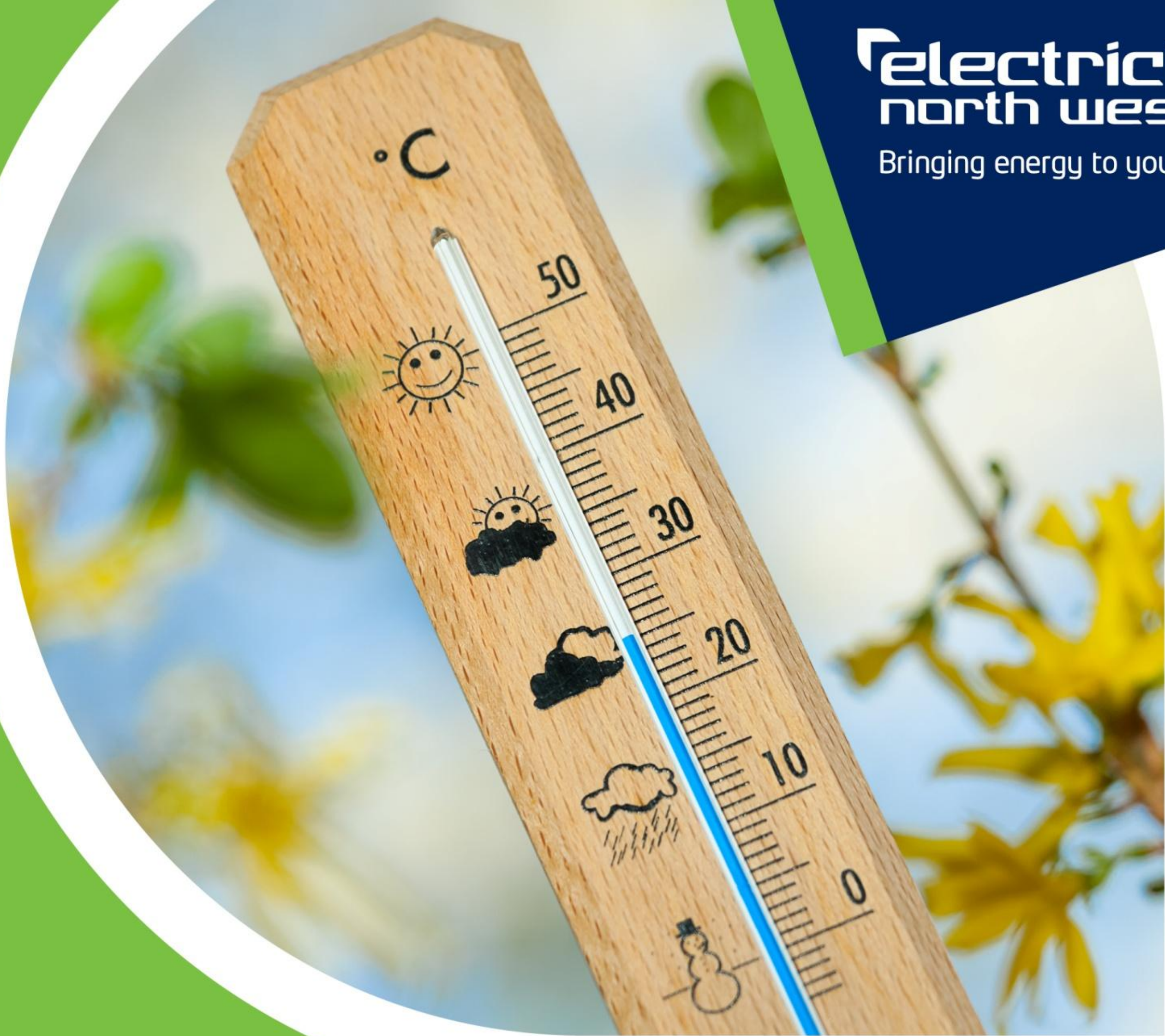

electricity north west
Bringing energy to your door

Celsius

Project Closedown Report

31 March 2020

Version	Date	Author	Status	Comments
V0.1	6 January 2020	Delroy Ainsworth	Draft	First draft
V0.2	31 January 2020	Delroy Ainsworth	Draft	Second draft
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REVIEW

Name	Role	Date
Dan Randles	Head of Network Innovation	31 March 2020

APPROVAL

Name	Role	Date
Steve Cox	Engineering and Technical Director	31 March 2020

CONTENTS

GLOSSARY OF TERMS

Term	Description
Active cooling	Cooling provided by actively controlled means e.g. fans
Ambient temperature	Temperature of the air surrounding a component
BAU	Business as usual
Cable	An underground conductor used to distribute electrical power, installed directly in the ground or in ducts or troughs
Capacity	The maximum amount of power that can be delivered by an asset
CBA	Cost benefit analysis
CCC	Electricity North West's customer contact centre
CNAIM	Common Network Asset Indices Methodology
Current	The flow of electricity through a conductor, measured in amperes (amps)
Demand	The amount of electrical energy that is being consumed at any given time
Distribution substation	A substation which usually contains high voltage (HV) switchgear, an HV/low voltage (LV) transformer, LV switchgear and short length of LV cable(s) and can be either pole- or ground-mounted
DNO	Distribution network operator
ENA	Energy Networks Association
GB	Great Britain
GRP	Glass reinforced plastic
High voltage (HV)	Voltages over 1kV
Hotspot temperature	The peak temperature reached at a position within a transformer winding which determines the maximum load the transformer can carry
LCNF	Low Carbon Networks Fund
LCNI conference	Low Carbon Networks & Innovation conference
LCT	Low carbon technology
MDI	Maximum Demand Indicator
NIC	Network Innovation Competition

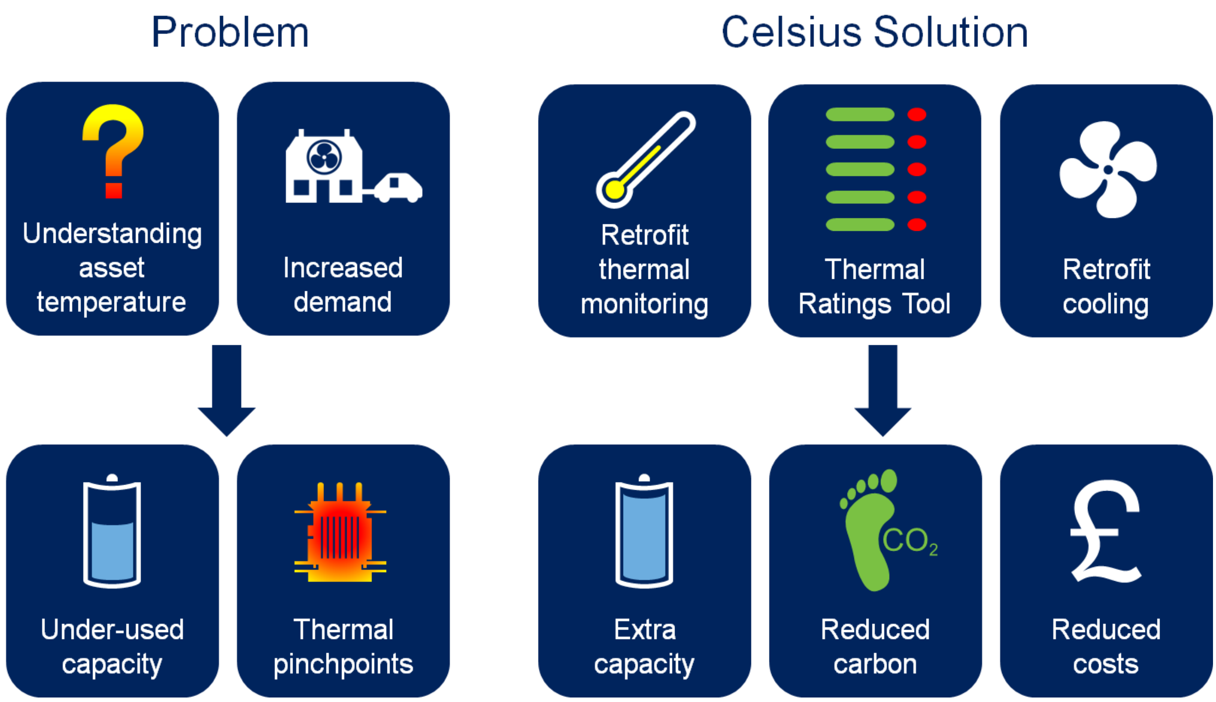
Term	Description
Passive cooling	Cooling provided by non-controlled means e.g. reflective paint, shading from sunlight
PPR	Project progress report
SDRC	Successful delivery reward criteria
Thermal coefficient	A derived constant by which the asset surface temperature needs to be multiplied to ascertain the hotspot temperature
Thermal constraint	The restriction of an electrical asset's capacity owing to that asset's operating temperature
Thermal headroom	The amount of thermal capacity available for use
Thermal Ratings Tool	Software/Microsoft Excel-based solution to calculate the available capacity at a site, based on inputs of temperature, substation environment and asset type

1 PROJECT BACKGROUND

Celsius is funded via Ofgem's Network Innovation Competition (NIC) funding mechanism. The project was authorised to commence in December 2015 and completed in March 2020.

Celsius explored innovative, cost-effective approaches to managing potentially excessive temperatures at distribution substations. Without management, asset temperature reduces network capacity and constrains the connection of low carbon technologies (LCTs).

Figure 1: Problem and solution illustration



Celsius identified potential thermal issues by establishing how different distribution substations behave thermally under a variety of operating and environmental conditions. Celsius has produced a more informed and accurate rating which better reflects the true thermal rating of distribution substation assets, and thereby unlocks capacity, using:

- **Retrofit thermal monitoring**: by measuring asset and ambient temperatures, and relating these to a range of environmental, load and seasonal factors, Celsius has enabled an understanding of the true thermal rating of these assets, which can be used in place of the traditional nameplate rating. This has provided an improved understanding of the capacity which could be accessed without further intervention.

- **Thermal Ratings Tool**: learning obtained from the retrofit thermal monitoring trials and subsequent analysis of the data was transferred into an accessible tool that can be used by all distribution network operators (DNOs) to better understand the capacity of both the existing and planned network.

In addition, Celsius identified, evaluated and demonstrated a range of retrofit cooling technologies that can be used to directly control the temperature of assets. By managing temperature in this way, Celsius successfully unlocked additional network capacity.

Surveys were used to establish customer perception of retrofit cooling technologies and compared their application with traditional alternatives such as reinforcement.

2 SCOPE AND OBJECTIVES

Celsius measures the temperature in distribution substations to identify where management is required. This reveals assets which are capable of an increase in thermal capacity, and thereby enables the more efficient adoption of LCTs by customers.

2.1 The problem

The UK government has committed to a target of achieving net-zero carbon emissions by 2050. At the start of the project DECC forecasts were predicting an increase of up to 60% in total electricity demand by this date. To meet this decarbonisation target, our customers are being encouraged to adopt eco-friendly lifestyles which is leading to an increase in the uptake of LCTs such as electric vehicles (EVs) and heat pumps (HPs), which is putting pressure on our network.

In addition, the government has recently brought forward their ban on the sale of petrol, diesel and hybrid vehicles by five years, to 2035, citing the urgency to cut carbon emissions further to reach their target. It is therefore anticipated that the increase in demand will be much higher and will occur much sooner than previously believed.

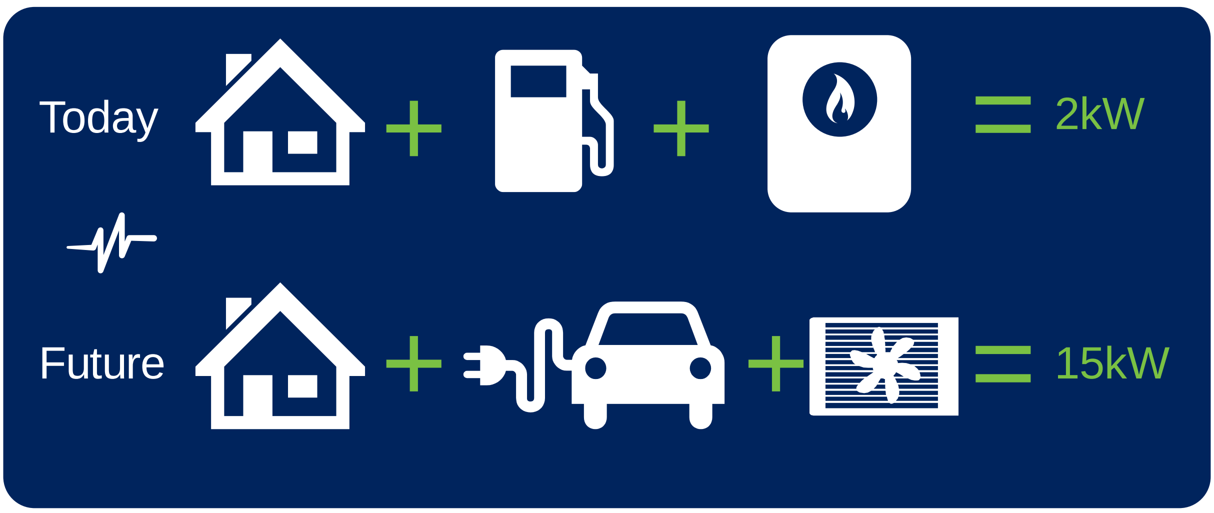
In low numbers, new LCTs can be accommodated on the existing network. However, the anticipated clusters of EV or HP connections will create voltage, harmonic and thermal issues.

Figure 2 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 of less than 2kW per customer.

Changing the gas heating to an electric alternative such as an HP would add 6kW per property alone. A new EV would add further load of 3.5-7kW. In addition to the impact associated with the size of these new loads, the duration of the load will also change significantly. EVs and HPs draw energy for much longer than standard domestic appliances such as kettles and electric showers, placing additional pressure on local networks.

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

Figure 2: Scale of the challenge (illustrative)



2.1.1 Thermal constraints

An increase in load means an increase in the current flowing on the network. The greater the 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.

2.1.2 Environment/location impact on asset temperature

Many factors can affect this profile, such as wind cooling, shade and sun glare (for outdoor sites); and building type, ventilation arrangements and substation layout (for indoor sites). These factors can significantly affect internal operating temperature.

To ensure that networks are operated safely, electricity assets have a manufacturer-assigned capacity rating, expressed in kVA, to indicate the maximum amount of energy they can carry. These static 'nameplate' ratings are a proxy for the maximum operating temperature that assets are designed for (the design temperature of a distribution transformer is based on a 20°C ambient).

However, 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 the nameplate rating, the traditional approach is to replace the asset with new, higher capacity equipment. This entails significant capital investment which customers pay for through their electricity bills.

2.2 The Celsius method

Celsius maximises the use of existing assets, which is central to Electricity North West's innovation strategy, by improving the understanding of the thermal behaviour of distribution substations. With greater knowledge of the behaviour of these assets, DNOs can support the connection of LCTs more quickly and at lower cost. This revolutionary method developed and demonstrated a two-step intervention approach.

Firstly, by using load monitoring and improved technology to measure temperatures, Celsius gathered data from a sample of 520 substations in a range of environmental, load and seasonal conditions. This sample was selected to be representative of 80% of the GB substation population.

The data gathered was analysed to:

- Explore the relationship between asset temperature, load characteristics and the surrounding environment,
- Establish a methodology to estimate hotspot temperature from measured external temperatures,
- Reveal latent capacity which can be released quickly with no further intervention.

Secondly, by releasing additional capacity through a range of retrofit cooling technologies, Celsius explored a range of technologies to increase capacity and demonstrated the benefits of each. The technologies were applied on 100 of the monitored distribution substations. This resulted in a 'buy order' of cooling interventions from which DNOs can choose.

2.3 The solution

Celsius developed an understanding of the operating temperatures of distribution transformers and cables, within a range of substation environments. The project also delivered alternative, innovative ways to optimise thermal capacity, leading to faster, cheaper connection of LCTs.

Celsius can save **£395 million** across GB **by 2050** through deferment of reinforcement and will enable DNOs to respond more quickly to potential constraints arising from the connection of clusters of LCTs.

Celsius has delivered:

- An enhanced understanding of asset temperature and its relationship with load and environmental factors,

- Recommendations and tools for the implementation of Celsius solutions to business as usual (BAU) activities. These include:

    - A functional specification for a reliable, low cost monitoring sensor pack for distribution cables and transformers,
    - A Thermal Ratings Tool to calculate the capacity of an asset, based on measured temperatures,
    - A range of retrofit cooling technologies to apply when the Thermal Ratings Tool indicates an intervention is required,
    - Studies to prove that the retrofit cooling technologies are acceptable to customers.

3 SUCCESS CRITERIA

The project success criteria have been categorised into the relevant workstreams as shown in the table below. Evidence for each of these criteria can be found in Appendix A.

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 highest scoring technologies, circulate workshop outcomes to DNOs and publish on the Celsius website by July 2017
TW.3	Publish cooling technology specifications and installation reports by November 2018

Criteria	Customer workstream
CW.1	Develop customer engagement plan and data privacy statement

Criteria	Customer workstream
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 technologies on the Celsius website by September 2019
CW.3.2	Publish additional customer survey analysis evaluating the change, if any, on the acceptability of innovative retrofit cooling technologies 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

Criteria	Trials and analysis workstream
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 technologies 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 121 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)

Criteria	Closedown and business as usual
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
Cl.3.1	ENA workshop with DNOs held by November 2016 (to agree areas of changes to Engineering Recommendations P15 and P17)
Cl.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
Cl.3.3	Incorporate relevant Celsius outputs into change proposal options for ER P15 and ER P17 and hold workshop with DNOs by January 2020
Cl.3.4	Submit proposals for changing ER P15 and ER P17 to ENFG by March 2020

4 EXECUTIVE SUMMARY

The Celsius project successfully delivered an improved understanding of the thermal performance of distribution assets. It identified that nameplate ratings do not reflect the true capacity of an asset and that existing, unused capacity could be made available. It also developed a highly innovative, cost-effective method of releasing this capacity.

The method is highly transferable to other DNOs and so the release of this latent capacity can benefit the whole of GB's electricity distribution network. It will contribute towards preventing or deferring the need for traditional reinforcement, which will be of huge benefit both financially for customers and for effective resource management by DNOs.

Celsius tested the following hypotheses (in the identified workstreams):

- 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),**
- Low cost sensors, attached to the exterior of an electrical asset, can be used to reliably establish internal operating temperature and enable a Thermal Ratings Tool **(trials and analysis workstream),**
- Capacity can be released quickly and at low cost by understanding the thermal performance of the distribution substation **(trials and analysis workstream),**
- Further capacity gains can be achieved through low cost, retrofit cooling technologies **(trials and analysis workstream),**
- Celsius does not have a detrimental impact on asset health **(trials and analysis workstream),**

- Customers within the Celsius trial areas will find the implementation of innovative retrofit cooling technologies as acceptable as traditional reinforcement **(customer workstream),**

- Customers who are educated on the need for and benefits of Celsius are significantly more likely to find it acceptable **(customer workstream)**.

4.1 Project outcomes

- The data gathered during the project provided a greater understanding of the thermal performance of the distribution assets.

- In most cases, the Celsius rating is higher than the nameplate rating and can be increased further with the addition of retrofit cooling.

- Celsius technologies can release additional capacity, without the need for customer shutdowns, generators or roadworks, which all cause disturbance and inconvenience to customers.

- Celsius technologies can be applied faster and at lower cost than traditional methods, enabling deployment at times of rapid change in network demand.

- Celsius technologies provide a significant carbon impact saving when compared to traditional reinforcement.

- Celsius has provided valuable learning about distribution substations and the factors that affect the temperature of network assets. This learning can be applied to new build substations, which may reduce the need for future intervention.

- Data obtained by the Celsius monitoring equipment can be used throughout the business. For example, the ability to remotely view load readings and see load profiles will be useful for system planning, which would traditionally require site visits to fit and retrieve load monitoring equipment.

4.2 Successful objectives met

All the SDRC objectives were met for the project.

A full list of these objectives and all supporting evidence is detailed in Appendix A.

4.3 Objectives not met

None. All objectives for the project have been met.

4.4 Project learning

From the measurement and analysis carried out during the project, most ground-mounted distribution transformers have the potential to release latent capacity. This was achieved through the calculation of an enhanced rating informed by temperature monitoring data.

Owing to the method developed in this project, learning outcomes are applicable to transformers with a nameplate rating of 300kVA or above only – this represents the majority of the installed asset base. However, scope remains for further analysis which could broaden this method to transformers rated at less than 300kVA.

The thermal performance of pole-mounted transformers is highly influenced by ambient temperature and their load utilisation is lower than ground-mounted units. For these reasons the correlation between load and temperature is low and any unused capacity cannot be calculated using the Celsius method.

The measurement data captured using the Celsius method provides wider benefits to the network operator, e.g. by facilitating more informed decisions in less time than traditional methods.

Customer surveys showed that 89% of customers in the trial areas found the implementation of Celsius cooling technologies acceptable, whereas only 62% reported that they were likely to find traditional reinforcement acceptable. This proves the key customer hypothesis that: '*Customers in the Celsius trial areas will find the implementation of innovative retrofit cooling technologies as acceptable as traditional reinforcement*.'

Noise complaints associated with active cooling, specifically the positive pressure technology (Passcomm system), imply that while it delivers effective and efficient cooling results, it may not be the most appropriate solution for all substations. This is particularly of note where substations are very close to domestic dwellings and where fan settings are set to deliver optimum cooling.

Despite this, the project has shown that notable levels of cooling can be achieved from such systems, without customer impact, by reducing the fan settings.

Analysis of these complaints reveals that noise is significantly more likely to negatively impact customers than changes to the appearance of a substation or its equipment.

The key customer workstream learning is that customer sensitivity, particularly in relation to noise, should be assessed on a site-by-site basis, and used to determine the most appropriate cooling technology. Wherever possible, this should be by means of a comprehensive acoustic assessment, particularly where intervention is planned at sites close to domestic properties.

The learning obtained provides high confidence that Electricity North West can implement the Celsius method across its distribution region with no detriment to those customers living in proximity to the sites.

Crucially, the project demonstrated that Celsius can be deployed without supply interruptions, significantly reducing the cost of its deployment while avoiding disruption to customers.

Owing to similarities in the technical specification and installation methods for these assets across all DNOs, these findings support the transferability of the Celsius method and suggest that all GB DNOs can apply Celsius to their network without customer impact.

5 DETAILS OF THE WORK CARRIED OUT

5.1 Retrofit monitoring

To calculate the enhanced Celsius rating, the maximum operating (hotspot) temperature and the three-phase load need to be measured.

The most difficult measurement to obtain is the hotspot temperature, as it is normally at the centre of the asset, and is therefore impractical and costly to measure using retrofit means.

To overcome this, the Celsius project developed a method to calculate the hotspot from measured external temperatures and other known information. This methodology is detailed in the Secondary network asset temperature behaviour report.

To verify the methodology, Celsius retrofitted internal temperature sensors to 12 existing transformers and compared these measurements with those from five 'smart transformers', with inbuilt internal temperature monitoring, which were installed as part of a previous innovation project.

The external temperatures were measured using sensors which are quick and easy to install, without the need for customer shutdowns.

Load and temperature data was then monitored at 520 representative distribution substations for a minimum period of 12 months to ensure all seasonal variations were captured. Details of the monitoring equipment used on the project can be found in the Equipment specification and installation report.

The 520 sites were selected using the following criteria:

- **Substation type, asset type (age, manufacturer, etc.) and surrounding environment:** substations were categorised using these factors to represent the substation population.

- **Loading:** feasibility work, carried out by Ricardo Energy & Environment, showed 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% were selected.

- **Types of load:** a range of commercial/domestic/industrial, urban/dense and urban/rural loads.

- **Practical considerations:** sites were selected with the requirements of the trial in mind; for example, the monitoring equipment relied on mobile phone communication for data transfer. Therefore, sites with poor or no coverage were omitted.

5.2 Thermal flow study

A Thermal flow study was carried out by the National Physical Laboratory (NPL) to provide detailed analysis of the heat and air flows within a variety of distribution substations. This provided evidence on the optimal configuration for indoor substations, including the location of vents and louvres.

The study showed that the most effective ventilation is achieved when there are vents on all four sides of a substation building. There is also a benefit to having vents situated closer to the heat source (the transformer).

These results were used in the retrofit cooling element of the project to inform the placement of additional vents and will inform the design of new substations.

5.3 Retrofit cooling

The project identified a range of cooling technologies which were presented to stakeholders at the Celsius cooling technology workshop held on 31 May 2017.

At this workshop a review of the technologies took place and a selection were chosen using the following criteria:

- Safety,
- Purchase cost,
- Technology readiness level,
- Installation,
- Environmental impact,
- Operational,
- Maintenance,
- Energy use,
- Customer impact.

To be consistent and fair in the selection, the following scoring mechanism was used:

1. Unknown or does not meet requirements,
2. Meets requirements,
3. Exceeds requirements.

Figure 3 shows the results of this review and scoring exercise.

Figure 3: Cooling technology scoring

Asset	Solution	Safety	Purchase Cost	TRL	Installation	Operational	Energy use	Environmental	Maintenance	Customer impact	Total	Acceptable
PMT	Black Paint	2	3	3	2	3	3	2	2	2	**22**	YES
PMT	White Paint	2	3	3	2	3	3	2	2	2	**22**	YES
PMT	PMT shade	2	3	3	2	3	3	3	3	2	**24**	YES
GMT	Black Paint	2	3	3	3	3	3	2	2	3	**24**	YES
GMT	White Paint	2	3	3	3	3	3	2	2	2	**23**	YES
GMT	Shade	2	3	3	3	3	3	3	3	2	**25**	YES
GMT	PV shade	1	1	3	2	2	3	3	2	2	**19**	YES
GMT	Cooling Plates	2	2	2	2	2	2	2	2	3	**19**	YES
GMT	Phase change material	1	1	2	2	2	2	2	2	3	**17**	YES
GMT	Flexible water cooled tubes	2	2	2	2	2	2	2	2	3	**19**	YES
GMT	Forced ventilation	2	2	2	2	2	2	3	2	3	**20**	YES
GMT	Improved ventilation chimney	2	3	2	2	3	3	3	2	2	**22**	YES
GMT	Improved ventilation	2	3	3	3	3	3	3	2	3	**25**	YES
GMT	Internal oil pump	1	2	1	1	2	2	2	1	3	**15**	More detail required
GMT	External oil heat sink	1	2	2	1	2	2	1	1	2	**14**	More detail required
Cables	Backfill 1 type solution	2	3	3	3	3	3	3	3	3	**26**	YES
Cables	Backfill 2 type solution	2	3	2	3	3	3	2	3	3	**24**	YES

The retrofit monitoring installed at 100 ground-mounted sites (60 passive installations and 40 active installations) was:

Passive cooling

- Five outdoor transformers equipped with shades to reduce solar gain,
- Ten outdoor transformers painted with anti-solar paint to prevent solar gain,
- 20 glass reinforced plastic (GRP) constructed substations fitted with extra vents, of which ten also had roofs painted with anti-solar paint to prevent solar gain,
- 19 brick-built substations fitted with extra vents,
- Two non-standard brick-built substations fitted with extra passive cooling vents (these were generally buildings with unusual site characteristics, such as very high ceilings),
- Four substations were fitted with thermally improved backfill around the LV cables, under the LV distribution board (where cables were laid in proximity of each other).

Active cooling

- 20 positive pressure systems (Passcomm unit). This system works by forcing air into the substation to create a positive pressure. Hot air is expelled out of the substation via high level vents,
- 20 negative pressure systems (Ekkosense unit). This system works by creating a negative pressure around the transformer. Air is extracted directly above the transformer and forced outside the substation via an external exhaust vent.

As the assets are close to where our customers live and work, it is possible they were more likely to notice audible or visual changes. To understand this fully, Celsius carried out a programme of customer engagement and surveys which delivered learning on customer perception of electricity networks, Celsius and the acceptability of the cooling solutions compared to traditional solutions.

During the project, Passcomm re-developed their cooling unit to reduce the size by approximately 40%. This smaller unit is lighter and easier to install, has less impact on the substation and has the potential to be quieter and more efficient as it has less filtration. Lessons learned from this installation can be found in Section 10.3 of this report.

Full details of the cooling equipment used on the project can be found in the Equipment specification and site installation report.

5.4 Asset health study

Any change in operation of network assets may impact an asset's health and subsequently its 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, an Asset health study report was carried out by the University of Southampton (UoS). Any impact from Celsius on asset health is summarised in Section 6.7.

5.5 Carbon impact assessment

A Carbon impact assessment was carried out by Futurofirma to determine the carbon impact benefits of applying Celsius technologies instead of traditional reinforcement of distribution transformers. Details are provided in Section 6.8.

5.6 Business as usual

A BAU process has been developed with appropriate reference to existing Electricity North West asset management processes. The development of these processes maximises the benefits from Celsius while making only minor updates to existing processes to ease BAU adoption.

As part of the BAU process, a BAU monitoring equipment specification has been created.

More detail of the BAU implementation can be found in Sections 6.9 and 13 of this report.

5.7 Customer engagement and feedback

The project hypotheses related to this activity were:

- Customers within the Celsius trial area will find the implementation of innovative retrofit cooling technologies as acceptable as traditional reinforcement,
- Customers who are educated on the need for the benefits of Celsius are significantly more likely to find them acceptable.

Direct customer engagement took place in three main phases.

An engaged customer panel (ECP) comprising ten domestic customers identified what type of materials would be most effective in engaging customers about Celsius in the subsequent phases of research, and which key components of the Celsius method needed to be communicated.

A baseline survey was conducted with 600 domestic customers and representatives of small to medium enterprises (SMEs). These customers were recruited in the trial network areas and were interviewed before the retrofit cooling technologies were installed. This established a benchmark against which to compare the results of the main customer survey.

The main survey was carried out after Celsius technologies were installed to measure any change in perception. Before completing the survey, half of the baseline participants were educated about the benefits of Celsius compared with traditional reinforcement.

A trial survey was conducted with 600 domestic and SME customers following the installation of retrofit cooling technologies to test the customer research hypotheses. The approach was to re-survey 150 of the 300 ‘educated’ sample of respondents that had taken part in the baseline survey. The remaining 450 respondents were new to the engagement with no prior education or involvement in the Celsius project.

5.7.1 Communicating with customers in the trial area

Celsius customer engagement activities were designed to deliver a comprehensive assessment of any customer impacts associated with the installation of retrofit cooling technologies at distribution substations. The methodology was also designed to assess how customer impact varies by the technology applied, environmental factors and customer groups.

The customer groups below were identified as being directly or indirectly involved in the Celsius project. The following summarises how these customers were engaged:

Customers who participated in ECP focus groups

An ECP was convened in July 2017 to evaluate and inform refinements to materials required to educate survey participants about Celsius. Project partner, Impact Research, was responsible for the recruitment of participants and delivery of the focus group meetings.

The outcome of this phase of research was documented in the Customer focus groups lessons learned report, published on 21 December 2017. The following literature was informed by this phase of engagement:

- Celsius customer leaflet, published 31 October 2017,
- Celsius summary factsheet, published 8 December 2017,
- Celsius baseline survey instrument, published on 28 February 2018.

Electricity North West customer contact centre (CCC) agents were briefed to ensure that any enquiries generated by these activities were captured and handled appropriately.

Customers on the trial networks participating in the Celsius survey

The key customer hypothesis of Celsius was that customers in the trial areas, who live or work close to distribution substations, would find retrofit cooling technologies as acceptable as traditional reinforcement.

To test this hypothesis, a customer survey was carried out before and after the installation of retrofit cooling technologies, to elicit any changes in perception. Analysis of this customer feedback was analysed to establish any disruption and overall levels of acceptability for each type of technology.

To test the secondary hypothesis, two versions of the Celsius survey instrument were produced: one version included communication material to educate customers about Celsius; the other omitted these materials.

A representative sample of 600 customers on Celsius trial networks were recruited to participate in the baseline customer survey, before the installation of cooling technologies. This survey population was split equally among customers who received the additional education materials and those who did not.

An equivalent number of 'trial' surveys were conducted after the technology installation. This population comprised customers that took part in the original baseline survey, along with a sample of previously unengaged individuals. Impact Research were responsible for the recruitment of survey participants and administration of the survey.

Customers on the trial networks who would experience planned supply interruptions for the installation of the network equipment

Although it was originally expected that customers might experience planned supply interruptions during the installation of certain cooling technologies, ultimately all technologies were fitted without the need for outages.

A reference to the possibility of planned supply interruptions in the customer leaflet was therefore removed in a revised version of the leaflet distributed during the main trial survey.

Other customers on trial networks not participating in the ECP or survey

Customers on Celsius trial networks who were not actively involved in Celsius customer research were not made aware of the project through any form of targeted awareness campaign.

Other electricity customers

In recognition of the potential wider customer benefits of Celsius, technical and customer learning outcomes were disseminated in a manner easily accessible to all customers and stakeholders via the following methods:

- *The Celsius website:* provided a library of published materials and other resources relating to the project,
- *Social media:* social media channels including Twitter, LinkedIn and YouTube were used to promote learning from the project. Examples can be seen in Appendix B,
- *Knowledge-sharing with consumer groups:* learning and outcomes were shared with organisations that have a specific interest in consumer and energy issues, including Ofgem and the Energy Networks Association. Details of key activities and events are published on the Celsius learning and dissemination webpage,
- *Internal communications channels:* an overview of the Celsius project and research outcomes were shared periodically with the wider Electricity North West community via the internal company magazine, intranet and the Celsius website.

6 THE OUTCOMES OF THE PROJECT

6.1 Transformer hotspot estimation

A wide range of factors were considered as inputs to the methodology for estimating the hotspot. The final methodology is based on inputs that produced the most consistent result using measurements that were accessible and achievable.

The selected method used temperatures measured at two locations:

- Ambient temperature in the substation measured at high level (approximately head height) and away from sources of heat or ventilation,
- Transformer surface temperature at top oil level, measured on the surface of the tank (as opposed to any cooling fins or radiator pipes).

The method also considered the transformer specification (either British standard, used before the 1970s, or European standard used after 1970s).

The method is described by the following equations:

British standard specification

$$T_{hs} = 2.1967\ T_{top\ oil} - 1.0595\ T_{amb} - 11.16$$

European standard specification

$$T_{hs} = 1.6541\ T_{top\ oil} - 0.5306\ T_{amb} - 1.97$$

Where T_{hs} is the hotspot temperature, $T_{top\ oil}$ is the transformer surface temperature, and T_{amb} is the ambient temperature in the substation.

The method was derived using the data collected from a subset of the trial sites which had increased monitoring, including internal oil temperature monitoring and hotspot monitoring.

This data did not come from a fully representative set of sites. For logistical reasons outdoor substations, GRP substations and metal kiosk substations were not included in the hotspot methodology dataset, and most of the transformers included in the trial had a rating above 500kVA. Additionally, there were difficulties in retrieving data from the 'smart transformers', and much of the data was for very lightly loaded conditions. There is therefore scope for further work to update and validate the hotspot calculation methodology for all distribution transformer types.

6.2 Transformer temperature factors

The data from the retrofit monitoring trial was analysed to understand how the factors below influence the operating temperature of a transformer.

- *Building type:* where the transformer is installed. This impacts the surrounding environment and therefore the operating temperature. The trial included these building types:
    - Outdoor (fenced enclosure),
    - Stone or brick building (stand-alone, purpose-built),
    - GRP enclosure,
    - Part of a larger building,
    - Metal kiosk,
- *Weather conditions:* impact the operating temperature of the transformer and are particularly dominant at times of low loading and in outdoor sites. Weather data from the Met Office was used which included temperature, wind speed and precipitation,
- *Harmonics and phase imbalance*: harmonics were recorded as total harmonic distortion and normalised by the apparent power. Phase unbalance was represented by the current flowing in the neutral of the LV busbars. Each of these were measured by the monitoring equipment,
- *Transformer age and specification*: the specification of the transformer is divided into two categories; British standard (used before the 1970s) and European standard (used after 1970s, with some overlap in use with British standard transformers),
- *Other site factors*: such as ventilation, layout and location.

The analysis found that although factors such as weather, ambient temperature and building type impact the overall operating temperature, the relationships are complex, and cannot be used to accurately derive the operating temperature. The correlation is not strong enough to build a model without using measured data.

6.3 Pole-mounted transformer temperature factors

The monitoring trial included 34 pole-mounted transformers. It was not possible to calculate the hotspot temperatures of these assets, as there were no examples of internal measurements available to build the model. The data was therefore analysed to understand the contributing factors for the surface temperature of the transformers.

The key findings included:

- The most dominant factor influencing the temperature of the transformer was ambient temperature. This is to be expected, as the transformers are exposed to the outdoor environment,
- The load had a significant impact, as most pole-mounted transformers are lightly loaded with average utilisations below 30%,
- Other factors, including precipitation, wind speed, residual current and weighted harmonic distortion, had very little impact on transformer surface temperature.

6.4 Cable temperature factors

The monitoring trial included monitoring the surface temperature of cables at 22 sites, totalling approximately 100 cables. These included cables in open air, ducts and buried in sand.

Data collected included loading, surface temperature of the cables, ambient temperatures in the cable environment and information about cable arrangements.

Analysis of this data found that the surface temperature of the cables was generally driven by the ambient temperature of the cable environment. Most of the cables monitored were lightly loaded, generally below 50% utilisation. Where cables were more heavily loaded, the surface temperature increased.

6.5 More informed transformer rating

The project determined a ‘more informed’ or Celsius rating for a transformer using two temperature measurements and three-phase power.

To determine the Celsius rating, the hotspot temperature was estimated as per the methodology summarised in Section 6.1. Transformer load and measured ambient temperature were used to build a model to estimate the load at which a transformer will reach its maximum design operating temperature for a given ambient temperature.

Taking the ambient temperature into account when determining this relationship produced more consistent results. Furthermore, it did not require any additional measurements as the ambient temperature was used to determine the hotspot temperature.

This approach was applied across the trial sites and it was found that most transformers have more capacity than their nameplate rating suggest, i.e. their Celsius rating was higher than the nameplate rating. However, there is significant variation from site to site.

Generally, the Celsius ratings were between 90% and 175% of the nameplate rating.

One site was determined to have a Celsius rating of approximately 71% of the nameplate rating. A GRP site, this is unusual because it operates at particularly high temperatures for its loading; it is located on an industrial/commercial site with a constant weekday load and a short overnight dip. The maximum estimated hotspot temperature is approximately 95°C, corresponding to a loading cycle which regularly reaches approximately 71%. Therefore, according to the Celsius rating, this site is loaded at the rated capacity.

There are nine sites for which the Celsius rating was considered unusually high, at > 175% of the nameplate rating, including some sites which were several times the nameplate rating. A key trend was identified, as six out of these nine sites were small, with ratings of 200kVA or below. These smaller transformers made up a relatively small proportion of the trial, and the hotspot estimation methodology did not include any transformers of this size. Therefore, these transformers were removed from the analysis.

Figure 4 shows the spread of Celsius ratings across a sample of the trial sites. The Celsius ratings are shown as 'per unit' (pu) measurements, to enable comparison.

Figure 4: Spread of Celsius ratings

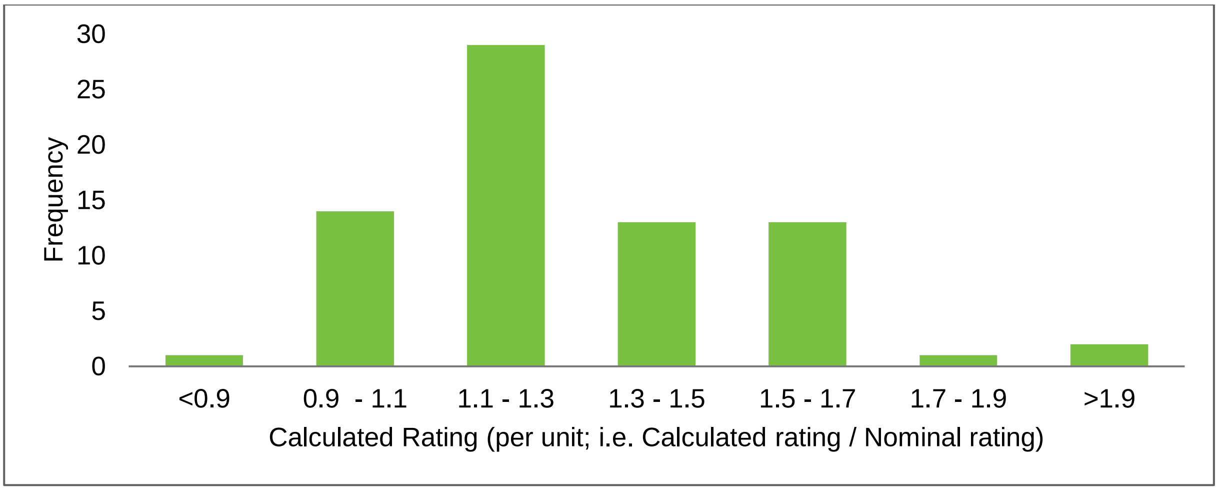


Figure 5 shows the Celsius rating by building type and demonstrates that outdoor (fenced enclosure) sites are more likely to have higher Celsius ratings than those indoors, which is expected as they can be effectively cooled by the weather.

Note that the resulting spread of sites between substation type, as indicated by the final column in the table below, is uneven, with relatively few GRP substations included.

Figure 5: Celsius ratings of site by building type

Building type	Average calculated rating (per unit)	Number of sites
Fenced enclosure	1.58	10
Glass reinforced plastic	1.07	4
Part of larger building	1.17	7
Stone/brick	1.28	52

Following consultation with the University of Southampton, it was decided that the Celsius rating should be capped at 50% above the nameplate rating to provide a measure of safety against significant overloading of transformers. This will remain until confidence grows through use of the Celsius ratings.

6.6 Retrofit cooling technologies

The retrofit cooling trial analysis compared the Celsius rating of a transformer before and after the installation of the cooling technology. The results of the trial are summarised in the table below.

Figure 6: Retrofit cooling technologies trial results

Technology	Findings
Improvements to natural ventilation for indoor substations	Improved natural ventilation was trialled in GRP substations, stand-alone brick substations and substations that were part of a larger building. In some cases, significant capacity can be released, of 11% or more of nameplate rating. However, in other cases, little or no improvement is found. It is recommended that this technology is only used where existing arrangements are inadequate. Further work is needed to understand how current ventilation performance can be assessed.
Active ventilation (i.e. fans) for indoor substations	Two types of active cooling technology were used: • a fan installed at a lower vent to draw in cool air (provided by Passcomm), • a fan and ducting over the transformer at a high-level vent to extract warm air (provided by Ekkosense). Both technologies showed a potential increase in the transformer Celsius rating. The most consistent, and with the highest improvement in rating, was the Passcomm system. This released approximately 14% of the nameplate rating on average, and in some cases increased the rating by more than 30% of nameplate rating. The Ekkosense technology is less consistent, sometimes providing over 20% additional capacity. However, many sites showed little or no improvement.
Protection from solar radiation for outdoor transformers	Two technologies were trialled with the aim of protecting outdoor transformers from solar heating: • white paint to reflect the solar radiation, • shades. This provided mixed results, with little consistent evidence of an improvement due to the change being made to the site.
Cable backfill	Showed some improvement of the heat transfer away from the cable; however, these results varied significantly between cables and a cable rating method could not be developed. Therefore, no improved rating could be established.

6.7 Asset health study

The primary thermal-related degradation mechanisms in transformers are the depolymerisation of the paper insulation and the evolution of gases from the insulating oil. Given that the oil could be replaced if required, the primary concern from an asset health/life perspective is the irreversible degradation of the paper winding insulation. There are three primary degradation pathways for the winding insulation (oxidative, hydrolytic and pyrolytic). The rate of all three mechanisms is increased at higher temperatures.

Electricity North West transformers are purchased with a 40-year notional life if operated at the nameplate rating. This assumes a winding hotspot temperature of no more than 98°C under continuous loading, and 105°C under normal cyclic loading conditions.

From the Asset health study carried out by the University of Southampton the following conclusions are drawn regarding the impact of Celsius on distribution transformers.

- Although the use of Celsius to deliver higher ratings on specific assets is likely to lead to an increase in the operating temperatures of these assets, remaining within the design thermal limits should ensure that the rate of thermal degradation does not shorten the life of the transformer to less than 40 years,
- When Celsius is deployed using physical temperature monitoring, ratings are determined based on the measured thermal parameters. The performance of the hotspot equations appears to be sufficient that there is little risk of design temperature limits being exceeded to an extent which would shorten the operational life of the transformer. As such, the asset health impact should also be small,
- Where the Celsius daily rating methodology is used to rate a transformer without the use of asset specific measurement data, it will be necessary to accept a greater operational risk,
- Changing the loading regime of an aged transformer will always carry some risk, especially if the load becomes more cyclic in nature.

6.8 Carbon impact assessment

The Celsius carbon impact assessment shows that, relative to traditional approaches, the Celsius monitoring and active retrofit cooling technologies, i.e. Passcomm and Ekkosense systems, provide opportunities for significantly reducing the life-cycle carbon emissions associated with demand-related thermal increases at distribution substations.

Where the monitoring alone identifies additional transformer capacity, this could realise savings of 3,934 kg CO_2e relative to traditional reinforcement (transformer replacement).

Each installation of the Passcomm or Ekkosense retrofit cooling solution (plus the Celsius monitoring equipment), has the potential to reduce carbon emissions by 3,863 kg CO_2e and 3,830 kg CO_2e respectively when compared with transformer replacement.

If rolled out across Electricity North West's area, Celsius has the potential to save 348,802 kg CO_2e per year; and if rolled out across GB, 4,513,905 kg CO_2e can be saved per year.

Full details can be found in the Carbon impact assessment report.

6.9 Business as usual implementation

The Celsius project was designed so that the learning developed could be translated into BAU operation within Electricity North West and other GB DNOs, to increase the capacity available within the LV distribution networks.

This is particularly beneficial as the demand on networks is expected to increase with the uptake of low carbon transport and heat technologies, thus additional capacity will facilitate a greater amount of load before network reinforcement is required.

To support this transition, the project investigated potential applications of the Celsius learning and how this could be integrated into existing processes. More detail on the BAU implementation can be found in Section 13 of this report.

6.10 Customer

The outputs of the trial survey were compared with the baseline results. The findings are summarised below and are fully documented in the Celsius customer survey report.

The trial customer survey was specifically designed to draw attention to the cooling technology deployed at the substation nearest to each respondent, to quantify the acceptability of each. These results were assessed against the outputs of the baseline survey, administered before the installation of retrofit cooling technologies, to provide a comparative measure.

The key hypothesis was proven: in the trial survey, 89% of all respondents found the retrofit cooling technology installed at their nearest substation acceptable, while only 62% found the described concept of traditional reinforcement acceptable. This demonstrates that customers are significantly more accepting of Celsius retrofit cooling technologies than traditional reinforcement.

A key finding associated with this research was that a surprisingly low proportion of customers (15%) noticed a change to their nearby substation during the technical trials. This suggests that most Celsius technologies had little or no customer impact. Unsurprisingly, domestic customers nearest to substations were the most likely to notice any change.

The analysis used a 1-10 point rating scale and the results report used ‘top 3 box’ percentages (T3B), i.e. a score of 8, 9 or 10 out of 10. This follows standard reporting practices.

Of the 15% of customers who noticed a change to a Celsius substation in the trial survey, 79% of this number gave a T3B score, indicating that they are accepting of the technology. There were differences between customers living/working near active and passive substation sites: only 68% of customers near an active site gave a T3B score compared with 86% of customers near a passive site. Figure 7 represents the T3B scores for each technology.

Figure 7: Acceptability of changes noticed by intervention type

Intervention technology	% T3B
Active intervention technology (net)	68%
• Cooling fan (positive pressure) Passcomm	72%
• Cooling fan (negative pressure) Ekkosense	63%
Passive intervention technology (net)	86%
• Vents and painted roof	83%
• Paint	86%
• Shading	100%
• Vents	86%

The secondary hypothesis was disproven: the level of education given did not significantly impact acceptability of Celsius. The analysis revealed that 89% of 'educated' customers found Celsius acceptable compared with 90% of 'non-educated' customers. However, only 62% of 'non-educated' respondents gave a score of 'completely acceptable' compared to 79% of 'educated' respondents, indicating that the level of education influenced the strength of opinion.

The findings do not indicate why education had no effect, but it is possible that educating customers can sensitise them to potential negative effects, which counteract the wider benefits of deploying new technologies. It is also possible that it was difficult for customers to relate the long-term cost comparisons between traditional reinforcement and the Celsius solutions to benefits they felt were specifically relevant to them.

Monitoring the effects of the Celsius trial on customers in trial areas

At the outset of the project, a customer strategy was developed to capture and manage enquiries generated from any aspect of the project. The CCC was briefed and the customer workstream liaised closely with the technical workstream and the CCC across the life of the project, to ensure that any issues were captured and appropriately managed.

During the project, nine customer enquiries associated with Celsius were received and investigated. These enquiries were managed by the Celsius project team, and a timely and appropriate resolution was attained. These enquiries are summarised below. The background, investigation process and outcome of these cases were fully documented in bi-annual project progress reports. Figure 8 provides a signpost to this information and the respective report.

Figure 8: Celsius-related customer enquiries

Nature of enquiry/observation	Number	Detail of case/resolution
*The following **four** enquiries were raised by customers in close proximity to cooling interventions*		
Noise disturbance from positive pressure active cooling (Passcomm system) – original model*	3	1 in PPR 5 (June 2018) 2 in PPR 6 (Dec 2018)
Increase in noise associated with a positive pressure active cooling (Passcomm system) – re-designed model	1	PPR 8 (Dec 2019)
*The following **two** enquiries were raised by customers in response to either being approached to/or participation in the baseline survey, prior to technology installation*		
Concern relating to potential for audible or aesthetic impact from undefined cooling technologies	1	PPR 5 (June 2018)
Concern relating to potential supply interruptions or disturbance during installation	1	PPR 5 (June 2018)
*The following **three** enquiries were raised by customers in response to being approached to /or participation in the trial survey*		
Concern about the authenticity of trial survey	2	PPR 7 (June 2019)
Noise disturbance from positive pressure active cooling (Passcomm system)*	1	PPR 7 (June 2019)

Nature of enquiry/observation	Number	Detail of case/resolution
In addition to the above, the project team conducted investigations into notable observations of change reported in the trial survey.		
Initial increase in noise after the installation of a negative pressure active cooling technology (Ekkosense system), which ceased after a few weeks.	1	PPR 7 (June 2019)
An increase in noise and vibrations from a passive intervention site – found to be unrelated to Celsius	1	PPR 7 (June 2019)

** From the above, a total of five complaints related to noise disturbance. These cases were all associated with the positive pressure active cooling technology (Passcomm system). All reports of noise disturbance from cooling technologies resulted in dialogue with the customer, on-site investigations and in all but one case, modifications to fan settings. These cases were subject to ongoing assessment to ensure the effectiveness of the actions taken in providing a permanent resolution to the complaint.*

The survey also provides evidence that customers living close to substations where active cooling technologies have been trialled are less accepting of these technologies than those near to passive sites and, unsurprisingly, those in closest proximity to the substations are most likely to be impacted.

Key customer workstream learning outcome

While the transformers fitted with the positive pressure system have demonstrated the greatest reduction in temperature, noise complaints and customer feedback suggest that it may not always be appropriate at all substations. Consideration should be given to customer sensitivities, on a site-by-site basis, before deployment as a BAU solution.

The potential for customer impact can be mitigated by:

- Mounting active cooling systems internally; however, this may not be possible or appropriate at all sites,
- Appropriate use of acoustic foam to act as a baffle,
- Reduction of the fan speed. The project has demonstrated this reduces noise and negates customer disturbance but impacts the overall effectiveness and cooling performance of the system,
- Utilising different fan settings at different times, i.e. reducing fan speeds overnight when network demand is reduced and ambient noise is lower.

7 PERFORMANCE COMPARED TO THE ORIGINAL PROJECT AIMS, OBJECTIVES AND SDRC

All the original project aims, objectives and SDRC have been completed, and a full list of all the SDRC and supporting evidence can be found in Appendix A.

8 REQUIRED MODIFICATIONS TO THE PLANNED APPROACH DURING THE COURSE OF THE PROJECT

8.1 Thermal Ratings Tool

The Thermal Ratings Tool is an output of the Celsius project. It predicts the Celsius ratings for distribution transformers by using data or information about the asset and its environment.

After the first round of analysis the intention was to create three different methods for this tool which required different levels of information.

- *The simplified Celsius rating:* a basic way of estimating the daily rating from only nameplate rating. This should be used as a first estimate only,
- *The full Celsius rating:* considers more temperature factor variables, including transformer characteristics and environment, but no measurement data. It is closer to the full estimated rating but should not be used as the final estimate to make decisions,
- *The Celsius daily rating*: based on temperature and load data from site, is a more accurate predictor of ratings. It will vary from day to day, so should be calculated over several days to understand thermal behaviour over an extended period.

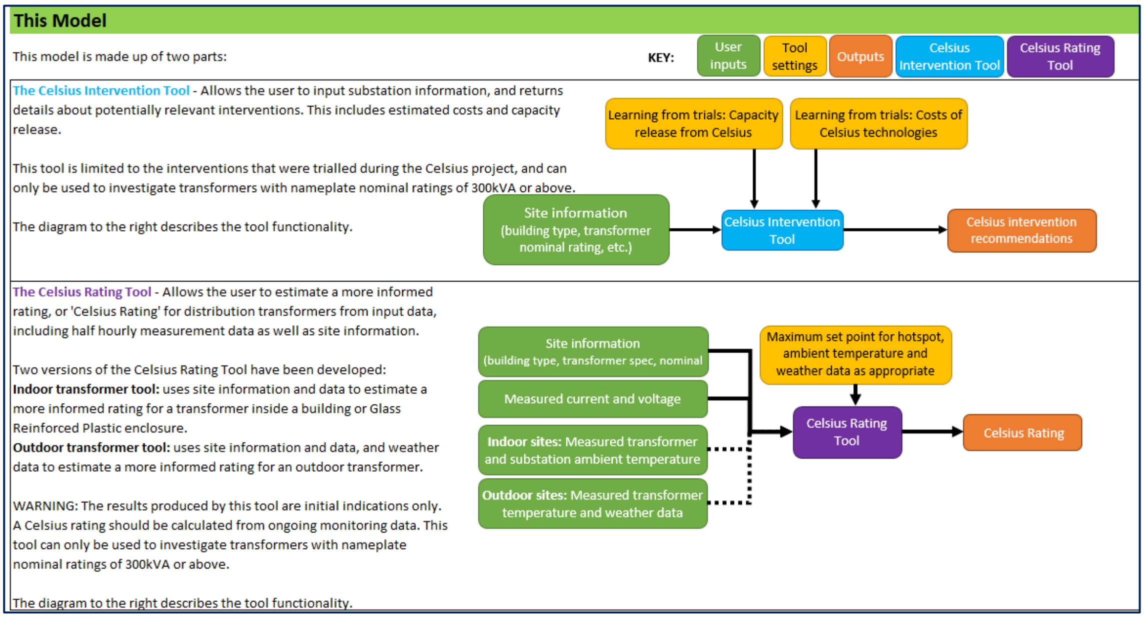
As the project progressed, it was discovered that sites with theoretically similar environmental conditions yielded varying results in practice because of differences in characteristics such as substation layout.

Therefore, applying a blanket thermal rating to similar site types was not possible and was removed as a potential output. Any applied rating must be obtained from measured data from each individual site. Therefore, the Thermal Ratings Tool evolved to provide the user with:

- *The Celsius intervention tool:* allows the user to input substation information and returns details about potentially relevant interventions,
- *The Celsius rating tool:* allows the user to determine a more informed 'Celsius rating' from input data, including half-hourly measurement data, in addition to site information.

Details of the Enhanced Thermal Ratings Tool functionality are illustrated in Figure 9 below.

Figure 9: Enhanced Thermal Ratings Tool screenshot



This revised approach provides several benefits over the original planned approach:

- Any substation with a Celsius rating applied will be constantly monitored which ensures the rating continues to be accurate as the demand and environment changes,
- Provides easily obtainable and useful load and temperature information to other areas of the business, i.e. for planning and operational purposes,
- Any monitored site will continue to provide learning about the thermal performance of distribution transformers and what factors contribute to this,
- Could potentially provide early warning of developing faults.

8.2 Cooling trial selection

Celsius measurements were taken at 520 distribution transformers (51 pole-mounted and 469 ground-mounted). The original plan is tabled in Figure 10 below:

Figure 10: Cooling selection trials

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

After the initial analysis of the data obtained from Trial 1, Trial 2 (retrofit cooling for pole-mounted transformers) was deemed to be impractical for the following reasons:

- The temperatures of pole-mounted transformers were found to be strongly influenced by weather/ambient temperature conditions and therefore the Celsius method could not be used without significant modification,
- As it was not possible to build up the estimation methodology, the hotspot temperature of a pole-mounted transformer is not as well understood as that of a ground-mounted transformer. It was therefore not possible to determine Celsius ratings for these transformers,
- The cost of replacing pole-mounted transformers is significantly lower than ground-mounted, so any potential cost savings from use of the Celsius method are lower than for ground-mounted transformers,
- Unlike ground-mounted transformers, the fitting of retrofit cooling to pole-mounted transformers would require planned customer interruptions and working at height. This significantly increases cost and customer disruption,
- Pole-mounted transformers are typically more rural and have fewer customers connected and are therefore less likely to be impacted by LCT clusters.

All 100 of the retrofit cooling sites were still completed successfully. In addition to the reasons listed above, not installing the retro-fit cooling technology on pole-mounted transformers provided the opportunity to install a higher number to ground-mounted transformers. This was beneficial to the project as ground-mounted transformers are more expensive to replace, and have more customers connected, meaning the benefits of the Celsius methodology are much greater.

8.3 ENA Engineering Recommendations (ER)

SDRC CI.3 relates to incorporating relevant Celsius outputs into change proposal options for ER P15 and ER P17.

The criteria included a workshop with DNOs, in which it was concluded that making changes to these Engineering Recommendations was not appropriate as the recommendations from the Celsius project are not currently in scope of the existing documents.

- Engineering Recommendation P15 is focused on overloading of transformers beyond rated temperatures, while the Celsius project is focused on maintaining the rated temperature.

- Engineering Recommendation P17 does not specifically cover cables at the voltages considered in this project, and Celsius has not produced recommendations focused on cables.

Therefore, Celsius will be disseminated to other DNOs via the ENA Transformer Assessment Panel (TAP) which is attended by transformer specialists from all GB DNOs. This group will be asked to consider if and how the recommendations from Celsius ought to be captured in national technical guidance.

8.4 Customer engagement and feedback

Methodology peer review

The overall survey methodology and proposed questionnaire were expected to have been peer reviewed by an external third party before the baseline research was launched. However, the project team struggled to re-engage the academic who agreed to conduct the critique at the outset of the project. Based on positive feedback from the ECP and a successful pilot, it was considered an acceptable risk to proceed with the baseline survey to avoid delay, thus mitigating detrimental impact on the overall research methodology.

Baseline customer survey

It was originally anticipated that this activity would have been completed by October 2017. However, complications in finalising the technical cooling site selection delayed the baseline survey. The rationale for the delay was to ensure that both the ‘educated’ and ‘non-educated’ baseline sample were recruited from trial Celsius networks. The baseline survey was completed between April and June 2018 and the delay had no detrimental impact on the research.

Trial customer survey

This phase of research took place between February and June 2019, slightly later than originally estimated due to slippage in the passive retrofit installation programme and technical snagging issues with active technologies. However, this approach ensured that cooling technologies (specifically active interventions) had been operating for a reasonable period, as intended. This ensured that customer feedback reflected the actual impact of the technology. The delay in administering the survey had no detrimental impact on the research.

Customer information card

A new proactive process was introduced to improve customer service where there was potential for disturbance associated with work at substations. This process was implemented while the project was in the technology installation phase and necessitated the issue of a notice to properties bordering the asset, with a description of the work and contact details.

In view of potential customer impact associated with some cooling interventions it was considered inappropriate to seek a derogation to exempt Celsius activity from this policy. The target survey population were those in closest proximity to substations because these customers were most likely to notice/be impacted by cooling interventions. As such, customers who took part in the survey also received the information card.

To establish if this process affected the secondary customer hypothesis that *'Customers who are educated on the need for and benefits of Celsius are significantly more likely to find it acceptable'* the trial survey instrument was amended to include questions to ascertain if respondents could recall being informed of changes at their local substation, and how they were informed of these changes.

Analysis concluded that the limited amount of information on the card was unlikely to have influenced the responses of the 'non-educated' sample, and this modification therefore had no detrimental impact on the research.

Customer enquiries

A robust strategy was developed to ensure that complaints or enquiries received about any aspect of Celsius were recorded and appropriately managed.

This strategy was enhanced prior to commencing the trial survey to draw attention to the cooling technology deployed at the substation nearest to each respondent. This was to ensure that any observation of change or impact was captured. This modification involved the following enhancements to the original methodology:

- A further briefing was delivered to CCC employees, in anticipation of enquiries generated by the test survey,
- Research fieldworkers were instructed to report immediately any negative impact associated with a Celsius cooling technology raised by survey participants during the face-to-face interviews. In these situations, the explicit consent of customers was obtained allowing interviewers to share the customer's details with the Celsius project team, in compliance with the requirements of the General Data Protection Regulation (GDPR) and the Data Protection Act 2018,
- To ensure that survey respondents independently had the opportunity and means of contacting the Celsius team directly, each trial survey respondent was provided with a copy of the general awareness leaflet. This provided an overview of the project and contact details and was handed to every participant at the end of their interview, regardless of whether they were part of the 'educated' or 'non-educated' sample.

This modification represented an enhancement to the method and had no detrimental impact on the research.

9 SIGNIFICANT VARIANCE IN EXPECTED COSTS

PD category	Total forecast (£000)	Budget (£000)	Variance
Contingency	**77**	**537**	**86%***

* The only exception to the +/- 10% difference to expected costs was for Technology Contingency spend. The use of existing monitoring equipment did not take place due to an issue raised by project partner Ricardo Energy & Environment. The cost and effort required to redeploy existing monitoring equipment and implement this into the data handling system was investigated and evaluated against deployment of new equipment. The outcome was that the cost and timescales associated with redeployment would have put the project delivery at risk, therefore new monitoring equipment was ordered for the affected sites. This was budgeted for in the contingency and did not negatively affect the project delivery. This was outlined in section 10 of PPR no2.

10 LESSONS LEARNED ON THE METHOD

The methods developed and trialled in the Celsius project included:

- A methodology to assess the temperature of substation assets,
- The calculation of a Celsius rating,
- The cooling of substations and their assets using retrofit cooling technologies.

These methods were successfully trialled, particularly for ground-mounted transformers. Figure 11 lists the methods as stated in the original project submission, how each was addressed in the project and if they led to further BAU recommendations.

Figure 11: Lessons learned table

Method as stated in the Full Submission	Inclusion in Celsius project	BAU recommendations
Method 1: Retrofit thermal monitoring of pole-mounted transformers	Monitoring installed at 34 pole-mounted transformer sites Analysis found that the transformer temperature is dominated by ambient, resulting from lightly loaded trial sites	No recommendations made, though monitoring could be applied to pole-mounted transformers under BAU if appropriate
Method 2: Retrofit thermal monitoring and cooling intervention for pole-mounted transformers	No specific trials included in the project for the following reasons: • Limited benefit due to the lower cost to replace pole-mounted transformers • Higher risk of trials due to the need to work at heights and in remote areas • Potential outages and additional cost for back-feeding during installation It was concluded that some technologies included in the retrofit cooling trials on	None

Method as stated in the Full Submission	Inclusion in Celsius project	BAU recommendations
	ground-mounted transformers could be applied to pole-mounted transformers; in particular, the solar reflective paint.	
Method 3: Retrofit thermal monitoring of ground-mounted transformers	Monitoring was installed at 449 ground-mounted transformer sites Methodologies were developed to estimate the operating hotspot temperature of the transformer, and to produce the Celsius rating	The retrofit thermal monitoring of ground-mounted transformers has been integrated into the BAU recommendations from the project
Method 4: Retrofit thermal monitoring and cooling intervention for ground-mounted transformers	Cooling technologies were installed at 96 ground-mounted transformer sites, including: • improved ventilation of indoor substations • active ventilation in indoor substations • shades or white paint to protect outdoor substations from solar radiation Some of these technologies proved significantly effective, and some were effective only in certain circumstances	The cooling intervention for ground-mounted transformers has been integrated into the BAU recommendations from the project
Method 5: Retrofit thermal monitoring of cable first leg out	Cable monitoring was installed at 22 substations, including approximately 100 cables. This included cable surface temperature monitoring, ambient temperature monitoring and cable load monitoring	No recommendations made, though monitoring could be applied to cables under BAU if appropriate
Method 6: Retrofit thermal monitoring and cooling intervention for cable first leg out	The cooling trial included a specially selected thermal backfill material for cables installed at four sites This was made up of bentonite and sand and was selected to improve effectiveness of heat escaping from the surface of the cable Limited learning was attained in this trial, due to the selected sites being lightly loaded	None

10.1 Cost benefit analysis

The cost benefit analysis (CBA) was carried out to determine the relative costs and benefits of Celsius compared to traditional methods.

The CBA focuses on meeting load growth in the network. This was regarded as the most appropriate case to model, as the benefits are to GB customers in the form of reduced spending on reinforcement.

The CBA involves comparing two cases:

- *Base case:* representative of the traditional reinforcement approach used for a transformer that is becoming overloaded,
- *Celsius case:* representative of the approach that would be possible with the Celsius methods.

These cases were determined for Electricity North West sites that are expected to be overloaded over the next 30 years, and the benefits are scaled to GB. The sections below summarise the methodology that was used to carry out the CBA.

10.1.1 Base case definition

The base case assumptions have been defined and agreed to represent the approach used in traditional reinforcement of a substation with load growth.

The assumed process once a substation is overloaded is detailed below.

Note that this assumed process did not seek to provide an accurate description of the reinforcement process for all sites, but to present a representative process that can be compared to the Celsius methods.

- *Validation:* the load is validated using data logging to ensure there is no error in reading,
- *Investigation of reconfiguration options:* it may be possible to reconfigure the network to pass some load from an overloaded transformer to a nearby transformer with spare capacity. This is a low-cost way of releasing capacity. In the business case, a release of between 0% and 10% capacity has been modelled,
- *Traditional reinforcement – where the existing transformer is less than 1000kVA:* this includes replacing an existing transformer with a larger one to provide further capacity without the need for additional substation infrastructure. The approach to transformer sizing is shown in Figure 12.

Note: As the CBA will be for 30 years of load growth, multiple interventions are often needed for the same site.

Figure 12: Transformer replacement table

Existing transformer	Replacement
50kVA, 100kVA, 200kVA	Removed from the analysis as the Celsius method is not validated for transformers of these sizes.
300kVA, 315kVA	500kVA
500kVA	800kVA
750kVA, 800kVA	1000kVA

- *Traditional reinforcement – where the existing transformer is 1000kVA:* transformers greater than 1000kVA are not currently used for distribution substations at Electricity North West. In this case, it is assumed that it is possible to release capacity through network reconfiguration (in addition to that described previously) and the reinforcement of an adjacent substation. It is assumed that an adjacent 500kVA transformer is replaced by a 1000kVA transformer, releasing 500kVA in capacity overall.

- *Additional substation:* Where load growth continues and exceeds the capacity release from reconfiguration and reinforcement options, then an additional substation is installed. It is assumed that the new substation will be 800kVA, and that on installation, the load will be shared between the new substation and the overloaded transformer. If load continues to grow, then the additional transformer can be upgraded to 1000kVA.

The following table provides cost and benefit details for each traditional reinforcement:

Figure 13: Cost benefit analysis assumption tables: Transformer replacement cost assumptions

Technology	Capital cost	Capacity release
Traditional: reinforcement to a 500kVA transformer	£17,408 Assumes no new plinth or generator is needed	59% - 67% Assuming existing transformer is between 300kVA and 315kVA
Traditional: reinforcement to an 800kVA transformer	£18,813 Assumes no new plinth or generator is needed	60% Assuming existing transformer is 500kVA
Traditional: reinforcement to a 1000kVA transformer	£18,813 Assumes no new plinth or generator is needed	25% to 33% Assuming existing transformer is between 750kVA and 800kVA
Traditional: installation of a new 800kVA substation	£75,000 Assumes near existing HV and LV network, land costs of £15k	80% Assuming existing transformer is 1000kVA (and remains in operation)

The traditional options used for the base case were selected to reflect a likely approach to reinforcing a substation with increasing load. It is assumed that there is no notable increase in operational costs.

10.1.2 Celsius case definition

The Celsius case is based on the BAU recommendations and represents the approach that can support a substation with load growth.

The assumed process is detailed below.

- *Celsius monitoring and Celsius rating:* installation of monitoring to validate the load readings and allow a Celsius rating to be calculated. The capacity released varies with site characteristic (see table below).

- *Cooling technology:* the Celsius project trialled several cooling technologies, and those included in the CBA are shown in the table below. The technologies selected are those which were most effective at releasing capacity. The analysis assumes the capacity release to be the average value based on the Celsius trials. The results for painting a transformer with white paint and shading it are inconclusive, therefore this solution was not included in the CBA.

- *Traditional reinforcement:* where the load exceeds the capacity release achieved through monitoring, improved rating and cooling, it is assumed that the site is reinforced using the traditional reinforcement approach described in Section 10.1.1.

As the CBA covers 30 years of load growth, it is possible that multiple interventions could be required for one site. For example, monitoring and cooling technologies may be installed, releasing additional capacity, but if exceeded after several further years of load growth reinforcement would be necessary.

The following table provides cost and benefit details for each Celsius technology, and equivalent traditional technology:

Figure 14: Cost benefit analysis assumption tables: Celsius interventions assumptions

Building type	Monitoring and more informed rating: used for all substations with transformers >300kVA	Cooling technology: a single intervention is selected for each building type, where appropriate
Stone / brick	Capacity release assumption: 25% Cost assumption: £974	Active ventilation of substations Capacity release assumption: 20% in addition to the capacity released by monitoring alone Cost assumption: £3,872
Part of a larger building	Capacity release assumption: 17% Cost assumption: £974	Improved passive ventilation of substations Capacity release assumption: 6% in addition to the capacity released by monitoring alone Cost assumption: £2,302
Glass reinforced plastic	Capacity release assumption: 7% Cost assumption: £974	Active ventilation of substations Capacity release assumption: 23% in addition to the capacity released by monitoring alone Cost assumption: £3,872
Fenced enclosure	Capacity release assumption: 41% Cost assumption: £974	No technology selected

The cost information for the Celsius technologies is based on trial experience and information provided by equipment suppliers.

There is uncertainty in this cost due to the range of site characteristics; for example, substation shape and size, ease of providing any required supply points, and ease of making structural changes. For this reason, a range of costs is given in the CBA report in many cases.

It is assumed that there is no notable increase in operational costs as a result of utilising the technologies, as any minor maintenance requirements will be in line with normal substation inspection timescales. This has been supported by information gained from suppliers of the active cooling technologies.

10.1.3 Electricity North West rollout scale

The assumptions used to calculate the Electricity North West rollout scale include:

- *Overloaded sites up to 2033:* the Future Capacity Headroom (FCH) model provides detail of the transformers that will be overloaded up until 2033 and their forecasted load growth over this time. This list was utilised to identify ground-mounted sites with up to 50% loading in 2018 as more heavily loaded sites would be reinforced in the short term. All sites with a nominal rating below 300kVA were removed. This provided approximately 1,100 sites that were considered potential 'Celsius sites'.
- *Load growth beyond 2033:* the load growth assumptions beyond 2033 was assumed to be 3.5% per year, which was calculated from the average load growth of the data between 2018 and 2033. Sensitivity analysis was carried out to investigate the sensitivity of the results to this assumption.
- *Sites becoming overloaded after 2033:* the FCH data was then used to estimate the number and profile of sites that will become overloaded in the years after 2033 up to 2050. It was assumed that the pattern and profiles of these sites are the same as the data up to 2033.

The resultant model included approximately 2,500 sites.

10.1.4 GB rollout scale

To estimate the benefits to GB, the results for Electricity North West were multiplied in proportion to the number of ground-mounted distribution transformers in GB. It is estimated that there are 220,000 ground-mounted secondary transformers in GB, of which 17,000 are in the Electricity North West area.

10.1.5 Modelling methodology

The model is based on an NPV calculation up to 2050 using a discount rate. Results are in 2019 values.

10.1.6 Results

The cost benefit analysis model results are shown in the table below:

Figure 15: Celsius rollout benefits

Rollout scale	Benefits of Celsius methods over traditional up to 2050 (£m)
Electricity North West	30
GB	387

These results assume a 3.5% load growth in the long-term forecast for each site (the short-term forecast for each site is provided by the FCH model as described in Section 10.1.3) and include no assumptions for capacity released through reconfiguration before reinforcement of transformers below 200kVA.

As described in Section 10.1.1, the default assumption includes some capacity release from reinforcement for an overloaded 1000kVA transformer, where it is assumed that reconfiguration and reinforcement of an adjacent substation can release capacity.

Sensitivity analysis was carried out into the impact of key assumptions in the modelling. The tables below show the results of this sensitivity analysis at GB scale.

Figure 16: Celsius benefits using various modelling scenarios: range of load growth assumptions

Modelling assumptions: long-term load growth of transformers	Benefits of Celsius methods over traditional up to 2050 at GB scale (£m)
2%	323
3.5% (default case)	387
5%	474

The load growth assumption makes a significant difference to the resulting benefits. However, even at modest load growth of 2%, Celsius still provides a significant benefit to customers.

Figure 17: Celsius benefits using various modelling scenarios: capacity release assumptions

Modelling assumptions: capacity release from reconfiguration	Benefits of Celsius methods over traditional up to 2050 at GB scale (£m)
No capacity release modelled for transformers less than 1000kVA (default case)	387
10% capacity release for all sites as they first become overloaded	362

The reconfiguration capacity release assumptions have limited impact on the model results. As the potential for capacity release from reconfiguration will be site specific, and the impact on the results is limited, this is not included in the analysis.

The results indicate the scale of the benefit associated with using Celsius compared to traditional methods.

It should be noted that the results do not include other innovative methods that are currently available, or that will become available, to support management of load in distribution networks. It is intended that the Celsius methods should become part of the toolkit of methods that any DNO can use as demand on the network changes over time.

10.2 Noise

Owing to their very nature, distribution substations tend to be located close to customers' properties.

Adding fan-based active cooling technologies can generate noise, and in a few cases (detailed in Section 6.8), this level of noise has created disturbance to customers and intervention was required.

As noise can be subjective, it is not always obvious which substations may cause disturbance to local residents. For example, one noise disturbance issue investigated in the trial was not discernible to residents of several properties nearest the substation, but impacted a customer living further from the site. Investigation of noise disturbance issues revealed the following:

- Fan settings can be altered to reduce noise levels. In some cases, the noise was only noticed at certain times, e.g. in the early hours of the morning when the ambient noise is low. In some cases, the fan settings could be reduced to remove the issue while still providing sufficient cooling.

  Learning: set fan profile so that a reduced fan speed is selected at night (load permitting). In most cases this aligned with times when load was at its lowest due to residential demand profiles.

- The Passcomm unit can be mounted internally or externally to accommodate different scenarios and substation layouts. Some externally mounted units were relocated internally following a report of noise disturbance, and this action resolved the issue.

  Learning: fit the unit internally where possible.

- In some cases, our visibility during the installation of Celsius technology appeared to increase customer sensitivity to noise from the existing transformer, which had previously been acceptable. Increased sensitivity triggered reports of disturbance even after noise from a Celsius technology had been eliminated.

  Learning: any work visible to the public can highlight unrelated issues.

10.3 Slimline Passcomm unit

During the project, Passcomm re-developed their cooling unit to provide the same level of cooling in a smaller, more efficient form. The unit was lighter, easier to install and had less effect on the physical space within the substation.

The new unit provided a level of cooling comparable to the original but has not noticeably reduced noise level or improved efficiency. As this bespoke trial unit was manufactured mid-trial, in response to customer feedback, scale costs are as yet unknown. The slimline unit could be developed for BAU depending on a revised CBA when scale costs are available.

10.4 Cable backfill sites

To obtain a baseline temperature for the underground LV cables, excavation was required to fit temperature sensors.

Some sites exhibited unusual data and, when checked, it appeared that the sensors had become dislodged when the backfill was installed. This delayed the analysis.

The technique of excavating around the LV cables and backfilling with a thermally improved backfill material (a mix of bentonite and silica sand) was used at four sites. Digging around live LV cables has inherent risks, and therefore only hand-digging was permitted. While this method is time-consuming and labour-intensive, it is standard practice for this work.

Backfilling with the new material was significantly more involved than traditional backfilling technologies, taking approximately five times longer to complete. This is due to the mixing process, which requires a large amount of water to achieve the correct consistency. It is also necessary to conduct an additional site visit to apply a finishing layer after a few weeks. Full details of the process can be found here: Cable cooling systems.

10.5 New build recommendations

The Thermal flow study produced by NPL aided the optimal placement of vents in distribution substations. This learning could also be applied to new build substations, ensuring optimal positioning of vents from the outset. This is particularly relevant to GRP substations, which currently have vent positions pre-determined.

Painting outdoor transformers with solar reflective paint demonstrated a reduction in temperature of the asset when in direct sunlight in some cases. This varied significantly from site to site, and so no definitive conclusions could be made, but fortunately none of these sites saw a reduction in rating and the technology had no detrimental customer impact. This technology could be applied to new outdoor transformers at a relatively small cost. An even more efficient and cost-effective approach would be to change this element of the transformer specification and have reflective paint applied upon manufacture.

11 LESSONS LEARNED FOR FUTURE INNOVATION PROJECTS

11.1 Wireless sensors

Lesson: the battery must have a sufficient lifespan to last the entire project.

Wireless temperature sensors made the installation much quicker and easier. It also meant that trailing wires were not present in the substation, eliminating potential trip hazards. The main consideration with wireless sensors was battery life, relative to the duration of the project. The resolution and frequency of data transmission significantly affects the battery life. Suitable parameters were set to ensure the batteries lasted the duration of the project.

11.2 Initial site data gathering

Lesson: recording as much data as possible at the beginning of the project would have been more efficient and saved time.

All data that was initially deemed necessary for each substation was gathered at the beginning of the project. However, when seemingly similar sites were found to be generating varying data, the sites were revisited to investigate and identify the differences. Some of these differences were explained by the position of the transformer in the substation, the number of vents, the proximity of vents to the transformer, the condition of vents and the size of the substation (in particular, ceiling height). While it seemed impractical to gather all this information for every site, doing so at the outset would have prevented several revisits.

11.3 Data quality

Lesson: checking the data capture regularly and addressing any issues early would be beneficial for future projects.

There were issues with the quality of data at some sites that may have been identified sooner and provided the project with more usable data.

11.4 Customer engagement and feedback

11.4.1 Celsius customer focus groups

The Customer focus groups lessons learned report documents the background and learning outcomes from **qualitative** customer research with an engaged customer panel. Specifically, it discusses how DNOs and their stakeholders can capitalise on this process by identifying and responding to challenges that may arise in future customer engagement activities of a similar nature. The following briefly summarises the key lessons learned from this phase of research:

- Customers are now significantly more aware of and engaged with environmental issues and decarbonisation ambitions. This has led to greater understanding and acceptance of expected increases in future electricity demand and the need for innovative solutions to facilitate the adoption of LCTs in the transition to a carbon neutral economy.

- It is critical, when relaying important information, to develop good customer communications material with focused content and design, to avoid any potential for literature being misconstrued as sales or marketing materials.

- Customers value being treated as individuals and, where possible or appropriate, personalised communication is the most effective method of securing the attention of intended recipients.

11.4.2 Celsius customer survey

The following summarises the lessons learned from the **quantitative** phase of customer research. This involved face-to-face customer surveys, which were conducted in three distinct phases.

Celsius pilot survey

Lessons learned from piloting the baseline survey are detailed in Section 4.2.1 of the Customer survey report, key highlights of which were reported in Section 2.4 of the fifth PPR, published on 8 June 2018. The pilot survey was conducted in January 2018 and involved 34 interviews with customers living near to four trial substations. The pilot resulted in minor changes to the survey to improve comprehension and the quality of responses.

Celsius baseline survey

Lesson: customers struggle to accept the concept of planned supply interruptions.

Background: it was originally thought that a small number of customers might experience a planned supply interruption to install cooling technologies. To ensure that respondents taking part in the baseline survey were aware of all potential impacts, the possibility of outages was referenced in an advisory leaflet, handed to the 'educated' sample of respondents. All technologies were subsequently retrofitted without the need for outages.

Learning outcome: the possibility of an outage was a cause for concern and highlighted that customers struggle to accept the concept of planned supply interruptions to upgrade electricity networks, unless they fully understand the personal benefits of the work. The advisory leaflet was updated for the test survey and all references to planned supply interruptions were removed. A summary of the key learning outcomes from the baseline research is documented in Section 8 of the sixth PPR published on 6 December 2018.

Celsius trial survey

The following is a summary of the main learning outcomes from administration and analysis of the trial survey. These lessons are documented in Section 5.3 of the Celsius customer survey report, published on 16 September 2019.

Lesson: Re-engaging respondents can be challenging.

Background: it was anticipated that there would be a level of attrition between the baseline and trial survey, and mitigation was therefore factored into the method by offering a higher incentive payment for participation in the trial survey. However, a significant number of the original 'educated' baseline respondents were unwilling or unable to re-engage in the second survey.

To achieve the target 're-engaged' quota to test the hypothesis, the sample was increased using a two-phased approach:

- Several 'non-educated' baseline survey respondents were re-contacted and educated about Celsius,
- An entirely new sample of customers, with no prior knowledge of the project, were recruited and educated, enabling them to provide informed responses.

Learning outcome: any future projects requiring repeated engagement should consider the approach adopted in Electricity North West's Second Tier LCNF project, CLASS, which had a much lower rate of attrition. This also offered higher value payments to retain respondents as the research progressed. However, in CLASS, this was combined with an effective communication strategy, which was maintained throughout the trial period.

Lesson: attaining required quotas is challenging when the target pool of research participants is limited.

Background: Celsius surveys were conducted face-to-face, on the doorstep, to ensure that respondents either lived or worked in the immediate vicinity of substations where a Celsius cooling technology had been installed.

Surveys were weighted towards active sites, on the basis that customers were more likely to notice a visual or acoustic change at these sites. As only 40% of the trial substations were retrofitted with active cooling, it was challenging to meet the quotas required to test the hypothesis robustly. Despite frequent interviewer visits to maximise surveys near active sites, the full quota was not met.

Learning outcome: future research projects that require the feedback of a limited pool of customers that meet specific criteria will require a similar, adaptable methodology.

Lesson: cash is more popular than e-vouchers as an incentive.

Background: respondents were less likely to agree to participate in the survey when they were offered an Amazon e-voucher instead of cash.

Learning outcome: based on feedback from fieldworkers, respondents' preference for a cash incentive was, in part, attributed to a lack of digital engagement and confidence in the authenticity of an e-voucher, or trust they would subsequently be issued with one.

The methodology was adjusted to provide a cash incentive to enable engagement with a more diverse sample of respondents. While this was successful, offering cash payments for participation in face-to-face, doorstep research can place interviewers in potentially vulnerable circumstances.

Lesson: research should be focused, and participants correctly identified.

Background: because of the challenges of engaging survey participants near trial substations, fieldworkers were allowed limited discretion to extend the range of the survey to properties that did not immediately border the site. The approach resulted in less valuable feedback than that which was attained from residents nearest the site.

Learning outcome: future customer research of a similar nature should take all practicable measures to ensure that a sufficient quota of respondents can be recruited from the target population, particularly where the sample is limited, and this requires a flexible approach.

Lesson: face-to-face research with customers can introduce sensitivities when engaging with vulnerable customer groups.

Background: the face-to-face research methodology highlighted sensitivities when cold calling customers who might be elderly, vulnerable or averse to an uninvited approach.

Learning outcome: while market research is exempt from cold calling due to the legitimate interest, best practice dictates that the occupants of properties displaying 'no cold caller' signage would not be open to participating in market research which has not been pre-arranged. As such, fieldworkers were instructed not to approach households with such signage and not to proceed with interviews where they considered a customer might be unable to make an informed decision about taking part in the research. This approach should be adopted in similar research with customers at their home address.

12 PROJECT REPLICATION

12.1 Equipment used during the trial

This trial used monitoring equipment from ASH Wireless Electronics which consisted of the following:

Hub: the Hub KHB01 acts as a low power radio concentrator featuring a cellular modem. The battery powered Hub is designed to gather a data log from local sensors four times a day and send it to the data management system via GPRS once a day.

Hex: Hex sensor KHX01 and 02 units can monitor six independent inputs using flying leads to measure temperature, voltage, or current. Hex sensor units can also be configured for power measurement and use paired voltage and current flying leads to measure power on three phases, and to calculate real and reactive power, total harmonic distortion (THD) for both voltage and current readings, and residual current and voltage in three-phase cases.

Temperature sensor: single temperature sensors KTS01 measure the temperature at a specific point, which is thermally close-coupled to the mounting magnet. The sensor can be magnetically mounted onto the side of a transformer to measure the surface temperature of assets or be used to measure ambient conditions by reverse mounting, exposing the magnet to the air.

These sensors fed data into a Celsius data management system which allows the user to access the data. For this trial, the data management system was created and managed by Ricardo Energy & Environment. This system also provided a web application that could be used by the installation teams on their smart phones. This was used for easy installation of equipment, pairing sensor units with location data, and storing of site information and photographs.

Full details of the monitoring equipment and data management system used can be found in the Equipment specification and site installation report.

12.2 Recommended equipment specification

To replicate the project, the equipment stated above would not necessarily have to be used, but any equipment should meet the key functional specifications:

- Temperature measurement shall be accurate to 0.1°C resolution and have an absolute accuracy of ± 1°C. The measurement accuracy shall hold over the range 0°C to +100°C. Temperature readings shall be taken every 30 minutes.

- Voltage readings shall be accurate to ± 1 V over the range 215-260V. Voltage RMS measurements shall be taken at least every five minutes, and the average of these readings over 30 minutes shall be recorded.
- Current measurements shall be in the range 0-2000A with 1% full scale accuracy. Current RMS measurements shall be taken at least every five minutes, and the average of these readings over 30 minutes shall be recorded.
- All data shall be transmitted to the data collection system at least once per day.
- All equipment shall be at least IP65 rated for environmental sealing, with IP67 rating for more vulnerable components such as Rogowski coils.
- The monitoring solution shall be designed for ease of installation, e.g. fixings via magnets or ties, wireless communications within the site, long life battery or scavenged power supply to limit on-site alterations, installation process supported by an installation application.
- The maintenance requirements of the monitoring solution shall be minimal, lasting for five years between substation visits. This includes the lifetime of any battery power supply. The frequency of maintenance visits should be aligned with internal procedure documentation.
- The equipment shall be capable of remote software updates.
- Notifications shall be sent if there is a fault in the operation of the monitoring equipment, e.g. if data is not being received. Where the equipment is battery-operated, there shall be notification of low battery levels so that site visits can be planned.

The back-end architecture supporting the monitoring system is an important specification decision. To implement the Celsius process into an existing network, there are several options for the back-end architecture. These are listed in Figure 18 below, with an indication of the positive and negative considerations associated with each. Some systems referenced are specific to Electricity North West, but the same process could be achieved for another network licensee.

Figure 18: Monitoring system options

Option	Benefits	Concerns
Use Electricity North West RTUs to pass the data into the SCADA system and develop a module to regularly process and produce required results	Equipment known and utilised by Electricity North West Established and secure Electricity North West SCADA and data processes Allows easy integration of notifications to trigger in short (near real time) timescales	RTUs are not present at 70% of sites currently, and the cost of installing at a non-RTU site might negate the Celsius business case Potentially significant task to integrate a Celsius rating module
Use a virtual RTU in the form of a mobile connection to iHost to pass the data into the SCADA system and develop a module to	Equipment known and utilised by Electricity North West Established and secure Electricity North West	Costs of this option need investigating. Potentially significant task to integrate a Celsius rating module Restricted in the choice of

Option	Benefits	Concerns
regularly process and produce required results	SCADA and data processes Allows easy integration of notifications to trigger in short timescales. May be lower cost than a full RTU	BAU monitoring solution
Use an independent monitoring and SCADA with the required module to produce the results, which are then passed into the asset records (manually in the short term, and then via an application program interface [API] in the longer term)	More market choice of monitoring and processing solution Opportunity to tailor the Celsius rating calculation module	Not part of the established and secure Electricity North West SCADA process (this may not be considered system-critical data, therefore the level of security needed might be lower) The timescales of notifications will be limited by the communications and integration with Electricity North West systems, e.g. notifications may be sent within a day

The monitoring data can be used to establish notifications which can be sent to key personnel. For example, notifications/alarms could be developed for high temperatures or significant change in demand. Notifications could be communicated in a useful format, for example via email or SMS, and may include actionable information such as instructions for inspections and suggestions for interventions.

In addition to the above, processes and authorisations within the organisation will need to be observed; any new equipment would go through network commissioning testing to ensure it is fit for purpose and suitable for installation on the network. Any relevant policy documentation will need to be complied with.

Full details on the equipment recommendations can be found in the BAU monitoring solution specification.

The Celsius methodology is not necessarily limited to the cooling interventions selected for the trial. There are many retrofit cooling technologies on the market that may provide varying levels of cooling at varying costs. Details and specifications of the cooling technologies trialled can be found in the Cooling equipment specification and installation report.

12.3 BAU costs

The costs for implementing the Celsius methodology have been quantified in Section 10.1 of this report. This is based on the equipment used for the trial and may vary if alternative equipment is used for a BAU rollout. Full details of the CBA can be found in the Cost benefit analysis and buy order report – final.

12.4 Customer engagement and feedback

The requirements to replicate customer research with an ECP, including the development of materials and a customer survey, are outlined in the Customer focus groups – lessons learned report published on 21 December 2017. This document provides guidance on the discussion framework and stimulus materials required for research of this nature, in addition to customer consent requirements. Section 6.3 of the report specifies the physical components required to replicate focus group meetings with an ECP.

13 PLANNED IMPLEMENTATION

13.1 Proposed process incorporating Celsius

In a BAU process that includes the Celsius method, certain distribution substations will have additional monitoring and can be treated slightly differently. These sites are referred to as 'Celsius sites'.

Celsius monitoring will be installed when a distribution substation has been identified as needing possible intervention, either for load growth or high temperature issues.

Note: Celsius would only be considered when there are no time constraints around the intervention (e.g. a connections request must be completed in a fixed time period). However, if the Celsius monitoring data already exists at that site, it will be used to support the planning study.

The configuration and specification of Celsius monitoring used minimal monitoring points to develop a practical low cost improved rating. Analysis of this data identified the most suitable monitoring positions. Celsius monitoring comprises:

- Transformer surface temperature measured at the top oil level,
- Ambient temperature measured away from the transformer or other heat or ventilation sources,
- Transformer demand measured through three phase current and voltage sensors.

The monitoring data will allow calculation of a more informed rating, or 'Celsius rating', which is determined by estimating the hotspot temperature within the transformer and comparing this with demand. This rating will be more accurate than the nameplate rating which is set by the manufacturer based on assumed operating conditions. In most cases, the Celsius rating will be higher than the nameplate rating. The methodology of estimating hotspot temperatures and calculating the Celsius rating have been developed and reported under the deliverables of the Celsius project.

The Celsius rating can be used in planning, asset management, network capacity and connections decisions, to enable the support of greater load growth without the need for network reinforcement.

This new rating, informed by more accurate demand and temperature data will be used in the Common Network Asset Indices Methodology (CNAIM) model, allowing more accurate indication of asset health and risk, potentially lowering the number of sites being referred for intervention.

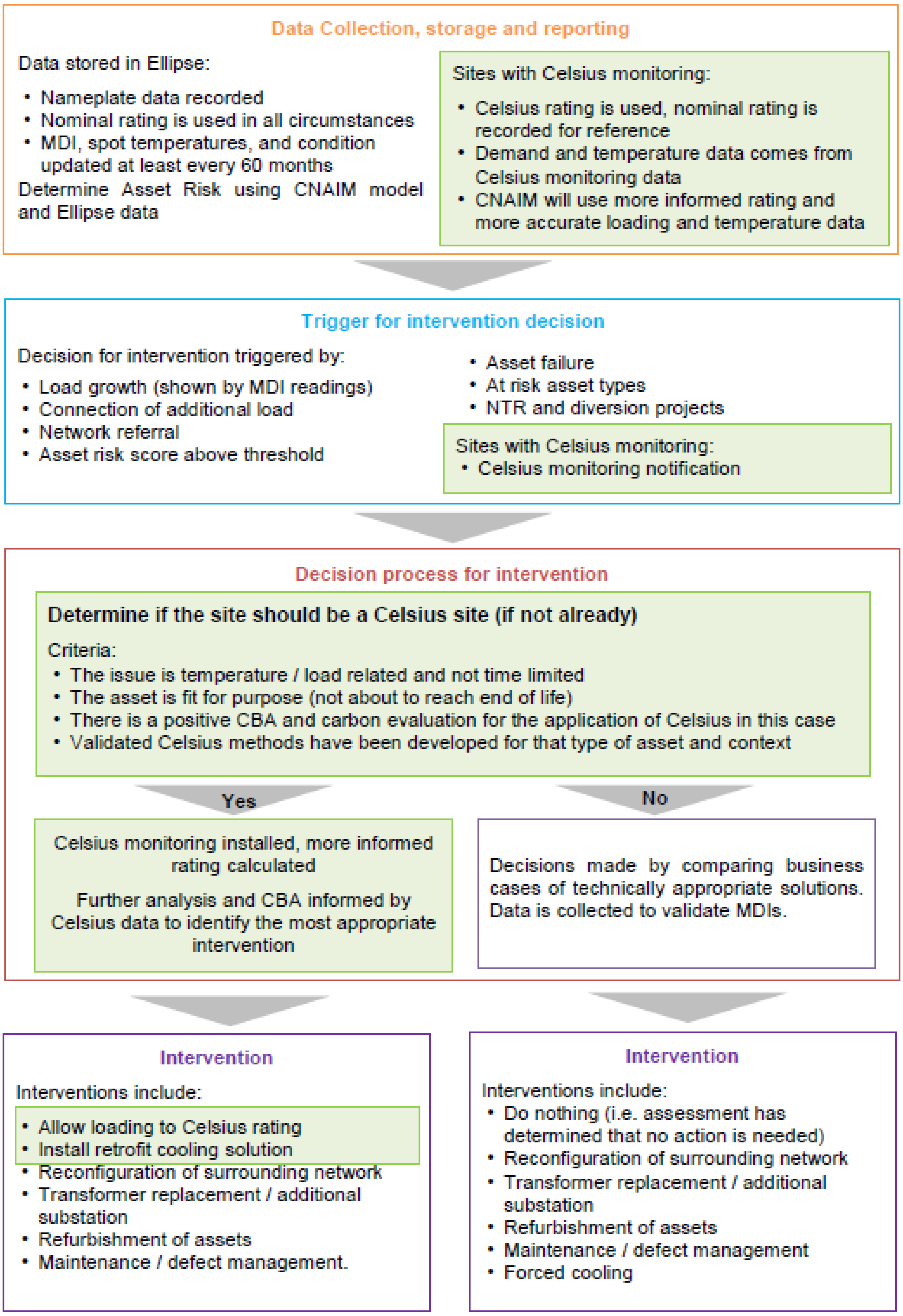
The data can also be used to produce notifications to warn of any developing issues, e.g. an unexpected temperature rise. These notifications will be carefully tuned to support timely reaction to warning signs of failure without over-triggering. It is envisaged that the notification will be sent as an email or SMS to key personnel and will indicate if the site needs visiting urgently.

The Celsius monitoring data can be used to enable optimised selection of intervention and to monitor the resulting benefits. Possible interventions include:

- Retrofit cooling technologies such as those trialled during the Celsius project,
- Demand side response,
- Network meshing,
- Network reconfiguration,
- Traditional reinforcement.

The chart below summarises the new asset management process which incorporates the outputs from the Celsius project. It illustrates all elements in the current process, alongside the new elements (highlighted in the green).

Figure 17: Celsius incorporated into current process



When a non-Celsius site is flagged for an intervention, the first step is to decide if it is economic to deploy Celsius monitoring. It is expected that the CBA will support monitoring in most situations, particularly where the issue is load or temperature related. This likely outcome is because Celsius monitoring is easily deployable and low cost once the procurement, communications and IT integration is established, and critically it will quickly confirm the demand and temperature profile of the site.

In common with the existing process, the maintenance team will decide whether intervention is required using the Celsius CBA. As the decision-making process becomes more complex, it will be developed further; it is envisaged that standard CBAs and carbon cases will be created to facilitate decision-making for standard sites, minimising the workload associated with developing new analysis for each application.

After Celsius monitoring has been installed an initial assessment of the more informed rating can be made and updated over time, as more data is collected. This will determine the potential capacity that can be released through the Celsius methods and allow assessment of the interventions.

The Celsius project developed methods to calculate a more informed rating for transformers. There are some potential gaps in the range of sites covered by the work to date, e.g. outdoor, GRP substations and metal kiosk transformers with a nominal rating below 300kVA. While further work is required to develop methods for these sites, some insight can still be gained from deploying Celsius monitoring.

The asset database will include the Celsius rating so that the asset management, planning and connections teams are aware that the substation has a modified rating. Labelling will be deployed on site to highlight that the nameplate rating is not correct and to refer colleagues to the asset database for the Celsius rating.

The Celsius methods should not allow a transformer to operate beyond its design temperature, but as these are new technologies, the probability of failure needs to be carefully considered. It is likely that the risk of failure will be reduced because of the monitoring, and the associated notifications, which will facilitate a prompt reaction to any signs of failure. Detailed analysis will be carried out on failed equipment at Celsius sites and compared with non-Celsius equipment to determine whether the Celsius process should be updated.

13.2 Benefits of Celsius BAU solution and process

There are several benefits of the Celsius BAU solution, including:

- *Direct capacity release from the more informed rating:* the more informed rating will be higher than the nominal nameplate rating in the majority of cases. This will mean that additional load can be supported before intervention is required.

- *More informed asset data in databases:* the rating, demand and temperature data for Celsius sites will be more accurate, allowing for more accurate inputs into the CNAIM model, leading to more informed investment decisions.

- *Demand and temperature data available:* the more detailed, half hourly data available for Celsius sites can be used to inform asset management, planning and connections decisions for that substation and surrounding network.

- *Ongoing reassurance from asset temperature notifications:* notifications can be generated from the data and sent to key personnel. They will aim to reduce risk that Celsius sites overheat or fail, while enabling operation closer to the safety margins.

- *Possible reduction in frequency of site visits:* it may be possible to reduce the frequency of visits to Celsius sites due to the increased visibility. It is recommended that this is carefully considered once the Celsius process is established.

- *Fast response to changing system demands:* Celsius methods can be used to buy time in a world where demand for network intervention is increasing and the available resources can pose a challenge. Celsius enables smarter decision-making by providing data and actionable information on Celsius sites.

- *Additional benefits from monitoring data:* increased network visibility can have significant advantages, and data collected can provide additional insight into current, voltage and imbalance of load on the network. It is recommended that additional studies are established to determine these opportunities.

13.3 Further work

There are several key areas where the methodology would benefit from further work to validate its applicability, the most significant of which are detailed below.

The main area for further validation is the hotspot estimation methodology. The method for hotspot estimation used in the project was based on the data collected from a subset of trial sites with increased monitoring, including internal oil temperature monitoring and hotspot monitoring. This sample did not include all site types; for logistical reasons, no outdoor, GRP or metal kiosk substations were included. Additionally, there were difficulties in retrieving data from the 'smart transformers' and much of it was based on lightly loaded conditions. It is therefore recommended that further work is required to update and validate the hotspot calculation methodology for all distribution transformer types.

Further areas of improvement are recommended to ensure that ongoing learning during BAU implementation will be incorporated into the methodology, including:

- *Ongoing Celsius rating refinement:* as data is collected for a wider range of heavily loaded sites, understanding of the Celsius rating can be developed to incorporate this new learning.

- *Ongoing improvement to estimating cooling technology benefits:* as additional cooling technologies are installed, any learning about the benefits and limitations can be added to that of the project. This can then be used to refine the CBA for selecting and designing interventions.

- *Ongoing addition of alternative interventions:* as further innovative technologies are implemented into BAU, including additional cooling technologies as well as other capacity release methods, they can be incorporated into the Celsius BAU process. In many cases, the availability of Celsius data would be beneficial when selecting and designing future interventions, including innovative technologies.

There is potential for further development of these methods to improve the benefits to GB DNOs, beyond the scope defined for this project. This includes:

- *Dynamic rating:* the Celsius methods are a positive step towards developing usable dynamic rating approaches for DNOs. The potential of dynamic rating for transformers in GB distribution systems can be significant, particularly when coupled with the ability to actively manage energy flows in the system, for example through demand side response, dynamic generation and storage, and dynamic network configuration. Providing a real time or dynamic rating would add significant value to these technologies by providing additional capacity that can be leveraged as needed, without the need to reinforce.

- *System visibility, forecasting and modelling:* gathering data at distribution substation level can provide value to the wider business by increasing the accuracy of operational and planning models and informing connections requests.

- *Investigation of other data aspects:* further insight could be gained from the monitoring gathered during this project as well as BAU implementation of the methods to understand the practical implications of phase unbalance and harmonics.

To continue to assess any potential asset health implications arising from the deployment of the Celsius methodology, the Asset health study carried out by The University of Southampton recommends that Electricity North West consider the following:

Monitoring: to continue to build confidence in the methodology, initially Celsius ratings should only be applied at sites where temperature monitoring equipment can be installed to verify that the transformer is not subject to excessive temperature rise. This is embedded in the BAU process, as defined.

- *Validation:* the 95% confidence limits in the 'full Celsius rating' are very broad for small transformers. This appears to be due to the form of the equations used, and the limit on the amount of data presently available. It is recommended that further validation work is undertaken. *This has been fixed in the amended analysis; the form of the Celsius rating equation has been amended to consider ratings in 'per unit' (normalised by nominal rating). Even with this amendment, the smaller transformers were found to have particularly extreme Celsius ratings. Transformers at 200kVA or below were removed from the trial for this reason.*

- *Rating ceiling:* it may initially be prudent to apply a cap to the Celsius rating applied on the network *(initial cap set to 150% of nameplate rating*). This could be reassessed as more data becomes available but would be a simple way of mitigating the risk associated with limited numbers of monitored transformers being subject to high loads. It is recommended that when determining the size of any cap, consideration is given to the condition of the transformer at the time. Although age may be a factor in this, other service experience, such as knowledge about the condition of other assets of the same design, may be relevant.

- *Site type:* limited data is available at present for some substation types, particularly GRP substations. Re-rating of these sites should be applied with caution until additional monitoring data is available.

- *Asset health monitoring:* where the Celsius methods are deployed to enable a transformer to take on additional load, it is recommended that Electricity North West consider an enhanced monitoring regime. This would ideally consist of routine oil sampling at intervals (including before the additional load is applied), to verify whether there is any significant trend in degradation markers within the oil.

14 LEARNING DISSEMINATION

This closedown report is a key element of the dissemination approach to ensuring the sharing of project learning.

A peer review of the closedown report was completed by UK Power Networks. Improvements and recommendations that would ease the understanding of Celsius by other DNOs, and enable them to replicate the system, were received and incorporated into the closedown report accordingly. A supporting letter from UK Power Networks can be found in Appendix D.

A full list of all the learning dissemination activities can be found in Appendix B.

15 KEY PROJECT LEARNING DOCUMENTS

Project progress reports and key learning documents are tabulated in Appendix C. A more extensive range of project-related key documentation can be found on the project website.

16 CONTACT DETAILS

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APPENDICES

A: SDRC and supporting evidence

Ref	Description	Date	Evidence
TW	**Technology workstream**		
1	Publish equipment specifications and installation reports	Sep 17	Interim report
2.1	Hold retrofit cooling workshop	May 17	Cooling technology selection report
2.2	Review of highest scoring technologies, circulate workshop outcomes to DNOs and publish on the Celsius website	July 17	Cooling technology selection report
3	Publish cooling equipment specifications and installation reports	Nov 18	Equipment specification and site installation report
CW	**Customer workstream**		
1	Send Customer Engagement Plan and Data Privacy Statement to Ofgem	Jun 16	Customer engagement plan Data privacy statement
2.1	Deliver customer focus group workshop	July 17	Customer workshop discussion guide and showcards
2.2	Publish lessons learned from testing customer communication materials on Celsius website	Dec 17	Customer focus groups lessons learned
3.1	Publish customer survey report quantifying the acceptability of innovative retrofit cooling technologies on the Celsius website	Sep 19	Customer survey report
3.2	Publish additional customer survey analysis evaluating the change, if any, in the acceptability of innovative retrofit cooling technologies by educating customers, on the Celsius website	Sep 19	Customer survey report
TAW	**Trials & analysis workstream**		
1.1	Raw temperature monitoring data to be available and retrofit cooling monitoring data to be available	July 17 Sep 18	Monitoring data
1.2	Publish asset temperature behaviour analysis report on Celsius website	Sep 18	Asset temperature report
2	Publish thermal flow study report and initial recommendations for substation design on Celsius website	Nov 17	Thermal flow study phase 1

Ref	Description	Date	Evidence
3	Publish low cost monitoring solution specification on the Celsius website	Sep 19	BAU monitoring solution specification
4.1	Develop Thermal Ratings Tool using monitoring data to evaluate site capacity on Celsius substations	Oct 18	Thermal ratings tool introduction
4.2	Develop and validate Thermal Ratings Tool using retrofit cooling trial data, and publish on Celsius website	Nov 19	Enhanced thermal ratings tool
4.3	Develop and validate Thermal Ratings Tool, combining input data from the monitoring and cooling trials, and publish user guide on Celsius website	Jan 20	Enhanced thermal ratings tool – final Enhanced thermal ratings tool guide
5	Publish the Cost Benefit Analysis and Carbon Impact Assessment reports, Celsius Business Case and buy order of retrofit cooling technologies on Celsius website	Dec 19	Carbon impact assessment Cost benefit analysis and buy order – final
6	Publish Asset Health Study report on Celsius website	Oct 18	Asset health study
LDW	**Learning & dissemination workstream**		
1	Launch Celsius project website	Jul 16	 Jane Stell – July 27 at 1:33pm Our Celsius project website is now live. The £5.5 million low carbon project will explore innovative, cost-effective ways of managing temperatures at distribution substations. This will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. Find out more at www.enwl.co.uk/celsius www.enwl.co.uk A co-ordinated approach to managing the temperature of electrical assets We use cookies to ensure that we give you the best experience on our website. If you continue without changi... www.enwl.co.uk/celsius
2	Publicise Celsius within Electricity North West via the Volt intranet site, email bulletins and/or Newswire company magazine	Jun 16	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 103 17 JUNE 2016 LATEST NEWS... **Celsius project hots up** Celsius Following Ofgem's announcement last November on our successful bid for funding, work on our latest innovation project, Celsius, is gathering pace. The first solution of its kind in Great Britain, the £5.5 million Celsius project will explore innovative, cost-effective ways of managing potentially excessive temperatures at distribution substations. This will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. The first stage of Celsius is to gather data from 520 substations, using new temperature monitoring equipment. The data will be analysed to improve our understanding of the relationship between an asset's temperature, load and environment and to develop a 'Thermal Ratings Tool'. Secondly, a range of cooling techniques will be trialled on 100 of the distribution substations to demonstrate the benefits of each technique. Our customer engagement plan will set out how we discuss any potential impact of the cooling techniques with customers and how we engage with all our stakeholders throughout the project. Celsius is funded under Ofgem's Network Innovation Competition which is an annual opportunity for electricity network companies to compete for funding for the development and demonstration of new technologies. Funding is provided for the best innovation projects which help all network operators understand what they need to do to provide environmental benefits, cost reductions and security of supply in the future. This is our fifth consecutive successful bid for this type of funding following in the footsteps of Capacity to Customers, CLASS, Smart Street and Respond. Project manager Damien Coyle said, "Since the start of the year, the Celsius project team have made great progress. We've begun regular meetings with our project partners ASH Wireless and Ricardo to develop the Celsius technology. We have selected the 520 substation sites which will be monitored as part of the project and are now busy designing the installation plan." If you would like to know more about Celsius, you can watch our animated video; visit our webpage; or you can find out about our other low carbon projects at www.enwl.co.uk/thefuture.

Ref	Description	Date	Evidence
		Mar 17	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 142 24 MARCH 2017 LATEST NEWS **Celsius project gathers steam** Work to deliver our £5.5 million innovation project Celsius is progressing well, 15 months into the four-year timeline. Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. The project will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. The first stage of Celsius is to gather data from 520 substations, using new temperature monitoring equipment. Project manager Damien Coyle told us, "The rollout of monitoring equipment is now in its final stages, with more than 300 of the sites installed and already gathering data. The data is being analysed by our project partner Ricardo to improve our understanding of the relationship between an asset's temperature, load and environment. "The result of this analysis will lead to the development of a 'thermal ratings tool' which will enable us to understand what additional capacity can be released from our substations. "We're also working with the National Physics Laboratory on a 'thermal flow study' to analyse the heat and air flows in substations. This will influence the design of our substations in the future and potentially show how air flow in existing substations can be improved." The second part of Celsius is to test a range of cooling techniques on 100 of the trial substations. We are now busy researching different cooling techniques which we will trial next year. As the cooling techniques will be deployed at substations close to homes and businesses, we will carry out a programme of engagement to understand any audible or visual impact of the techniques on our customers.
		Mar 18	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 194 29 March 2018 LATEST NEWS **Celsius starts to cool down substations** As part of our pioneering Celsius project we are installing a range of cooling techniques at 100 substations across the region which will help prepare our network for renewable energy and keep costs down for customers. Over the next 12 months techniques such as improved ventilation, heat extraction fans and alternative kinds of backfill material for underground cables will help cool down substations and maximise the use of our assets. The cooling techniques will be installed at 100 of the 520 sites where temperature monitoring equipment was fitted last year. Data from the substations is being used to understand how the environment and temperature affect the electrical equipment and how cooling can help release more power onto the electricity network. At the same time we'll be carrying out a series of surveys to find out what customers living near the substations think of the new techniques. Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. The project will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. Find out more at www.enwl.co.uk/celsius or if you have an idea for an innovation project please contact us.
		Mar 19	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 245 22 March 2019 LATEST NEWS **Celsius project hots up** We're only part-way through our pioneering Celsius project but it's already "business as usual" for one of our new cooling techniques. As part the project we've installed a range of techniques at 100 substations across the region which will help prepare our network for renewable energy and keep costs down for customers. Techniques such as improved ventilation, heat extraction fans and alternative kinds of backfill material for underground cables are helping to cool down substations and maximise the use of our assets. Project manager Delroy Ainsworth said, "As well as the Celsius trial sites, we've installed one of our "Passcomm" units at a substation in Manchester to help cool down a transformer which was starting to over-heat. We're now working to identify another site to install a redesigned Passcomm unit which is smaller and more efficient but still provides the same cooling effect. "We're only part-way through the trials but we're already able to demonstrate that the cooling techniques can be used effectively – which is great news. We're now starting to incorporate Celsius techniques into our business as usual processes." Throughout the trials we're gathering data from the trial substations to understand which of the different techniques are most effective and how the environment and temperature affect our electrical equipment. At the same time we're also carrying out a series of surveys to find out what customers living or working near to the substations think of the new techniques. The final phase of this research is under way which will help us to decide which of the Celsius techniques are most suitable under different network and environmental conditions. Find out more on our website or if you have an idea for an innovation project please contact us.

Ref	Description	Date	Evidence
		Mar 20	

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ISSUE 296 27 March 2020

LATEST NEWS

Celsius project is hot stuff

This month sees the closedown of our pioneering Celsius project, the first solution of its kind in Great Britain. As part of the project we have successfully trialled 'thermal monitoring' at 520 substations across the North West, and installed a range of retrofit cooling techniques at 100 of the trial sites.

Usually the amount of power we transmit through a transformer is limited by its manufacturer's rating which protects it from overheating. But thermal monitoring allows us to better understand the temperature of the transformer and release its full available capacity.

In addition we trialled a range of retrofit cooling techniques, such as improved ventilation, heat extraction fans and alternative kinds of backfill material for underground cables, which help to cool down substations and maximise the use of our assets.

The £5.5 million project has proved that capacity can be released simply by installing thermal monitoring, and the addition of the retrofit cooling techniques can release even more capacity. Both techniques reduce long-term costs for customers, avoid early asset replacement and prepare our network for renewable energy.

If rolled out across our network, Celsius techniques could save customers £31 million over the next 30 years, and £399 million if rolled out across Britain.

Dan Randles, Head of Network Innovation, said, "We are delighted by the success of the Celsius project and confident it will follow in the footsteps of our other industry-leading projects, CLASS and Smart Street, which are already business as usual and bringing substantial benefits to our customers.

"One of the Celsius substation cooling techniques has been so successful during the trial that we've already started using it as 'business as usual' to avoid potentially costly replacement of assets".

Throughout the trials we gathered data from the trial substations to understand which of the different techniques were most effective and how the environment and temperature affect our electrical equipment. At the same time we carried out a series of surveys to find out what customers living or working near to the substations thought of the new techniques.

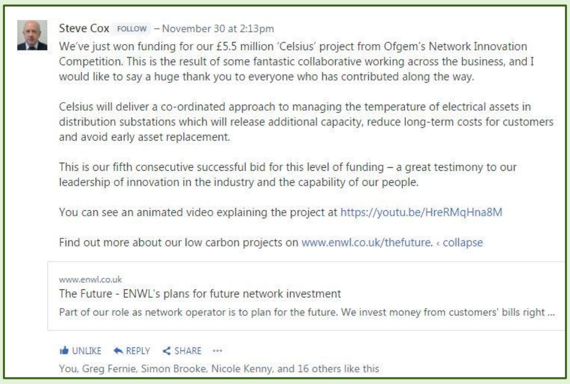
The next steps for the project are to publish a detailed closedown report on our website and to incorporate Celsius techniques into our business as usual processes.

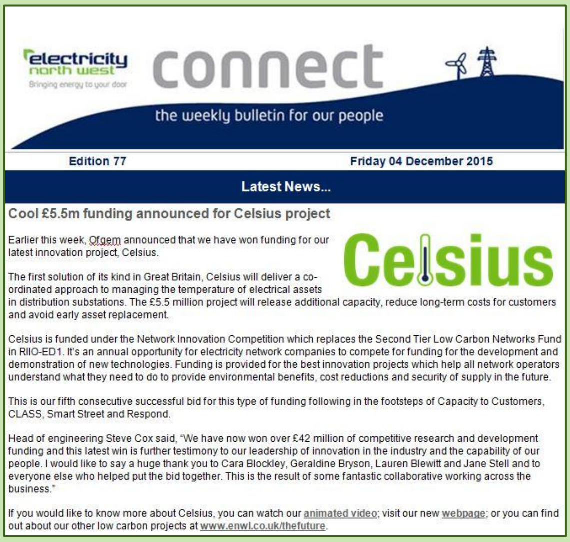
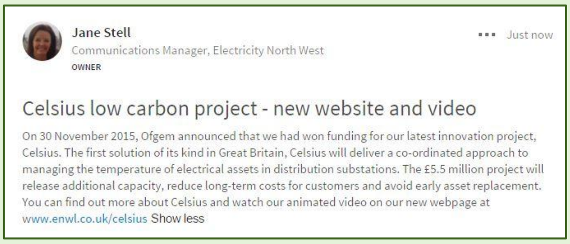
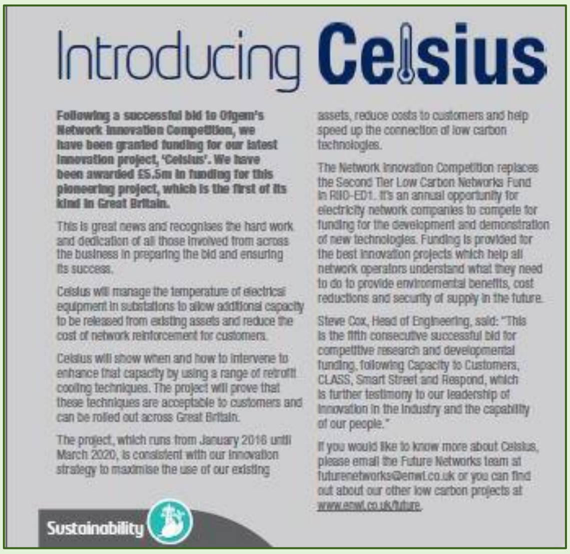
Find out more about Celsius on our website, or if you have an idea for an innovation project please contact the innovation team.

Ref	Description	Date	Evidence
3	Publish advertorials annually	Oct 16	Advertorial
		Oct 17	Advertorial
		Oct 18	Advertorial
		Oct 19	Advertorial
4	Participate at four annual LCNI conferences	2016	Slide presentation
		2017	Slide presentation
		2018	Slide presentation
		2019	Slide presentation
5	Hold annual knowledge sharing events. Provide one-to-one briefing sessions	Sep 16	Webinar recording Webinar slides and feedback
		Sep 17	Slide presentation and survey results
		Sep 18	Slide presentation
		Dec 19	Slide presentation
6	Issue project progress reports in	Jun 16	Project progress report

Ref	Description	Date	Evidence
	accordance with Ofgem's June and Dec production cycle and publish on the Celsius website	Dec 16	Project progress report
		Jun 17	Project progress report
		Dec 17	Project progress report
		Jun 18	Project progress report
		Dec 18	Project progress report
		Jun 19	Project progress report
		Dec 19	Project progress report
CI	**Closedown & business as usual handover phase**		
1.1	Produce Celsius closedown report	Jan 20	This document
1.2	Complete and publish peer review of Celsius closedown report	Mar 20	See Appendix D
2	Publish Electricity North West's approach to managing thermal constraints at distribution substations on the Celsius website and train planners/ operational engineers on new codes of practice	Mar 20	Approach to managing thermal constraints
3.1	ENA workshop with DNOs (to agree areas of changes to Engineering Recommendations P15 and P17)	Nov 16	Workshop presentation Workshop presentation – Ricardo
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	Feb 17	Initial review
3.3	Incorporate relevant Celsius outputs into change proposal options for ER P15 and ER P17 and hold workshop with DNOs	Jan 20	Workshop presentation
3.4	Submit proposals for changing ER P15 and ER P17 to ENFG	Mar 20	TAP dissemination as agreed with ENA, Celsius has been added to the agenda for the next meeting

B: Celsius learning and dissemination activities

Date	Activity	Audience	Evidence
Nov 2015	Celsius introductory video on YouTube	All stakeholders	You Tube
Nov 2015	Introductory webpage on Electricity North West innovation website	All stakeholders	Webpage 
Nov 2015	Press release announcing Celsius funding	Media	Press release
Nov 2015	Celsius funding announced on Yammer	All employees	
Nov 2015	Celsius funding announced on Twitter	All stakeholders	
Nov 2015	Celsius funding announced on LinkedIn	All stakeholders	

Date	Activity	Audience	Evidence
Dec 2015	Employee announcement in Connect weekly e-bulletin	All employees	 electricity north west Bringing energy to your door connect the weekly bulletin for our people Edition 77 Friday 04 December 2015 Latest News... Cool £5.5m funding announced for Celsius project Celsius Earlier this week, Ofgem announced that we have won funding for our latest innovation project, Celsius. The first solution of its kind in Great Britain, Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations. The £5.5 million project will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. Celsius is funded under the Network Innovation Competition which replaces the Second Tier Low Carbon Networks Fund in RIIO-ED1. It's an annual opportunity for electricity network companies to compete for funding for the development and demonstration of new technologies. Funding is provided for the best innovation projects which help all network operators understand what they need to do to provide environmental benefits, cost reductions and security of supply in the future. This is our fifth consecutive successful bid for this type of funding following in the footsteps of Capacity to Customers, CLASS, Smart Street and Respond. Head of engineering Steve Cox said, "We have now won over £42 million of competitive research and development funding and this latest win is further testimony to our leadership of innovation in the industry and the capability of our people. I would like to say a huge thank you to Cara Blockley, Geraldine Bryson, Lauren Blewitt and Jane Stell and to everyone else who helped put the bid together. This is the result of some fantastic collaborative working across the business." If you would like to know more about Celsius, you can watch our animated video; visit our new webpage; or you can find out about our other low carbon projects at www.enwl.co.uk/thefuture.
Dec 2015	Web page and video promoted on LinkedIn	All stakeholders	 Jane Stell Communications Manager, Electricity North West OWNER ••• Just now Celsius low carbon project - new website and video On 30 November 2015, Ofgem announced that we had won funding for our latest innovation project, Celsius. The first solution of its kind in Great Britain, Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations. The £5.5 million project will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. You can find out more about Celsius and watch our animated video on our new webpage at www.enwl.co.uk/celsius Show less
Jan 2016	Employee overview on the Volt intranet	All employees	 Customer and Business Services Commercial Energy Solutions Finance Networks Strategy and Tech Operations North Operations South Celsius On 30 November 2015, Ofgem announced that we have won funding for our latest innovation project, Celsius. The first solution of its kind in Great Britain, Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations. The £5.5 million project will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. 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. Problem Understanding asset temperature Increased demand Under-used capacity Thermal pinchpoints Celsius Solution Thermal Ratings Tool Retrofit thermal monitoring Retrofit cooling Extra capacity Reduced carbon Reduced costs Related Items Type Name Celsius full submission redacted Add new document
Jan 2016	Article on new project in NewsWire internal magazine	All employees	 Introducing Celsius **Following a successful bid to Ofgem's Network Innovation Competition, we have been granted funding for our latest innovation project, 'Celsius'. We have been awarded £5.5m in funding for this pioneering project, which is the first of its kind in Great Britain.** This is great news and recognises the hard work and dedication of all those involved from across the business in preparing the bid and ensuring its success. Celsius will manage the temperature of electrical equipment in substations to allow additional capacity to be released from existing assets and reduce the cost of network reinforcement for customers. 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 Great Britain. The project, which runs from January 2016 until March 2020, is consistent with our innovation strategy to maximise the use of our existing assets, reduce costs to customers and help speed up the connection of low carbon technologies. The Network Innovation Competition replaces the Second Tier Low Carbon Networks Fund in RIIO-ED1. It's an annual opportunity for electricity network companies to compete for funding for the development and demonstration of new technologies. Funding is provided for the best innovation projects which help all network operators understand what they need to do to provide environmental benefits, cost reductions and security of supply in the future. Steve Cox, Head of Engineering, said: "This is the fifth consecutive successful bid for competitive research and developmental funding, following Capacity to Customers, CLASS, Smart Street and Respond, which is further testimony to our leadership of innovation in the industry and the capability of our people." If you would like to know more about Celsius, please email the Future Networks team at futurenetworks@enwl.co.uk or you can find out about our other low carbon projects at www.enwl.co.uk/future. Sustainability

Date	Activity	Audience	Evidence
Jun 2016	Article in Connect e-bulletin	All employees	Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 103 17 JUNE 2016 LATEST NEWS... **Celsius project hots up** Celsius Following Ofgem's announcement last November on our successful bid for funding, work on our latest innovation project, Celsius, is gathering pace. The first solution of its kind in Great Britain, the £5.5 million Celsius project will explore innovative, cost-effective ways of managing potentially excessive temperatures at distribution substations. This will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. The first stage of Celsius is to gather data from 520 substations, using new temperature monitoring equipment. The data will be analysed to improve our understanding of the relationship between an asset's temperature, load and environment and to develop a 'Thermal Ratings Tool'. Secondly, a range of cooling techniques will be trialled on 100 of the distribution substations to demonstrate the benefits of each technique. Our customer engagement plan will set out how we discuss any potential impact of the cooling techniques with customers and how we engage with all our stakeholders throughout the project. Celsius is funded under Ofgem's Network Innovation Competition which is an annual opportunity for electricity network companies to compete for funding for the development and demonstration of new technologies. Funding is provided for the best innovation projects which help all network operators understand what they need to do to provide environmental benefits, cost reductions and security of supply in the future. This is our fifth consecutive successful bid for this type of funding following in the footsteps of Capacity to Customers, CLASS, Smart Street and Respond. Project manager Damien Coyle said, "Since the start of the year, the Celsius project team have made great progress. We've begun regular meetings with our project partners ASH Wireless and Ricardo to develop the Celsius technology. We have selected the 520 substation sites which will be monitored as part of the project and are now busy designing the installation plan." If you would like to know more about Celsius, you can watch our animated video; visit our webpage; or you can find out about our other low carbon projects at www.enwl.co.uk/thefuture.
Jul 2016	Yammer update	All employees	Andy Howard Follow – July 13 at 11:16am from iPhone Celsius monitoring trial installation commencing today in a very cool and wet Manchester Sensors to be fitted on over 500 distribution sites to help better understand how our assets react to load and if and how we can use this learning to change the ratings of the equipment installed LIKE REPLY SHARE ··· Matt Tregilgas, Phil McFarlane, Geraldine Bryson, and 4 others like this
Jul 2016	Website	All stakeholders	www.enwl.co.uk/celsius
Jul 2016	Industry newsletter	All stakeholders	Newsletter page
Jul 2016	Website promoted on Yammer	All employees	Jane Stell – July 27 at 1:33pm Our Celsius project website is now live. The £5.5 million low carbon project will explore innovative, cost-effective ways of managing temperatures at distribution substations. This will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. Find out more at www.enwl.co.uk/celsius www.enwl.co.uk A co-ordinated approach to managing the temperature of electrical assets We use cookies to ensure that we give you the best experience on our website. If you continue without changi...
Aug 2016	Webinar promoted on Linked In	All stakeholders	electricity north west Bringing energy to your door Announcement in Low Carbon Networks Forum Celsius webinar, Thursday 1 September 2016 Jane Stell Communications Manager, Electricity North West Register for our first webinar on our innovative project, Celsius, at https://www.eventbrite.co.uk/e/celsius-webinar-2016-registration-26917765762. Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. You can find out more about Celsius at www.enwl.co.uk/celsius.

Date	Activity	Audience	Evidence
Aug 2016	Webinar promoted on Twitter	All stakeholders	**ElectricityNorthWest** @ElecNW_News Join us on Thurs 1 Sept for our #future networks Celsius #webinar. For more information & to register visit: goo.gl/bhN8VE 1:49 pm - 19 Aug 2016 **Celsius Webinar 2016** Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. The £5.5 million... Eventbrite @eventbrite
Sep 2016	Webinar	All stakeholders	Webinar recording Webinar slides and feedback
Sep 2016	Webinar recording promoted on Linked In	All stakeholders	Jane Stell Communications Manager, Electricity North West OWNER ••• Just now **Watch our new Celsius webinar** On 1 September we held our first webinar for our Network Innovation Competition project, Celsius. Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. You can watch a recording of the webinar at http://www.enwl.co.uk/celsius/about-celsius/videos-and-podcasts Show less
Sep 2016	Webinar recording promoted on Twitter	All stakeholders	**ElectricityNorthWest** @ElecNW_News Catch up on our low carbon Celsius project by watching our first webinar here enwl.co.uk/celsius/about-... #poweringthefuture 11:06 am - 2 Sep 2016
Sep 2016	Webinar promoted internally in Connect e-bulletin	All employees	**Connect** The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 114 2 SEPTEMBER 2016 **LATEST NEWS...** **First webinar for Celsius** Celsius Yesterday we held our first webinar for our Network Innovation Competition project, Celsius. The webinar included an outline of the project, an update on our progress to date and provided our stakeholders with an opportunity to ask questions and engage with the project team. Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. The £5.5 million project, which runs from January 2016 until March 2020, will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. Project manager Damien Coyle who presented the webinar said: "Webinars are a great opportunity to reach our stakeholders and promote our innovation projects. Using this kind of technology means we can share information and engage with an audience without everyone having to travel to one place – which is great for our carbon footprint." If you would like to see the webinar you can watch a recording, see the slides or for more information on the project visit the Celsius website.
Oct 2016	Advertorial	Industry stakeholders	Advertorial
Oct 2016	LCNI conference	Industry stakeholders	Slide presentation
Oct 2016	Industry newsletter	All stakeholders	Newsletter page

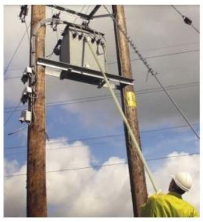
Date	Activity	Audience	Evidence
Oct 2016	Promotion of LCNI conference in internal magazine and Connect e-bulletin	All employees	 Innovation Flying the flag at our industry conference Innovation as business as usual We have already seen a number of our innovation projects adopted into our day-to-day processes People  Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 120 14 OCTOBER 2016 LATEST NEWS... **Flying the flag at our industry conference** Earlier this week many of our colleagues attended the Low Carbon Networks & Innovation Conference at Manchester Central. As the conference took place in our region, Electricity North West co-hosted the event with the Electricity Networks Association. This meant we had a great opportunity to promote our brand and fly the flag for Electricity North West. Around 1300 delegates attended the three-day event which showcased our network innovation projects through a programme of project-focused presentations and workshops. Our innovation team presented on a number of themes, including a workshop on our strategy for the future of customer service, and our key innovation projects: Celsius, Respond, Smart Street and CLASS. There was also an opportunity to share findings from our smaller-scale projects on oil regeneration and demand scenarios. Engineering & Technical Director, Steve Cox, said: "This year's event has been better than ever. It's a fantastic way to see firsthand how our sector is changing. It was also a great year for Electricity North West as co-host. Our new exhibition stand stood out from the crowd with our distinctive branding and the creative ways we used to promote our innovation strategy and our projects." You can find out more about the conference and watch out short highlights video at www.enwl.co.uk/lcni2016. Back to top
Jan 2017	Innovation roadshow	All employees	
Mar 2017	Article in Connect e-bulletin	All employees	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 142 24 MARCH 2017 LATEST NEWS **Celsius project gathers steam** Work to deliver our £5.5 million innovation project Celsius is progressing well, 15 months into the four-year timeline. Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. The project will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. The first stage of Celsius is to gather data from 520 substations, using new temperature monitoring equipment. Project manager Damien Coyle told us, "The rollout of monitoring equipment is now in its final stages, with more than 300 of the sites installed and already gathering data. The data is being analysed by our project partner Ricardo to improve our understanding of the relationship between an asset's temperature, load and environment. "The result of this analysis will lead to the development of a 'thermal ratings tool' which will enable us to understand what additional capacity can be released from our substations. "We're also working with the National Physics Laboratory on a 'thermal flow study' to analyse the heat and air flows in substations. This will influence the design of our substations in the future and potentially show how air flow in existing substations can be improved." The second part of Celsius is to test a range of cooling techniques on 100 of the trial substations. We are now busy researching different cooling techniques which we will trial next year. As the cooling techniques will be deployed at substations close to homes and businesses, we will carry out a programme of engagement to understand any audible or visual impact of the techniques on our customers.

Date	Activity	Audience	Evidence
Apr 2017	Celsius promoted on Twitter	All stakeholders	
May 2017	Industry newsletter	All stakeholders	Newsletter page
Jul 2017	Innovation learning event on social media	All stakeholders	
Jul 2017	Innovation learning event on social media	All stakeholders	
Jul 2017	Innovation learning event on social media	All stakeholders	
Jul 2017	Innovation learning event	All stakeholders	Slide presentation and survey results
Jul 2017	Promoting ECPs on Twitter	All stakeholders	
Aug 2017	Industry newsletter	All stakeholders	Newsletter page
Oct 2017	Advertorial	All stakeholders	Advertorial

Date	Activity	Audience	Evidence
Nov 2017	Industry newsletter	All stakeholders	Newsletter page
Dec 2017	LCNI conference	Industry stakeholders	Slide presentation
Jan 2018	Industry newsletter	All stakeholders	Newsletter page
Mar 2018	Internal comms	Mar 2018	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 194 29 March 2018 LATEST NEWS **Celsius starts to cool down substations** As part of our pioneering Celsius project we are installing a range of cooling techniques at 100 substations across the region which will help prepare our network for renewable energy and keep costs down for customers. Over the next 12 months techniques such as improved ventilation, heat extraction fans and alternative kinds of backfill material for underground cables will help cool down substations and maximise the use of our assets. The cooling techniques will be installed at 100 of the 520 sites where temperature monitoring equipment was fitted last year. Data from the substations is being used to understand how the environment and temperature affect the electrical equipment and how cooling can help release more power onto the electricity network. At the same time we'll be carrying out a series of surveys to find out what customers living near the substations think of the new techniques. Celsius will deliver a co-ordinated approach to managing the temperature of electrical assets in distribution substations and is the first solution of its kind in Great Britain. The project will release additional capacity, reduce long-term costs for customers and avoid early asset replacement. Find out more at www.enwl.co.uk/celsius or if you have an idea for an innovation project please contact us.
Apr 2018	Industry newsletter	All stakeholders	Newsletter page
Jul 2018	Innovation learning event on Twitter	All stakeholders	
Jul 2018	Learning event in internal Connect e-bulletin	All employees	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 208 6 July 2018 LATEST NEWS **Innovation on show** Earlier this week our innovation team held their second annual learning event at the Manchester Museum of Science and Industry. Around 50 industry stakeholders, including representatives from other Distribution Network Operators (DNO) and project partners, attended the event and listened to presentations on our innovation strategy and our portfolio of projects. Our Innovation Manager Paul Turner was joined by Innovation Engineers Paul Marshall, Ben Ingham and Dr Geraldine Paterson, who presented on our Respond, Smart Street and Celsius projects. Distribution Systems Operator (DSO) Transition Manager, Steve Shaw provided an update on our distribution system operator vision and strategy. In the afternoon delegates took part in a choice of breakout sessions on: Sentinel, presented by Kieran Bailey and Kelvatek; ATLAS, presented by Dr Christos Kaloudas; community energy presented by Helen Seagrave; and the Value of Lost Load, presented by Tracey Kennelly, and our partner Impact Research. At the end of the event, delegates were challenged to an innovation quiz to see if they were paying attention to the presentations! Feedback from delegates was extremely positive with 95% rating the overall event as good or excellent. You can see all the day's presentations including our delegate feedback poll on our website. If you have an idea for an innovation project please get in touch with the team.

Date	Activity	Audience	Evidence
Jul 2018	Innovation learning event	All stakeholders	Slide presentation
Aug 2018	Industry newsletter	All stakeholders	Newsletter page
Aug 2018	Media release	All stakeholders	Media release
Aug 2018	Celsius on Twitter	All stakeholders	
Aug 2018	Celsius in local media	All stakeholders	 LANCASTER GUARDIAN £5.3m project aim is to keep costs down Electricity North West Celsius substation cooling. **Electricity North West is trialling a range of cooling techniques at 100 substations across the region, including two in Morecambe and one in Lancaster, to prepare the electricity network for renewable energy and keep costs down for customers.** The trial is all part of a £5.3 million pioneering project called Celsius, which is the first of its kind in Great Britain. Techniques such as improved ventilation, heat extraction fans and alternative kinds of material for filling cable trenches, will cool down substations and help get more out of the substation equipment. The sites were chosen to be representative of the majority of substation types and locations across Great Britain and include 72 sites in Greater Manchester, 19 sites in Lancashire and nine sites in Cumbria.
Sep 2018	Advertorial	All stakeholders	Advertorial

Date	Activity	Audience	Evidence
Oct 2018	Industry newsletter	All stakeholders	Newsletter page
Oct 2018	LCNI conference	Industry stakeholders	Slide presentation
Jan 2019	Customer contact centre briefing	Contact centre colleagues	Evidence on file
Mar 2019	Industry newsletter	All stakeholders	Newsletter page
Mar 2019	Article in Connect e-bulletin	All employees	 Connect The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 245 22 March 2019 LATEST NEWS **Celsius project hots up** We're only part-way through our pioneering Celsius project, but it's already 'business as usual' for one of our new cooling techniques. As part the project we've installed a range of techniques at a hundred substations across the region which will help prepare our network for renewable energy and keep costs down for customers. Techniques such as improved ventilation, heat extraction fans and alternative kinds of backfill material for underground cables are helping to cool down substations and maximise the use of our assets. Project manager Delroy Ainsworth said: "As well as the Celsius trial sites, we've installed one of our 'Passcomm' units at a substation in Manchester to help cool down a transformer which was starting to over-heat. We're now working to identify another site to install a redesigned Passcomm unit which is smaller and more efficient but still provides the same cooling effect. "We're only part-way through the trials, but we're already able to demonstrate that the cooling techniques can be used effectively – which is great news. We're now starting to incorporate Celsius techniques into our business as usual processes." Throughout the trials we're gathering data from the trial substations to understand which of the different techniques are most effective and how the environment and temperature affect our electrical equipment. At the same time we're also carrying out a series of surveys to find out what customers living or working near to the substations think of the new techniques. The final phase of this research is under way which will help us to decide which of the Celsius techniques are most suitable under different network and environmental conditions. Find out more on our website or if you have an idea for an innovation project please contact us.
Oct 2019	Advertorial	All stakeholders	Advertorial
Oct 2019	Industry newsletter	All stakeholders	Newsletter page
Oct 2019	LCNI conference	Industry stakeholders	Slide presentation
Nov 2019	Learning event	Industry stakeholders	Slide presentation

Date	Activity	Audience	Evidence
Mar 2020	Article in Connect e-bulletin	All employees	**Connect** The weekly bulletin for our people Stay connected... electricity north west Bringing energy to your door ISSUE 296 27 March 2020 LATEST NEWS **Celsius project is hot stuff**  This month sees the closedown of our pioneering Celsius project, the first solution of its kind in Great Britain. As part of the project we have successfully trialled 'thermal monitoring' at 520 substations across the North West, and installed a range of retrofit cooling techniques at 100 of the trial sites. Usually the amount of power we transmit through a transformer is limited by its manufacturer's rating which protects it from overheating. But thermal monitoring allows us to better understand the temperature of the transformer and release its full available capacity. In addition we trialled a range of retrofit cooling techniques, such as improved ventilation, heat extraction fans and alternative kinds of backfill material for underground cables, which help to cool down substations and maximise the use of our assets. The £5.5 million project has proved that capacity can be released simply by installing thermal monitoring, and the addition of the retrofit cooling techniques can release even more capacity. Both techniques reduce long-term costs for customers, avoid early asset replacement and prepare our network for renewable energy. If rolled out across our network, Celsius techniques could save customers £31 million over the next 30 years, and £399 million if rolled out across Britain. Dan Randles, Head of Network Innovation, said, "We are delighted by the success of the Celsius project and confident it will follow in the footsteps of our other industry-leading projects, CLASS and Smart Street, which are already business as usual and bringing substantial benefits to our customers. "One of the Celsius substation cooling techniques has been so successful during the trial that we've already started using it as 'business as usual' to avoid potentially costly replacement of assets". Throughout the trials we gathered data from the trial substations to understand which of the different techniques were most effective and how the environment and temperature affect our electrical equipment. At the same time we carried out a series of surveys to find out what customers living or working near to the substations thought of the new techniques. The next steps for the project are to publish a detailed closedown report on our website and to incorporate Celsius techniques into our business as usual processes. Find out more about Celsius on our website, or if you have an idea for an innovation project please contact the innovation team.

C: Key project learning documents

Project progress reports

Title	Date	Website link
Project progress report no 1	9 June 2016	Progress report no 1
Project progress report no 2	9 December 2016	Progress report no 2
Project progress report no 3	9 June 2017	Progress report no 3
Project progress report no 4	9 December 2017	Progress report no 4
Project progress report no 5	8 June 2018	Progress report no 5
Project progress report no 6	6 December 2018	Progress report no 6
Project progress report no 7	7 June 2019	Progress report no 7
Project progress report no 8	9 December 2019	Progress report no 8

Key learning documents

Title	Date	Summary
Technology		
Cooling technology selection report	May 17	Final scoring and selection of cooling technologies following workshop with other distribution network operators, held in May 2017.
Cooling technology selection report	July 17	Describes the monitoring equipment deployed on the Celsius project, including specifications, installation and data management.
Equipment specification and site installation report	Nov 18	Describes the cooling equipment deployed on the Celsius project including specifications and installations.
Customer		
Customer engagement plan	Jun 16	Sets out how we will engage with customers during the project to assess any impact of the Celsius cooling technologies.
Data privacy statement	Jun 16	How we will manage customers' personal data during the Celsius project and how we comply with the Data Protection Act 1998.
Customer focus groups lessons learned	Dec 17	Results and learning associated with testing Celsius communication materials, to be used as part of the customer survey.
Customer survey report	Sep 19	This report references the key findings from three phases of engagement carried out to quantify the acceptability to customers of the Celsius retrofit cooling technologies.
Trials		
Thermal flow study phase 1	Nov 17	Report from the National Physical Laboratory which analyses the heat and air flows in substations.
Asset temperature report	Sep 18	Analysis of the findings from Stage 1 of the Celsius trials which aims to develop a detailed understanding of the operating temperature of assets.

Title	Date	Summary
Asset health study	Oct 18	A review of the asset health implications of deploying Celsius technologies on the Electricity North West network.
BAU monitoring solution specification	Sep 19	Specification and requirements of a business as usual monitoring solution which will allow more informed transformer ratings to be estimated.
Enhanced thermal ratings tool – final	Nov 19	Thermal ratings tool enhanced with data and analysis gathered during the retrofit cooling trials.
Carbon impact assessment	Dec 19	Report on the carbon impact of Celsius technologies compared to traditional interventions.
Cost benefit analysis and buy order – final	Dec 19	Cost benefit analysis and buy order for the Celsius technologies developed during the project and recommended for business as usual.

D: Closedown report peer review

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Mr D Ainsworth
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M6 6AP

25 March 2020

Dear Mr Ainsworth

Celsius Closedown Report peer review

Thank you for having the opportunity to review the Celsius project closedown report. It was interesting to read the outcomes of the project and the learning obtained through the trials. From the closedown report, it is understood that the project has been able to demonstrate that:

- in most cases, the Celsius rating is higher than the nameplate rating and this can be increased further with the addition of retrofit cooling;
- the Celsius techniques can be applied faster and at lower cost than traditional methods, which enables them to be deployed at times of rapid change in the network demand; and
- the project has provided valuable learning about distribution substations and the factors that affect the temperature of network assets.

The report was clear and understandable with sufficient information included to allow other Network Operators the opportunity to consider the learning and recommendations when faced with distribution substations that are beginning to see periods of high load close to the rating of assets.

Finally, members of the Asset Management team are interested in the planned implementation section describing the BAU approach to considering whether Celsius interventions were appropriate or traditional reinforcement was required. They are aware of the project outcomes and are considering the use of the enhanced thermal ratings tool and intervention tool to defer transformer reinforcement.

Yours sincerely

P Lang

Peter Lang
Senior Technology Transfer Engineer
UK Power Networks