading.

The deployment of retrofit cooling is also still valid without LCT uptake as the benefits will still be observed and quantified to be used in future assessments. The methodologies to be developed in Celsius can be applied to any distribution network, regardless of the load type, to understand whether new loads can be accommodated.

Risks, mitigation and contingency plans

A key aspect of our Project management methodology is the capability to manage risks and issues. Celsius will employ the proven risk and issues process currently in operation in Electricity North West, but modified from our previous experience in the delivery of LCN Fund projects. The risk and issues model employed considers risks and issues that are business as usual and those specifically related to Celsius, all of which will be articulated in a common format.

Appendix G contains a table of risks, mitigating and contingency actions identified prior to the start of the Celsius Project; as well as the format and description of the Electricity North West scoring matrix used to evaluate the identified risk and controlled risk following use of any mitigating action(s). Mitigation and contingency creation and definition form a key part of our risk management strategy. The Project management team and Project steering group will use this methodology to continually identify and review Celsius risks, their mitigating action(s) and controls to ensure that risks are managed in priority order. When a risk is raised the Project management team will be responsible for creating a mitigation action that can be brought into play should the risk be realised. Standard topic areas in the risk identification process include cost monitoring management, particularly considering cost overruns or shortfalls in Direct Benefits.

The Project steering group will also identify the circumstances that may lead to the Project being suspended, until such time as sufficient risk mitigation has occurred to enable on-going management of the risk or issue; or to halt the Project and defer further commitment until agreement has been reached with Ofgem on how to proceed.

Section 7: Regulatory Issues

Celsius will have a positive impact on the future design and operation of distribution networks and will reduce costs for customers.

It is not anticipated that the Celsius Project will require any derogation, licence consent or licence exemption for its delivery.

Long-term regulatory impact

It is expected that Celsius will have positive implications for the design and operation of distribution networks in future years.

The learning from Celsius will:

- Enable efficient thermal capacity management through delivering a low cost monitoring specification and Thermal Ratings Tool,
- Provide planning engineers with a proven suite of retrofit cooling interventions enabling lower cost solutions to thermal constraints,
- Inform approaches to new substation design standards for optimal thermal performance.

This will potentially drive change in the following areas:

- Greater accuracy on the forecasts of interventions for load-related capital expenditure using the Thermal Ratings Tool,
- Reduced capital programme costs for load-related capital expenditure from a proven suite of retrofit cooling interventions,
- New substation design standards for optimal thermal performance to reduce whole life costs.

Section 8: Customer Impact

Celsius will ascertain whether retrofit cooling techniques have an impact on customers and if the application of these techniques is as acceptable as traditional reinforcement.

Electricity North West aims to delight customers in everything that it does to support our goal of being the leading energy delivery business. To achieve this we must continue giving great customer service while providing a reliable and efficient electricity supply for the best value for money.

Celsius will assess and manage the operating temperature of network components to maximise the capacity of distribution assets and facilitate connection of demand and generation while minimising reinforcement costs. Celsius will benefit customers by facilitating faster connection of LCTs with less disruption all at a lower cost.

The first step of Celsius will include installing temperature and load monitoring at 520 substations across the Electricity North West network area. The second step will be to install retrofit cooling techniques at 100 of the initial trial sites.

These assets may be in close proximity to domestic and/or commercial customers' premises. It is envisaged that the techniques used will, in some cases, change the appearance or sound associated with assets. During the trials and analysis phase of the Project we propose to engage with customers and undertake surveys to establish customer perception and acceptability of the cooling interventions.

Before contacting our customers to invite their participation, we will work with our customer Partner, Impact Research, to draft and issue to Ofgem a Customer Engagement Plan and Data Privacy Statement.

Impact Research will carry out a sufficient number of surveys with customers to reliably prove or disprove the hypothesis 'customers within the Celsius trial areas will find the implementation of innovative retrofit cooling techniques as acceptable as traditional reinforcement'. A level of acceptability will be established for each type of retrofit cooling technique which will make it possible to differentiate between the various interventions based on customer feedback.

Based on previous experience of engaging with customers, Electricity North West will commit to educating customers about the need for Celsius and the benefit of the Method to them. This should prove or disprove a secondary hypothesis that 'customers who are educated as to the need for and benefits of Celsius are significantly more likely to find it acceptable'. The methodology will seek to quantify the value of educating customers about the problem, the solution and the benefits.

This builds on the learning from Electricity North West's Second Tier LCN Fund project, Smart Street, which underpinned its customer awareness campaign by conducting a robust post-distribution evaluation exercise, to assess the overall success and impact of the communication materials. The learning from this research will be utilised to optimise Celsius communication materials.

Customer engagement will evaluate the hypothesis linking the investment in education to an increase in acceptability of Celsius. Electricity North West is unaware of previous studies that have tested customer engagement in this way to demonstrate investment on return.

Electricity North West will work with Impact Research to determine the communication materials required to educate customers and agree how this information is presented. This could include a video, Celsius website, customer leaflet, a letter, visual stimuli and/or an FAQ. An in-depth qualitative exploration exercise will take place to test general perception of the Celsius Project and initial reactions to the retrofit cooling techniques through the use of face-to-face focus groups.

A baseline survey will be conducted with domestic customers on the trial substations prior to the retrofit cooling techniques being applied. The data collected from the baseline will serve as a benchmark with which to compare the results of the customer survey conducted after the changes have been applied, thus acting as a measurement of any change in perception.

The quantitative research on customers' perceptions will encompass 'test' and 'control' groups, with customers in groups A and B being given extra information about the Project; and customers in groups C and D not being given the extra information.

Figure 8.1: Customer survey, acceptability of retrofit cooling

	Celsius baseline (pre-trial)	Celsius test group (post retrofit)
Education: Yes	A	B
Education: No	C	D

Structuring the customer engagement in this way will enable us to quantify the impact of sensitising customers to the changes that are going to be made before they happen. This is a secondary benefit of the customer engagement and therefore fewer surveys will be conducted with customers that have been educated, although there will be a sufficient number to prove/disprove the hypothesis.

In total 600 baseline surveys will be conducted, split 50/50 amongst those who have, and those who have not, been given extra information about Celsius. In a follow-up test survey, once the retrofit cooling techniques have been applied, 600 customers will be surveyed, 450 of which will be new to the engagement and will have received neither prior education nor taken part in any survey related to the Project beforehand.

Impact Research will aim to survey 150 out of the 300 customers that took part in the baseline survey and who were educated in the follow-up test survey. This will provide a sufficient sample of pre-educated customers for analysis purposes.

The proposed re-contact activity relies on half of the customers who took part in the baseline survey and who were educated about the Project agreeing to take part in a second survey. In the event of original participants being unavailable or unwilling, Impact Research will achieve as many interviews as possible amongst the original survey population and then educate previously unengaged customers in order to achieve the target of 150 test surveys.

Figure 8.2: Customer survey, impact of educating customers on reasons for Celsius

	Celsius baseline	Celsius test survey
Education: Yes	300	150
Education: No	300	450

The sample for the baseline and test survey will be split into three aggregate regions: urban, dense urban and rural. The profile of customers that take part in the surveys will be matched to Acorn, a powerful consumer classification that segments the UK population. By analysing demographic data, social factors, population and consumer behaviour Acorn provides precise information and an understanding of different types of consumer. This is an important addition to the Customer Engagement Plan for Celsius given the different environments that substations are located in.

Figure 8.3 provides an overview of the likely approach.

Figure 8.3: Customer survey

Baseline
25 minutes (no education) or 30 minutes (with education)

- Socio-demographic
- Awareness of Electricity North West and overall satisfaction
- General perception of street furniture
- Awareness of existing asset location, appearance, size, noise level
- Attitude/acceptance towards a change in asset location, appearance, size, noise level
- Noticed any changes?
- Design features/barriers

Test survey
(not originally educated)
25 minutes

- Socio-demographic
- Awareness of Electricity North West and overall satisfaction
- General perception of street furniture
- Awareness of existing asset location, appearance, size, noise level
- Attitude/acceptance towards a change in asset location, appearance, size, noise level
- Noticed any changes?
- Design features/barriers

Test survey
(educated before)
15 minutes

- Overall satisfaction
- Noticed any changes?
- Attitude/acceptance towards a change in asset location, appearance, size, noise level
- Design features/barriers

These customer surveys will be administered face-to-face and each customer will be offered an incentive of £25 to take part in the survey, either through a personal incentive paid upon completion of the interview or a charitable donation.

There is a possibility that customers on certain Celsius trial networks may experience planned supply interruptions associated with the installation of essential monitoring equipment or cooling interventions. Electricity North West will take all practicable steps to install Celsius enabling technologies without the temporary isolation of customers' supplies and will consider whether it is possible to backfeed from an adjacent substation or attach a generator for the duration of installation activities.

However, where this is unavoidable, we will manage these impacts through business as usual processes and provide all impacted customers with standard written notification prior to the planned supply interruptions, in accordance with Guaranteed Standard procedures.

It has been assessed that the maximum impact of these interruptions will not be in excess of eight hours and the number of customers affected will be minimal. In the case of internal monitoring, installations will occur at 21 substations. The retrofit cooling trials will be demonstrated on 100 substations but only a subset of these may require an interruption.

Electricity North West appreciates that some of its customers have additional requirements due to disability, being elderly or having a chronic illness. We have a strong history of promoting safety and security at the homes of these vulnerable customers. Amongst other things, we maintain a priority services register (PSR) of customers who have special requirements or who may be vulnerable during a power outage. The register enables the company to provide appropriate assistance to these customers, where required. We will use this register to identify vulnerable customers with additional requirements and issue notification to them well in advance of the interruption. This will ensure that they are able to make alternative arrangements and that Electricity North West can appropriately manage any specific needs, where necessary, to mitigate the impact of the planned supply interruption. We anticipate that the incentive penalty protection required for the small number of planned supply interruptions for the installation and decommissioning of Celsius equipment will be £99 104, based on 2015/2016 prices. The calculation of the incentive penalty protection is outlined on page 21.

Should customers report a notable effect or dissatisfaction attributed to the implementation of retrofit cooling techniques in their local area, the matter will be immediately and thoroughly investigated by the Celsius Project team and possible solutions explored. Where appropriate, and in consultation with the customer/s, suitable interventions will be offered to attain a mutually agreeable resolution. In the unlikely event that a resolution to the complaint is not achievable, Electricity North West may consider halting the particular retrofit cooling technique on that specific part of the network.

Feedback received from customers, stakeholders and Partners may be used to revise plans throughout the Project life in order to continually improve the customer engagement strategy. The Celsius Project will share all customer communication materials and findings, and the team will consult Ofgem in advance of any significant changes from the original approach.

Managing customer enquiries

We will create a number of communication channels so that customers will find it simple to raise any questions or concerns at a time convenient for them using the following channels:

Telephone: Electricity North West operates an enquiry service that is continuously staffed and can be contacted 24 hours a day and seven days a week on 0800 195 4141.

Written correspondence: The Celsius Project team can be contacted at the following address: Celsius Project Team, Technology House, Salford, M6 6AP.

Celsius website: The Celsius website will contain all relevant information including trial areas, customer activities, Project literature and Project team contact details. Frequently asked questions will be posted on the website and updated regularly. If a customer is unable to find an answer to a specific issue, a 'contact us' function will allow them to submit their query so that a representative from the Project team can respond via the customer's preferred feedback method.

Social media: Electricity North West holds Twitter, Facebook, Linked In and You Tube accounts and can provide updates or responses to customer enquires via these channels.

The Celsius Project team will seek to respond to all queries as soon as possible and in all cases, within ten working days.

Section 9: Successful Delivery Reward Criteria (SDRCs)

Criteria	Technology workstream
TW.1	Install and commission monitoring equipment
TW.2	Hold retrofit cooling workshop with DNOs to vote on technology options
TW.3	Install and commission retrofit cooling technologies
Evidence	
TW.1	Publish equipment specifications and installation reports by September 2017
TW.2.1	Hold retrofit cooling workshop by May 2017
TW.2.2	Review of highest scoring technologies, circulate workshop outcomes to DNOs and publish on the Celsius website by July 2017
TW.3	Publish cooling equipment specifications and installation reports by November 2018

Criteria	Customer workstream
CW.1	Develop Customer Engagement Plan and Data Privacy Statement
CW.2	Design, create and test customer communication materials using a customer focus group
CW.3	Deliver the customer surveys and report the findings
Evidence	
CW.1	Send Customer Engagement Plan and Data Privacy Statement to Ofgem by June 2016
CW.2.1	Deliver customer focus group workshop by July 2017
CW.2.2	Publish lessons learned from testing customer communication materials on Celsius website by December 2017
CW.3.1	Publish customer survey report quantifying the acceptability of innovative retrofit cooling techniques on the Celsius website by September 2019
CW.3.2	Publish additional customer survey analysis evaluating the change, if any, in the acceptability of innovative retrofit cooling techniques by educating customers, on the Celsius website by September 2019

Criteria	Trials and analysis workstream
TAW.1	Monitoring data collected and analysed
TAW.2	Thermal flow study
TAW.3	Develop functional specification for low cost monitoring solution
TAW.4	Develop, deliver and validate the Thermal Ratings Tool using outputs from the monitoring and cooling intervention trials
TAW.5	Undertake Cost Benefit Analysis and Carbon Impact Assessment
TAW.6	Conduct Asset Health Study
Evidence	
TAW.1.1	Raw temperature monitoring data to be available from July 2017; and retrofit cooling monitoring data to be available from September 2018
TAW.1.2	Publish asset temperature behaviour analysis report on Celsius website by September 2018
TAW.2	Publish thermal flow study report and initial recommendations for substation design on Celsius website by November 2017
TAW.3	Publish low cost monitoring solution specification on the Celsius website by September 2019
TAW.4.1	Develop Thermal Ratings Tool using monitoring data to evaluate site capacity on Celsius substations by October 2018
TAW.4.2	Develop and validate Thermal Ratings Tool using retrofit cooling trial data, and publish on Celsius website by November 2019
TAW.4.3	Develop and validate Thermal Ratings Tool, combining input data from the monitoring and cooling trials, and publish user guide on Celsius website by January 2020
TAW.5	Publish the Cost Benefit Analysis and Carbon Impact Assessment reports, Celsius Business Case and buy order of retrofit cooling techniques on Celsius website by December 2019
TAW.6	Publish Asset Health Study report on Celsius website by October 2018

Criteria	Learning and dissemination workstream
LDW.1	Develop and launch the Celsius Project website
LDW.2	Produce internal general awareness materials
LDW.3	Produce a series of advertorials detailing Celsius and its progress
LDW.4	Attend annual LCNI conference
LDW.5	Hold knowledge sharing events
LDW.6	Issue Celsius six-monthly Project progress reports to Ofgem and on Celsius website
Evidence	
LDW.1	Launch Celsius Project website by July 2016
LDW.2	Publicise Celsius within Electricity North West via the Volt intranet site, email bulletins and/or Newswire company magazine by June 2016, March 2017, March 2018, March 2019 and March 2020
LDW.3	Publish advertorials annually by October 2016, October 2017, October 2018 and October 2019
LDW.4	Participate at four annual LCNI conferences from 2016 to 2019
LDW.5	Hold annual knowledge sharing events in September 2016, 2017, 2018 and December 2019. Provide one-to-one briefing sessions
LDW.6	Issue Project progress reports in accordance with Ofgem's June and December production cycle and publish on the Celsius website

Criteria	Closedown and business as usual
Cl.1	Produce and initiate peer review of the Celsius closedown report
Cl.2	Update Electricity North West's codes of practice for design standard and operation of distribution substations
Cl.3	Draft necessary change proposals to ENA Engineering Recommendations (ENA ER) P15 (Transformer Loading Guide) and P17 (Distribution Cable Ratings) and submit proposals to the Energy Networks Futures Group (ENFG)
Evidence	
Cl.1.1	Produce Celsius closedown report by January 2020
Cl.1.2	Complete and publish peer review of Celsius closedown report by March 2020.
Cl.2	Publish Electricity North West's approach to managing thermal constraints at distribution substations on the Celsius website by March 2020 and train planners/ operational engineers on new codes of practice

CI.3.1	ENA workshop with DNOs held by November 2016 (to agree areas of changes to Engineering Recommendations P15 and P17)
CI.3.2	Publish any areas for change identified at the ENA workshop and publish change proposal options to ER P15 and ENA ER P17 on Celsius website by February 2017
CI.3.3	Incorporate relevant Celsius outputs into change proposal options for ER P15 and ER P17 and hold workshop with DNOs by January 2020
CI.3.4	Submit proposals for changing ER P15 and ER P17 to ENFG by March 2020

Section 10: List of Appendices

Appendix number	Title
A.1	Benefits Tables
A.2	Base Case Method and Solution (Business Case)
B.1	Technical Description
B.2	Site Selection Indicative Methodology
B.3	Trial Size Methodology
C	Potential Interventions Analysis
D	Review of other Thermal Ratings Projects
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F	Project Plan
G	Risks and Issues Register and Contingency Actions
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Appendix A.1: Benefits Table

Figure A.1.1 below shows the key for the completion of the financial benefits and capacity released. Figures A.1.2 and A.1.3 for the Celsius Method is referenced by trial number.

Figure A.1.1: Nomenclature key for Figures A.1.2 and A.1.3

Method	Thermal management of the distribution network
Trial 1	Retrofit thermal monitoring of pole-mounted transformers
Trial 2	Retrofit thermal monitoring and cooling intervention for pole-mounted transformers
Trial 3	Retrofit thermal monitoring of ground-mounted transformers
Trial 4	Retrofit thermal monitoring and cooling intervention for ground-mounted transformers
Trial 5	Retrofit thermal monitoring of LV cable first leg out
Trial 6	Retrofit thermal monitoring and cooling intervention for LV cable first leg out

Financial benefits

Figure A.1.2 below shows the financial benefits for the techniques proposed in the Celsius Project.

Figure A.1.2: Celsius financial benefits

Financial benefit (£k) – per individual solution on an NPV basis								
				Benefit (£k)				
Scale	Trial	Method cost (£k)	Base Case cost (£k)	2020‡	2030	2050	Notes	Cross references
Post-trial deployment (individual solutions)	1	[redacted]	9.6	-	0.8	1.7	See below	
	2	[redacted]	9.6	-	0.8	2.0		
	3	[redacted]	19.2	-	1.7	4.7		
	4	[redacted]	19.2	-	1.7	9.6		
	5	[redacted]	3.4	-	0.03	0.14		
	6	[redacted]	3.4	-	1.0	0.9		

‡ Benefits are not presented in 2020 as the Celsius Project completes in 2020.

Financial benefit (£m) – scaled up to Electricity North West and GB including NPV effects								
				Benefit (£m)				
Scale	Trial	Method cost (£k)	Base Case cost (£k)	2020*	2030	2050	Notes	Cross references
Electricity North West scale	1	[redacted]	9.6	-	1.6	3.3	See below	
	2	[redacted]	9.6	-	1.6	4.0		
	3	[redacted]	19.2	-	6.7	18.3		
	4	[redacted]	19.2	-	6.7	37.3		
	5	[redacted]	3.4	-	0.04	0.21		
	6	[redacted]	3.4	-	1.5	1.4		
GB scale	1	[redacted]	7.5	-	34	69	See below	
	2	[redacted]	7.5	-	33	81		
	3	[redacted]	19.2	-	86	237		
	4	[redacted]	19.2	-	87	483		
	5	[redacted]	3.4	-	1	3		
	6	[redacted]	3.4	-	20	18		

* Benefits are not presented in 2020 as the Celsius project completes in 2020.

The assumptions applied to the calculation of net benefits are as follows:

- All costs are in 2014/2015 prices,
- Method and Base Case costs are the asset costs for individual deployment of each of the six trials, as described in Appendix A.2: Method and Base Case methodologies and tabulated in Figure A.2.1,
- When applying the DECC 1 scenario, we acknowledge there is a variety of initial asset loadings, and that due to the clustering of LCT uptake, a range of future load growth paths. This is reflected in the modelling by considering nine representative load growth paths from 2019-2050, rather than just one average load growth. The overall timing and volumes of asset overloads have been verified with the detailed results from the future capacity headroom model based on the DECC 1 scenario. It is assumed that if this scenario is experienced in Electricity North West, the corresponding load profiles are also applicable at GB scale,
- Investment for the Base Case is triggered following asset overload,
- Investment for Celsius thermal monitoring is triggered at 80% of asset nameplate rating value followed by investment in a cooling intervention in the year in which further capacity is required, for applicable trial numbers,
- Net benefits are considered on an NPV basis for nine cost profiles corresponding to the defined load profiles in order to model the timing of investment,
- As equipment costs are uncertain over the period from now to 2050, costs are assumed to be constant,
- To represent the net benefit of the Celsius Method to customers, we follow the approach in the Ofgem RIIO-ED1 CBA template v4, in terms of the financing of DNO expenditure, the valuation of losses including their carbon value and social discount rates.

Representative pole-mounted and ground-mounted transformer sizes (50kVA and 500kVA) and LV cable first leg cable sizes (185mm^2 cross-sectional area conductor) are used for the cost benefit analysis. These sizes were selected based on the average of distribution network asset sizes for the population of assets experiencing overloading in the DECC 1 scenario to 2050. Individual net benefits may vary for smaller or larger assets following these load profile. However, the use of representative sizes enables a simple quantification of likely typical net benefits.

Trials 2, 4 and 6 are based on a generic cooling intervention being applied to assets for the purposes of calculating net benefits. For ground-mounted transformers this is based on a retrofitted fan; and for LV cables this is based on a cable backfill with improved thermal properties. A range of cooling interventions will be tested during the Celsius Project for pole- and ground-mounted transformers and for LV cables which should provide a number of cost-effective cooling interventions and further refinement of the forecast net benefits.

Electricity North West scale

The assumptions applied to calculate the net financial benefits for Celsius on the scale of the Electricity North West area are described below. Please note that net benefits for thermal monitoring trials and for thermal monitoring and retrofit cooling interventions for each asset eg pole-mounted transformers, are presented in isolation and should not be summated.

- *Trial 1:* Thermal monitoring is applied to the volume of pole-mounted transformers (1 937) experiencing overloading in the DECC 1 scenario from 2019 to 2050,
- *Trial 2:* Thermal monitoring and cooling interventions are applied to the volume of pole-mounted transformers (1 937) experiencing overloading in the DECC 1 scenario from 2019 to 2050,
- *Trial 3:* Thermal monitoring is applied to the volume of ground-mounted transformers (3 884) experiencing overloading in the DECC 1 scenario from 2019 to 2050,
- *Trial 4:* Thermal monitoring and cooling interventions are applied to a volume of ground-mounted transformers (3 884) experiencing overloading in the DECC 1 scenario from 2019 to 2050,
- *Trial 5:* Thermal monitoring is applied to the volume of LV cable first legs out (1 506) experiencing overloading on ground-mounted transformers of brick or stone construction or located in fenced enclosures, in the DECC 1 scenario from 2019 to 2050. The design of the LV cable first leg out for these substation types has been identified as most feasible for the application of a cooling intervention,
- *Trial 6:* Thermal monitoring and a cooling intervention is applied to the volume of LV cable first legs out (1 506) as in trial 5 experiencing overloading in the DECC 1 scenario from 2019 to 2050.

Great Britain scale

The assumptions applied to calculate the net financial benefits for Celsius on the scale of GB are described below:

- *Trials 1 and 2:* Pole-mounted distribution transformers in the Electricity North West area number 17 105 compared to 350 939 in Great Britain in 2014. Net benefits for Great Britain are scaled up on this basis assuming that the proportion of pole-mounted transformers that experience overloading across Great Britain under the DECC 1 scenario is similar to the Electricity North West area. The population distribution of transformer ratings is assumed to be similar between Electricity North West and Great Britain,
- *Trials 3 and 4:* Ground-mounted distribution transformers in the Electricity North West area number 16 773 compared to 217 055 in Great Britain in 2014 excluding London Power Networks ground-mounted transformers. A small number of London Power Network distribution substations have some differences in load profile and seasonality of peak demand and may therefore not be as suitable for the Celsius Method. This will be further explored with our Partner UK Power Networks during delivery of the Celsius Project. Net benefits for Great Britain are scaled up on this basis assuming that the proportion of ground-mounted transformers that experience overloading across Great Britain under the DECC 1 scenario is similar to the Electricity North West area. The population distribution of transformer ratings is assumed to be similar between Electricity North West and GB,
- *Trials 5 and 6:* Net benefits for Great Britain for LV cables first leg out are scaled on the basis of the percentage of ground-mounted transformers in the Electricity North

West area compared to Great Britain. This assumes that the population of ground-mounted substations of brick or stone construction or located in fenced enclosures, ie LV cabling design amenable to a cooling intervention, is of a similar proportion for Great Britain. Analysis of Smart Grid Forum workstream 3 results for proportions of LV feeder types in Great Britain and Electricity North West which is indicative of distribution substation design suggests that this is reasonable. The population distribution of LV cables first leg out specification eg cross sectional area, installation, grouping and thus rating is assumed to be broadly similar between the Electricity North West area and Great Britain.

Capacity release

Figure A.1.3: Celsius capacity release

Capacity release (kVA)

		Benefit				
Scale	Trial	2020	2030	2050	Notes	Cross references
Post-trial deployment (individual solutions)	1	-	2.9	8.8	See below	
	2		3	10		
	3	-	26	68		
	4	-	39	213		
	5	-	6	15		
	6	-	21	105		

Capacity release (MVA)

		Benefit				
Scale	Trial	2020*	2030	2050	Notes	Cross references
Electricity North West scale	1	-	5.7	16.9	See below	
	2		6.2	19.3		
	3	-	101.5	264.8		
	4	-	153.0	827.8		
	5	-	8.4	21.9		
	6	-	31.0	158.6		
GB scale	1	-	116	348	See below	
	2		127	396		
	3	-	1 314	3 427		
	4	-	1 980	10 713		
	5	-	109	285		
	6	-	402	2 053		

* Benefits are not presented in 2020 as the Celsius Project completes in 2020.

Capacity release is based on the average capacity release for distribution assets following nine load growth profiles from 2019 to 2050 based on the DECC 1 scenario, consistent with the financial benefits. Appendix A.2 provides further description of the Celsius methodology. Please note that capacity release for thermal monitoring trials and for thermal monitoring and cooling interventions trials for each asset, eg pole-mounted transformers, are presented in isolation and should not be summated.

Trials 1 and 2: Thermal monitoring of pole-mounted transformers may provide up to 13% additional thermal capacity, or more, depending on local ambient temperature and loading conditions. A cooling intervention may provide a further 5%. A representative 50kVA pole-mounted transformer is modelled based on the average rating for pole-mounted transformers in the DECC 1 scenario from 2019 to 2050. If load continues to increase and the 50kVA pole-mounted transformer is replaced with a 100kVA pole-mounted transformer, the Celsius Method is redeployed when triggered at an appropriate level of loading.

Trials 3 and 4: Thermal monitoring of ground-mounted transformers may provide up to 13% additional thermal capacity, or more, depending on local ambient temperature and loading conditions. A cooling intervention may provide up to a further 30%. A representative 500kVA ground-mounted transformer is modelled based on the average rating for ground-mounted transformers in the DECC 1 scenario from 2019 to 2050.

If load continues to increase and the 500kVA ground-mounted transformer is replaced with an 800kVA ground-mounted transformer, the Celsius Method is redeployed when triggered at an appropriate level of loading.

Trials 5 and 6: Thermal monitoring of LV cable first legs out may provide 4% additional thermal capacity above current rating (405 amp cyclic rating for 185mm^2 cross-sectional aluminium conductor laid direct in ground, four grouped cables at 150mm spacing[16]) depending on ambient temperature conditions and soil resistivity. A cooling intervention may provide up to a further 20%. A representative 185mm^2 rated LV cable is modelled based on the average rating for overloaded of LV cables in the DECC 1 scenario from 2019 to 2050.

If load continues to increase and the 185mm^2 LV cable is then replaced with a 300mm^2 LV cable, the Celsius Method is redeployed when triggered at an appropriate level of loading. In the case of cable backfill, this would remain intact, providing further capacity benefits.

Electricity North West scale

Capacity release for each Celsius trial is calculated using the same assumptions for net financial benefits on the scale of the Electricity North West area.

Great Britain scale

Capacity release for each Celsius trial is calculated using the same assumptions for net financial benefits on the scale of the Great Britain distribution network.

[16] Electricity North West, Code of Practice 203 Current Ratings Underground Cables, Issue 5, January 2014.

Appendix A.2: Method and Base Case Methodologies

Financial analysis of the Celsius Method and traditional distribution network reinforcement showed that Celsius provides significant net benefits and reduction in implementation time while delivering additional capacity release.

A thermal constraint is defined as peak load exceeding 100% of nameplate rating. Once a distribution transformer asset becomes thermally constrained, the most efficient method currently in use is to replace it with a higher rated asset. Alternatively, an additional distribution substation is installed as close as possible to the centre of the load, and the load is split between the existing and new substations.

The Celsius and Base Case methodologies are described below for each trial.

For Celsius, thermal monitoring and cooling interventions defer traditional reinforcement. Celsius is redeployed on replacement assets when triggered at an appropriate level of loading.

Trials 1 and 2

A representative 50kVA rated pole-mounted transformer is modelled based on the average rating for overloaded pole-mounted transformers in the DECC 1 scenario from 2019 to 2050. For the Base Case, the 50kVA pole-mounted transformer is replaced with a 100kVA pole-mounted transformer followed by a 200kVA pole-mounted transformer if load increases further.

In the Celsius Method, retrofit thermal monitoring is applied once the transformer reaches or exceeds 80% of rated capacity and a cooling intervention is applied as load increases above the additional capacity release, provided by the thermal monitoring. If load then continues to increase above the additional capacity release provided by the cooling intervention, the 50kVA pole-mounted transformer is replaced with a 100kVA pole-mounted transformer and Celsius is redeployed on that asset when triggered at an appropriate level of loading.

Trials 3 and 4

A representative 500kVA rated ground-mounted transformer is modelled based on the average rating for overloaded ground-mounted transformers in the DECC 1 scenario from 2019 to 2050. For the Base Case, the 500kVA ground-mounted transformer is replaced with a 800kVA ground-mounted transformer followed by a 1000kVA ground-mounted transformer and then a new ground-mounted transformer if load increases further.

In the Celsius Method, retrofit thermal monitoring is applied once the transformer reaches or exceeds 80% of rated capacity and a cooling intervention is applied as load increases above the additional capacity release, provided by the thermal monitoring. If load then continues to increase above the additional capacity release provided by the cooling intervention, the 500kVA ground-mounted transformer is replaced with an 800kVA ground-mounted transformer and Celsius is redeployed on that asset when triggered at an appropriate level of loading.

Trials 5 and 6

A representative 185mm^2 LV cable is modelled based on the average rating for overloaded of LV cables in the DECC 1 scenario from 2019 to 2050.

For the Base Case, the 185mm^2 LV cable is replaced with a 300mm^2 LV cable followed by an additional 300mm^2 LV cable if load increases further.

In the Celsius Method, retrofit thermal monitoring is applied once the LV cable reaches or exceeds 80% of rated capacity and a cooling intervention is applied as load increases above the additional capacity release provided by the thermal monitoring. If load then continues to increase above the additional capacity release provided by the cooling intervention, the 185mm^2 rated LV cable is replaced with a 300mm^2 LV cable and Celsius is redeployed on that asset when triggered at an appropriate level of loading. For a cable backfill cooling intervention, it is assumed that this remains in situ when the cable is replaced.

Figure A.2.1 shows the asset costs, capacity released in terms of facilitated demand connections and implementation time for each trial.

Figure A.2.1: Summary of cost, capacity and implementation time for Celsius and Base Case

		Asset cost, £	Planning and installation time, weeks	Capacity released, kVA
Trial 1	Celsius	[redacted]	4	6.6
	Base	9 600	12	50
Trial 2	Celsius	[redacted]	2	9.1
	Base	9 600	12	50
Trial 3	Celsius	[redacted]	4	51
	Base	19 200	12	300
Trial 4	Celsius	[redacted]	2	201
	Base	19 200	12 – 24	300
Trial 5	Celsius	[redacted]	4	12
	Base	3 400	12	93
Trial 6	Celsius	[redacted]	4	70
	Base	3 400	12	93

Assumptions for Figure A.2.1

Costs

- The costs shown in Figure A.2.1 are the asset costs of the traditional and Celsius techniques,
- Base Case asset replacement costs are based on Electricity North West experience for comparable network reinforcement consistent with RIIO-ED1 average costs and refined through further engagement with Electricity North West employees,
- It is worth noting that bespoke designs apply in around 30% of traditional distribution network reinforcement cases in Electricity North West, corresponding to higher capital costs, although this is not included in the financial benefits modeling,
- Celsius asset costs are based on research and engagement with manufacturers of cooling interventions as well as discussions with Electricity North West operational employees for guidance on installation requirements. Costs for monitoring are based on a simple temperature transducer and monitor. This would be installed based on loading estimated from smart meter data reaching a trigger point,
- See Appendix A.1 for a detailed set of assumptions on the calculation of the financial benefits.

Capacity release

- See Appendix A.1 for a detailed set of assumptions on the calculation of the capacity released.

Planning and installation times

- Delivery times (comprising planning and installation time) were based on consultation with Electricity North West employees with network monitoring and reinforcement works experience and should be comparable with delivery times for similar traditional reinforcement measures by other distribution network operators.

Appendix A.3: Estimated Carbon Impact of Celsius

Overview and approach

Carbon impact assessments for previous Electricity North West LCN Fund projects have identified assets, losses (operations) and enabled customer activities (facilitated impacts) as the main categories for determining the emissions associated with distribution network interventions. It is a project-based carbon accounting approach, using input from life cycle assessments; a similar approach is appropriate to Celsius.

In summary, asset impacts arise from the production and installation of new infrastructure; they are estimated by quantifying the materials involved and referring to life cycle assessment data. Operational impacts arise from the ongoing consumption of electricity in network losses or requirements for maintenance; they are estimated using the future marginal grid emissions factors and life cycle assessments as per assets. Facilitated impacts may arise where increased network capacity enables the more rapid connection of low carbon technologies (LCTs) that are expected to have comparatively lower emissions than traditional 'baseline' technologies. These putative reductions are not accounted for distinctly due to their inherent uncertainty, and risk of double counting.

Carbon benefits are provided by Celsius through deferment of asset replacement. For each DECC 1 representative load growth profile, asset requirements are estimated quantitatively through time to 2050 for the Celsius Method and traditional reinforcement approach and converted to a carbon impact using life cycle emissions estimates. Asset carbon for network assets is based on values prepared by the Tyndall Centre for Climate Change Research at the University of Manchester for previous Electricity North West LCN Fund bids. Asset carbon for retrofit thermal monitoring and retrofit cooling devices is estimated based on device weight and material and is comparatively low compared to asset carbon for distribution transformers and LV cables. The scale of asset carbon in tonnes of CO_2 does not change in time but the NPV cost associated with it does.

Retrofit thermal monitoring and cooling will be checked and maintained during regular substation visits and are not expected to result in material operational costs or carbon impact.

Conversely, grid carbon is expected to increase with Celsius due to an increase in network losses as existing distribution transformers and LV cables are utilised at higher current. Loss characteristics vary with asset temperature and cooling interventions may help to reduce losses that are increasing due to higher currents. The increase in network losses due to higher current for transformers and cables with retrofit monitoring and cooling interventions will be studied in further detail during Celsius. This could potentially improve the financial benefits and the carbon impact.

The carbon impact of traditional reinforcement and Celsius is shown in Figure 3.8 for representative secondary assets on a high and low load growth path derived from the DECC 1 scenario. Carbon emissions are higher for the high load growth path compared to the low load growth path. Also, for lower load growth paths, Celsius is beneficial in comparison to traditional reinforcement.

While the life extension enabled by Celsius makes a significant difference to financial net benefits, the monetised carbon impact through asset carbon and grid carbon is marginal.

Summary

A preliminary assessment of the carbon impact of Celsius suggests that losses rather than assets dominate the impact profile. The potential increase in network losses for both transformers and cables due to increasing current is highly dependent on load profiles and will be studied in further detail during the Celsius Project to improve understanding of the grid carbon impact.

The direct carbon impact for Celsius is expected to arise through deferment of asset replacement. Studies of capacity release and the respective time saved in deploying LCTs will be conducted during the Project delivery to better understand potential reductions for wider rollout.

Appendix B.1: Celsius Technical Description

Contents

B.1.1: Background

This technical paper outlines methodologies to facilitate successful implementation of the Celsius Project. A high level outline of the operating principles and proposed functionality is provided, including the expected implementation methods of the various products and algorithms.

To meet the decarbonisation challenge laid down by the Government, customers will be encouraged to adopt new low carbon technologies (LCTs) such as electric vehicles and heat pumps. Growth in demand and distributed generation, including the adoption of these LCTs, will lead to an increase in load on the network.

The level of load, specifically load current, on the network has a relationship with the operating temperature of network assets. This results in the operating temperature of network assets increasing as load increases. The amount of heat released is proportional to the square of the current that flows, meaning that a small increase in load can lead to a relatively significant increase in the temperature of network assets.

Network assets have capacity ratings, expressed in amps, which indicate an upper limit to the current an asset can carry without causing damage or accelerating its ageing. However, in practice, this limit is actually a proxy to temperature, as it is generally the increase in temperature caused by the current flow that has the potential to cause these issues. Other aspects, such as harmonics and asset environment, can also contribute to the heating of network assets, but they are not normally taken into account when managing the network load.

Daily variations in ambient temperature mean that a declared rating at a given temperature is a compromise to avoid excessive hot spot temperatures. Therefore, the nameplate rating for a particular asset's capacity is constant irrespective of its surroundings, or its operational circumstances. In practice, the actual load-carrying capability will be significantly affected by the wide range of physical environments and load types that different network assets may experience. This is likely to be further affected by the increase in LCT uptake, which is likely to lead to changes in load types and an increase in harmonic currents flowing on the network.

All of this indicates that using temperature, as well as knowing other relevant aspects such as load type, harmonics and environment, would be a more effective approach to managing the thermal performance of network assets.

As load, and therefore temperature, increases, 'thermal pinch points' can develop at locations such as distribution substations, where currents are at their highest. Traditional techniques for addressing pinch points include reinforcement of the network with larger transformers and higher rated cables which have a higher capacity and therefore a higher nameplate rating.

Celsius will develop an improved understanding of the operating temperatures of key assets within distribution substation environments, and then develop tools and methodologies for using this understanding to improve network and asset management. Celsius will go on to evaluate and demonstrate alternative, innovative ways to optimise thermal capacity, such as retrofit cooling and thermal management technologies.

The improved understanding of the thermal performance of network assets enables maximum use to be made of existing network assets. Celsius will increase network capacity, deferring the need for network asset replacement, and leading to faster, cheaper connection of low carbon technologies.

B.1.2: Celsius Method

Celsius seeks to identify potential thermal issues by establishing how different distribution substations in differing environments behave thermally under a variety of load and environmental conditions.

Celsius will develop the following methodologies to better understand the real thermal ratings of distribution substation assets in order to unlock capacity:

- *Retrofit thermal monitoring:* By using improved technology to measure asset and ambient temperatures, and relating these to a range of environmental, load and seasonal factors, Celsius will enable understanding of real thermal ratings of assets, rather than the nominal ratings that are used today. This will allow improved understanding of the amount of latent capacity which could be accessed without further intervention,
- *Retrofit cooling*: Celsius will identify, evaluate and demonstrate technologies that can be used to directly manage the temperature of assets. By managing temperature in this way, Celsius will deliver additional capacity release.

The key outputs of the Celsius Project for application in business as usual will be:

- A Thermal Ratings Tool that will allow network operators to better understand the operating temperature of assets based on measured values and when to intervene,
- Details of a range of retrofit cooling solutions to apply when the Thermal Ratings Tool indicates an intervention is required,
- A set of recommendations for a business as usual process to incorporate the learning of the Celsius Project including a specification of a low cost temperature monitoring solution for distribution substations and proposed changes to ER P15 and ER P17.

B.1.3: Retrofit thermal monitoring

Approximately 520 distribution substations will be fitted with monitoring equipment. These sites will be selected to be representative of the majority of the GB distribution substations, and will include both pole- and ground-mounted substations.

Load monitoring equipment is already installed at 113 distribution substations. Wherever possible, this will be used to gain full advantage of this previous funding. In some cases the existing equipment may need to be re-located.

The configuration of monitoring across each distribution substation has been designed to gain the most insight, while delivering value for money. This results in different monitoring configurations which are listed below:

Monitoring Type 1 – to be deployed at 134 ground-mounted distribution substations, recording the following information:

- *External transformer temperature*: Two external transformer temperatures for example in line with the top and bottom oil,
- *Environment and other asset temperature:* 12 temperature measurements over the substation, including high and low ambient temperatures, and measurements of substation assets such as the ring main unit, the LV board and cables,
- *Asset loading:* Detailed power monitoring of the transformer load, including real and reactive power, voltage, current, unbalance and harmonics.

Monitoring Type 1a – to be deployed at 21 of the 134 ground-mounted substations, recording the same information as Type 1 with the following additions:

- *Internal transformer temperature:* One site will use an existing transformer fitted with fibre optic sensors. The remaining 20 sites will have two internal temperature sensors, installed via existing breathers,
- *External transformer temperature:* 12 additional external transformer temperatures, located in various positions, for example in line with the top and bottom oil, at or close to points on cooling fins or tubes, on and near connections and bushings.

Monitoring Type 2 – to be deployed at 335 ground-mounted substations, recording the following information:

- *External transformer temperature:* Two external transformer temperatures for example in line with the top and bottom oil,
- *Environment and other asset temperature:* 12 temperature measurements over the substation, including high and low ambient temperatures, and measurements of substation assets such as the ring main unit, the LV board and cables,
- *Asset loading:* Simple power monitoring of the transformer load using voltage and current measurement of one phase on the LV side of the transformer. Where this is not practical, due to access limitations, alternative approaches will be found.

Monitoring Type 3 – to be deployed at 51 pole-mounted substations, recording the following information:

- *External transformer temperature:* Two external transformer temperatures for example in line with the top and bottom oil,
- *Environment temperature:* The ambient temperature,
- *Asset loading:* Detailed power monitoring of the transformer load, including real and reactive power, voltage, current, unbalance and harmonics.

The Celsius trial measurements will be taken for a period of 12 months to ensure all seasonal variations are captured. It is envisaged that a 30-minute sample rate with 3% accuracy will be adequate, due to the relatively long time constants associated with temperature changes within assets.

During the installation of the monitoring equipment a survey on the substation environment will be completed, including taking photographs. This will be used to capture the characteristics that may have a significant impact on asset temperature, but are not otherwise recorded; for example recording adjacent buildings or vegetation providing shade.

Data will be sent to a data centre hosted by our Partner Ricardo-AEA using GPRS communications. The machine to machine SIM cards for these communications will be provided by Ricardo-AEA and will be roaming SIMs, meaning that they are capable of choosing the network with the best signal.

During the trial period, local weather data will also be collected. As far as possible, this will be collected from available sources using existing weather stations. Additional weather monitoring will be implemented where necessary.

3.1: Data analysis

Celsius proposes the hypothesis that external temperature measurements can be used to gain an understanding of corresponding internal hotspot temperatures. The internal and external transformer temperature measurements will be used to validate this link.

The relationship between internal and external temperatures for cables is already understood and described in ENA Engineering Recommendation P17. This relationship will be used as a starting point in this analysis.

The data gathered from the monitored distribution substations will be analysed to explore the relationship between asset temperature, load characteristics and the surrounding environment. This analysis will include data from a number of different sources:

- Data collected from monitoring implemented as part of Celsius,
- Site information and characteristics recorded during installation process,
- Historical and other recorded data kept by Electricity North West,
- Weather data for the local area.

This will be used to provide an evaluation of the remaining capacity of the substation assets. It is expected that this more accurate capacity evaluation will identify thermal headroom beyond that identified using traditional asset ratings; this capacity could be released to avoid or defer reinforcement. It should be noted that this evaluation may show assets which are already thermally overloaded and in this case the site must either be referred to business as usual processes for upgrading, or alternatively one of the retrofit cooling techniques applied.

To further improve the analysis, the trials will need to include a wide range of load profiles and types. In order to ensure this is included, it may be necessary to alter the load profile at some sites, for example by switching to change the network topology.

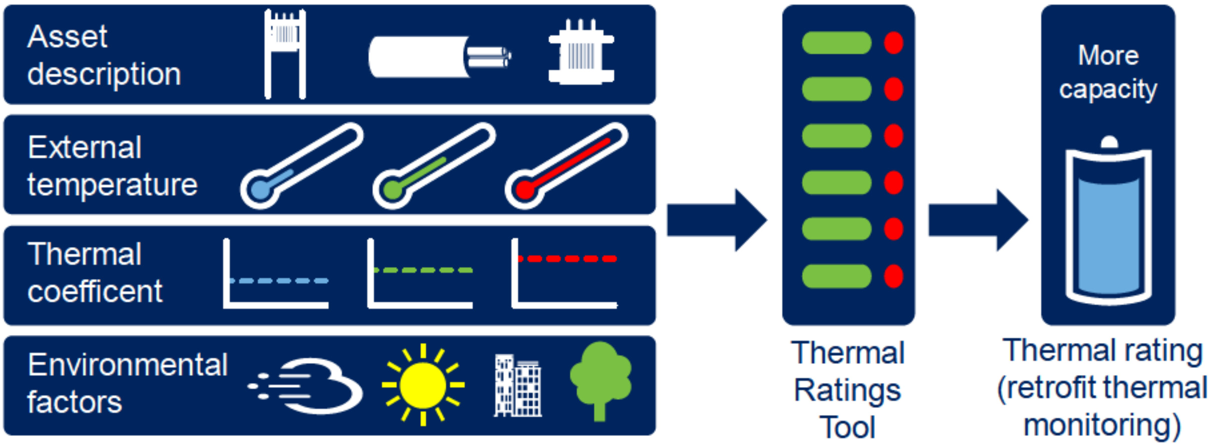
It may also be beneficial to seek out data sets from other LCN Fund projects, such as UKPN's Second Tier project FUN-LV, Electricity North West's First Tier project Low Voltage Network Solutions, etc.

3.2: Thermal Ratings Tool

A key focus of Celsius is to develop usable outcomes. In order to achieve this, the learning from the retrofit thermal monitoring trials and analysis will be formalised and transferred into a simple tool that can be used by operations and planning employees at any network operator, to better understand the capacity of the existing or planned network.

This tool will be in the form of a simple Microsoft Excel 'look-up' table or similar. This table will require minimal inputs such as temperature and environment to produce an indication of the site capacity. This tool will then be made available to all GB DNOs.

Figure B1.1: Retrofit thermal monitoring



B.1.4: Retrofit cooling

Celsius will explore the use of retrofit cooling technologies to release further capacity from the distribution substation assets. These can take many forms, including passive techniques such as painting transformers with reflective paint or using new backfill material for cable ducts, and active techniques such as fitting fans to transformers. At this time all potential cooling intervention techniques are in scope. See Appendix C for more information about potential intervention options and their selection.

Investigation of techniques

The first stage of this part of Celsius is an investigative piece to understand all the available technologies. The investigation will identify potential technologies, and consider various aspects of each one, including:

- Installation process and requirements,
- Operation process and requirements,
- Safety implications,
- Environmental aspects,
- Energy consumption,
- Capacity benefit estimation,
- Cost and benefits and,
- TRL (technology readiness level).

This investigation stage will include a workshop to discuss cooling options with other DNOs. The output will be a shortlist of techniques to trial at 100 distribution substations which will be a subset of the substations used for the retrofit thermal monitoring. A smaller site selection process will be carried out to determine which techniques are to be deployed at which sites, informed by the findings and experience of the retrofit thermal monitoring.

Trialling of techniques

Once the cooling interventions are installed a period of monitoring will be conducted using the retrofit thermal monitoring equipment. Limited additional monitoring may be required to provide information about the operation of the cooling technology. For example, if the cooling technology is an active technique, such as a fan, there will need to be an indication of when the intervention is operational. This data will be collected into the same data management system, and analysed alongside the other monitoring data.

As with the retrofit thermal monitoring trial, these measurements will be taken for a period of 12 months to understand seasonal variations.

Data analysis

The data gathered will be analysed to understand the effect of the cooling intervention on capacity released. This analysis will take into account the technology, the substation environment and the specific application. This will include comparing the asset temperatures before and after installation, normalising for weather, loading and other conditions.

A cost benefit analysis will be carried out to assess the benefit of the deployed technique when compared to business as usual techniques to gain the same capacity released.

Thermal Ratings Tool

This work will be formalised and translated into the Thermal Ratings Tool as an enhancement.

This tool will automate the evaluation of the potential gain in capacity of each technique for different applications and environments. This could be used to inform operators and planners of the range of potential solutions relevant to a given application, and indicate aspects such as potential costs, benefits and installation requirements. This will be made available to all GB DNOs.

B.1.5: Thermal flow study

This will be additional research into the heat and air flows within indoor substations and the optimal locations of vents and louvres. This will be carried out through the use of modelling and experimental techniques and will investigate the macro flows and movement of air and heat within a substation building. The modelling will be further exploited to evaluate potential cooling methods, particularly where those methods are easily applicable to the modelling methods.

This will feed into a number of aspects of the Project, including investigating the use of retrofit changes to existing ventilation as a potential cooling method, and providing recommendations for business as usual practices, particularly around the design of new build substations.

This will be in two phases:

Phase 1: Investigating the configurations and ventilation within existing substations. This will concentrate on a small number of example configurations that will be selected to represent modern substation design. The investigation will be informed by the data from the substation monitoring deployed in Celsius, and further validation monitoring may be implemented. The outcome of this phase will be a set of recommendations for business as usual new build substation design, and potentially recommendations for retrofit changes for existing ventilation, particularly where there are existing thermal issues.

Phase 2: Providing recommendations and predictions from the evaluation carried out in phase 1 to feed into the retrofit cooling technology selection and trial design. This will have potential advantages in predicting the benefits of these technologies, and assisting in designing the installation configurations.

B.1.6: Processes and specifications for business as usual

It is a key aim of Celsius to ensure that the learning and outputs are easily transferable to business as usual. Therefore, one of the outputs will be a review of the relevant distribution transformer and cables Engineering Recommendations informing a change request submission to the ENFG and a set of processes and specifications.

These processes will depend on the findings of the Project, but an expected outline business as usual process is illustrated in figure B.1.1.

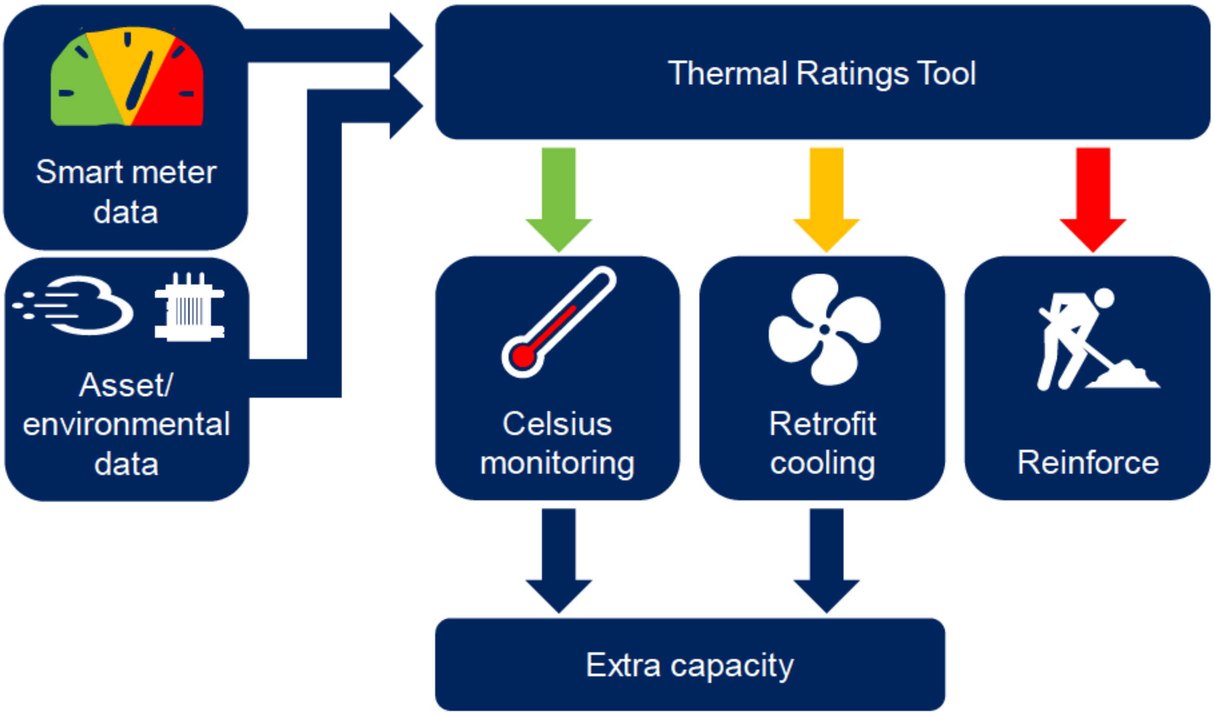
Determine initial thermal rating: Substation load data and asset information such as substation fabric is used to gain an initial view of thermal capacity using the Thermal

Ratings Tool. This may enable the release of some capacity, for example where assets are in environments which allow for natural cooling. When the capacity reaches a predefined trigger point, retrofit thermal monitoring can be deployed.

Deploy retrofit thermal monitoring: The retrofit thermal monitoring solution will be designed and implemented to provide the required information for minimum cost. The measurements will be an input to the Thermal Ratings Tool to determine a more accurate thermal capacity. This will enable the identification of any further capacity that may be released. When the capacity reaches a further predefined trigger point, additional intervention is required. This may take two forms:

- *Retrofit cooling:* An appropriate set of cooling technologies will be identified by the Thermal Ratings Tool, along with its associated information such as costs, potential benefits, and installation requirements. One of these can be selected from the list and implemented in order to cool the asset and release further capacity,
- *Reinforcement:* It is possible that no cooling technology will be suitable or the load may continue to rise beyond the capabilities of the cooling technology. In these cases, the asset will be reinforced using traditional techniques.

Figure B.1.1: Celsius as business as usual



To support this process, the outputs of Celsius will include the following:

- Recommendations of a suitable business as usual process, including relevant trigger points and interventions,
- Functional specification for a low cost retrofit thermal monitoring solution which will include:
    - Specification for the purchase of sensors,
    - Details of what to monitor,
    - Details of where to monitor on asset,
    - Details of type and how many monitors,
- Thermal Ratings Tool – A workbook or database tool to enable users, with minimal inputs, to assess the capacity of a site and obtain a prioritised list of recommended cooling interventions,
- Specifications for the different cooling techniques,
- Recommendations on which cooling techniques provide the best fit in terms of capacity release, cost and customer acceptance.

Appendix B.2: Site selection methodology

B.2.1: Introduction

This appendix describes the proposed methodology for the selection of distribution substations to be included within the six Celsius trials. The proposed methodology has been developed to allow the selection of representative samples covering different environments, asset design and uptake of low carbon technologies. The aim is to ensure that the trial population will be representative of the majority of GB distribution substations and their assets, based on aspects such as substation enclosure, asset ratings and specifications.

The substations selected will cover a range of asset ages and specifications installed in differing environments. To ensure learning from Celsius is relevant into the future, the proposed methodology will look to include areas where there have been clusters of low carbon technology installations such as electric vehicles and heat pumps.

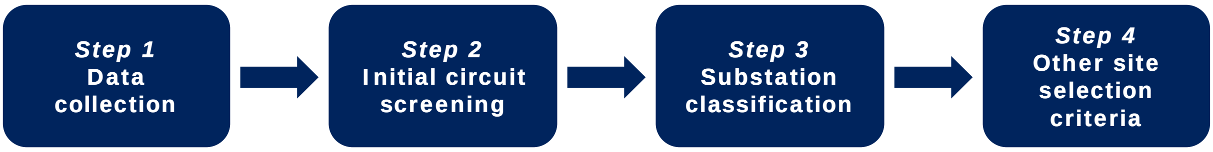
The site selection for Celsius is described below.

B.2.2: Retrofit thermal monitoring

The aim of the retrofit thermal monitoring is to develop an understanding of the relationship between asset temperature and environmental and loading characteristics. The sites will be selected so that the trial population will be representative of the majority of GB secondary network substations based on characteristics such as substation enclosure types, asset ratings and specifications.

The site selection methodology is outlined below, using the following steps:

Figure B.2.1: Retrofit thermal monitoring site selection steps



Step 1: Data collection

The Celsius trial will be conducted on a large population of distribution network assets. Therefore, site selection will be informed by a desktop data collection exercise to establish:

- Geographical location, which can be used to determine physical surroundings and situation information,
- Substation type and construction,
- Further site specific information, such as number of LV ways,
- Site load data based on either physical monitoring or modelling,
- Presence of existing projects and known LCT connections.

Step 2: Initial circuit screening

The purpose of the initial screening stage is to discount the sites that are not suitable based on any vital 'must' or 'must not' criteria.

Any distribution substations with assets due for replacement during the lifetime of Celsius will not be included in the site selection.

Feasibility work carried out by Ricardo-AEA showed that the relationship between load and temperature is significantly weaker where loading levels are low, as in these cases, asset operating temperature is more heavily influenced by ambient temperatures. Therefore, only sites with loading levels above 25% will pass the initial screening.

Step 3: Substation classification

Substations will be classified according to the following criteria:

- Substation structure,
- Transformer specification,
- Transformer rating.

The most common categories are then identified to cover the majority of the substation population.

Substation structure

The following structures are considered in the selection methodology and represent the different environments that assets are placed in.

- Pole-mounted substations,
- Outdoor fence enclosed substations,
- Substations in a brick or stone building,
- Substations in a glass, reinforced plastic enclosure,
- Substations in a metal kiosk,
- Substations incorporated into part of a larger building (including underground).

Transformer specification

The transformer specification will indicate the build and design of the transformer, and may also be an indication of transformer and substation age as some specifications were only in use for limited periods in time. These aspects are relevant to the likely thermal performance of the assets.

Transformer rating

The transformer rating influences the thermal performance of the assets, as higher rated equipment is likely to have more thermal mass and can be used as a proxy for the rating of the cables within the distribution substation.

Step 4: Other site selection criteria

A range of different site characteristics will be targeted within the trial. This is partially achieved through the categorisation of sites, but there are a number of other characteristics which may also impact the thermal behaviour of assets and therefore should be considered in the selection process. These include:

- Substation loading levels,
- Substation load type (may be estimated based on location, and can be summarised as urban, semi-urban, rural, remote rural, and where possible, industrial, residential etc),
- Substation characteristics – for example, the number of LV ways from the site may indicate the impact of having multiple cables in close proximity.

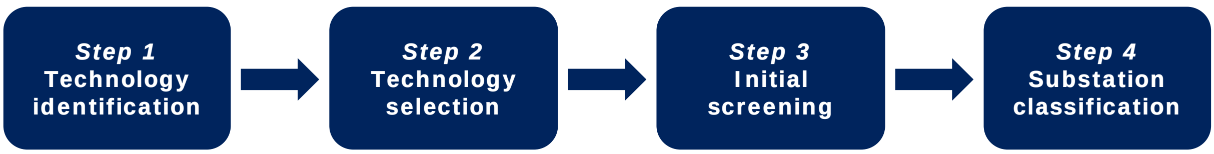
We will also consider areas where there are known clusters of low carbon technology installations such as electric vehicles and heat pumps. Where possible, examples of such areas will be included into the trial.

B.2.3: Retrofit cooling

The objective of the retrofit cooling trials is to develop and demonstrate potential retrofit cooling technologies, and gather data to be analysed to determine their impacts on asset thermal performance.

In addition to site selection a technology selection methodology will be utilised. Both are outlined below, using the following steps:

Figure B.2.2: Retrofit cooling trial site selection steps



Step 1: Technology identification

A large and diverse range of potential cooling technologies are suitable for evaluation during the Celsius Project.

As part of the preparatory work undertaken for Celsius, Electricity North West ran a call for innovation via the Energy Innovation Centre for retrofit cooling technologies that may be relevant for the Celsius Project. The aim was to provide additional information on potential retrofit cooling methods to feed into the planning of the Project, and to identify early potential technologies and suppliers.

A detailed study will be carried out during Project delivery to evaluate these potential cooling technologies, through the use of desktop study and market research, as well as discussions with potential suppliers and developers. This activity will produce conclusions on the relative costs and estimated benefits of the technologies.

Step 2: Technology selection

As detailed above, we intend to select a diverse range of technologies to trial. However, a number of other aspects will need to be considered alongside this requirement. Cooling intervention selection will be carried out following a robust process, where each of the technologies is scored based on a range of criteria, for example:

- Purchase costs,
- Technology readiness level,
- Installation considerations,
- Operational costs,
- Environmental considerations (carbon footprint etc),
- Estimated benefits,
- Additional features.

This process will be carried out during the retrofit thermal monitoring step of the Project, so that the early capacity analysis findings can be taken into account. For example, there may be information around the nature of the causes of thermal issues that may affect the choice of technology to demonstrate.

Step 3: Initial screening

The 100 sites for the retrofit cooling installation will be selected from the 520 sites used for the retrofit thermal monitoring.

Step 4: Substation classification

The sites will be classified based on the following criteria:

- Technology type,
- Physical constraints,
- Customer acceptance.

Technology type

Certain technology types will only be suitable for deployment in particular environments eg painting of transformers is only applicable to outdoor sites.

Physical constraints

Consideration will be given to the space required for the technology in relation to the space available on site.

Customer acceptance

As part of the customer workstream we will survey customers' acceptance of the new technologies. If a particular technology is likely to cause issues with customers we will seek an alternative site.

Appendix B.3: Trial Size Methodology

B.3.1: Retrofit thermal monitoring

Using the substation classification criteria from the site selection methodology an analysis of the Electricity North West asset database has been carried out to determine the appropriate size and make-up of the trial population. The results of the analysis are presented in Figure B.3.1.

Figure B.3.1: Substation categories from preliminary analysis

Type	Number of categories identified	Target number per category	Total number of distribution substations
Ground-mounted	67 categories represent over 90% of the population	Seven examples of each category will be included in the trial, including: • Two examples will be fitted with monitoring type 1 (including Type 1a) totalling 134 distribution substations • Five examples will be fitted with monitoring type 2 totalling 335 distribution substations	469
Pole-mounted	17 categories represent over 90% of the population	Three examples from each category will be fitted with monitoring type 3 totalling 51 distribution substations	51
Total			**520**

B.3.2: Retrofit cooling

A range of diverse retrofit cooling technologies will be selected within Celsius to demonstrate the potential benefits of cooling distribution substation assets. To understand this range, a set of general substation groups will be identified with technologies selected from each area.

As technology selection must also be based on the assessment of the technologies themselves and the suitability of the substation, not all groups will be represented. However, this activity helps ensure that the relevant areas of the market have been explored and where possible will be considered for inclusion within the trial.

An example of a potential set of groups is given in the table below, based on the type of technology and its application. These groups reflect the intention to concentrate on the cooling of transformers and cables as well as substations as a whole. This is based on the understanding that these are the assets where issues are most likely to be felt.

Figure B.3.2: Potential retrofit cooling groups

Technology type	Technology application	Example
Passive (no moving parts or power consumption)	Transformer cooling	Additional fins added to the transformer to increase natural heat radiation from the asset or changing the insulating oil for an alternative cooling fluid with better thermal properties
	Cable cooling	Installation of a backfill material into cable ducts designed to enable more effective heat transfer and dissipation
	Substation cooling	Adding additional vents to allow more effective removal of heat out of the substation
Active (with moving parts and the ability to actively control operation)	Transformer cooling	Installation of a fan on the transformer to better distribute heat and make better use of existing cooling fins
	Cable cooling	Pumping cooling fluid through ducts
	Substation cooling	Addition of fan or air conditioning units

Examples of each group will be selected and then best options for demonstration discussed at the DNO retrofit cooling workshop. It is expected that different variations of the same technology solution may be included (for example different designs of fans or different types of backfill material).

Each chosen technology will be installed into multiple sites, in order to provide a thorough understanding of the technology and its application and performance within different conditions and environments. It is assumed that a minimum of five sites will be used for each technology and a total of 100 trial sites for the retrofit cooling technology trial.

This high level analysis has been used to determine the likely size of the trial. In practice, the characteristics of the chosen technologies may not exactly reflect this profile, for example, it is possible that no viable active cable cooling technologies may be found, but there are many viable and interesting opportunities in passive substation cooling. Such issues and decisions will be addressed during the Project.

Appendix C: Retrofit Cooling Technology Identification

There is a large and diverse range of potential cooling technologies that may be relevant for investigation during the Celsius Project. As part of the preparatory work undertaken for Celsius, Electricity North West ran a call for innovation via the Energy Innovation Centre, for retrofit cooling technologies that may be relevant for the Celsius Project. The aim was to source additional information on potential cooling methods for the planning of the Project, and to identify early potential technologies and suppliers. This call resulted in 16 responses.

Figure C.1 below shows examples of cooling technologies, including those from the responses for the call for innovation, with their asset application, their potential cost, installation timing requirements and capacity release potential. The values given in the table are based on available information and engineering knowledge, and are indicative estimates only. Appendix B.2 details the technology and associated site selection methodology.

Figure C.1: Retrofit cooling technology – potential application, cost, installation timing and capacity released

Retrofit cooling technique	Application	Cost (£)	Nominal capacity released	Installation timing
		L <£1k M ≈£3k H ≈ £8k	L <5% M 5-15% H >15%	L < 1 day M 1-3 days H > 3 days
Painting enclosures or casings	Indoor substation enclosures, transformers, other assets	L	L	L
Highly conductive backfill for cable ducts	Cable ducts	M	L	M
Heat sink	Indoor and outdoor transformers	L	M	M
Chimney/venting	Indoor substations	M	M	M
Pump for circulating oil	Indoor and outdoor transformers	H	H	H
Cooling jacket	Indoor substation	H	H	H
Fan installation (including piezoelectric)	Indoor and outdoor transformers	M	H	M
Improved substation ventilation	Indoor substations	M	M	M
Heat recovery to district heating	Indoor substations	H	H	H
Extra fins added to transformers	Indoor and outdoor transformers	L	L	M
Thermal containment	Indoor	H	H	H
Alternative oil	Indoor and outdoor transformers	M	H	M

C1.2: Explanation of retrofit cooling technique

Described below are the known optimal retrofit cooling techniques being considered in the trial.

Painting: The ideal paint for electrical equipment is one that has relatively low absorption and high emissivity so the asset will absorb little radiation heat from the sun or surroundings while allowing internal heat to be emitted efficiently.

Highly conductive backfill for cable ducts: Use of a cable trench backfill material that has a lower and more stable thermal resistivity than standard (regional) soil resistivity eg fluidized backfill, can improve on underground cable heat transfer and dissipation. Alternatively for underground cables laid in ducts, a cooling fluid/air could be pumped through the ducts.

Heat sink: Passive heat sink material fitted to existing transformer radiator or use of air forced convection to facilitate heat exchange with heat sink material.

Chimney/venting: The installation of a short chimney or multiple vents in a substation enclosure to allow the release of hot air from the substation including creating a potential pressure difference to enable removal of hot air.

Pump: Transformer cooling can be increased by retrofitting an oil pump between the transformer oil tank and the radiator. The pump increases the flow of oil through the radiators, which improves heat dissipation, and is operated via a simple control system that activates pump operation once transformer load (or internal/external temperature) increases above a certain level.

Cooling jacket: An enclosed heat exchanger jacket with cooling fluid pumped through that is fitted to the transformer external radiators or tank to improve heat dissipation.

Fans (including piezoelectric): To increase transformer cooling, fans can be retrofitted to or close to external radiators. Similar to oil pumps, these are operated via a simple control system that activates fan operation once transformer load (or internal/external temperature) increases above a certain level. Transformer pumps and fans can be used collectively to provide additional cooling.

Improved substation ventilation: Substation inlet and outlet vents are designed to draw cooling air flow across the electrical equipment based on engineering rules-of-thumb. The addition of more vents may improve the removal of heat out of the substation. Fans may also be fitted to substation vents to increase natural air flow through the enclosure, or air conditioning units fitted, controlled by thermostats and humidistats.

The number, positioning and size of vents and fans can be optimised using computational fluid dynamics studies to model thermal flows in detail. This will inform future substation design for a range of standard configurations, taking into account fume, fire and sound considerations.

Heat recovery to district heating: Heat exchange with transformer to provide passive water heating to local dwellings.

Addition of extra fins to transformers: Fins can be fitted to the transformer tank to increase convective and radiative cooling from the asset. The cooling fins act like a heat sink similar to those found on electronic circuit boards. This technique is broadly similar to the use of corrugations in a transformer tank wall. However, no oil would flow through the fins and therefore the removal of heat would be lower than that of a corrugated tank.

Thermal containment: Use of thermal zoning around specific assets to improve substation ventilation.

Change insulation oil: The oil within a transformer extracts heat from the windings and transports it to the radiators for dissipation. The oil in a distribution transformer can be replaced with a modern oil with improved thermal properties.

Appendix D: Review of other Thermal Ratings Projects

Celsius builds on the learning from previous projects with an element of thermal ratings innovation. These have been undertaken through IFI and First and Second Tier LCN Fund projects and include projects from our international review of concepts. The majority of these projects were focussed on higher voltage assets. There are also several international projects that have explored the use of thermal asset ratings. Figure D.1 provides an overview of the related projects and the incremental learning that is relevant to Celsius.

Figure D.1: Incremental learning

Innovation funding mechanism	Project name	Delivering DNO	Learning
IFI	Distribution Transformers Real Time Thermal Rating	ENWL	Use of ambient temperature measurements, heat run test data and hot spot temperature measurements captured to develop a thermal model. This learning will be utilised as part of the work to develop the thermal coefficients for transformers.
NIA	Distribution Asset Thermal Modelling	ENWL	An extension of the IFI project to finish the work and incorporate cable modelling. Deliverables of this project are a planning tool for cables that will allow us to model low carbon technology uptake, future loads and their effect on LV cables, and a thermal failure tool for transformers. The tools developed in this project will be used in conjunction with the Thermal Ratings Tool to support investment decisions as part of business as usual processes.
T2 LCN Fund	FUN-LV	UKPN	Development and use of wireless temperature sensors to measure the surface temperature of transformers, cables and ambient conditions within distribution substations. Use of that data to convert a measured temperature to a demand profile on transformers and cables. The methodologies to do this were validated using measured load and temperature examples. This learning will be directly utilised in that the temperature monitoring systems to be developed for Celsius will be based on those used in FUN-LV; the learning on the relationship between load, ambient temperature and asset temperature developed as part of FUN-LV will be built upon in Celsius.

Innovation funding mechanism	Project name	Delivering DNO	Learning
T2 LCN Fund	Customer Led Network Revolution	NPg	Use of measured thermal, load and environmental data to derive dynamic primary transformer and cable ratings. Top oil temperature and load was measured for primary transformers and ambient temperature and load for distribution transformers. Soil ambient temperature and thermal resistivity was measured for 33kV and 6kV cables. Celsius considers enhancement of the continuous maximum rating for distribution transformers which are operated up to rating under normal circuit conditions. Under this operating regime, it becomes more important to maintain the hot spot temperature less than 98°C to minimise risk of additional ageing.
IFI	Environmental Monitoring of Distribution Substations	NPg	Use of substation ambient temperature measurements and environmental data captured at 20 different substations of varying building design and location. This will inform asset management strategies and future substation design. This could be further enhanced through correlation of substation ambient temperatures with load. This learning will be utilised in the correlation of temperature and load as part of the asset temperature behaviour analysis.
T1 LCN Fund	Distribution Network Visibility	UKPN	Proof of concept of transformer loading to external transformer temperature relationship. Model of ageing and real-time rating of distribution transformers based on measured transformer loading and external housing temperature, and ambient temperature and weather data. This learning will be utilised as part of the work to develop the thermal coefficients for transformers.
T2 LCN Fund	Flexible Networks for a Low Carbon Future	SPEN	Use of thermal and load monitoring to derive an enhanced seasonal rating. For example, for St Andrews primary transformers, an enhanced rating that is 14% greater than nameplate is achieved while maintaining an acceptable windings hot spot temperature. This is broadly consistent with the estimated capacity release (13%) from Celsius retrofit thermal monitoring of distribution transformers although no details of the load profile or ambient temperature profile are available for comparison.

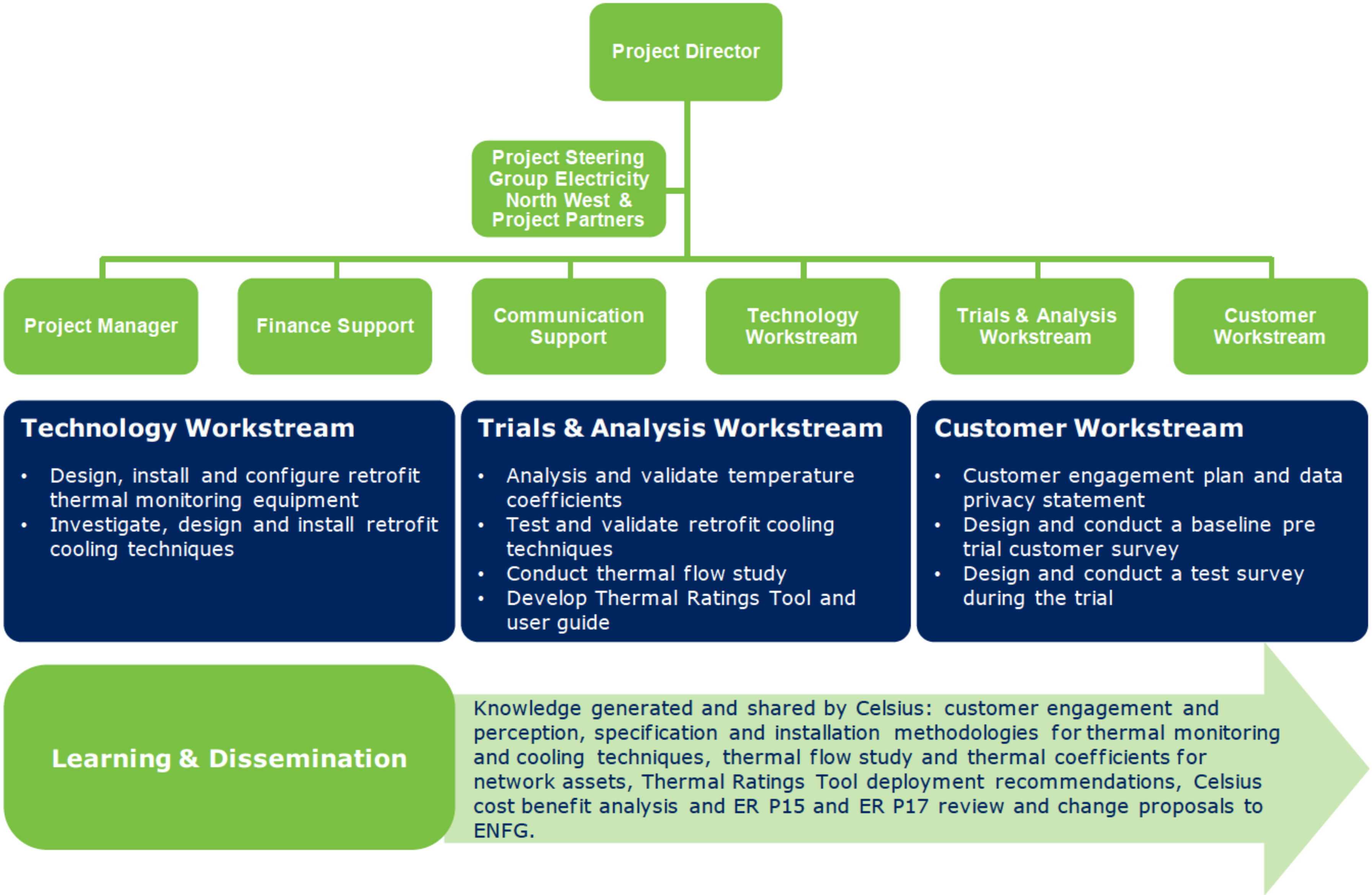
Innovation funding mechanism	Project name	Delivering DNO	Learning
T2 LCN Fund	FALCON	WPD	Use of measured thermal, load and environmental data to derive dynamic transformer, overhead line and cable ratings. Temperature monitoring was installed for 11kV overhead lines and underground cables. Ambient temperature was monitored at substations along with wind speed monitoring and solar irradiation. Primary transformer internal tank, top and bottom oil temperatures were monitored. The use of a dynamic network rating (DNR) approach was also explored with development of an 11kV network model and comparison using measured load and weather data from a trial network area in Milton Keynes[17]. Potential gains in dynamic rating were compared to static rating for the different network assets – transformers, overhead lines, and cables through a network case study, indicating modest capacity gains on a network wide basis. It was noted that the dynamic rating may be lower than the static rating on a summer's day. This learning showed that capacity can be released by monitoring of temperatures which is the basis for Celsius.
IFI	Transformer Temperature Fibre Optic Monitoring	UKPN	Use of fibre optic and top oil temperature monitoring on a 30MVA power transformer to derive enhanced seasonal ratings. This learning showed that capacity can be released by monitoring of temperatures which is the basis for Celsius.
NIA	Enhanced Real-Time Cable Temperature Monitoring	SPEN	12 months of measured thermal data for 33kV cable circuits identified additional thermal capacity, temperature hotspots and causes of temperature bottlenecks. This learning showed that capacity can be released by monitoring of temperatures which is the basis for Celsius.

[17] Yang J., Bai X., Strickland D., Jenkins L., Cross A.M., Dynamic Network Rating for Low Carbon Distribution Network Operation – A U.K. Application, IEEE TRANSACTIONS ON SMART GRID, VOL. 6, NO. 2, March 2015.

Innovation funding mechanism	Project name	Delivering DNO	Learning
T1 LCN Fund	Power Transformer Real Time Thermal Rating	UKPN	Use of measured thermal (ambient, top-oil and bottom oil) and environmental data to derive dynamic transformer thermal ratings on a power transformer. It is estimated that transformers may be loaded up to 20% above static seasonal rating and this will be tested in the UKPN project. Additional cooling fans installed to improve cooling and increase capacity. This learning showed that capacity can be released by monitoring of temperatures and application of retrofit cooling which is the basis for Celsius.
T1 LCN Fund	Temperature Monitoring Windfarm Cable Circuits	SPEN	Use of measured thermal and environmental data to derive thermal coefficients and dynamic cable ratings. This learning showed that capacity can be released by monitoring of temperatures which is the basis for Celsius.
International	Dynamic Transformer Rating Project	Unison Networks Limited, New Zealand	Unison Networks implemented Dynamic Transformer Rating (DTR) on most of the power transformers in its distribution network[18]. The DTR scheme utilised an in-house developed DTR algorithm that was designed based on the IEC60076-7 Loading Guide for Oil Immersed Power Transformer Standard. The algorithm sampled real-time data from various sensors installed in the networks and translated them into dynamic rating and insulation loss of life information for each transformer. Thermal capacity release figures were not reported. Learning to be gained from international perspective of dynamic thermal ratings implementation.
International	Unlocking distribution network capacity through real-time thermal rating for high penetration of distributed generation (DGs)	Finland distribution network	Learning on relationships between customer loads and distributed generation output with thermal responses of underground cables, overhead lines and distribution transformers[19]. Measurements of ambient temperature, weather and soil temperature were used.

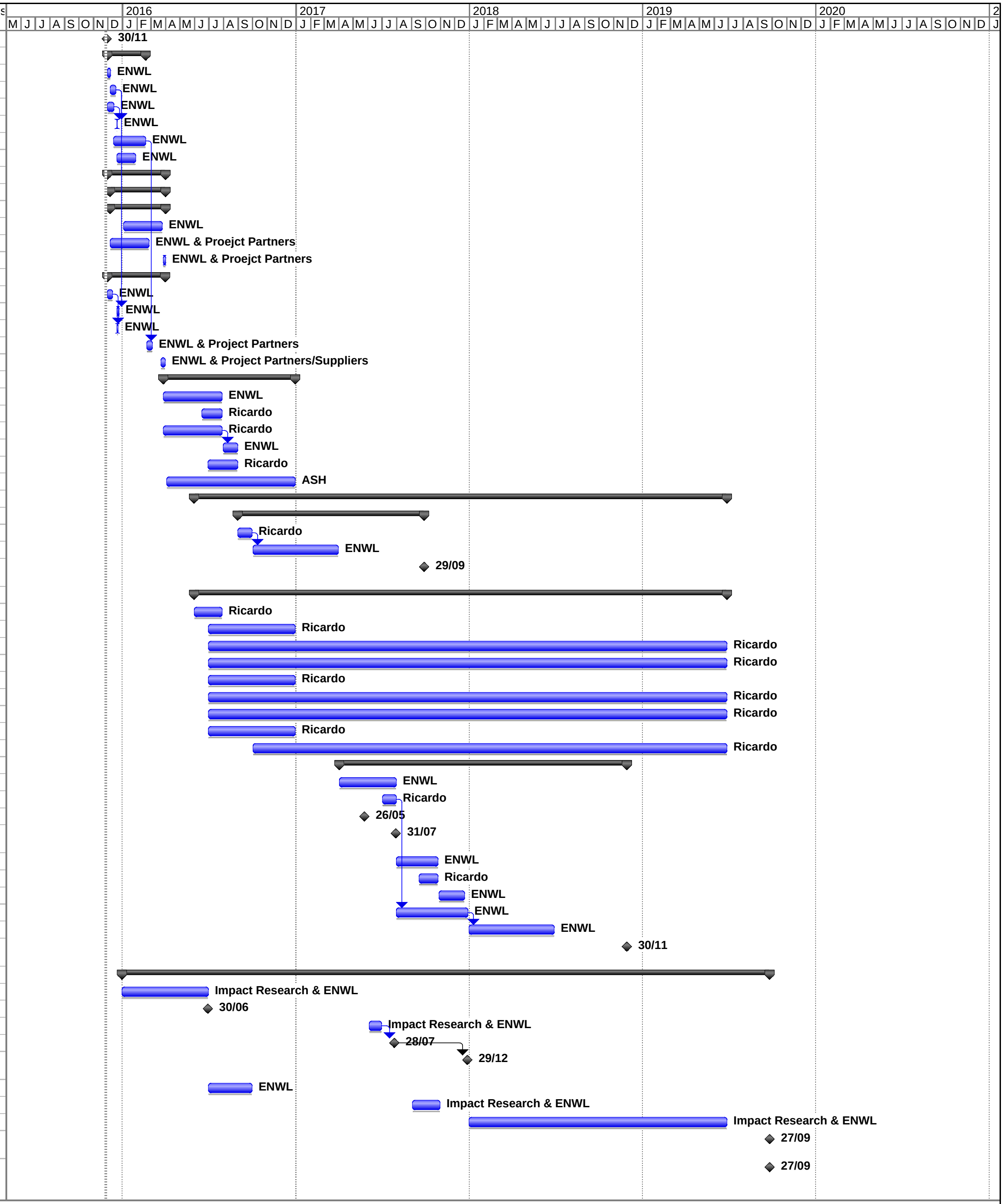
[18] Jalal T.S., Rashid N., van Vliet B., Implementation of Dynamic Transformer Rating in a Distribution Network, Power System Technology (POWERCON), 2012 IEEE International Conference on power System Technology, Oct. 30 2012-Nov. 2 2012.
[19] Degefa M.Z., Humayan M., Safdarian A., Koivisto M., Millar R.J., Lehtonen M., Unlocking distribution network capacity through real-time thermal rating for high penetration of DGs, Electric Power Systems Research, Volume 117, December 2014, Pages 36–46.

Appendix E: Organogram



Appendix F: Project Plan

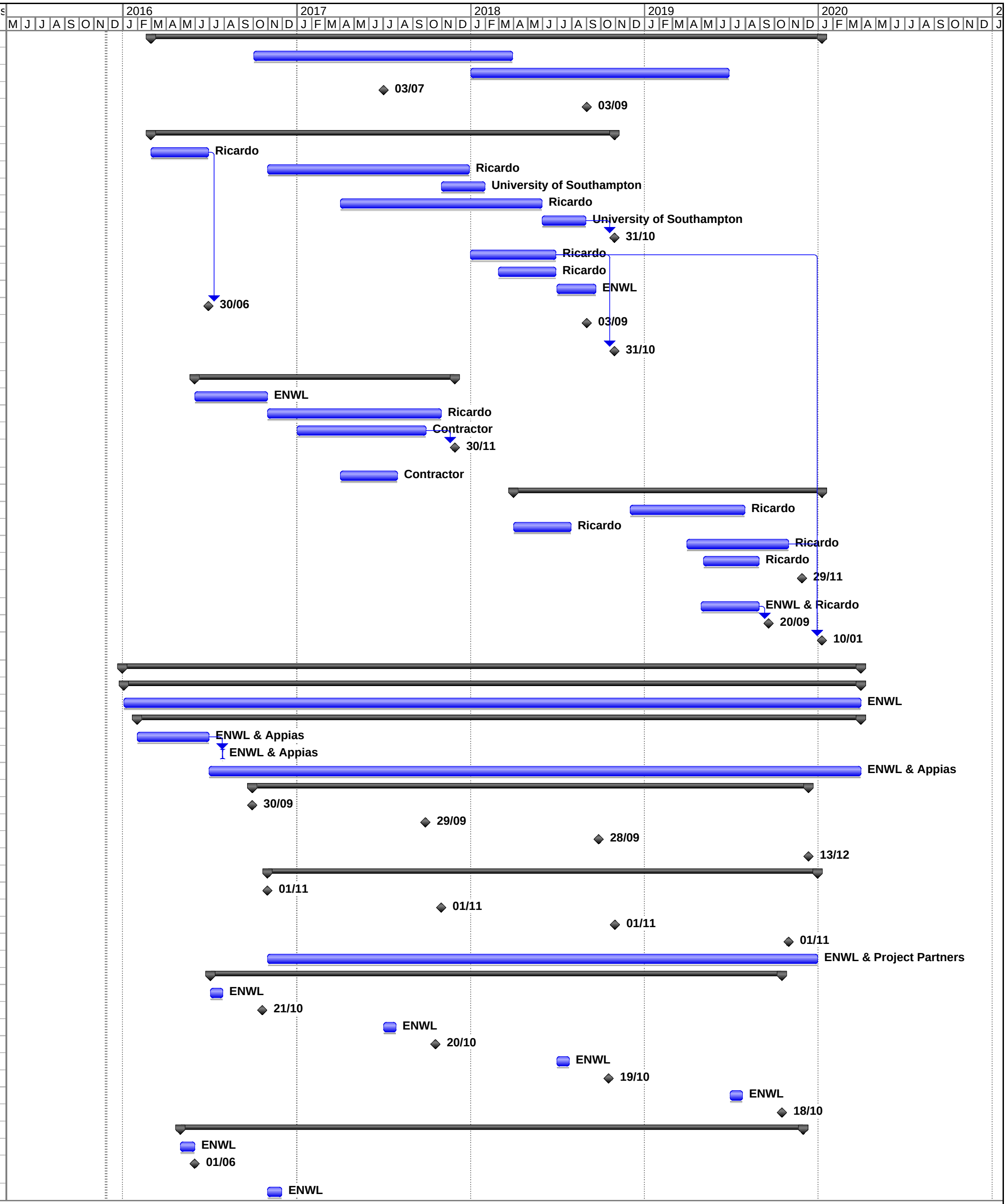
ID	Task Name	Duration	Start	Finish	Predecessors
1	**NIC Fund Award Announcement**	0 days	Mon 30/11/15	Mon 30/11/15	
2	**Phase 1a) Project Readiness**	**59 days?**	**Tue 01/12/15**	**Fri 19/02/16**	
3	Project Governance Embedded into existing Governance Structure	5 days?	Tue 01/12/15	Mon 07/12/15	
4	Review and agree Project Direction	10 days?	Mon 07/12/15	Fri 18/12/15	
5	Develop and send out partner contracts	10 days?	Tue 01/12/15	Mon 14/12/15	
6	Place order for thermal monitoring sensors	1 day?	Mon 21/12/15	Mon 21/12/15	4,5
7	Review and negotiate contracts	50 days?	Mon 14/12/15	Fri 19/02/16	
8	Design, develop and issue the Project Implementation Document	30 days?	Mon 21/12/15	Fri 29/01/16	
9	**Phase 1b) Mobilisation**	**89 days?**	**Tue 01/12/15**	**Fri 01/04/16**	
10	**Project Management Office Start-Up**	**85 days?**	**Mon 07/12/15**	**Fri 01/04/16**	
11	**Identify & Mobilise Project Management Office**	**85 days?**	**Mon 07/12/15**	**Fri 01/04/16**	
12	Identify & Mobilise Project Team	60 days?	Mon 04/01/16	Fri 25/03/16	
13	Partner Resourcing	60 days?	Mon 07/12/15	Fri 26/02/16	
14	Project Management Office and Partner Resources Mobilisation Meeting	5 days?	Mon 28/03/16	Fri 01/04/16	
15	**Financial & Contractual**	**88 days?**	**Tue 01/12/15**	**Thu 31/03/16**	
16	Identify and implement project budget controls with ENW	9 days?	Tue 01/12/15	Fri 11/12/15	
17	Set up project bank account	5 days?	Mon 21/12/15	Fri 25/12/15	4
18	Financial controls established	3 days?	Mon 21/12/15	Wed 23/12/15	16
19	Partnership relationship discussions	10 days?	Mon 22/02/16	Fri 04/03/16	7
20	Contractual agreement signed	7 days?	Wed 23/03/16	Thu 31/03/16	
21	**Phase II - Site Selection and Trial Design**	**200 days?**	**Mon 28/03/16**	**Fri 30/12/16**	
22	Finalise site selection methodology	90 days?	Mon 28/03/16	Fri 29/07/16	
23	Peer review of site selection methodology	31 days?	Fri 17/06/16	Fri 29/07/16	
24	Finalise trial design	90 days?	Mon 28/03/16	Fri 29/07/16	
25	Define Installation Plan (Schedule)	23 days?	Mon 01/08/16	Wed 31/08/16	24
26	Develop a site survey sheet	45 days?	Thu 30/06/16	Wed 31/08/16	
27	Monitoring Equipment Procurement	195 days?	Mon 04/04/16	Fri 30/12/16	
28	**Workstream - Technology**	**803 days?**	**Wed 01/06/16**	**Fri 28/06/19**	
29	**Equipment Implementation**	**281 days?**	**Thu 01/09/16**	**Fri 29/09/17**	
30	Training on installation of equipment	22 days?	Thu 01/09/16	Fri 30/09/16	
31	Installation of retrofit thermal monitoring sensors	130 days?	Mon 03/10/16	Fri 31/03/17	30
32	TW.1 Publish equipment specifications and installation reports by September 2017	0 days	Fri 29/09/17	Fri 29/09/17	
33	**IT Implementation**	**803 days?**	**Wed 01/06/16**	**Fri 28/06/19**	
34	Finalise data handling and IT Plan	43 days?	Wed 01/06/16	Fri 29/07/16	
35	Data communication set up	131 days?	Fri 01/07/16	Fri 30/12/16	
36	Data communication ongoing support	781 days?	Fri 01/07/16	Fri 28/06/19	
37	Data communication services	781 days?	Fri 01/07/16	Fri 28/06/19	
38	Data management initiation	131 days?	Fri 01/07/16	Fri 30/12/16	
39	Data management ongoing support	781 days?	Fri 01/07/16	Fri 28/06/19	
40	Data management services	781 days?	Fri 01/07/16	Fri 28/06/19	
41	Data validation set up	131 days?	Fri 01/07/16	Fri 30/12/16	
42	Data quality / Data validation	715 days?	Mon 03/10/16	Fri 28/06/19	
43	**Retrofit cooling**	**434 days?**	**Mon 03/04/17**	**Fri 30/11/18**	
44	Investigation of Potential Cooling Methods	86 days?	Mon 03/04/17	Mon 31/07/17	
45	Peer review of potential cooling methods	21 days?	Mon 03/07/17	Mon 31/07/17	
46	TW.2.1 Hold retrofit cooling workshop by May 2017	0 days	Fri 26/05/17	Fri 26/05/17	
47	TW.2.2 Review of highest scoring technologies, circulate workshop outcomes to DNOs and publish on the Celsius website by July 2017	0 days	Mon 31/07/17	Mon 31/07/17	
48	Cooling Trial Design and site selection	64 days?	Tue 01/08/17	Fri 27/10/17	
49	Peer review of cooling site selection	30 days?	Mon 18/09/17	Fri 27/10/17	
50	Define installation plan (schedule)	40 days?	Mon 30/10/17	Fri 22/12/17	
51	Technology Procurement	109 days?	Tue 01/08/17	Fri 29/12/17	45
52	Installation of retrofit cooling techniques	130 days?	Mon 01/01/18	Fri 29/06/18	51
53	TW.3 Publish cooling equipment specifications and installation reports by November 2018	0 days	Fri 30/11/18	Fri 30/11/18	
54	**Workstream - Customer**	**975 days?**	**Fri 01/01/16**	**Fri 27/09/19**	
55	Develop Customer Enagaement Plan and Data Privacy Statement	130 days?	Fri 01/01/16	Thu 30/06/16	
56	CW.1 Send Customer Engagement Plan and Data Privacy Statement to Ofgem	0 days	Thu 30/06/16	Thu 30/06/16	
57	Design communication materials to share with customers	20 days?	Mon 05/06/17	Fri 30/06/17	
58	CW.2.1 Deliver customer focus group workshop	0 days	Fri 28/07/17	Fri 28/07/17	57
59	CW.2.2 Publish lessons learned from testing customer communication materials on Celsius website	0 days	Fri 29/12/17	Fri 29/12/17	58
60	Customer contact centre training and briefing	66 days?	Fri 01/07/16	Fri 30/09/16	
61	Baseline customer surveys	42 days?	Mon 04/09/17	Tue 31/10/17	
62	Trial customer surveys	390 days?	Mon 01/01/18	Fri 28/06/19	
63	CW.3.1 Publish customer survey report quantifying the acceptability of innovative retrofit cooling techniques on the Celsius website by September 2019	0 days	Fri 27/09/19	Fri 27/09/19	
64	CW.3.2 Publish additional customer survey analysis evaluating the change, if any, in the acceptability of innovative retrofit cooling techniques by educating customers, on the Celsius website by September 2019	0 days	Fri 27/09/19	Fri 27/09/19	



Task | Progress | Summary | External Tasks | Deadline

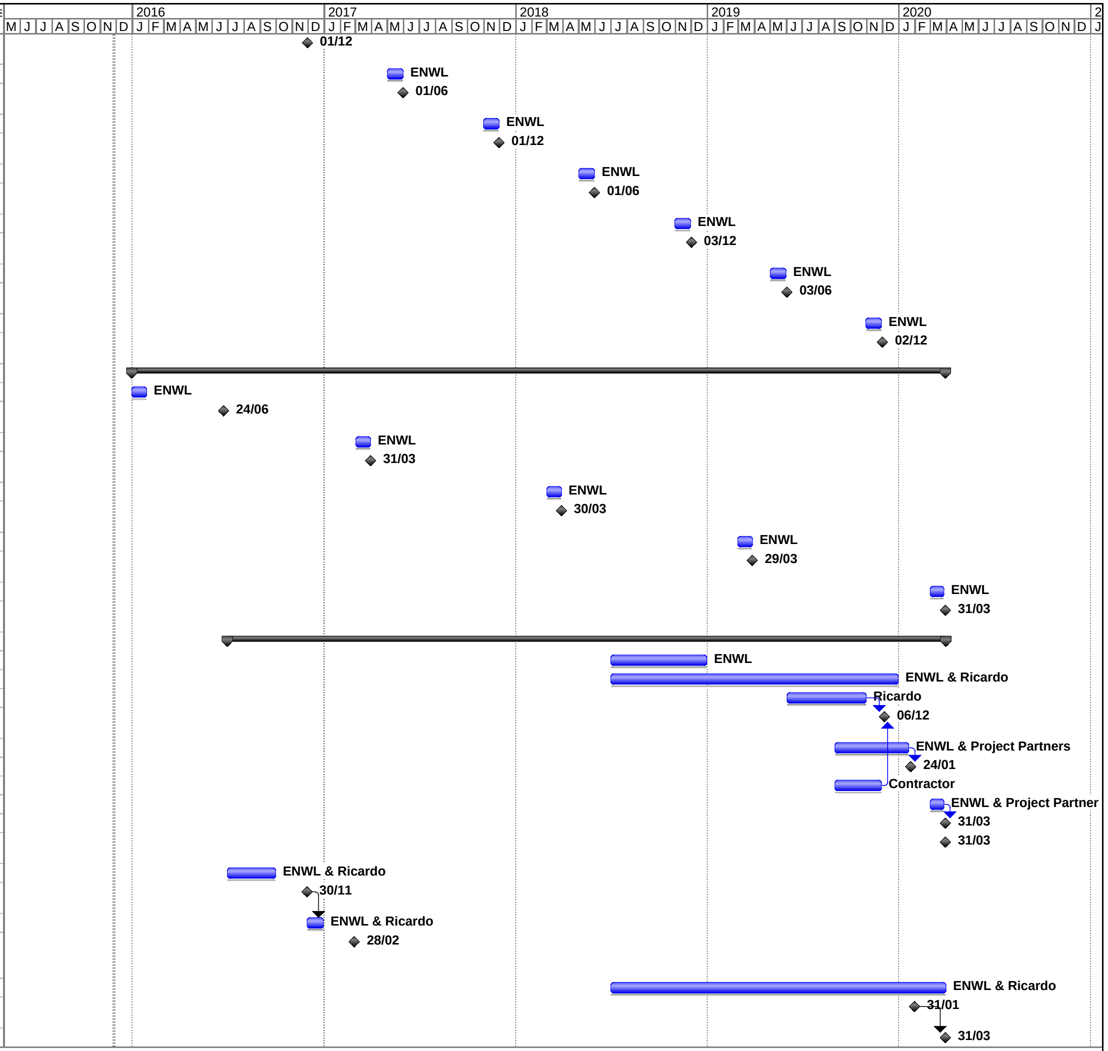
Split | Milestone | Project Summary | External Milestone

ID	Task Name	Duration	Start	Finish	Predecessors
65	**Workstream - Trials & Analysis**	**1008 days?**	**Tue 01/03/16**	**Fri 10/01/20**	
66	Retrofit thermal monitoring trial (step 1)	390 days?	Mon 03/10/16	Fri 30/03/18	
67	Retrofit coolling trial (step 2)	389 days?	Tue 02/01/18	Fri 28/06/19	
68	TAW.1.1 Raw temperature thermal monitoring data to be available from July 2017	0 days	Mon 03/07/17	Mon 03/07/17	
69	TAW.1.1 Raw temperature retrofit cooling monitoring data to be available from September 2018	0 days	Mon 03/09/18	Mon 03/09/18	
70	**Retrofit thermal monitoring analysis**	**696 days?**	**Tue 01/03/16**	**Wed 31/10/18**	
71	Review existing Literature	87 days?	Tue 01/03/16	Wed 29/06/16	
72	Analysis - hotspot temperature calculation	304 days?	Tue 01/11/16	Fri 29/12/17	
73	Peer Review of calculation	66 days?	Wed 01/11/17	Wed 31/01/18	
74	Analysis - temperature factors	304 days?	Mon 03/04/17	Thu 31/05/18	
75	Asset Health Study	66 days?	Fri 01/06/18	Fri 31/08/18	
76	TAW.6 Publish Asset Health Study report on Celsius website by October 2018	0 days	Wed 31/10/18	Wed 31/10/18	75
77	Thermal Ratings Tool - Development and Validation	130 days?	Mon 01/01/18	Fri 29/06/18	
78	Celsius Capacity Evaluation Methodology Development	87 days?	Thu 01/03/18	Fri 29/06/18	
79	Celsius Capacity Evaluation	60 days?	Mon 02/07/18	Fri 21/09/18	
80	Publish Literature Review	0 days	Thu 30/06/16	Thu 30/06/16	71
81	TAW.1.2 Publish asset temperature behaviour analysis report on Celsius website by September 2018	0 days	Mon 03/09/18	Mon 03/09/18	
82	TAW.4.1 Develop Thermal Ratings Tool using monitoring data to evaluate site capacity on Celsius substations by October 2018	0 days	Wed 31/10/18	Wed 31/10/18	77
83	**Thermal Flow Study**	**391 days?**	**Wed 01/06/16**	**Thu 30/11/17**	
84	Thermal Flow Study Tender	109 days?	Wed 01/06/16	Mon 31/10/16	
85	Thermal Flow Study Support	261 days?	Tue 01/11/16	Tue 31/10/17	
86	Thermal Flow Study	195 days?	Mon 02/01/17	Fri 29/09/17	
87	TAW.2 Publish Thermal Flow Study Report and initial recommendations for substation design on Celsius website by November 2017	0 days	Thu 30/11/17	Thu 30/11/17	86
88	Additional Studies (retrofit cooling)	86 days?	Mon 03/04/17	Mon 31/07/17	
89	**Retrofit Cooling Analysis**	**464 days?**	**Mon 02/04/18**	**Fri 10/01/20**	
90	Cooling Technology Performance Analysis	173 days?	Mon 03/12/18	Wed 31/07/19	
91	Assessment of cooling technologies costs	87 days?	Mon 02/04/18	Tue 31/07/18	
92	Cooling Intervention Tool - Development and Validation	154 days?	Mon 01/04/19	Thu 31/10/19	
93	Cooling Technology Demonstration Evaluation Report	85 days	Mon 06/05/19	Fri 30/08/19	
94	TAW.4.2 Develop and validate Thermal Ratings Tool using retrofit cooling trial data, and publish on Celsius website by November 2019	0 days	Fri 29/11/19	Fri 29/11/19	
95	Development of low cost monitoring solution	88 days?	Wed 01/05/19	Fri 30/08/19	
96	TAW.3 Publish low cost monitoring solution specification on the Celsius website	0 days	Fri 20/09/19	Fri 20/09/19	95
97	TAW.4.3 Develop and validate Thermal Ratings Too,l combining input data from the monitoring and cooling trials, and publish user guide on Celsius website	0 days?	Fri 10/01/20	Fri 10/01/20	92,77
98	**Workstream - Learning & Dissemination**	**1108 days?**	**Fri 01/01/16**	**Tue 31/03/20**	
99	**External Learning & Dissemination**	**1107 days?**	**Mon 04/01/16**	**Tue 31/03/20**	
100	One-to-one sessions available throughout the Project	1107 days?	Mon 04/01/16	Tue 31/03/20	
101	**Celsius Website**	**1087 days?**	**Mon 01/02/16**	**Tue 31/03/20**	
102	Design, build, install, test and commission Celsius website	109 days?	Mon 01/02/16	Thu 30/06/16	
103	LDW.1 Launch Celsius Project website	1 day	Fri 29/07/16	Fri 29/07/16	102
104	Support & maintenance of Celsius website	978 days?	Fri 01/07/16	Tue 31/03/20	
105	**Knowledge Sharing Events**	**835 days?**	**Fri 30/09/16**	**Fri 13/12/19**	
106	LDW.5 Hold annual knowledge sharing events and provide 121 sessions	0 days	Fri 30/09/16	Fri 30/09/16	
107	LDW.5 Hold annual knowledge sharing events and provide 121 sessions	0 days	Fri 29/09/17	Fri 29/09/17	
108	LDW.5 Hold annual knowledge sharing events and provide 121 sessions	0 days	Fri 28/09/18	Fri 28/09/18	
109	LDW.5 Hold annual knowledge sharing events and provide 121 sessions	0 days	Fri 13/12/19	Fri 13/12/19	
110	**Conference Attendance**	**826 days?**	**Tue 01/11/16**	**Tue 31/12/19**	
111	LCNI Annual Conference 2016	0 days	Tue 01/11/16	Tue 01/11/16	
112	LCNI Annual Conference 2017	0 days	Wed 01/11/17	Wed 01/11/17	
113	LCNI Annual Conference 2018	0 days	Thu 01/11/18	Thu 01/11/18	
114	LCNI Annual Conference 2019	0 days	Fri 01/11/19	Fri 01/11/19	
115	LDW.4 Participation at four annual LCNI Conferences	826 days?	Tue 01/11/16	Tue 31/12/19	
116	**Advertorials**	**859 days?**	**Mon 04/07/16**	**Fri 18/10/19**	
117	Advertorial 1 - Publicise Celsius	20 days?	Mon 04/07/16	Fri 29/07/16	
118	LDW.3 Publish advertorial	0 days	Fri 21/10/16	Fri 21/10/16	
119	Advertorial 2 - Publise progress & Learning	20 days?	Mon 03/07/17	Fri 28/07/17	
120	LDW.3 Publish advertorial	0 days	Fri 20/10/17	Fri 20/10/17	
121	Advertorial 3 - Publise progress & Learning	20 days?	Mon 02/07/18	Fri 27/07/18	
122	LDW.3 Publish advertorial	0 days	Fri 19/10/18	Fri 19/10/18	
123	Advertorial 4 - Publise progress & Learning	20 days?	Mon 01/07/19	Fri 26/07/19	
124	LDW.3 Publish advertorial	0 days	Fri 18/10/19	Fri 18/10/19	
125	**Ofgem Six Monthly Reports**	**935 days?**	**Mon 02/05/16**	**Mon 02/12/19**	
126	Preparation of Report 1	22 days?	Mon 02/05/16	Tue 31/05/16	
127	LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Wed 01/06/16	Wed 01/06/16	
128	Preparation of Report 2	22 days?	Tue 01/11/16	Wed 30/11/16	



Task		Progress		Summary		External Tasks		Deadline
Split		Milestone		Project Summary		External Milestone	

ID		Task Name	Duration	Start	Finish	Predecessors
129		LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Thu 01/12/16	Thu 01/12/16	
130		Preparation of Report 3	22 days?	Tue 02/05/17	Wed 31/05/17	
131		LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Thu 01/06/17	Thu 01/06/17	
132		Preparation of Report 4	22 days?	Wed 01/11/17	Thu 30/11/17	
133		LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Fri 01/12/17	Fri 01/12/17	
134		Preparation of Report 5	22 days?	Wed 02/05/18	Thu 31/05/18	
135		LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Fri 01/06/18	Fri 01/06/18	
136		Preparation of Report 6	22 days?	Thu 01/11/18	Fri 30/11/18	
137		LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Mon 03/12/18	Mon 03/12/18	
138		Preparation of Report 7	22 days?	Thu 02/05/19	Fri 31/05/19	
139		LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Mon 03/06/19	Mon 03/06/19	
140		Preparation of Report 8	22 days?	Thu 31/10/19	Fri 29/11/19	
141		LDW.6 Issue Project progress reports issued in accordance with Ofgem's June and December production cycle and publish on the Celsius website	0 days	Mon 02/12/19	Mon 02/12/19	
142		**Internal Learning & Dissemination**	**1107 days?**	**Fri 01/01/16**	**Tue 31/03/20**	
143		Produce materials for the Volt / Weekly Connect Email - Publicise Celsius	20 days?	Fri 01/01/16	Thu 28/01/16	
144		LDW.2 Publicise Celsius within Electricity North West via the Volt intranet site, email bulletins and/or Newswire company magazine	0 days	Fri 24/06/16	Fri 24/06/16	
145		Produce materials for the Volt / Weekly Connect Email - Progress & Learning	20 days?	Fri 03/03/17	Thu 30/03/17	
146		LDW.2 Publicise Celsius within Electricity North West via the Volt intranet site, email bulletins and/or Newswire company magazine	0 days	Fri 31/03/17	Fri 31/03/17	
147		Produce materials for the Volt / Weekly Connect Email - Progress & Learning	20 days?	Fri 02/03/18	Thu 29/03/18	
148		LDW.2 Publicise Celsius within Electricity North West via the Volt intranet site, email bulletins and/or Newswire company magazine	0 days	Fri 30/03/18	Fri 30/03/18	
149		Produce materials for the Volt / Weekly Connect Email - Progress & Learning	20 days?	Fri 01/03/19	Thu 28/03/19	
150		LDW.2 Publicise Celsius within Electricity North West via the Volt intranet site, email bulletins and/or Newswire company magazine	0 days	Fri 29/03/19	Fri 29/03/19	
151		Produce materials for the Volt / Weekly Connect Email - Progress & Learning	20 days?	Mon 02/03/20	Fri 27/03/20	
152		LDW.2 Publicise Celsius within Electricity North West via the Volt intranet site, email bulletins and/or Newswire company magazine	0 days	Tue 31/03/20	Tue 31/03/20	
153		**Phase III - Close Down and BAU Transition**	**978 days?**	**Fri 01/07/16**	**Tue 31/03/20**	
154		Review of Current BAU Process	131 days?	Mon 02/07/18	Mon 31/12/18	
155		Development of BAU Process	392 days?	Mon 02/07/18	Tue 31/12/19	
156		Analysis of the costs and benefits of Celsius	109 days?	Mon 03/06/19	Thu 31/10/19	
157		TAW.5 Publish the Cost Benefit Analysis and Carbon Impact Assessment reports, Celsius Business Case and buy order of retrofit cooling techniques on Celsius website	0 days	Fri 06/12/19	Fri 06/12/19	156,160
158		Development of close down report	101 days?	Mon 02/09/19	Mon 20/01/20	
159		CI.1.1 Produce Celsius close down report	0 days	Fri 24/01/20	Fri 24/01/20	158
160		Carbon Impact Assesment	65 days?	Mon 02/09/19	Fri 29/11/19	
161		CI.1.2 Complete and publish peer review of Celsius closedown report	20 days?	Mon 02/03/20	Fri 27/03/20	
162		Celsius close down report issued to Ofgem and published on Celsius website	0 days	Tue 31/03/20	Tue 31/03/20	161
163		CI.2 Publish Electricity North West's approach to managing thermal constraints at distribution substantions on the Celsius website and train planners/operational engineers	0 days	Tue 31/03/20	Tue 31/03/20	
164		Initial Document Review of ER P17 and P15 and Identification of Areas Relevant to Celsius	66 days?	Fri 01/07/16	Fri 30/09/16	
165		CI.3.1 ENA workshop with DNOs held by November 2016 (to agree areas of changes to Engineering Recommendations P15 and P17)	0 days	Wed 30/11/16	Wed 30/11/16	
166		Collate comments and proposed areas of change and initial proposals for modifications	23 days?	Wed 30/11/16	Fri 30/12/16	165
167		CI.3.2 Publish any areas for change identified at the ENA workshop and publish change proposal options to ER P15 and ENA ER P17 on Celsius website by February 2017	0 days	Tue 28/02/17	Tue 28/02/17	
168		Use Celsius outputs to validate modifications and prepare documentation necessary for the	457 days?	Mon 02/07/18	Tue 31/03/20	
169		CI.3.3 Incorporate relevant Celsius outputs into change proposal options for ER P15 and ER P17 and hold workshop with DNOs by January 2020	0 days	Fri 31/01/20	Fri 31/01/20	
170		CI.3.4 Submit proposals for changing ER P15 and ER P17 to ENFG by March 2020	0 days	Tue 31/03/20	Tue 31/03/20	169



Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Appendix G: Risks and Issues Register and Contingency Actions

The risk model employed by Electricity North West in the delivery of Electricity Network Innovation Competition projects looks at risks in much the same holistic manner as the proven risk model employed by Electricity North West at a corporate level. However, using previous experience, the risk and issues register has been refined to better reflect the increased significance of impacts at a project level. In this model, risk impact areas have been categorised into time, cost and scope/quality which are given a score of 1 to 5 along with the likelihood of occurrence. The resulting product of these two ratings is used to score and rank the risks on the project. The risk model determines an 'uncontrolled' risk score. However, if control measures are applied, aimed at reducing the hazard and/or mitigating the risk, it should be possible to produce a controlled risk score that is lower than the uncontrolled risk. The format of the Electricity North West Network Innovation Competition risk scoring matrix is below.

Risk impact descriptors

RISK AREA	1 Negligible	2 Minor	3 Moderate	4 Significant	5 Serious
Time	There will be no impact on deliverables. No re-planning necessary	Any delays are likely to be small ie <one week and manageable. Minor re-planning necessary	Some delays likely to project/programme milestones, but the overall project/programme delivery date will not be affected. An element of re-planning will be necessary	There is likely to be a delay which causes the overall project/programme delivery end-date to slip. Significant re-planning will be essential	There is likely to be a delay which causes the overall project/programme delivery end-date to slip. Serious re-planning will be essential
Cost	£0	<£10k	<£20k	<£50k	>£50k
Scope/ Quality	There will be no impact on the overall quality of the deliverables in the project/programme. All requirements will still be met	There will be negligible impact (if any), on the overall quality of the deliverables in the project/programme. Most, if not all requirements will still be met	Some requirements will not be met, or a small number of business process(es) will need to be modified to accommodate shortcomings in the delivery	A significant number of requirements will not be met, or business process(es) will need to be modified to accommodate shortcomings in the delivery	Major requirements, key to the success of the delivery, are not likely to be delivered as planned

Risk probability descriptors

5	Almost certain	>80%
4	Likely	60-80%
3	Moderate	30-60%
2	Low	10–30%
1	Rare	<10%

Risk score

Impact					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5
	Probability				

The following potential risks have been identified. These risks have been based on the scoring matrix set out above and linked to the Project phase or workstream in which they will occur.

Project phase/ workstream	Description	Probability score	Impact score	Mitigating action/contingency action	Revised probability score	Revised impact score
Mobilisation	There is a risk that the Project Partners are not able to mobilise their resources in time because of other commitments leading to a delay in achieving potential milestones which could have a Project reputational and financial repercussion.	3	4	Suitable partnership agreements that ensure collaborative working, value for customers' money and achievement of learning objectives in a timely manner have been identified for all Partners. A project initiation document will be issued to the Project Partners to ensure that all parties are ready.	1	4
				Contingency: Electricity North West will seek new Partners should existing Partners fail to mobilise.		
Technology	There is a risk that the lead time for delivery, installation and/or configuration of the thermal monitoring sensors may lead to a delayed start on the monitoring trial.	4	5	Project plan specifies that a purchase order will be raised to procure the sensors allowing the Partner to begin manufacture. Regular meetings/reports to track progress against the plan. Commitment to additional operational resource should any delays occur to the installation, testing and commissioning programme.	2	5
				Contingency: Flexibility is built into the installation programme; phased installation plan starts in autumn 2016 to be completed by spring 2017. *A full year's data for comparison with the cooling trial could be gained by overlapping these tasks more than planned.*		

Project phase/ workstream	Description	Probability score	Impact score	Mitigating action/contingency action	Revised probability score	Revised impact score
Technology	There is a risk that sites with existing load monitoring may not be suitable or the existing monitoring units may require a software/hardware update for the sites to be included in the Celsius Project.	3	4	Allowance in budget and plans to move some existing load monitors if necessary. Communications with manufacturers of existing equipment to identify solutions early. Allowance in budget and plans to carry out updates. *Contingency: New power monitoring units, supplied by Project Partner Ash Wireless will be installed where this is deemed most cost-effective.*	3	2
Technology	There is a risk of monitoring equipment failure leading to a requirement for additional resource to attend site to fix or replace.	3	4	Phased rollout of equipment to ensure systems are working properly before all sites are installed. Some remote monitoring and diagnostics will be possible, for example of performance of the communications and through data validation. *Contingency: Budget for additional resource.*	3	2
Technology	There is a risk that internal transformer monitoring or retrofit cooling methods (and their installation) may have an impact on the network as a whole leading to disruption or outage.	1	5	The technical and installation issues and requirements will be assessed before any installation is carried out, which should identify any risk at an early stage to allow this to be mitigated, or for the technology to be discounted from the trial. *Contingency: If any issues occur, then the technology will be removed and made good at the earliest signs.*	1	2

Project phase/ workstream	Description	Probability score	Impact score	Mitigating action/contingency action	Revised probability score	Revised impact score
Technology	There is a risk that there is inadequate signal at sites and communication outages or battery life issues could prevent data being sent to data management system for the duration leading to gaps in data sets.	3	4	The data communications will use 'roaming' SIM cards, the signal will be checked prior to installation, if required an aerial will be installed. If inadequate signal the site will be excluded from the trial. Data will be sent once a day, any failures to send data will be identified automatically and corrected. Data being received will be continuously validated to identify missing or unrealistic data, so issues will be identified quickly. Battery life requirements have been defined and agreed at an early stage. *Contingency: Select sites without signal issues. Where gaps in data occur, analysis can be carried out on the remaining data, and where necessary, missing data will be simulated. Sensors that are still required will be replaced.*	2	2
Technology	There is a risk that a lack of suitable retrofit cooling technologies and vendors may result in a poor response to invitations to tenders, leading to reduced competitiveness of quotes and reduced value for money.	2	4	A call for innovation in Celsius development showed that products are available from a number of vendors. A thorough market search will identify as many options as possible. *Contingency: Early vendor engagement. If there is significant difficulty in identifying enough suitable technology vendors, then the cooling trial can be implemented with fewer technology types.*	2	2

Project phase/ workstream	Description	Probability score	Impact score	Mitigating action/contingency action	Revised probability score	Revised impact score
Technology	There is a risk that the lead time for the retrofit cooling techniques may lead to a delay in the installation of this technology and delay the start of the monitoring trial.	3	3	During technology selection, each technology will be assessed based on a number of characteristics, including readiness and deployment issues. This will reveal early potential issues. *Contingency: Flexibility is built into the installation programme with a phased installation plan starting in winter 2018 and to be completed by summer 2018. If delays are unavoidable, then technology analysis could be carried out using less than one year's data. The limitations to the assessment caused by this will be identified.*	2	2
Customer	There is a risk that customers on trial networks might notice a visual or audible impact from a local retrofit intervention, or be inconvenienced during the installation of the technology. This risk might result in a breakdown in customer relationship and reputation.	3	2	To ensure that there is no public or reputational damage to Electricity North West, Celsius will embed a process to quickly and appropriately manage any customer impacts. *Contingency: Customer impact will be carefully considered during site selection. This will mitigate against deploying specific interventions on certain networks where the risk of an adverse customer impact, specific to the customer/network/asset/ environment type, from a particular technique, is considered excessively high.*	2	1

Project phase/ workstream	Description	Probability score	Impact score	Mitigating action/contingency action	Revised probability score	Revised impact score
Learning dissemination	There is a risk that attendance at events may be low due to the number of projects and knowledge dissemination events already taking place. Learning may be inhibited due to stakeholders having different interests and learning styles	2	3	Electricity North West will try where possible to merge dissemination events and choose dissemination channels optimised to achieve maximum reach and coverage. Dissemination will be carried out through multiple communication channels including 121 briefings	2	2
				Contingency: Interested parties are able to contact the Project Team for any queries and request additional information.		
Closedown	There is a risk that new obligations and guidance will be released on key deliverables, such as the closedown report (eg the need to get it peer-reviewed) leading to a longer preparation and review period required.	3	3	Communication channels from Ofgem will be monitored and any updates to such requirements identified as early as possible.	3	3
				Contingency: Additional time is allowed for closedown reporting and a DNO Partner embedded in the Project to provide ongoing review and challenge throughout Project delivery.		

Appendix H: Project Partner and Supplier Details

Name	Type of organisation	Funding provided	Contractual relationship with Electricity North West	Role of Project Partner	Funding benefits to Celsius
ASH Wireless	ASH is a creative electronics design consultancy SME. They are experts in sensing technologies and have a track record in providing bespoke monitoring solutions to the utility industry. They have specific experience in providing sensor solutions for electricity substations, including asset surface and ambient temperature monitoring	[redacted]	ASH will be a Partner organisation. Terms and conditions that include the NIC default IPR arrangement have been shared and agreed. This will govern the scope and obligations of Partner involvement	• To supply a complete retrofit monitoring solution including thermal monitors and power monitoring • To provide ongoing support throughout the installation, commissioning and operation of the retrofit thermal monitoring workstream • Project governance and knowledge dissemination	ASH is providing a discount on equipment and will provide further contribution by way of time and expertise for Project governance and knowledge dissemination
Ricardo-AEA	Ricardo-AEA is a technical consultancy organisation with experience in all aspects of power generation, transmission and distribution. They have experience in the delivery of innovation projects including LCNF, IFI and NIA projects. Their experience includes collecting, analysing and interpreting network data and developing usable information, including substation load and temperature data	[redacted]	Ricardo-AEA will be a Partner organisation. Terms and conditions that include the NIC default IPR arrangement have been shared and agreed. This will govern the scope and obligations of Partner involvement	• To analyse trial data and develop a methodology to understand the relationship between asset temperature, load characteristics and surrounding environment • To determine the impact of the cooling technologies on the demonstration sites • Develop a tool and specifications for a low cost temperature sensor, • Recommendations for BAU rollout including ER P15 and ER P17 review and change proposals • Knowledge dissemination	Ricardo-AEA is providing a discount across the activities

Name	Type of organisation	Funding provided	Contractual relationship with Electricity North West	Role of Project Partner	Funding benefits to Celsius
UK Power Networks (UKPN)	UK Power Networks is the electricity distribution network operator across London, the South East and East of England. The company has undertaken related or forerunner projects and is well placed to inform the scope and provide support to the Project in an advisory capacity	[redacted]	UKPN will be a Partner organisation. Terms and conditions that include the NIC default IPR arrangement have been shared and agreed. This will govern the scope and obligations of Partner involvement	• Work with Ricardo-AEA and Electricity North West to develop site selection methodology, installation plan and guide for future retrofit thermal monitoring solution • Participate in evaluation and selection of retrofit cooling techniques • Knowledge dissemination	UKPN will provide Project governance and advice at no cost to the Project
Impact Research	Impact Research is a specialist marketing research organisation	[redacted]	Impact will be a Partner organisation. Terms and conditions that include the NIC default IPR arrangement have been shared and agreed. This will govern the scope and obligations of Partner involvement	• Lead the customer survey engagement • Learning and dissemination support	Impact Research is funding additional interviews with customers to support the development of the customer survey report
University of Southampton (UoS)	The University of Southampton will provide academic support for the Project. It is a known expert in electricity network engineering, in particular in the field of electricity cables. The university also has significant capabilities in the field of transformer design	N/a	UoS will be a supplier. Terms and conditions that include the NIC default IPR arrangement have been shared and agreed. This will govern the scope and obligations of supplier involvement	• Peer review of the analysis methodology of the retrofit temperature sensor part of the Project • An investigative study on the impact of Celsius on the lifetime health of network assets	University of Southampton is a supplier to the Celsius Project. Therefore no contribution applies

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Steve Cox
Future Networks Manager
Electricity North West Limited
304 Bridgewater Place
Birchwood Park
Warrington
WA3 6XG

27 July 2015

Dear Steve

LETTER OF SUPPORT FOR ELECTIVITY NORTH WEST LIMITED - NIC PROJECT 'CELSIUS'

Ricardo-AEA is delighted to have been selected as a partner to work with Electricity North West on the Celsius project.

The Celsius project will aim to develop methods for the management of thermal constraints at distribution substations. This includes firstly developing solutions to better understand the effect of localised conditions on asset temperature, and then investigating and demonstrating methods to intervene to manage temperature. This will enable network operators to quickly release thermal capacity within network assets, enabling faster and lower cost connections and potentially deferring the need to uprate assets.

This is an exciting and innovative project with real potential to impact the operation of network assets in the Electricity North West network, and in other networks over Great Britain, bringing benefit to network customers.

Ricardo-AEA has significant capability in all aspects of power generation, transmission and distribution. We have experience in the delivery of innovation projects including LCNF, IFI and NIA projects. This experience includes collecting, analysing and interpreting network data and developing usable information, and this has included substation load and temperature data. This puts Ricardo-AEA in an excellent position to contribute to the project.

We look forward to working closely with Electricity North West and the other Celsius project partners on this project. In the event Electricity North West's bid for funding is successful and are awarded a contract to support the Celsius project, Ricardo-AEA will participate under sub-agreement terms to be agreed with Electricity North West at a later date.

Yours sincerely

Daryl A Field
Commercial Manager

Registered Office:
Newington House
237 Southwark Bridge Road
London SE1 6NP

Registered in England and Wales No: 3870728

Company:
UK Power Networks
(Operations) Limited

Mr S Cox
Electricity North West Limited
304 Bridgewater Place
Birchwood Park
Warrington
WA3 6XG

28 July 2015

Dear Steve

Letter of Support for Celsius

UK Power Networks owns and maintains the electricity distribution network across London, the South East and East of England. Like Electricity North West Limited, we are responsible for upgrading power equipment to meet our customers' energy needs.

We are delighted to join Electricity North West as a Project Partner for their Network Innovation Competition submission, Celsius.

By developing crucial knowledge for temperature management of distribution substations, the Celsius project will provide a new approach to managing thermal capacity, something that we are very keen to see demonstrated.

We continually engage with Electricity North West, as a fellow distribution network operator, this collaboration builds on that relationship to share learning on solutions to common problems.

We will be offering our support by providing input and guidance on the design of retrofit thermal monitoring activities and the selection of retrofit cooling techniques. All activities will be wholly funded by UK Power Networks as our contribution to this exciting project.

Yours sincerely,

PP Martin Wilcox
Head of Future Networks
UK Power Networks

Return Address:
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ASH Wireless Electronics Ltd.
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ASH
■ CREATIVE WIRELESS ELECTRONICS ■

Steve Cox
Electricity North West Ltd
304 Bridgewater Place
Birchwood Park
Warrington
WA3 6XG

23rd July 2015

Celsius: Substation Thermal Ratings Project for Network Innovation Competition

ASH are delighted to support Electricity North West and Ricardo-AEA as a partner in the Network Innovation Competition. We will support ENW in the implementation and governance of the project, and in the gathering and dissemination of the knowledge resulting from it.

The Celsius project is to enable an understanding of the thermal behavior of low voltage substations and their assets, in relation to loading, substation configuration and material, and external environment. The project will aim to monitor the temperature of multiple assets (transformer, LV board, cables etc.), ambient temperatures within different parts of the substation, and load monitoring (using current and voltage, and calculating real and imaginary components of power).

We believe that this understanding of the thermal behaviour of substations will lead to ensuring a more reliable supply at the same time as enabling more effective and efficient use of network assets in a power distribution environment that is changing due to edge generation by renewable sources.

ASH are an electronics design consultancy who specialise in Wireless Communications, and have particular expertise in sensing and low power radio solutions.

ASH have designed electronics equipment for Ricardo-AEA for several projects involving sensing and telemetry for power distribution installations.

Yours Sincerely

Richard Lucas
Business Engineering Manager

Impact Research

Impact Research Ltd.
Quintet 3
Churchfield Road
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Surrey
KT12 2TZ
United Kingdom

Cara Blockley
Electricity North West Limited
304 Bridgewater Place
Birchwood Park
Warrington
WA3 6XG

24th July 2015

Ref: Celsius Project

Dear Cara,

Impact Research is very pleased to be part of the consortium of Partners to provide customer engagement for the Celsius Project to support the UK's transition to a low carbon economy.

Celsius will show that a DNO can efficiently increase the capacity available for connection of LCTs through the smart utilisation of existing assets whilst maintaining asset health and customer satisfaction.

The Celsius Project is innovative and we are delighted to play a significant part in assessing domestic customers' acceptance of the Method during the Trial period.

Impact Research's role includes, but is not limited to, recruiting and interviewing customers to reporting on the Trial findings and disseminating them to key stakeholders. Impact Research recognises the importance of its involvement and will be fully committed to the success of Celsius.

Impact Research has experience working on other customer engagement projects under the LCN Fund umbrella utilising both qualitative and quantitative research techniques. Ensuring a strong and robust method to provide reliable results are factors central to our approach.

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We are delighted to have been invited by Electricity North West to be part of the consortium of Partners, and I have full confidence the team at Impact Research will deliver a successful, high quality and robust project.

Yours sincerely,

Darryl Swift
Manager Director

tnei
enterprise with energy

24 July, 2015

Ref: 10346-001 R0

Copy: Sent by email only

Cara Blockley
Electricity North West Limited
Hartington Road
Preston
PR1 8LE

Dear Cara,

TNEI is pleased to write a letter of support for the Electricity North West Limited Celsius project.

Over the next few decades, there is forecast to be a significant decarbonisation of heat and transport with these energy requirements increasingly being met through the distribution network. Innovative solutions that provide both value for money to customers and can be rapidly deployed are needed at the HV/LV network interface to address future thermal constraints.

TNEI is actively involved in supporting a number of LCNF and NIC projects across Great Britain as a provider of power systems consultancy and software services. We have supported Electricity North West in developing the business case for the Celsius project bid. Celius shows significant potential to effectively mitigate thermal pinch points in the distribution network by delivering additional capacity rapidly and at low cost to where it is needed. This will contribute to the evolution of a more efficient distribution network across Great Britain.

Yours sincerely,

Rachel Hodges
BEng (Hons), MIET

Managing Director

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Steve Cox
Electricity North West Limited
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23/07/2015

Dear Steve,

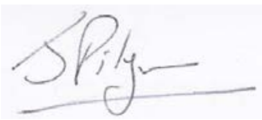
CELSIUS Project – Electricity Network Innovation Competition

The Tony Davies High Voltage Laboratory (TDHVL) is a leading research centre in high voltage engineering in the UK. We have significant experience in the thermal modelling of high voltage assets across a range of voltage levels, and are well aware of the benefits which network operators can gain from having a better understanding of the thermal state of their assets. We are very pleased to be able to give our support to the CELSIUS Network innovation Competition project through providing access to our technical expertise in the thermal modelling/current rating of electrical network assets. Having undertaken related projects in this area, we hope that the expertise we can provide will prove valuable as the project progresses towards trialling potential solutions.

We recognise that innovative techniques need to be developed to support the assessment of asset operating temperatures within the distribution network. The planned focus on developing methods which are low cost, and hence necessarily involve the deployment of a minimal amount of physical hardware, is vital in developing a solution which can be deployed widely across UK distribution networks.

We look forward to working with you further on the CELSIUS project in the future.

Yours sincerely



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Appendix J: Glossary

Ambient temperature	Temperature of the air surrounding a component
BAU	Business as usual
Cable	An underground conductor used to distribute electrical power, typically buried directly in the ground or installed in ducts or troughs
Capacity	The amount of power that can be delivered by an asset
Carbon Plan	Sets out how the UK will achieve decarbonisation within the framework of UK's energy policy: to make the transition to a low carbon economy while maintaining energy security, and minimising costs to consumers, particularly those in poorer households
Current	The movement of electrons through a conductor, measured in amperes, milliamperes and microamperes
Demand	The amount of electrical energy that is being consumed at any given time
Department of Energy & Climate Change (DECC)	The government department that works to make sure the UK has secure, clean, affordable energy supplies and promotes international action to mitigate climate change
Distribution substation	A substation which contains high voltage (HV) switchgear, an HV/LV transformer, LV switchgear and short length of LV cable(s) and can be either pole- or ground-mounted
Distribution network operator (DNO)	The owner and/or operator of an electricity distribution system and associated assets
Diversity	A factor which is applied to demands to take into account that not all connected demands are operating at the same time or at their maximum rating
Electric vehicle (EV)	A vehicle which uses one or more electric motors or traction motors for propulsion
Energy Innovation Centre (EIC)	The Energy Innovation Centre exists to bring energy innovation and industry together in the UK as we move towards a low carbon future
Energy Networks Association (ENA)	The industry body funded by GB electricity transmission and distribution licence holders and gas transporter licence holders. It lobbies on common issues in the operating environment, at domestic and European levels, and provides technical services for the benefit of members
Expression of interest (EoI)	An invitation to express an interest in providing services or products
Harmonic currents	When a linear electrical load is connected to the system, it draws a sinusoidal current at the same frequency as the voltage (though usually not in phase with the voltage). Current harmonics are caused by non-linear loads

Heat pump (HP)	An electric device that absorbs heat from its surroundings which can be used to heat radiators, underfloor heating systems and hot water
High voltage (HV)	Voltages over 1kV up to, but not including, 22kV
IET	The Institution of Engineering and Technology
Innovation Funding Incentive (IFI)	Scheme established under previous price control settlements. IFI encouraged licensees to invest in appropriate research and development activities designed to enhance the technical development of networks and to deliver value (ie financial, supply quality, environmental, safety) to end customers
Low Carbon Networks Fund (LCN Fund)	Funding to encourage the DNOs to innovate to deliver the networks we will need for a low carbon economy
Low carbon technology (LCT)	A type of technology which operates with substantially fewer carbon emissions than traditional equivalent
Low voltage (LV)	This refers to voltages of 1kV and below
Reinforcement	Network development to relieve an existing network constraint or facilitate new load growth
Retrofit cooling	Techniques that can be applied to existing assets to reduce operating temperature
RfI	Request for information
RfP	Request for proposal
RIIO-ED1	Electricity Distribution Price Control that will run from 2015 to 2023
RIIO-ED2	Electricity Distribution Price Control that will run from 2023 to 2031
Secondary network	Assets including cables, transformers and switchgear that carry electricity from the higher voltage network equipment and distribute it to homes and properties at 240v
Smart meter	Next generation electricity meters offering a range of intelligent functions
Substation	A point on the network where voltage transformation occurs
Switchgear	Device for opening and closing electrical circuits
Technology readiness level (TRL)	Method of assessing and defining maturity of technology
Thermal coefficients	The constant which the external temperature needs to be multiplied by to ascertain the hotspot temperature
Thermal constraints	The restriction of an electrical asset's capacity due to the operating temperature

Thermal headroom	The amount of capacity available for use
Thermal Ratings Tool	Software/Microsoft Excel-based solution which will calculate the available capacity at a site based on inputs of temperature, substation environment and asset type
Transformer	Device that changes the network voltage without changing the frequency
WEET	Westminster Energy, Environment & Transport

Appendix K: Full Submission Spreadsheet

List of changes

This section documents the changes from the original Celsius Full Submission version ENWEN 01, submitted on 29 July 2015, to this version, ENWEN 01/02, submitted on 27 October 2015. The table below details each change and the reason for the change.

All additions to the Celsius Full Submission and Appendices documents are easily identifiable as they are coloured red.

Location	Change	Reason	Generated
Section 1.5.1	NIC funding request amended to reflect additional SDRC commitments and improved BAU/rollout activities	Improved learning and dissemination	Expert Panel
Section 1.5.2,	Network licensee compulsory contribution increased in line with above	Improved learning and dissemination	Expert Panel
Section 1.5.4,	External funding increased	Improved learning and dissemination	Expert Panel
Section 1.5.5,	Total project costs increased in line with above	Improved learning and dissemination	Expert Panel
Section 2.1, page 3	Amended Figure 2.1 title to include 'illustrative'	Clarification	Q&A question 1
Section 2.1, page 6	Confirm additional business as usual preparation activities through proposing changes to Engineering Recommendations P 15 and P 17	Improved learning and dissemination	Expert Panel
Section 2.2, page 7	Confirm DNO collaboration on selection of retrofit cooling	Improved learning and dissemination	Expert Panel
Section 2.2, page 8	Confirm change proposals for ER P15 and ER P17	Improved learning and dissemination	Expert Panel
Section 2.3, page 10	Confirm DNO collaboration on selection of retrofit cooling	Improved learning and dissemination	Expert Panel
Section 2.4, page 10	Changes to ISP: updated Celsius cost and contribution values	Improved learning and dissemination	Expert Panel
Section 4a and Figure 4.1, page 17	Confirm time to release capacity through retrofit thermal monitoring	Clarification	Expert Panel
Section 4 (b), page 21	Updated Figure 4.4 to show small increase to no. of days for ENWL and Ricardo-AEA related to improved BAU/rollout activities.	Improved learning and dissemination	Expert Panel
Section 4 (b), page 21 - 22	Justification of the value of incentive penalty protection	Clarification	Q&A question 32

Location	Change	Reason	Generated
Section 4 (b), page 21 - 25	Updated values, pie charts and graphs showing revised cost and contribution figures	Improved learning and dissemination	Expert Panel
Section 4 (b), page 25	Inclusion of change proposals to Engineering Recommendations	Improved learning and dissemination	Expert Panel
Section 5, Figure 5.1, page 30	Add Engineering Recommendation change proposal process and identify the project partners responsible	Improved learning and dissemination	Expert Panel
Section 5, Figure 5.2, page 31	Include one-to-one stakeholder sessions	Improved learning and dissemination	Expert Panel
Section 5, Figure 5.3, page 32	Dissemination programme amended to incorporate new SDRCs and tie Celsius outputs to knowledge sharing events	Improved learning and dissemination	Expert Panel
Section 6, Figure 6.2, page 35	Updated with new activities and SDRC amendments	Improved learning and dissemination	Expert Panel
Section 6, Figure 6.2, page 36	Closedown description includes new Engineering Recommendation change proposal commitments	Improved learning and dissemination	Expert Panel
Section 8, page 41	Sentence added to direct reader to justification for the incentive penalty protection value	Clarification	Q&A question 32
Section 9, page 42	SDRC, TW.2 amended to include voting by DNOs on cooling technologies and additional evidence TW.2.2	Improved learning and dissemination	Expert Panel
Section 9, page 43	Changes to trials and analysis workstream SDRC TAW.5 to include Carbon Impact Assessment and additional SDRC TAW.6 for Asset Health Study	Improved learning and dissemination	Expert Panel
Section 9, page 44	Changes to learning and dissemination workstream SDRCs. Includes additional date in LDW.2 and changes to knowledge sharing events including one-to-one sessions	Improved learning and dissemination	Expert Panel
Section 9, page 44	Evidence for Cl.2 expanded to include training of planners and operational engineers	Improved learning and dissemination	Expert Panel
Section 9, page 44 & 45	New SDRC, Cl.3 for activities to enable change proposals to two engineering proposals to support rollout and four new evidence requirements for this additional SDRC	Improved learning and dissemination	Expert Panel
Appendix A.2, Figure A.2.1, page 53	Confirm time to release capacity through retrofit thermal monitoring	Clarification	Expert Panel

Location	Change	Reason	Generated
Appendix B1, B.1.2: Processes and specifications for business as usual, page 56	Add Engineering Recommendation change proposals to outputs of Celsius	Improved learning and dissemination	Expert Panel
Appendix B1, B.1.4: Retrofit cooling, page 58	Confirm DNO collaboration on selection of retrofit cooling	Improved learning and dissemination	Expert Panel
Appendix B1, B.1.6, BAU, page 59	Confirm change proposals to ENFG of ER P15 and ER P17 as an output of Celsius	Improved learning and dissemination	Expert Panel
Appendix B2, B.2.3, Technology selection, page 63	Confirm timing of cooling technology selection	Clarification	N/a
Appendix B3, B.3.2, Retrofit cooling, page 65	Amended text to reflect that cooling interventions to be trialled will be selected at a DNO workshop. A minimum of five of each of the selected types will be trialled. The total number of sites will be 100	Clarification	Expert Panel
Appendix D, page 68	Additional Network Innovation Allowance project, Distribution Asset Thermal Modelling included	Clarification	Technical Consultants
Appendix E, organogram, page 77	Amended to include additional commitments to submit change proposal for Engineering Recommendations to ENFG	Improved learning and dissemination	Expert Panel
Appendix F, Project Plan, page 78 – 80	New SDRCs added	Improved learning and dissemination	Expert Panel
Appendix H, Project partner and supplier details, page 82	Increased funding provided from Ricardo and outline of additional responsibilities for Engineering Recommendation change proposals	Improved learning and dissemination	Expert Panel
Appendix K, Full submission spreadsheet, page 93	Amended to include additional activities for Engineering Recommendation change proposals and amended Net Benefits tab	Clarification	Expert Panel