Energy Efficiency Directive

An assessment of the energy efficiency potential of the gas and electricity infrastructure of Great Britain

Contents

1. Introduction

This section describes the directive, the overall objectives and structure of the report.

1.1. The directive

The Energy Efficiency Directive (EED) was agreed by Member States in 2012 and the transposition deadline was 5 June 2014. The EED covers multiple aspects of the energy system; from supply, transformation, transmission and distribution to consumption.

The EED required Member States to set themselves a non-binding national energy efficiency target by 30 April 2013 and seeks to ensure the achievement of the EU's 2020 target to reduce primary energy consumption by 20% compared to a 2007 business as usual projection.

In June 2014, the UK passed certain provisions of the EED through "The Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014". Regulation 6, shown in Figure 1, established an obligation on the Gas and Electricity Markets Authority (GEMA) to report to the Secretary of State on the energy efficiency potential of the energy networks in Great Britain (GB) and the cost-effective measures to improve their energy efficiency.

> *"Before or on 30th June 2015 the Gas and Electricity Markets Authority must deliver to the Secretary of State –*
>
> *(a) an assessment of the energy efficiency potentials of the gas and electricity infrastructure of Great Britain in particular regarding transmission, distribution, load management and interoperability, and connection to energy generating installations, including access possibilities for micro energy generators;*
>
> *(b) a list identifying concrete measures and investments for the introduction of cost-effective energy efficiency improvements in the network infrastructure, with a timetable for their introduction."*

Figure 1 – Regulation 6 extract[1]

This report has been compiled in accordance with the above requirement. Ofgem[2] has engaged with the energy network companies in GB to carry out this assessment. This report presents the findings to date from this engagement. A separate assessment of energy networks in Northern Ireland is being prepared by the Northern Ireland Authority for Utility Regulation.

1 http://www.legislation.gov.uk/uksi/2014/1403/regulation/6/made

2 The Office of Gas and Electricity Markets (Ofgem) supports GEMA in its day to day work

1.2. How GB is fulfilling the assessment requirement

The EED Regulation 6 asks for an assessment of the energy efficiency potentials of the gas and electricity infrastructure of GB. One way to improve energy efficiency is to reduce wastage. In the gas sector this wastage is referred to as shrinkage and in the electricity sector as losses. Reducing shrinkage and losses is recognised as the most effective method of improving energy efficiency of networks. The potential for shrinkage and loss reduction will be the focus of this assessment.

Two working groups were set up in 2014 after the regulation was transposed into law; one for gas and one for electricity. Each group focused on their area of expertise. This report brings together the findings of these workshops to date, on assessing the current and future potential for reducing losses on GB's gas and electrical networks. The objectives of these working groups were:

- To gather information on the companies' shrinkage or loss reduction measures;
- To assess the costs and benefits of employing these measures; and
- To agree a timetable for the adoption of concrete measures and identify other potential measures.

Both working groups have presented their findings in this report. Ofgem is seeking views from wider stakeholders on the contents of this assessment report, from 12 March until 9 April 2015. It asks whether this report fulfils the requirements of the Directive, and whether any other information is required. Ofgem will analyse these responses and work with the working groups to complete the assessment report. The final report will be delivered to the Secretary of State on 30 June 2015.

1.3. Structure

This report has two distinct sections; firstly on electricity and secondly on gas. Both follow the same logic and structure. A background on losses/shrinkage will be provided, giving a technical overview, and details of the regulatory approach, the outputs of which have been used as the base information for this assessment. This is followed by an overview of GB's networks today, setting current estimates of losses/shrinkage volumes on GB's networks that we can carry out the assessment of the energy efficiency potential against. Then the barriers, enablers and uncertainties are explained. These are factors that affect the potential of loss/shrinkage reduction which must be taken into consideration.

The center of the report is the current measures section. This describes what current measures are being adopted by the companies, covering distribution and transmission networks. Timeframes for current measures in line with the current price control periods (GD1, ED1 and T1) are also provided. This is followed with the potential measures section describing measures that have been identified as being potentially effective at reducing shrinkage/losses at some point in the future, but are currently not economically or technically feasible.

Both the electricity and gas sections of the report will be followed with a conclusion to the assessment.

Electricity Networks

2. Background on losses

A description of the different types of losses is provided with a background of the technical aspects. This will identify the types of losses the report will cover.

2.1. What are losses?

The amount of energy that enters an electricity network is more than the amount that is delivered to customers. The principal reason for this is that an electricity network consumes energy in the process of delivering power to customers. This is known as a **technical loss**.

Energy lost, not directly as a function of the delivery to customers, is referred to as a **non-technical loss**. This mainly covers extraction of electricity from the network, i.e. theft.

All companies are obliged to run an efficient and economic system as a condition of their Licence. An efficient and economic system is one where losses are managed to the most economic level.

2.1.1. Technical losses

Technical loss is made up of two elements; a fixed amount (a function of the network itself, irrespective of the usage of the network) and a variable amount which is dependent on the amount of energy moving through the network. The variable loss will change as demand increases and decreases. Additional factors such as the effect of network imbalance, power factor and power quality can also have an impact on technical losses.

Fixed losses

The fixed element of losses is the energy which is required when plant such as transformers or conductors are energised. For example, as transformers require electrically produced magnetic fields to operate, the energy used to create these fields is dependent on the applied voltage, but is essentially fixed as the applied voltage is relatively stable while they are energised.

Variable losses

The variable element of losses is created due to the heating effect of energy passing through conductors. These conductors have a small resistance and when currents are passed through them, they heat up. This heating effect is a function of the resistance and the square of the current flowing through the conductor. High load (when an item of equipment is running near or at full capacity) produces proportionally more losses than when an item of plant or network is partly loaded.

The resistance of a cable reduces as its cross sectional area increases so the effect of losses is reduced in larger cable sizes. There is a very similar variable loss element created through the wires and windings which are found in all transformers. The cross sectional area of winding conductors, and the material used for them, dictates the level of losses seen in transformers.

Imbalance

The UK network operates on three phases where energy is mostly transported along three conductors. A network which is not balanced across all three phases will have higher currents in at least one phase. Due to the non-linear relationship of losses with the current, these imbalanced currents can increase losses compared to a “balanced” flow.

The nature of the GB low voltage (LV) network, which distributes energy using mostly a three phase system, with primarily single phase customers connected, dictates that there will always be a certain degree of imbalance. This imbalance is changing all the time as the connected loads increase and decrease. On higher voltage networks, imbalance can be caused by multiple factors including the uneven distribution of single phase transformers or two wire spurs. In order to rebalance the network, first the imbalance must be identified and then the connection redistributed across the three phases. It is worth noting that perfect balance is not possible as the load will ebb and flow throughout the day as customers use energy as they need it.

Power factor

Power factor is a ratio between the real power and apparent power flowing through a conductor. Apparent power is the scalar product of the current and the voltage of the conductor. Where the power factor is less than unity the total current has to increase to deliver the required amount of power, and hence the losses increase. Traditionally larger industrial and commercial installations have had a bigger impact on power factor, however it is implicit with all energy usage, including domestic customers.

2.1.2. Non-technical losses

Energy lost that is not directly related to the transportation of electricity through the system is categorised as a non-technical loss. Such as in substation buildings and their associated equipment. In substations, energy is consumed by the following systems:

- Battery charging
- Transformer cooling (fans and pumps)
- Protection and control systems
- Substation auxiliary supplies – heating, lighting and security systems.

Situations where there is no registered supplier at a connection point or no meter installed also occur from time to time. In many cases however, non-technical losses are due to illegal activities for example, bypassing the meter.

2.2. Regulatory approach to managing losses[3]

Ofgem has placed licence obligations on the companies to ensure that losses are as low as reasonably practicable. This is combined with the requirement for all companies to justify expenditures in their business plans on managing network losses, as part of their carbon reduction methodology. The information provided in the companies' losses strategies has been used as the basis for this report.

2.2.1. Distribution Networks

The GB electiricy distribution network operators (DNOs) consist of six large incumbent companies and a multitude of smaller independent distribution network operators (IDNOs). The six DNOs are illustrated in Figure 2. Both DNOs and IDNOs are regulated by Ofgem through a licence, which includes a requirement to keep losses as low as reasonably practicable.

Figure 2 – Who operates GB's electricity distribution networks?[4]

[3] https://www.ofgem.gov.uk/ofgem-publications/47067/riioed1decoverview.pdf
[4] http://www.energynetworks.org/info/faqs/electricity-distribution-map.html

RIIO-ED1 losses mechanism

The latest price control period; called Revenue = Incentives + Innovation + Outputs – Electricity Distribution 1 (RIIO-ED1) that runs from 1 April 2015 to 31 March 2023 introduced a losses reduction mechanism comprising:

- A licence obligation for DNOs to ensure that losses are as low as reasonably practicable;
- A licence obligation for DNOs to investigate and resolve any cases of 'relevant theft of electricity' from their distribution systems;
- A requirement to maintain and act in accordance with a Distribution Losses Strategy;
- Ex-ante funding for efficient loss reduction activities;
- A reporting requirement on loss reduction actions taken and actions planned each year; and
- A discretionary reward for efficient and innovative loss reduction initiatives of up to £32m available over the RIIO-ED1 period.

Electricity Distribution Losses Management Obligation and Distribution Losses Strategy:

The licensee must:

- "**Design, build, and operate its Distribution System** in a manner that can reasonably be expected **to ensure** that **Distribution Losses are as low as reasonably practicable"**
- "**maintain a Distribution Losses Strategy** and must keep it under review and **where necessary modify it** from time to time **to ensure that it remains**:

  (a) **calculated to ensure that Distribution Losses are as low as reasonably practicable**; and

  (b) based upon an **up-to-date cost-benefit analysis."**
- "Undertake **all reasonable cost-effective steps** within its power to **resolve any cases of Relevant Theft** of Electricity from its Distribution System."
- "**Report on its actions to manage Distribution Losses and to deal with Relevant Theft of Electricity** in accordance with the requirements of any relevant RIGs issued" and "**publish information about those actions"**

Figure 3 – RIIO-ED1 Licence condition overview

The RIIO-ED1 strategy decision also states that DNOs should set out proposals to establish a reliable losses baseline in ED1 to enable the introduction of an incentive mechanism in ED2 (1 April 2023 to 31 March 2031).

2.2.2. Transmission networks

Three companies own GB's onshore transmission networks, illustrated in Figure 4. Transmission Network Owners (TOs) are required to publish a strategy setting out how they intend to minimise transmission losses over the price control period.

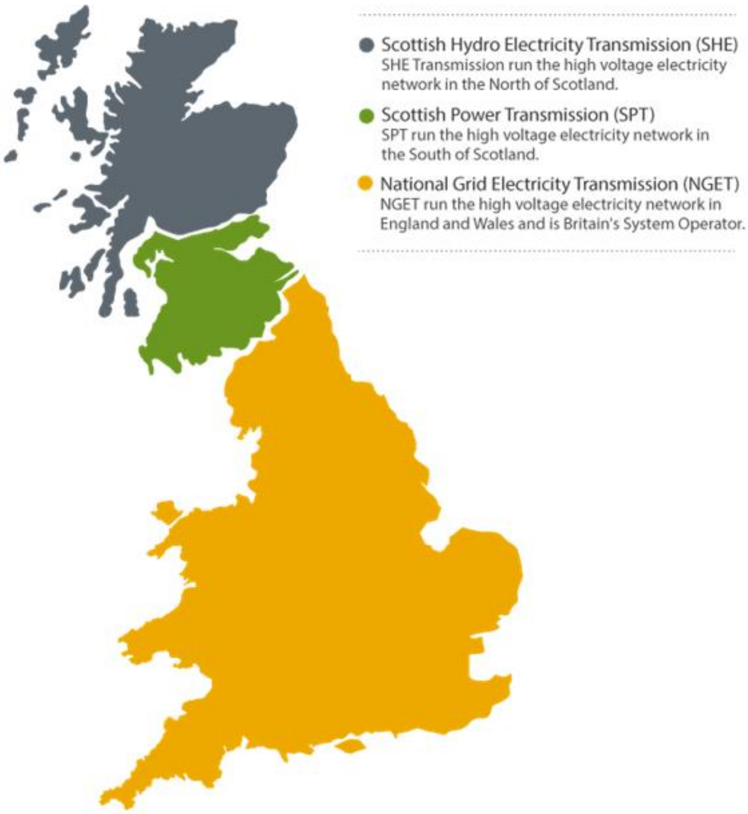

Figure 4 – Who owns GB's electricity transmission networks?[5]

The TO licence condition on losses provides guidance on what the losses strategy should include. It should include but is not limited to:

- a description of the methodology used by the licensee to take transmission losses into account when planning load related reinforcements to the licensee's Transmission System;
- a description of the licensee's methodology to take transmission losses into account when the licensee is planning non-load related asset replacement programs on the licensee's Transmission System;
- a description of how the licensee determines the optimal specifications in relation to transmission losses arising from the operation of new equipment in its asset procurement processes;

[5] https://www.ofgem.gov.uk/network-regulation-%E2%80%93-riio-model/energy-network-how-it-works-you

- a summary of key developments to the licensee's Transmission System and estimates of the impacts those developments will have on transmission losses on the licensee's Transmission System;
- a summary of the licensee's asset replacement programs and estimates of the impacts those programs will have on transmission losses on the licensee's Transmission System; and
- a description of the potential application of new and alternative technologies to the licensee's Transmission System during the Price Control Period and the impact these technologies may have in relation to transmission losses.

The TOs are required to publish an annual losses report for the previous year which should include in reasonable detail the level of losses on its system, a progress report on the implementation of its strategy and any revisions it has made to the strategy.

As the System Operator (SO) for the National Electricity Transmission System in GB, National Grid Electricity Transmission (NGET) is required to publish and maintain an up to date explanation of how transmission losses are taken into account when procuring Balancing Services in order to balance electricity supply and demand. NGET is also required to publish monthly data showing the total volume of historic transmission losses and an indication of the cost of transmission losses from the NETS. Additionally NGET is required to publish information or provide details of the location of information which:

- identifies and explains the expected drivers that may impact the total volume of expected transmission losses on the NETS over the course of the next ten years; and
- a description of how the licensee takes expected transmission losses over the course of the next ten years into account when undertaking its planning activities in relation to the Balancing Services Activity.

3. GB's networks today

A description of current losses on GB's networks that will act as the baseline for assessing the losses reduction potential.

3.1. GB system losses

The total energy lost on the GB network is estimated by subtracting the volume of energy units known to be delivered to customers from the volume of units that originally entered the network.The cost of the losses is apportioned amongst customers and forms part of a customer's electricity bill. While the current losses calculation is a good guide to overall performance, it has a number of limitations. For example, today's domestic metering does not record when energy is used between each reading. Meters record the volume of energy, therefore it is not possible to completely align measurements of energy entering and leaving the network. Similarly, this estimate is complicated by the use of non-metered energy, including fraudulent use (theft).

In 2013, losses as a proportion of demand on GB's networks were estimated to be 7.2 per cent.[6] Losses can be split into three components; transmission losses, distribution losses and theft, demonstrated in Figure 5. It is clear from Figure 5, that distribution networks account for the majority of electricity network losses.

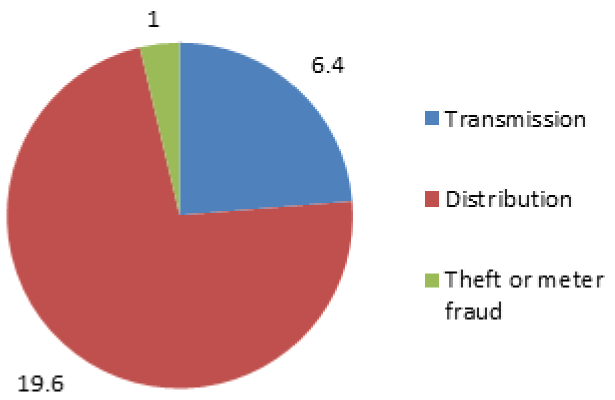

Figure 5 – Losses as a proportion of electricity demand in 2013 (TWh)[6]

[6] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337649/chapter_5.pdf

3.2. Distribution losses

Figure 6 gives an indication of how the losses are distributed across the distribution network assets.[7]

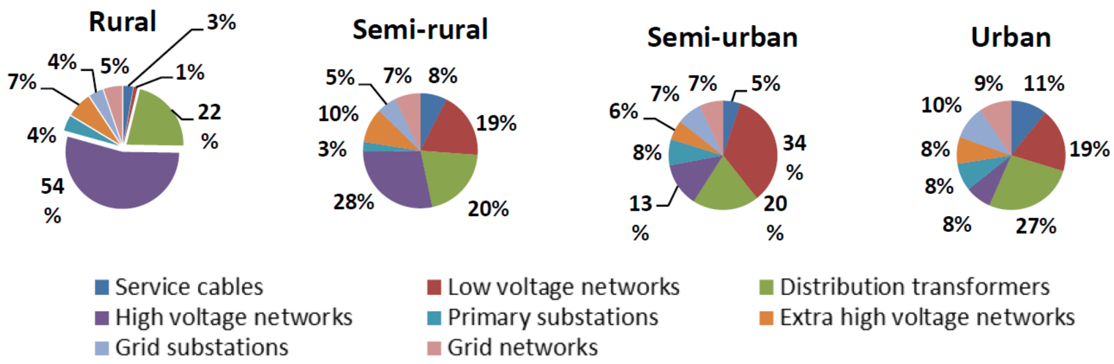

Figure 6 – Breakdown of losses across distribution networks in four types of network

The breakdown in Figure 6 indicates that at the distribution level, LV networks produce proportionally the most losses. Across these types of networks, the service cable and LV cables supplying electricity to properties account for 25% of distribution losses. The distribution transformers add another 22% with the high voltage (HV) network accounting for another 25%. The extra high voltages make up the remaining 28%.

3.3. Transmission losses

Transmission losses are calculated by NGET on an annual basis, based on metered generation and demand data. The calculation is based on the latest applicable settlement metering currently available for generation, demand and French / Moyle Interconnector Balancing Mechanism Units (BMUs), together with operational metering for the boundaries between the Scottish Hydro Electric and Scottish Power systems and the Scottish Power and England and Wales systems.

Overall the losses arising from the GB transmission system are calculated by taking the difference between the sum of infeed to and the sum of the offtakes from the transmission system. This is carried out using data from the Elexon SAA-I014 data feed[8]. At a GB level the Total Generation (sum of positive metered active power) and Total Demand (sum of negative metered active power) values can be used.

[7] http://www.westernpower.co.uk/docs/Innovation-and-Low-Carbon/Losses-strategy/SOHN-Losses-Report-Executive-Summary.aspx

[8] https://www.elexon.co.uk/data-flow/settlement-report-saa-i014-also-known-as-the-s0142/

The losses for the three GB transmission areas are presented in Table 1.

Losses volumes (TWh)	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
East / West	4.80	5.12	5.15	4.92	5.36	4.22	5.23	4.93	4.45
South Scotland	0.58	0.69	0.74	0.67	0.49	0.53	0.55	0.44	0.49
North Scotland	0.22	0.30	0.29	0.37	0.29	0.24	0.36	0.27	0.38
GB	**5.60**	**6.10**	**6.18**	**5.96**	**6.14**	**4.99**	**6.14**	**5.64**	**5.32**

Table 1– Annual Transmission losses per region

3.4. Interoperability

Interoperability is the ability to make systems work together (inter-operate) and takes into account social and organisational factors that impact system to system performance. This report focuses on the measures in place to reduce losses and therefore the term interoperability is understood to relate to the systems defined in this report working together to reduce losses. In this section the systems are considered to be electricity transmission and electricity distribution.

This section discusses how interoperability is addressed and accounted for in terms of loss reduction.

Whole system planning

The GB model has clearly defined boundaries of ownership and responsibility for the management of losses. Recent licence changes require the companies to produce and publish loss strategies that identify the measures in place to manage losses.

The responsibility for loss management resides with the individual company as set out in section 2.2, however there is an implicit requirement for the transmission owner and the distribution owner to coordinate work. The Planning Code[9] objective is to promote TO / User interaction in respect of any proposed development on the user system which may impact on the performance of the transmission system.

When work is implemented or undertaken that could impact either networks, interaction occurs, including the exchange of information from both parties in order that planning and development can be undertaken in accordance with the relevant Licence Standards. Loss management is now a factor of the Licence Standards mentioned in section 2.2 and, by default, it is a consideration in the proposed development.

[9] The Grid Code; Planning Code; PC.2.1

Both cases of the Planning Code requirements and the Operating Code requirements involve the flow of information about the development plans and the current state and the future state of the network and both contain measures that will mitigate losses.

As these loss mitigation measures are recorded against the asset (for example, transformers, conductors), for the purposes of this report the loss reduction measure is also reported against the asset. In this scenario it can be demonstrated where the benefit lies, which will prevent double accounting of losses. For completeness, this process does not capture upstream and downstream indirect losses that may be gained through these actions.

4. Barriers, enablers and uncertainties

4.1. Enablers

Losses reduction mechanism

In the latest electricity distribution price controls, Ofgem introduced a losses reduction mechanism consisting of four components: licence obligation, loss reduction expenditure in the business plans, annual reporting and discretionary reward (see section 2.2). This ensures DNOs have access to funding for cost effective loss reduction measures, have an up to date strategy on how to reduce losses on their networks and have a financial and reputational incentive to reduce losses.

Ofgem developed a standard cost benefit analysis spreadsheet for network companies so they could take a 'whole life' approach to network reinforcement. This tool takes into account the cost of losses at £48.42/MWh (in 2012-13 prices). This approach is expected to facilitate the implementation of loss reduction solutions that may not have been considered previously.

Distributed generation

Generation produced and used locally can result in a reduction in the requirement to transfer energy over large distances and hence result in a saving in network losses. There are a number of specific regulatory measures in place to support the uptake of distributed generation. In the UK, an incentive scheme is in place for companies to help facilitate the connection process from a customer perspective. The scheme is referred to as 'Incentive on Connections Engagement' (ICE)[10] and comes into force in 2015. The incentive requires the companies to report on their strategy for engaging with relevant stakeholders in the connections process (see Figure 7).

[10] https://www.ofgem.gov.uk/ofgem-publications/91745/riio-ed1guidanceice041214.pdf

> ***Background***
> *1.1 Connecting customers to the network is a critical function of electricity distribution licensees ("licensees") that delivers benefits both to individual customers and society more broadly. A good connection service that aligns with customers' needs allows for new homes to be habitable, businesses to commence operations and distributed generators to export low-carbon energy.*
>
> *1.2 Through our engagement with connection customers during the development of RIIO-ED1 it became apparent that the needs and demands of small, mainly domestic connection customers were different to the needs of larger, often commercial connection customers.*
>
> *1.3 The aim of this incentive is to replicate the effects of competition and drive licensees to understand and meet the needs of larger connections customers (as outlined in paragraph 1.5). This may involve improving timeliness of connections, extending the provision of information or enhancing the overall customer experience. This incentive may also improve coordination with other utility connection providers and facilitate connection customers participating in joint connection arrangements*

Figure 7 –Extract from 'Incentive on Connections Engagement Guidance Document'

Lower network utilisation

Losses are comparatively higher when the network utilisation is running near to capacity, reducing the time that the network is near capacity will relatively reduce the losses; particularly those at LV and HV levels. Therefore the most simplistic 'enabler' available is to increase the capacity of the network; this could be increasing conductor / transformer size or reducing peak power flows.

Lowering the time that the network is running at capacity can be realised by installing larger or more assets, which means more initial network investment and therefore an initial increase in cost. However there is a balance between network investment and reducing losses. The concrete measures in this report reflect a positive total life cycle benefit.

Smart meters give customers an opportunity to manage their usage, if suppliers send price signals. This has the potential for customers to reduce their demand at traditionally high utilisation periods (which would attract a higher charge) to comparatively lower periods (attracting a lower charge). It must however be noted that the price signals will likely be supplier led and outside the direct control of the companies.

Demand Side Management & Smart Meters

Demand Side Management (DSM) describes the active participation of customers by reducing their energy consumption at particular times of need. The use of DSM may be dependent on the implementation of suitable tariffs. The most simplistic example of this is the use of storage heaters, which charge overnight on a low rate tariff such as 'Economy 7'.

It is feasible that an excess of generation, leading to lower tariffs, coincident with conventional times of maximum demand could lead to a pronounced network peak above that currently experienced. This may be further compounded in an area with a high uptake of Electric Vehicles and other low carbon technologies. Smart Meters will support the creation of time-of-use and dynamic tariffs and could have the benefit of reducing peak demand and consequently losses.

By the end of 2020, smart meters are expected to replace manually read gas and electricity meters in homes and small businesses. Smart meters give customers an opportunity to manage their usage if they receive price signals. This has the potential for customers to move their demand from traditionally high periods (which would attract a higher charge) to lower periods (attracting a lower charge). The overall effect is that the traditional peak periods of the day (16:00 until 19:00) could flatten. A secondary effect is that losses will be lower. It must however be noted that the price signals to domestic customers will likely be supplier led and potentially outside of the direct control of NOs.

In its Smart Meter Impact Assessment, the Department of Energy & Climate Change (DECC) has assumed a reduction in losses, due to the roll out of smart meters, at a benefit of £0.5 for electricity and £0.1 to £0.2 for gas per meter, per year. This equates to a total net present gross benefit of avoided losses of £428m for the domestic sector and £93m for the non-domestic sector, over an 18 year period.[11]

Innovation

Innovation is important in GB, as electricity networks are evolving in a way they were not originally designed for. Ofgem has introduced incentive and innovation funding mechanisms to facilitate network companies in trialling innovative technological, operating and commercial arrangements described in this section. A range of innovation projects relevant to reducing losses and increasing network efficiency are provided in Appendix 1.

RIIO framework (RIIO-T1 and RIIO-ED1)

The RIIO model has a number of elements that are designed to drive innovation. Some innovative measures may be more expensive initially, however where the long term benefits are positive, innovation is an efficient choice.

Where the commercial benefit of innovation is unclear, companies may not have a strong driver to pursue those options. The RIIO model includes a time-limited innovation stimulus package that builds on the Low Carbon Networks Fund,

[11] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/78666/IA-Feb.pdf

supplementing the other incentives to support these projects. This package consists of an annual competition, a limited funding allowance and a mechanism to fund the roll-out of successful innovation trials.

Network innovation competition (NIC)

The NIC is an annual competition for funding larger-scale innovative projects that have the potential to deliver carbon or other environmental benefits to consumers. It adopts principles such as partnership working and shared learning.

Network innovation allowance (NIA)

This will provide innovation funding for small projects with the companies self-certifying against published criteria. The companies set out an innovation strategy as part of their business plans. Ofgem assessed the quality of these strategies, and, based on the assessment, set the NIA for each company at between 0.5 and 1 per cent of base revenue, depending on the quality of their strategy.

Innovation Roll-out Mechanism

This enables companies to apply for additional funding within the price control to roll-out a proven innovation where it meets defined environmental criteria.

4.2. Barriers

Economics

The physical laws that govern electricity transmission and distribution dictate that losses will always be present within the network. Hypothetically, it is possible to design a network that represents the absolute lowest electrical loss achievable. Due to the historical design of GB's networks there will be some compromise which considers cost vs benefit. This includes providing minimum cost connections, asset replacement and general reinforcement.

Smart Metering losses

Smart meters are designed to record consumption of energy (electricity and gas) and relay the information to the energy suppliers and DNOs. Due to the increasing functionality of the new meters, the energy consumed by smart meters is greater than existing metering. As the energy to supply the meters is on the DNO side of the meter, they are classed as a system loss (as per existing meters).

Table 2 shows an estimate of smart meters energy usage from parasitic losses, (based on maximum permitted losses stated in the Metering Instrument Directive) against existing meters:

Meter Type	Existing Metering Losses	Smart Meter Losses	Increase in Losses
Gas meter	0W electrical (gas pressure driven)	1W	1W
Single Phase Single Element Electricity Meter	2W	3W	1W
Single Phase Twin Element Electricity Meter	2W	3W	1W
Poly Phase Electricity Meter	5W	7W	2W
In Home Display	0W	0.6W	0.6W
Communications Hub	0W	1W	1W
Total (single phase)	2W	4.6W	2.6W
Total (poly phase)	5W	8.6W	3.6W

Table 2 - Smart meter energy consumption estimates

The existing electricity meters on GB's networks are estimated to contribute around 2.5% of overall losses. As can be seen in Table 2, the energy usage of parasitic losses from a domestic smart meter typical household will increase energy usage from around 2W to over 5W (gas meter, single phase electricity meter, in home display and communications hub). The initial effect of the Smart Meter rollout will increase the contribution meters make to network losses; albeit providing additional functionality to significantly reduce peak demand, and in turn losses. It is for this reason that smart meters feature in both the 'enablers' and 'barriers' section.

Conductor replacement strategies

High temperature, low sag conductor systems and the composite core conductors, ACCC (Aluminium Conductor Carbon Core) and ACCR (Aluminium Conductor Composite Reinforced), have been developed to facilitate required increases in circuit capacity. Although these conductors have the capability to double the capacity of existing circuits, this also increases losses.

Power quality

Domestic customer loads have changed slowly over the last 20 years where passive devices such as incandescent lamps and iron core transformers have been replaced with compact fluorescent and LED lamps and switched-mode power supplies. The switch to LED lights from incandescent bulbs has increased energy efficiency, and therefore reduced losses, as has moving towards switch mode power supplies which are also more efficient than the traditional iron core transformers. Compared to traditional devices, these modern devices have a non-linear effect on voltage and current waveform.

Typical domestic harmonics levels are increasing due to Low carbon Technologies and energy efficient appliances. Desk top studies suggests net growth in harmonics The net effect is that losses can change due to power quality experienced on the network.

The effect is known as power quality and, although these devices meet European Union (EU) regulations, the net effect on the system is a change in the losses. The losses in some cases are lower, and in some cases are higher. In either case the overall result is difficult to predict.

Non-firm generation connections

To allow the connection of generation in areas where reinforcement is required, which traditionally would be a firm connection, alternative connection arrangements can sometimes be offered. All of these solutions can increase the utilisation of the network so can have a relative detrimental effect by increasing losses.

For customers who are downstream of a single constraint item, a connection can be offered which allows generation to flow when the constraint is not a limiting factor but restricts generation flow when the constraint becomes active. Losses are generally considered to be the same or increased due to an increase in overall utilisation.

4.3. Uncertainties

Low Carbon Technologies

Generation on the LV and HV networks are projected to be mainly photovoltaic (PV) and wind generation. DECC has published 'low', 'medium' and 'high' trajectories for the future uptake of these technologies.[12] These show that the capacity of PV and wind installations on distribution networks alone could double from 2012 to 2020.

When an embedded generator is generating energy, the load on the circuits supplying energy to local demand may be reduced. When local generation matches local demand, the power flow on these circuits could reduce to zero. As a result, the variable losses on these circuits and on the upstream transformer will also be reduced to zero. However, this is unlikely to coincide with maximum demand on the system, where variable losses on the system are highest. Because there are many different demand and generation scenarios, there are also circumstances when embedded generation can increase losses on the network by increasing the amount of energy flowing on the circuit.

DECC projections show increased levels of embedded generation and an uptake of Low Carbon Technologies, energy distributed is therefore expected to increase. For instance, modelling suggests potential significant uptake of heat pumps and electric vehicles in GB (see Figures 8 and 9). If these loads are not properly managed to minimise the increase in network peak demand, they will significantly

[12] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/370648/Final_Report_-_Impact_of_Policy_that_Drives_Low_Carbon_Technologies_on_Distribution_Networks_.pdf

increase the load on the network and the associated variable losses will increase quadratically. This will cause the overall value of losses to increase, unless this increase can be offset by other factors, for example smart control devices that actively manage the energy use of these devices.

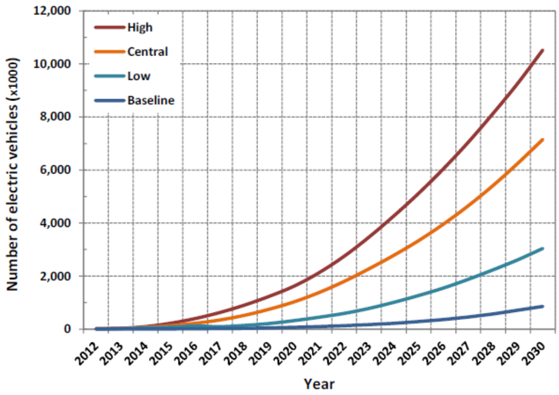

Figure 8 – DfT's trajectories for electric vehicle uptake[13]

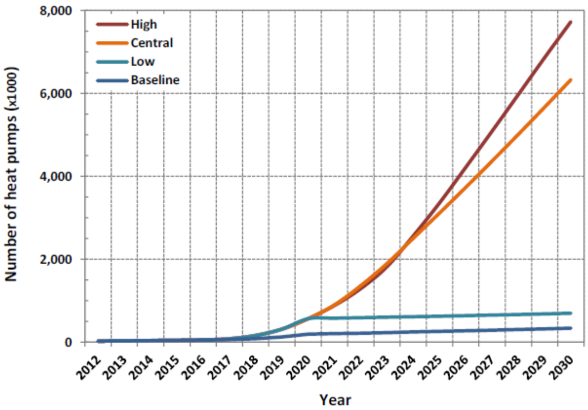

Figure 9 – DECCs trajectories for heat pump uptake[13]

4.4. Cost of electricity and carbon

The future costs of electricity and carbon have a strong influence on the losses reduction measures that are adopted by the companies. A low cost of electricity and carbon means that measures introduced to lower losses could have a negative net present value. Conversely a higher electricity and carbon price can make measures deliver a positive net present value. A low cost of electricity and carbon assumed for network investment decisions can represent a major barrier for adopting low loss network design and implementation.

[13] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/370648/Final_Report_-_Impact_of_Policy_that_Drives_Low_Carbon_Technologies_on_Distribution_Networks_.pdf

5. Distribution network current measures

Describes what current measures are being adopted by DNOs for reducing losses. Timeframes for current measures are in line with the current price control period.

5.1. Measures to reduce losses

This section examines the concrete measures put in place by the DNOs. A brief description of each measure is given with a forecast of its loss benefit. The data that supports the forecast of loss reduction can be found in the individual losses strategies as published by each DNO. The cost benefit of each measure is calculated using a baseline losses benefit of £48/MWh as set out in Ofgem's Cost Benefit Analysis guidance.

A requirement on the DNOs is to produce a Losses Strategy. Each DNO strategy provides detailed information on the measures that they have and will be introducing to manage and reduce losses. The detail given in this report is an abridged and anonymised commentary on the DNO losses strategies.

5.1.1. Proactive Replacement of Transformers

The EU Ecodesign Directive

The EU Directive – 2009/125/EC – mandates the adoption of Ecodesign transformers for distribution networks in two phases, from 2015 and 2020. The Ecodesign requirements are for improved transformer fixed and variable losses performance in 2015 and further improved in 2020.

Replacement of old transformers

Old distribution transformers (for example those that pre-date circa 1958) were built to a range of designs and specifications which preceded the current specifications. Older transformers were produced using a core manufacturing process that resulted in efficiencies that are approximately 60% poorer than modern transformer designs. Proactive replacement of these high loss transformers is more cost effective from a losses perspective than replacement based on the condition of the asset alone.

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Replacement of old transformers	£m benefit	0.07	0.42	0.75	1.09	1.43	1.64	1.84	1.97
	MWh saved	1,532	8,573	15,590	22,600	29,588	33,809	38,028	40,717

Low Loss Transformers

The benefits of purchasing transformers that outperform the latest EU transformer efficiency directive[14] (Tier 1 & Tier 2) at Primary level (33kV/11kV) have been considered. The increase in initial capital costs to install transformers that go beyond this directive can be economically viable in some cases over the lifetime of the plant.

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Low loss transformers	£m benefit	0.70	0.42	0.75	1.09	1.43	1.64	1.84	1.97
	MWh saved	14,422	24,245	32,598	41,097	49,765	58,420	70,254	81,122

Transformer sizing

Installing a larger capacity transformer than necessary from a thermal rating perspective reduces the utilisation of the transformer. Over the lifetime of the asset, the higher initial cost can be offset in some cases by the long term loss reduction.

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Transformer sizing	£m benefit	-	0.01	0.02	0.03	0.03	0.04	0.05	0.06
	MWh saved	0	174	346	520	694	867	1,040	1,214

5.1.2. Cables and Overhead Lines

Replacement of conductors

DNOs replace underground cables and overhead lines primarily at the end of their life. In the context of this report, replacement of cables to increase the capacity for customers is classified as a reinforcement activity.

Replacement is traditionally considered a 'like for like' activity which means that the capacity of the new conductor is similar to the existing asset. Usually conductors which are oversized reduce conductor resistance (relative to existing utilisation levels). This can have the added benefit of improving network performance, i.e. voltage drop, current carrying capacity and earth loop impedance and reduce losses.

[14] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0548&from=EN

Oversizing conductors

The use of larger conductors than the minimum required to meet the load has been adopted where the long term loss reduction is financially beneficial. Different conductor sizes are used dependent on the nature of the work.

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Oversizing of conductors	£m benefit	0.03	0.34	0.65	0.95	1.25	1.56	1.87	2.19
	MWh saved	601	7,110	13,356	19,572	25,918	32,156	38,708	45,260

Optimizing conductors

When a conductor requires changing, the choice of the material of the replacement conductor can have an effect on the loss.This optimization of a particular overhead line or cable is subject to local conditions (for example sheltered areas through valleys or exposed areas on top of moors) and this optimization can lead to improvement in losses where it is financially beneficial.

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Optimizing conductors	£m benefit	0.33	0.51	0.64	0.79	0.95	1.12	1.39	1.64
	MWh saved	6,926	10,463	13,121	16,382	19,623	23,079	28,713	33,939

Limitations

The activities above are predominantly driven when a conductor is planned to be replaced due to age. Cost benefit analysis demonstrates that the significant cost element of a cable replacement is the excavation element, which can more than offset any loss reduction benefits. This means that a proactive program of cable replacement for losses only cannot be justified.

Increasing the capacity of a conductor to reduce losses is a pragmatic approach; however the benefits of loss reduction are proportional to the capacity. In certain circumstances the additional released capacity can be taken up by connecting additional customers/loads over and above what was planned. This in turn increases the relative losses on the network through increased utilisation of the conductor and the corresponding assets to near capacity (e.g. transformers that feed the conductors).

5.1.3. Voltage uprating/rationalisation

It is possible to upgrade some networks to a higher voltage utilising existing cables without significant additional costs. This upgrade, although capacity driven, will consider the losses savings over the lifetime of the equipment to provide a robust cost benefit analysis as to whether a particular network should be upgraded. In particular the upgrade of legacy 6.6kV networks to 11kV has sometimes proven to be a cost effective measure for capacity upgrades with significant associated losses savings.

5.1.4. Non-technical losses

Theft in Conveyancing Activities

Revenue protection implemented activities include:

- Planning and also undertaking targeted customer site visits and meter inspections;
- Responding to tampering notifications and 'tip-offs' from a range of stakeholders;
- Replacing meters and making installations safe;
- Effecting repairs to electricity services and mains supplies;
- Assessing unrecorded energy and updating information systems accordingly;
- Liaising with enforcement agencies;
- Participating on industry and government groups regarding energy theft;
- Storing meters where interference has been identified for evidence purposes;
- Providing stakeholder training and awareness initiatives; and
- Preparing cases for enforcement action and pursuing prosecutions.

Conveyance & settlement inaccuracies

Situations arise where energy is delivered and consumed but is not accurately recorded in the electricity settlement system and therefore becomes lost energy. The main causes of these non-technical losses include missing and unregistered metering points, incorrect recording of the energisation status for metering points and incorrect registration of metering system information leading to inaccurate customer consumption data. Such non-technical losses are often regarded as 'Conveyance' related. DNOs work closely with suppliers and metering service providers to improve settlement data and metering point registration accuracy. DNOs will continue to focus on reducing the numbers of metering points without a registered supplier and some operators have already implemented tighter controls on the allocation of new Metering Point Administration Numbers (MPANs) to property developers.

DNOs will also continue to proactively monitor the number (and check the status) of metering points registered as disconnected and de-energised by suppliers. They will cooperate fully in Elexon Audits to check settlement data and resolve any inaccuracies identified with corresponding commitments to refine internal processes to prevent any reoccurrences.

During the roll-out of smart metering, where high volumes of meters will be changed within relatively short timeframes, DNOs will work with all relevant stakeholders to develop robust industry procedures to ensure settlement.

Unmetered supplies

Non-technical losses associated with unmetered supplies can be attributed to incomplete database records of unmetered customer loads, inaccurate equipment inventories and errors regarding the assumed demand characteristics. Typically these considerations result in the under-recording of unmetered energy consumption.

DNOs continue to work with main unmetered supplies customer groups to ensure equipment inventories are regularly updated. DNOs actively pursue customers where inventories have not been received. A proportionate approach will be adopted to improving the accuracy of unmetered supply records by targeting the largest customers, which typically include councils and local authorities.

Where customers are unwilling to engage regarding asset inventories for their unmetered supplies, DNOs reserve the right to undertake selective and targeted equipment audits in order to establish accurate consumption information for inclusion in energy settlements.

5.2. Operational measures to reduce losses

5.2.1. Voltage control

Voltage Control

Historically voltage reduction has been used to reduce demand during generation shortages, as much of the load has been 'voltage dependent' (eg filament lamps and resistive heating). As the resistance of these devices is largely fixed, applying a lower voltage reduces the current drawn, less power is transferred and hence overall load is reduced. For resistive heating, the energy output will be reduced, but as the load is temperature driven, so the same energy will be required over a longer time. The net effect is that the same energy is delivered over a longer period of time and hence there is no change in the energy requriements or loss improvement. For filament lamps, the lamp will dim, thus providing less visible light.

There is scope to reduce the network voltage and remain within the statutory voltage parameters. Reducing the voltage will reduce the overall power requirements and makes a small contribution to loss reduction.

Increasingly more load is 'voltage independent', as it is fed via a switched mode power supply, which effectively changes its impedance based on voltage (such as HF fluorescent, LED, PCs VFD fed motors).[15] Therefore lowering voltage may not, in all circumstances, lead to the demand savings as desired and could actually increase losses.

[15] Carbon Trust [2011] – "Voltage Management" Technology Guide (CTG045)

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Voltage control	£m benefit	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.06
	MWh saved	164	328	492	656	820	984	1,148	1,312

5.2.2. Interoperability

Optimising voltage profile

Optimising voltage at all voltage levels will provide the best assurance of meeting statutory obligations under ESQCR[16] Regulation 27(3) (b), (c) and (d). Maintaining voltage at the lowest permissible level within the statutory limits will also ensure that variable losses (as a percentage of energy supplied) are minimised. In practice, determining busbar voltage set points is a compromise between achieving the ideal voltage level from an energy efficiency perspective and practical considerations regarding the need to ensure adequate automated voltage control (AVC) relay operating bandwidths and operating time delays.

[16] Electricity Safety, Quality and Continuity Regulations.

6 Distribution network potential measures

This section describes measures which have been identified as being potentially effective at reducing losses at some point in the future, but are currently not feasible. This is typically for technical or economic reasons.

6.1 Potential measures to reduce losses

6.1.1 Cables and overhead lines

Conductor type

Increasing the cross sectional area is a beneficial action in reducing losses. However, an alternative may be to change the conductor material from aluminium to copper. Copper has a lower resistivity and therefore reduces the losses on the network. The downside is that copper is more expensive than the current option of aluminium alloy and the current cost benefit analysis identifies aluminium as the preferred option. As the price of materials changes, this option may become viable.

6.1.2 Transformers

Reduced Winding Resistance

Further loss reduction over and above the current measures can be gained through transformer design and specification. A method of reducing copper losses is to reduce the resistance of the windings. This can be either by reducing the resistivity of the winding material or increasing the cross sectional area of the windings or reducing the number of windings[17].

There is a trade-off when reducing winding resistance, such as increasing core size to accommodate the larger windings which in turn leads to increased iron losses in the core. This then influences the X/R ratio of the unit and can lead to more onerous network fault level requirements.

Cast Resin Transformers

Instead of using oil as a dielectric medium, an epoxy resin is used to encapsulate the windings. The main advantages of cast resin transformers are that they are virtually maintenance free, moisture resistant, flame retardant and self-extinguishing. This makes them ideal for integration within buildings, where the risk of fire is a primary concern.

The losses from cast resin transformers follow similar principles to oil filled transformers, namely core and winding losses. However, as cast resin

[17] Heathcote [1998] – "J&P Transformer Book"

transformers can be placed within buildings they can often be located closer to the load centre which reduces losses in LV sub mains cabling.

6.1.3 Network configuration

There has been a drive to reduce the number of customers connected to a single LV feeder and therefore an overall reduction in the number connected to HV feeders. The knock on effect of this is that the load on these circuits is also reduced, therefore reducing utilisation and the relative losses on the circuit. The drive of losses to reduce the number of customers on a feeder or to reduce its overall length requires analysis to establish the optimum balance.Albeit at an increased cost to serve as more assets are employed.

6.1.4 Power quality

Power quality is the fitness of electric power for consumer devices. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all.

This section examines potential opportunites to reduce losses due to power quality methods. This includes harmonics and power factor correction.

Power quality - harmonics

Consumer equipment is designed to be compliant to specific standards, but the combined effect of multiple devices can lead to low power quality and possibly an increase in losses. Modelling studies are carried out by the companies to ensure that these problems do not occur.

While "power quality" is a convenient term for many, it is the quality of the voltage — rather than power or electric current—that is actually described by the term. Power is simply the flow of energy, and the current demanded by a load is largely uncontrollable.

Power quality is usually described as a set of values of parameters, such as:

- Variation in voltage magnitude
- Transient voltages and currents
- Harmonic content in the waveforms for AC power

Power quality is dependent on the nature of the appliances that are connected to the network. An example would be air conditioning, heat pumps or solar PV inverters. These devices can cause the normal sinusoidal waveform to become distorted. Significant cases of distortion can increase the losses on the network.

Equipment can be installed onto the network to reduce the effects of harmonics.

Power quality – Phase balancing

Phase balancers, often in conjunction with voltage regulators, have historically been used on a selective basis to maintain voltage within statutory limits on long rural LV feeders where achieving phase and voltage balance has otherwise proved to be problematic. Such traditional devices produce losses in their own right and, particularly in the case of moving-coil voltage regulators, incur an on-going maintenance cost. However the concept of balancing feeders with significant imbalance can have substantial savings in losses. The most simplistic measure is for overhead line networks to transfer single phase customers onto a lightly loaded phase. This simplistic solution will be completed before considering regulators or power electronic solutions.

It must be recognised that phase balancing is a 'course setting' as imbalance is a real time phenomenon and a perfectly balanced will change as customers change their energy usage and therefore become unbalanced.

Power quality – Power factor correction

Power factor is a ratio between the real power flowing through a conductor and the apparent power flowing through the same conductor. The most efficient power transfer takes place when the power factor is at unity. Power factor correction could be installed at various points of the system. The most efficient use of power factor correction is at the load. For bulk customers this is often at the customer's switchboard and at the consumer level within certain devices (such as adding a capacitor in parallel with the magnetic choke in fluorescent light fittings).

The use of power factor correction in residential installations is not generally proven to be technically or financially feasible as most of the requirements are captured within manufacturing standards for consumer products and very low levels of correction potential remain in individual properties. The cost and complexity of individual installations would outweigh the benefit. Of greater benefit would be the option of installing power factor correction at distribution substations, where the power factor effects multiple customers can be addressed, which would bring HV power factor towards unity.

6.1.5 Legacy network design rationalisation

The remaining networks operating at the now discontinued voltage levels of 22kV and 6.6kV will gradually be replaced through natural evolution and investment synergies. In general, this will provide losses reduction opportunities due to the (higher) standard voltages now employed, i.e. 33kV (or 132kV) and 11kV. However, there are, in addition, discrete pockets of non-standard network architecture which, due to their age and component obsolescence, are the subject of more specific asset replacement programmes. These will provide further opportunities to reduce losses albeit subject to practical limitations inherent in their legacy designs.

6.1.6 Optimizing Network design

Networks are electrically separated via switches colloquially called open points. These open points are strategically positioned to optimise customer numbers, load and to also reduce switching operations under first circuit outages. Moving an open point to better balance customer numbers between two or more feeders usually results in the balancing of load.

As the networks evolve, original network configurations can become inefficient. In certain cases it is beneficial to modify the existing circuits or substation configurations to enhance the operational flexibility of the substation, this can lead to loss reduction in some cases.

6.1.7 Use local renewable generation to support substation auxiliaries

It is noticeable that other public and private organisations have become more aware and active in recognising applications of local renewable generation to support local demand. Examples are: petrol stations, supermarkets, office blocks, road signs and parking meters.

The use of PV and wind power could be used to offset the energy used by substation auxiliaries. There are also synergy benefits with substation battery charging and black start capability or other prolonged loss of EHV substation supply.

6.1.8 Network reinforcement

The network companies are coordinating the boundary transfer arrangements and determining the most economic and efficient design solution. This ensures that the three systems are developed and operated in a coordinated fashion.

The coordination and alignment of reinforcement plans can lead to improved efficiencies on the network through coordinated design.

6.1.9 Active Network Management

Some parts of the distribution network are constrained by more than a single constraint factor. One solution is a dynamic generation control system including power electronics that alter power flows and dynamically calculate circuit ratings to provide the highest generation capacity possible in the network. The net effect is that utilisation is dynamically managed, and this may increase or decrease losses compared to the traditional reinforcement measure as the dynamic management can be set to optimise losses.

6.2 Operational measures to reduce losses

6.2.1 Switching out under-utilised plant

At times of low load at twin transformer major substations, the combined iron and copper losses of the two transformers can be higher than the equivalent iron losses and copper losses of one transformer. A counter situation is that with more efficient transformers, the potential future opportunity is reduced. At these times losses could be saved by switching out one of the transformers and re-energising it when the load increased.

The disadvantages of this would be security of supply, as if there was a fault on the single transformer, the de-energised transformer would have to be re-energised and loaded up. This would not be instantaneous. Other disadvantages include circuit breaker wear, as they would be operated more regularly than under normal conditions.

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Switch out underutilised plant	£m benefit	0.21	0.31	0.38	0.46	0.55	0.64	0.82	1.00
	MWh saved	4,392	6,562	8,007	9,679	11,477	13,434	17,045	20,743

6.2.2 Distributed Generation (DG) challenges and network support

Distributed Generation (DG) may provide opportunities for improved network management, including management of losses. For example, DG could help optimise power flows by achieving a better overall balance between generation and demand and hence help to flatten network demand profiles. Even where a suboptimal level of balance between localised generation and demand might cause a localised increase in losses, the overall impact might still be to reduce overall losses due to reductions in upstream power flows required to serve downstream demand. Moreover, if more of the losses are being supplied by renewable energy sources, then the overall carbon footprint of losses will be reduced. Whilst the responsibility for dispatch of generation is unlikely to fall on DNOs in the foreseeable future, this does not preclude a DNO entering into contractual relationships with DG operators to provide ancillary services such as network support or as part of an agreed curtailment arrangement.

6.2.3 Substation ambient temperature

In all major substations (primary substation, supply and grid supply points) indoor equipment rooms are temperature controlled. This is usually in the form of resistive electric heaters, controlled via a thermostat to allow switchgear and associated control equipment to function correctly.

There is an existing initiative being delivered to install dehumidifiers at a number of major substation sites and this will have a variable impact due to present practice in the setting of temperature controls. When considering losses, dehumidifiers present a lower energy consumption than the equivalent electric heaters, which translates into a lower parasitic loss on the network.

6.3 Measures to reduce network reinforcement

6.3.1 Smart meters

Smart Meters will give suppliers the functionality to offer a greater range of tariffs including more time of use based tariffs. Where these are used to move load away from peak times there will be a consequential reduction in overall losses due to the reduced times when distribution equipment is operating at its maximum rating.

Smart meters can also be used to schedule certain loads and increase the overall level of utilisation of the network. This will reduce the level of physical network reinforcement required by creating a more consistent and flatter load profile. The details of the benefits of Smart Meters can be seen in section 4.1.

6.3.2 Demand side response

There would be potential benefits in terms of avoided investment in capacity and reduced increases in losses if the potential increase in peak demand could be suppressed through peak-shifting - i.e. either through direct controls, intelligent autonomous controls (or smart appliances) or simply time-of-use tariff incentives to encourage consumers to avoid peak demand periods where practicable. For example, home charging of electric vehicles could generally be restricted to night-time off-peak periods (ideally except consumers with electric space and water heating, or served by parts of the network which are already night-peaking such as off-mains gas areas) without loss of convenience.

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Demand Side Response	£m benefit	0.12	0.17	0.21	0.26	0.31	0.36	0.46	0.55
	MWh saved	2,470	3,619	4,467	5,428	6,459	7,572	9,485	11,450

7. Transmission network measures

7.1 Transmission operators approach to losses

The biggest impact on transmission losses foreseen is from changing generation connections and a move to more intermittent generation located towards the periphery of England and Wales, Scotland, and embedded into the distribution networks. To facilitate new connections the transmission network is being developed including new and upgraded circuits. Loading patterns are becoming more dynamic than previous as renewable generation outputs change across the country with weather patterns. A large proportion of the new renewable generation is connecting within Scotland which is increasing Scottish power flows as power flows to demand in the south and therefore losses increase with the increased power flows.

Transmission losses may be seen to increase due to new generation siting away from demand requiring greater use of the transmission network and therefore leading to higher losses. Some transmission loss reduction may happen due to growing capacities of embedded generation siting close to demand and taking loading off the transmission network.

Losses are considered as part of the transmission system development together with the asset life cycle, satisfying customer requirements and maintaining system security. Efforts are made to reduce transmission losses whenever economically viable, however reducing losses often conflicts with maximising the use of existing assets and avoiding new infrastructure build.

At transmission level, the transmission system is already highly efficient with the optimum voltage levels being selected to best balance investment, operation and network capability. As the system has developed, parts of the network have been upgraded to ensure capability meets requirements and losses are kept in check. The premature replacement of assets with modern, lower loss designs or the construction of new circuits could allow losses to be reduced but with the high cost of transmission assets, cost benefit analysis does not typically support such actions for loss reduction alone. Where losses have an impact on investment decisions they are assessed as part of a Whole Life Value Framework.

7.2 System operator

It must be recognised that the GB electricity System Operator has very limited control over transmission losses as only around 3% of the total system energy goes through the Balancing Mechanism. Market developments outside of System Operator control form the majority of loss changing events. As very little control of losses can be exerted by the System Operator the Transmission Losses Incentive that used to be applied has now been replaced with a reputational incentive. To allow continued monitoring of transmission losses they are publically reported as part of Monthly Balancing Services Statements.

7.3 Losses Control Measures

The following collection of transmission related loss control measures represent actions that are currently being applied or are actively being investigated. In applying the measures, the aim is to minimise losses as far as possible in a way that balances capital investment, operational control and environmental impact.

7.3.1 The application of low-loss equipment

Transformers

The losses from transformer core steel have reduced significantly in the last 40 years, driven by improvements in steel alloys, processing and increasing loss capitalisation values. The loss capitalisation value used is now predominantly driving the lowest loss commonly available grade steel to be used. It is possible that market pressure will stimulate development and production of steels with losses up to 10% lower than this in the next few years.

Variable (load) losses are greatly influenced by the capitalisation value, and would therefore decrease if higher capitalisation values were used. Exceptions to this are the largest transformers (e.g. 1100MVA interbus transformers and Quad Boosters) that are constrained by allowable transport weights. Employing the loss capitalisation method using the existing capitalisation values provides the best value for consumers. Early replacement of large transmission transformers is not typically economically feasible before the end of normal asset life.

Conductors

Specifying conductor replacement involves the replacement of old or low rated conductors with larger diameter conductors, which is principally driven by an increase in transmission capacity, but also reduces line resistance and associated losses. For the same material, a smaller diameter conductor will have a higher resistance and hence, greater losses. There is a potential down side to reconductoring from a system loss perspective, since increased utilisation of the line will increase current flow and increase losses much more than any resistance change would reduce losses.

Non-load related asset replacements

Transmission Owner non-load related conductor replacement schemes will in general employ All Aluminium Alloy Conductor (AAAC), which was developed in the late 1980’s. The Transmission owners specify a lower DC resistance than the BS standard in order to reduce system losses. DC resistance reductions are optimised whilst not compromising the mechanical strength of the alloy.

The AAAC alloy was developed solely to reduce transmission losses and is designated as an extra high conductivity (EHC) alloy conductor. This is the conductor type of choice for all non-load related schemes as it is relatively inexpensive, robust, easy to install and maintain.

Load related asset replacements

Where a significant increase in capacity is required (load related schemes) high temperature, low sag conductor systems such as GAP and the composite core conductors, ACCC (Aluminium Conductor Carbon Core) and ACCR (Aluminium Conductor Composite Reinforced) have been developed. These conductors have the capability to double the capacity of existing circuits; however this doubling also increases losses accordingly if the circuit utilisation is increased.

Cables

In general, transmission requirements are for cable systems with high current ratings. This will act as a driver to reduce losses to enable higher current ratings. For example, the requirement for increased current ratings may lead to the introduction of larger cross sectional cables than the 2500mm² currently used. As these have a lower resistance, they will produce lower losses per MW of active power transmitted. However increases in power transfer requirement usually lead to a corresponding increase in utilisation which will also tend to increase the variable losses of a cable system. The lifetime losses are typically less than 10% of the capital cost of the cable system. The requirement to maximise current ratings and minimise capital costs of a cable system require that the losses are reduced to the optimum level.

7.3.2 Transmission development and reinforcement

As part of load related transmission planning and asset management, consideration of losses forms part of the project evaluations. Some of the developments that can show positive benefit to loss reduction include:

Upgrade in voltage level

By upgrading 275kV circuits to 400kV the circuit losses may be reduced by 20% to 40% dependant on loading. A joint research project between University of Manchester, EPL Composite Solutions, SSE and National Grid has developed a new composite cross-arm design to make the overhead line part of the upgrade potentially easier and more cost efficient.

New circuits

Load related works that require additional circuits will potentially have a beneficial effect on losses by reducing circuit loading and therefore losses.

De-energising or removing unnecessary equipment

If equipment is found to be unnecessary and it is removed it could lead to a reduction in losses. The recently completed disconnection of Inverkip 400kV substation from the network, included the disconnection of 80 circuit-km of overhead line is estimated to have provided an annual reduction in losses of at least 2 – 3GWh.

7.3.3 Alternatives to network reinforcement

Demand side management

Demand side management is an area with significant potential benefit in terms of reducing network peak, however not fully within the control of the transmission owners. Research projects completed in this area have shown positive results in terms of reducing peak demand and hence a losses benefit. The management of demand in this manner will be of interest to the system operator and supply businesses. It is at yet unclear if this can be managed from a Network Operator perspective or must be supplier led.

Time of use tariffs

The rollout of 'Smart Metering' will provide the functionality to implement time of use tariffs at a half hourly level. This as a significant opportunity to firstly reduce peak demand at different times across varying locations and hence reduce network losses. However this is an area which will likely be supplier driven meaning that there could be a conflict between the interests of the various system actors.

Energy storage

SHET have completed extensive work in energy storage projects and the specific modelling of utilising energy storage purely for losses mitigation. Through this work a very good understanding of the potential benefits has been developed. The CBA work completed from a losses perspective proved that it is not cost effective to implement storage to reduce losses alone. Losses will however be considered in more detail when making a justification for energy storage.

Technology use

The use and effect of technology, both new and existing will be evaluated for application on the transmission network to look for opportunity to improve network performance in a cost effective and reliable manner.

7.4 Explanation of status of losses tables

In order to demonstrate the impact that transmission developments will have on losses, an assessment has been made using winter peak analysis and reported in table in appendix 2. As the analysis is scenario based and operating conditions can vary significantly the suggested losses effects should be taken as indicative only and subject to variation.

Gas networks

8 Introduction to gas networks assessment

This section of the report has been compiled in accordance with the requirement to undertake an assessment of the energy efficiency potentials of the gas infrastructure and identify concrete measures for cost-effective improvements. Ofgem has worked with the energy network companies in GB on the report through a Gas Working Group that included all the Gas Distribution Networks (GDNs) and National Grid Gas Transmission (NGGT).

For the assessment of the energy efficiency potentials of the gas networks the working group has focused primarily on shrinkage. As shrinkage is the measure of gas both lost and used in the operation of the networks, it is the most accurate way to establish the efficiency of the transmission and distribution of gas in GB. In our assessment we decided to focus on examining the optimal balance between the costs associated with investing in measures to detect and reduce shrinkage, and the benefits through energy savings of such investments. Quantifying allows the companies to make informed investment decisions to improve and maintain the gas networks.

9 Background on Shrinkage

9.1 Gas Distribution

The GB gas infrastructure[18] transports gas to approximately 21.5 million gas customers, through 282,000km of pipes. The GB gas infrastructure is amongst the oldest in the world and recent figures show that gas meets over 50% of GB energy demand.

Section 9.1.a of the Gas Act 1986 requires gas transporters to "develop and maintain an efficient and economical pipe-line system for the conveyance of gas" [19] and the Pipeline Safety Regulations 1996 require network operators to ensure that pipelines are "maintained in an efficient state, in efficient working order and in good repair".[20]

Shrinkage represents the difference in volume between the gas entering the GDN systems and the total volume of gas used by customers. If this volume of gas is not quantified it would not be possible to make a true evaluation of the volume actually transported through the networks on behalf of Gas Shippers. It is the dominant element of the GDNs' Business Carbon Footprint (BCF) and accounts for around 1% of Great Britain's Greenhouse Gas Emissions. The three elements of shrinkage are:

- **Leakage (94% of shrinkage)** – forms by far the largest element of shrinkage and relates to un-combusted gas emissions to the environment from GDN pipelines. Emissions can be split into three high level groups: those from distribution mains, distribution services and above ground installations.
- **Theft of Gas (4% of shrinkage)** – includes situations where, for whatever reason, end users are unaccounted for and are utilising unrecorded gas.
- **Own Use Gas (2% of shrinkage)** – is gas that is used in the running of the network, an example of gas falling into this category would be gas used for the purposes of preheating at pressure reduction stations.

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[18] More information on GB Energy Networks is available on the Energy Networks Association website: http://www.energynetworks.org/modx/assets/files/news/publications/GTTN/GTTN%202013_Website%20version.pdf

[19] The Gas Act 1986 – Part 1, 9.1.a

[20] The Pipeline Safety Regulations 1996 – Part 2, Maintenance, 13.

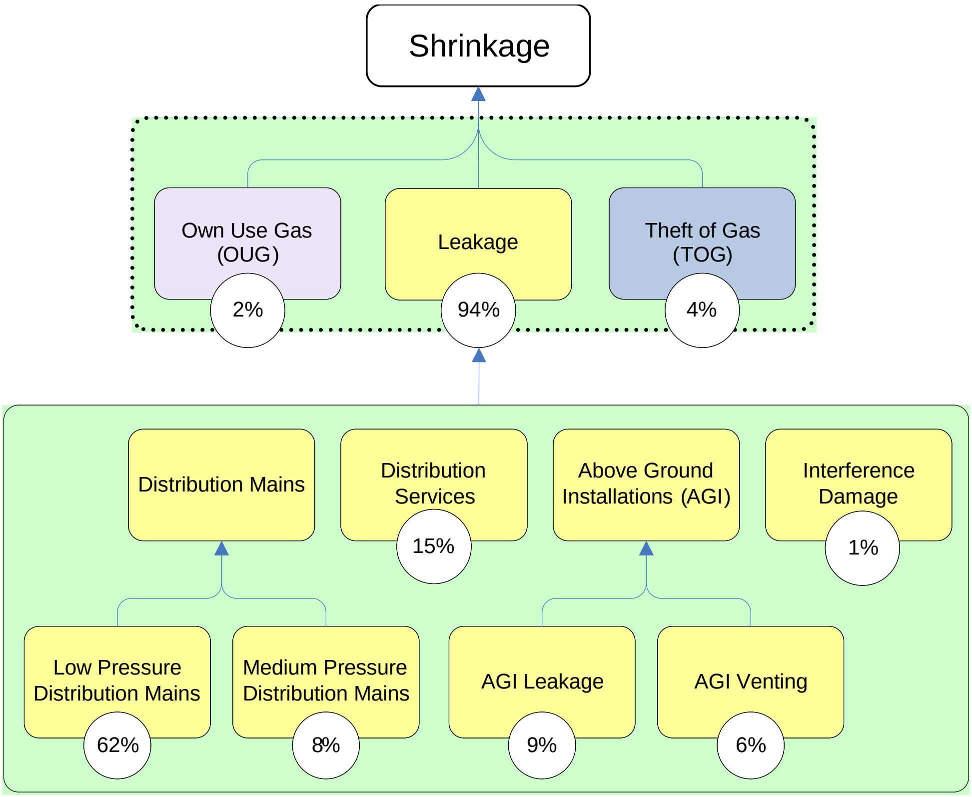

Figure 10 – Percentage components of shrinkage, average of GDN's 2013-14 RRP

9.2 Gas Transmission

In GB, gas can enter the National Transmission System (NTS) through beach reception terminals, LNG import terminals, interconnectors or from gas that had previously been extracted and held in storage. Gas exits the NTS to supply power stations, large industrial customers, storage sites and the Distribution Networks.

NTS shrinkage covers the gas and electrical energy which is used in operating NTS compressors, and the gas that cannot be accounted for and billed in the measurement and allocation process. Section N of the Uniform Network Code (UNC) – Transportation Principal Document,[21] provides further details on how shrinkage is determined, assessed and notified to users.

NTS shrinkage is broken down in to three categories:

- **Compressor fuel usage (CFU)** – CFU shrinkage is the energy used to run gas compressors to transport gas through the NTS. There are currently 24 gas compressor sites within the NTS, each containing a number of separate units. The compressor fleet is primarily used to support four key functions:

[21] UNC – Transportation Principal Document http://www.gasgovernance.co.uk/sites/default/files/Transportation%20Principal%20Document%20(Consolidated,%20printable%20version)_0.pdf

- ensure that gas is transported efficiently around the network based on the physical supply and demand pattern;
- provide system flexibility in meeting rapidly changing use and conditions;
- meet agreed pressure obligations to NTS customers; and
- facilitate maintenance.

- **Calorific value (CV) shrinkage** – CV shrinkage is the energy difference between delivered and billed energy of a charging zone as a consequence of applying the Flow Weighted Average Calorific Value process, in accordance with the Gas (Calculation of Thermal Energy) Regulations 1996 (amended in 1997).
- **Unaccounted for gas (UAG)** – UAG is the quantity of gas which remains after taking into account all measured inputs and outputs from the system, Own Use Gas (OUG), CV shrinkage and the daily change in NTS linepack. UAG is primarily a measure of the cumulative uncertainty of all individual instruments connected to the system.

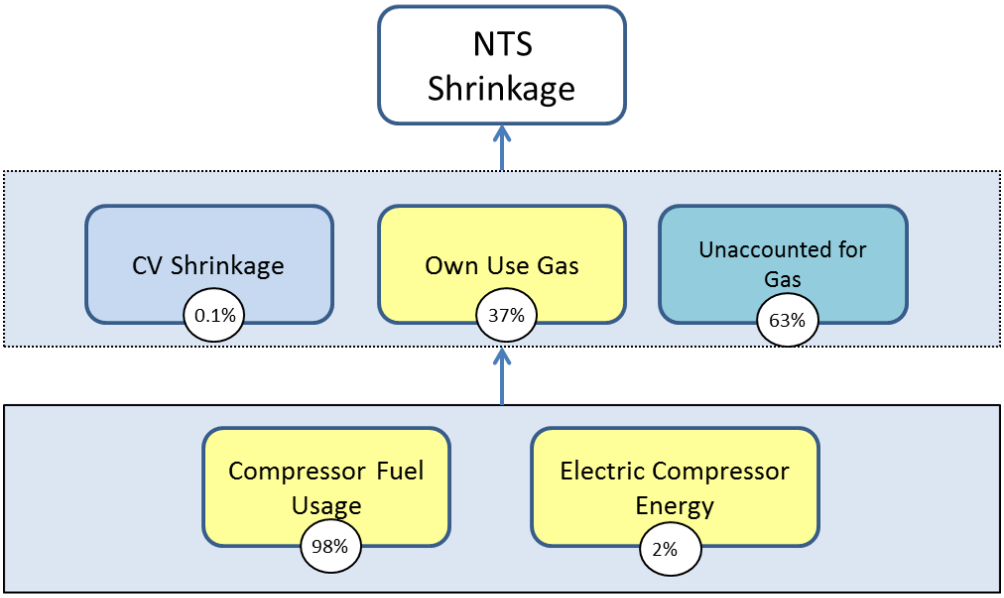

Figure 11 – Percentage components of NTS Shrinkage, based on 2013-14 regulatory reporting pack (RRP)

10 Gas networks today

The RIIO (Revenue = Incentives + Innovation + Outputs) regulatory framework, introduced in April 2013, is a new performance based model for setting the network companies' price controls which will last eight years. RIIO is designed to encourage network companies to:

- Put stakeholders at the heart of their decision-making process;
- Invest efficiently to ensure continued safe and reliable services;
- Innovate to reduce network costs for current and future consumers; and
- Play a full role in delivering a low carbon economy and wider environmental objectives.

10.1 Gas Distribution

GDN performance baselines have been set for both overall shrinkage and, separately, leakage. These baselines set out the reductions that GDNs are expected to deliver over the price control period, based on the ex-ante allowances and associated outputs Ofgem has set. The GDNs can earn rewards or face penalties, depending on their position relative to their baselines. The GDNs' baselines are based upon a number of factors, including:

- The forecast of:
  - the length of live mains in a network, over the price control period, by diameter and material;
  - the number of services in a network over the price control period;
  - the number of above ground installations in a network over the price control period; and
  - replacement activity.

- The Shrinkage Model assumptions of:
  - the percentage split between metallic and plastic service pipes;
  - Mono-ethylene glycol (MEG) saturation;
  - the impact of replacement activity upon average system pressure (ASP); and
  - mains, services and AGI leakage rates

GDNs have output commitments in place to reduce shrinkage and leakage from their networks by 20% over the price control period. This equates to a baseline reduction of 421GWh from 1st April 2013 to 31st March 2021. The chart below sets out the GDNs' performance to date.

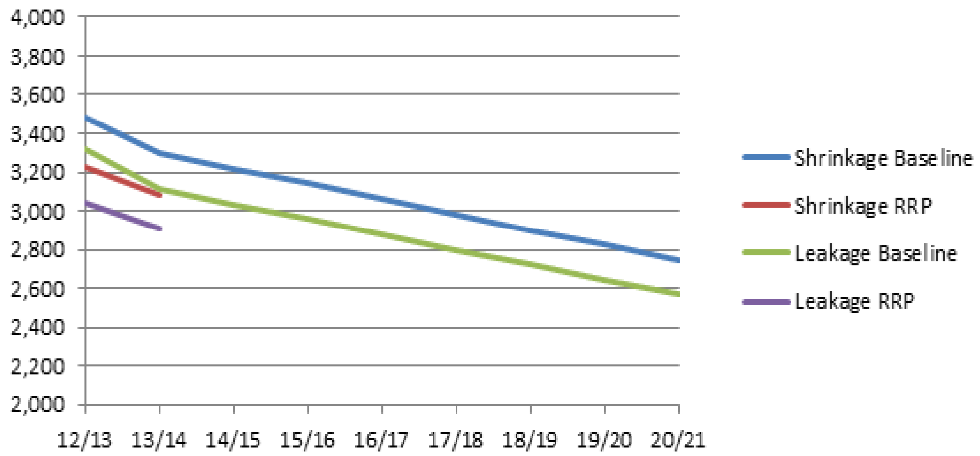

Figure 12 – Graph showing Shrinkage & Leakage Baselines and 2013-14 performance

Under the UNC, GDNs are responsible for purchasing gas to replace that lost through shrinkage. An efficient level of funding has been set out in RIIO-GD1, which can be recovered through Gas Transportation Charges. This provides the GDNs with an incentive to control shrinkage from their networks to avoid having to purchase more gas than they have been funded for. GDNs will also be able to keep a share of any efficiency savings for the remainder of RIIO-GD1.

Releases of uncombusted gas have additional environmental impacts. To target this area of shrinkage, an additional output incentive has been introduced for RIIO-GD1. The Environmental Emissions Incentive (EEI) uses the social cost of carbon set by the Department of Energy and Climate Change (DECC) to form an incentive unit value. The GDNs are then rewarded or penalised for improvements or deteriorations in leakage performance.

For the RIIO-GD1 price control, Ofgem has also introduced a rolling incentive mechanism which provides eight years of benefit or penalty for the GDNs, irrespective of the timing of investments and delivery of enduring reductions during the price control period.

In addition to the outputs above, the GDNs are also required to report on:

- scope 1 and scope 2 BCF emissions (excluding shrinkage);
- connections;
- fuel poor connections; and
- facilitation of biomethane connections.

These activities may potentially have an impact on the energy efficiency of the gas distribution network and are discussed in detail in the Current Measures section of the report.

10.2 Gas Transmission

Under RIIO-T1, NGGT have financial and reputational System Operator incentives on the level and cost profile of shrinkage gas. Special Condition 3D(i) of the NTS Gas Transporter Licence obliges NGGT to establish and publish an annual NTS Shrinkage Incentive Methodology Statement detailing the rules used for determining forward levels of gas and electricity volume targets, cost reference prices and the method used to assess efficiency levels for CV and CFU against outturn volumes. A copy of the Shrinkage Incentive Methodology Statement for the current year is available on National Grid's website.[22]

The statement is reviewed, updated and published annually. Shrinkage procurement and energy efficiency assessments are analysed against the statement. NGGT baseline calculations are then independently audited to ensure compliance with the rules set out in the statement.

The shrinkage incentive incorporates an assessment of energy efficiency performance for each given year. This ensures continuous improvement is encouraged in line with the relevant methodology statement, where assessments are undertaken to reward or penalise NGGT against the effectiveness of its shrinkage management activities.

Under Special Condition 3D.23, NGGT is required to undertake a wholesale review of the statements to support the commencement of any modifications from April 2017. NGGT expects to commence the review processes during 2015.

Figure 13 below shows the last five years of shrinkage volumes on the NTS. This shows an overall reduction in 2013-14 of over 40% from 2009-10 levels. The reduction can be mainly attributed to the work undertaken by NGGT and meter asset owners to address significant meter asset issues, which contributed to higher levels of UAG. In addition, there has been a reduction in CFU due to a combination of changes to underlying supply patterns, installation of new, more energy efficient compressor units and enhancements to operational planning processes on fleet management and system configuaration.

It should be noted that a significant amount of the reduction below can be attributed to a reduction in UAG. Improvements in UAG shrinkage are generally due to more accurate billing of gas usage and therefore, improvements in performance under these areas will not increase the energy efficiency of gas transmission infrastructure.

[22] Methodology Statement: http://www2.nationalgrid.com/uk/industry-information/gas-system-operator-incentives/nts-shrinkage/

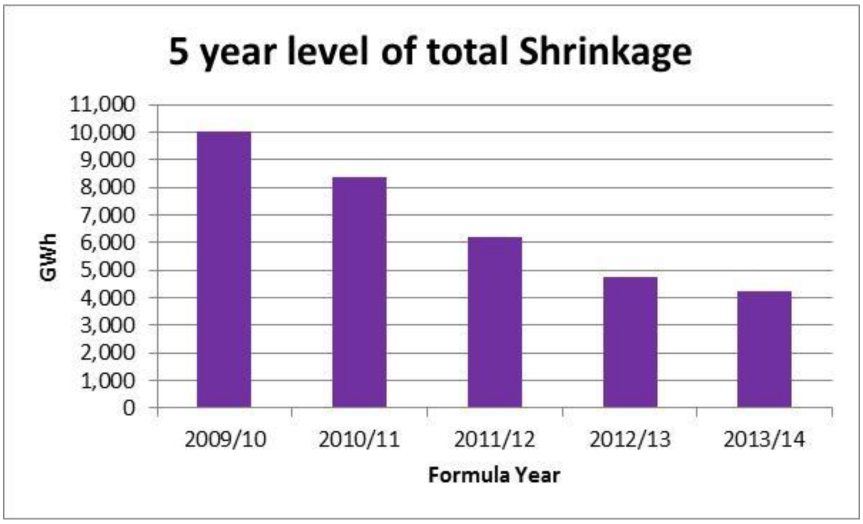

Figure 13 –Total Shrinkage level for last 5 formula years

11 Barriers, enablers and uncertainties

There are a number of factors that are outside of the gas network companies' control which have the potential to limit the realisation of any energy efficiency potential on the gas networks.

11.1 Government Policy

The government needs to maintain a balance between security of supply, sustainability and affordability. In order to achieve this, it will determine the appetite to tackle energy efficiency challenges. It will also influence certain aspects of the system more directly such as the connection of new gas sources, including biomethane, to the gas network through mechanisms such as the Renewable Heat Incentive (RHI).

11.2 Regulatory Framework

Government direction on the balance between sustainability and affordability will then impact Ofgem in setting the Regulatory Framework that network companies will work within. The Regulatory Framework will determine the cost-effective balance / cost-benefit threshold for delivering environmental outputs and factors such as funding, incentives and innovation mechanisms.

11.3 Consumer behaviour

Government and Ofgem's regulatory policies will also drive consumer behaviour and their energy efficiency. This will ultimately limit the ability of the energy networks to which they are connected, to improve the energy efficiency of the networks. An example of where government policy has resulted in a significant step change in consumer energy efficiency behaviour is the mandating of condensing boilers.

11.4 Uncertainties

Each year NGGT publishes its Future Energy Scenarios (FES)[23] which provides a detailed analysis of a range of plausible and credible conclusions for the future of energy. The scenarios flex the two variables of affordability and sustainability, giving the following four scenarios:

- Gone Green
- Slow Progression
- No Progression
- Low Carbon Life

[23] The 2014 UK Future Energy Scenarios can be found at: www.nationalgrid.com/feswww.nationalgrid.com/fes

NGGT's 2014 FES outline the level of uncertainty expected around future gas supplies, in particular around shale gas. There is potential that shale gas will be a significant new source, but, even between the two lowest carbon scenarios, the volumes differ from none under the 'No Progression' scenario to 32 bcm/year in the early 2030's in the 'Low Carbon Life' scenario.

As a result, NGGT's network needs the capability to manage a wide range of potential supply patterns. The uncertainty as to which pattern may occur on a given gas day is increasing and could increase further into the future. The variation between the two scenarios above highlights one of the many factors that directly impact NGGT's use of compression (further information can be found in the 2014 Gas 10 Year Statement[24]). These challenges make it difficult to predict compressor usage going forward and to set year on year targets for improvements in CFU levels.

[24] The 2014 Gas Ten Year Statement can be found at: www.nationalgrid.com/gtyswww.nationalgrid.com/gtys

12 Concrete measures

This section of the report explains the measures, which will have an impact on energy efficiency that the GDNs and NGGT have committed to delivering. In Final Proposals,[25] Ofgem set the "cost-effective" threshold for gas network companies to deliver their outputs. The RIIO efficiency mechanism incentivises the GDNs and NGGT to find more cost-effective ways of delivering their outputs by allowing them to keep a share of any efficiency for the remainder of the price control period. Ofgem has also provided a suite of output incentives which encourage over-delivery of certain outputs within the set allowances.

12.1 Gas Distribution

Shrinkage measures

GDNs have RIIO-GD1 output commitments against three primary outputs: shrinkage, leakage and fuel poor connections.

Shrinkage Incentive and the Environmental Emissions Incentive (EEI)

Shrinkage is funded through the GDN Transportation Charges. The GDNs have two incentives to minimise gas transportation losses:

- **Shrinkage Incentive** – incentivises the reduction in volume of gas lost from the network. Licensees receive an allowance to replace gas lost through shrinkage. If licensees need to replace less gas than they have received an allowance for, they share the savings with customers. If they need to spend more than the allowance, then they share any cost over runs with customers.
- **EEI** – provides an incentive to manage the leakage element of shrinkage. Where the reported level of leakage are above the forecast level, the EEI allows GDNs to capture the environmental benefit associated with the reduction in carbon emissions, at the level of DECC's traded cost of carbon. Likewise, if the volume of leakage is higher than forecast, GDNs incur the associated environmental cost.

Both these mechanisms provide the GDNs with the incentives to reduce the levels of gas lost from the networks. The reward or penalty applied is equal to the non-traded carbon price in the case of the EEI and a reference gas commodity price in relation to the shrinkage efficiency incentive. Baselines for both these incentives were established and agreed through the settlement of the RIIO-GD1 price control, and GDN performance is measured against these baselines with reward for out-performance or penalties for under performance.

[25] RIIO-GD1: https://www.ofgem.gov.uk/publications-and-updates/riio-gd1-final-proposals-%E2%80%93-overview
RIIO-T1: https://www.ofgem.gov.uk/publications-and-updates/riio-t1-final-proposals-national-grid-electricity-transmission-and-national-grid-gas-%E2%80%93-overview

Leakage

The GDNs are undertaking a number of works to reduce leakage on their networks:

- **Replacement of Metallic Mains & Services** – over the RIIO-GD1 period, the GDNs plan to replace a significant proportion of the remaining low pressure metallic mains & services on their network. Mains & Services replacement accounts for over 90% of the total reduction in leakage per annum. The iron mains replacement programme includes the flexibility to select pipes for replacement based on a range of criteria that provide additional customer benefits in terms of financial value and asset performance but also environmental benefits in terms of leakage reduction.
- **Gas Conditioning** – using liquid fogging agents injected into networks at strategic locations to condition the joints on ferrous mains. This swells the lead/yarn joints and restricts the leak path. Used appropriately, this method can reduce the rate of leakage from cast iron pipes by 4% relative to what it otherwise would have been.
- **Average System Pressure Control** – reducing average system pressure to reduce the amount of gas leaking while ensuring a reliable system that meets all demand conditions, including peak winter conditions, is a major objective. Much of the UK gas distribution network is under intelligent pressure control which minimises network pressures and thus leakage. There is an on-going programme to install new pressure control systems for further leakage reduction. There is also an allowance provided in RIIO-GD1 to maintain the existing systems to avoid an increase in pressures which will directly increase leakage.
- **Network Reinforcement** – reinforcements are planned where growth in demand is forecast to avoid the raising of pressures and associated leakage rates. Strategic network reinforcements (non-growth related) are also identified and justified on their ability to achieve further reductions in system pressure and deliver additional reductions in leakage and improvements in asset and network performance.

The table below shows the benefits over the RIIO-GD1 period of some of the leakage measures.[26] The benefits presented below have been calculated based on the investment for each individual year. For the purposes of this report the benefits are not cumulative but are discrete for each year.

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[26] The benefits of the gas distribution measures were calculated using leakage figures in 09/10 prices (based on the figures in the Transportation licence) and using carbon emissions figures in 2014 real prices (based on DECC's short term carbon values).

		15-16	16-17	17-18	18-19	19-20	20-21
Mains replacement	£ benefit	£32,940,248	£39,998,151	£47,340,817	£54,527,008	£61,888,267	£69,413,851
	MWh saved	95,304	98,984	93,755	94,793	91,654	92,659
Services relaid and transferred	£ benefit	£8,206,327	£10,002,385	£11,805,287	£13,524,393	£15,240,634	£16,951,748
	MWh saved	18,086	18,606	16,835	16,697	15,736	15,631

Table 3: Gas Distribution concrete measures - leakage

Shrinkage (Excluding Leakage)

Own Use Gas (OUG) – This is currently measured as a percentage of annual through-put with no direct reduction commitment. The majority of the GDNs' OUG is linked to the requirement to pre-heat gas entering their systems from the NTS. The GDNs' preheating requirements are currently delivered via aging Water Bath Heaters or more modern Boiler Package Technologies. However, there are several key issues that GDNs currently face when appraising options for preheating technologies:

- the whole life costs and, in particular, the carbon impact of currently available technologies is not understood; and
- secondly there has been limited research and development in this area resulting in limited financially viable alternatives to existing technologies.

Ofgem awarded funding for a Network Innovation Competition project to investigate the options for modernising gas preheaters in a low carbon environment (more information on this project is available in the innovation section below).

Theft of Gas – All of the GDNs recognise the potential for customers to be taking unmetered gas from their networks and have set up dedicated teams within their businesses to address the issue. They have been active in the development of the Theft of Gas Code of Practice managed by the Supply Point Administration Agreement and have developed a clear set of guidance for industry parties on how to approach theft of gas investigations.

These efforts have been focused on ensuring robust processes are in place to resolve cases of illegally taken gas (through physical tampering upstream of the ECV or through lack of supply contract), substantially reducing the number of outstanding shipperless and unregistered sites as well as implementing measures to prevent new shipperless/unregistered site creation.

In addressing the outstanding workload of shipperless/unregistered sites on behalf of industry GDNs implemented a project led by Xoserve[27] which during 2014 sent letters and then commenced site visits to almost 23,000 sites nationally. When GDNs reported back to Ofgem in October 2014, 38% of these sites had been cleared either through data cleansing or supplier registration and work is still on-going.

In order to reduce the number of newly created shipperless/unregistered sites several measures have been implemented by GDNs and industry including Uniform Network Code and MAMCoP modifications, amended industry processes and enhanced customer communications. All of these measure combined should greatly reduce the likelihood of new sites taking gas without a supply contract.

12.1.1 Activities with potential energy efficiency impacts

Fuel Poor Connections

GDNs continue to support the alleviation of fuel poverty, where gas is the most efficient heating source. Customers connected to the gas distribution networks under the Fuel Poor Connection Scheme would previously have been using a more inefficient and expensive source of energy to heat their homes and cook with, so this scheme provides them with an opportunity to reduce their carbon footprint as well as their energy bill.

Ofgem is in the middle of a consultation process to review the Fuel Poverty Network Extension Scheme, which is the mechanism that allows the GDNs to provide new gas connections to qualifying households. The GDNs' recommendations to Ofgem include giving them more tools and flexibility to reduce fuel poverty, including delivering off-gas grid solutions.

The current policy approach ensures eligible customers are entitled to a Fuel Poor Voucher towards the cost of their gas supply connection (the voucher value is for a pre-determined maximum amount). These include customers that:

- reside within the 20% most deprived areas, as measured by the Government's Index of Multiple Deprivation (IMD);
- fall within the priority group (low income households or over 70 years of age) for measures under the Carbon Emissions Reduction Target; or
- are in fuel poverty based on the standard Government definition – customers who spend more than 10% of their disposable income on all household fuel to maintain a satisfactory heating regime.

[27] Xoserve is jointly owned by the five major gas distribution Network companies and National Grid's gas transmission business. It delivers transportation transactional services on behalf of all the major gas Network transportation companies and provides one consistent service point for the gas Shipper companies. http://www.xoserve.com/index.php/xoserve-film/

During RIIO-GD1, the GDNs' innovative approaches will continue to deliver, low cost gas connections to vulnerable customer groups in the following ways:

- **One-off Connections**: when customers apply for a connections, GDNs identify those who are eligible for the Fuel Poor allowance (in an eligible IMD area), which helps this vulnerable customer group get gas connections. The funding is capped at the Standard NPV of transportation revenues for an individual domestic connection with the customer required to pay any additional amounts.
- **Network Extensions**: worked with a number of stakeholders, including local authorities, housing associations and community groups, to identify off network mains extension schemes to qualifying communities to provide gas connections and in house services such as new gas heating systems and other related energy efficient measures.

Since the introduction of the Fuel Poor scheme in 2009 there have been 58,000 customers connected to gas across the UK. Over the RIIO-GD1 period GDNs have a target of 77,450 connections (in 2013-14 performance was 15,612 connections). The table below shows projected benefits over the RIIO-GD1 period.[28]

		15-16	16-17	17-18	18-19	19-20	20-21
Fuel poor connections	£ benefit	£420,348	£567,018	£731,740	£904,413	£1,083,705	£1,273,049
	MWh saved	0	0	0	0	0	0

Table 4: Gas distribution concrete measures - fuel poor connections

Connecting New Sources of Gas

Increasing quantities of renewable gas from anaerobic digestion (biomethane) and thermal gasification (bioSNG) will efficiently facilitate continued use of gas for heating while helping to meet the 2050 Green House Gas reduction targets.

The GDNs are playing a key role in facilitating projects to inject biomethane in to the grid. Although they do not currently have an output commitment on the number and capacity of biomethane connections to their networks during RIIO-GD1, they have set a target to connect approximately 180 projects by 2021. To date, the GDNs have connected 4 projects supplying gas to heat over 10,000 homes on an average day (as set out in the table below). These projects are all different, and include examples of each type of anaerobic digestion feedstock: food waste, human waste and break crops.

[28] The benefits have been calculated using carbon emissions figures in 2014 real prices (based on DECC's short term carbon values).

	Pre RIIO-GD1	2013-14 RRP (within year)	Total to date	RIIO GD1 Target
Number of Plant Connected	2	2	4	178

Table 5: Connecting New Sources of Gas

During RIIO-GD1, GDNs will monitor and report on the number of biomethane connections / capacity connected. GDNs developed an indicative forecast of future total capacity associated with biomethane entry connections, which was consistent with the central forecast from the Committee of Climate Change. The GDNs' forecast suggested that government policy and incentives would stimulate a target of 7TWh/annum of biomethane injection by 2020 and GDNs will monitor this as a leading indicator of renewable gas connections.

Alongside these targets to facilitate Biomethane connections to the networks, GDNs are also actively supporting the connection of other sources of gas, including BioSNG via the Network Innovation Competition (NIC) and hydrogen. There is an on-going NIC funded project being carried out in the Scottish town of Oban. This project is attempting to demonstrate the viability of utilising a wider range of gas sources safely and effectively in the networks.

Business Carbon Footprint (excluding Shrinkage)

Although shrinkage volumes continue to dominate GDNs' BCF, they will also focus on other areas of carbon emissions. The RIIO-GD1 Regulatory Framework introduced a requirement on GDNs to report annually on their carbon dioxide (CO2) equivalent emissions, using a standard framework for reporting BCF (excluding shrinkage). Two main areas of focus for BCF are company transport (scope 1) and energy consumption (scope 2).

Scope 1 emissions relate to company transport and are measured on business mileage claims for company cars and litres of fuel consumed for commercial vehicles. The majority of GDNs' transport emissions are generated from their commercial fleet vehicles and, as such, GDNs are working to invest in more sustainable fleets that will reduce their impact on the environment. More specifically, GDNs are investigating the opportunity to participate in a Compressed Natural Gas (CNG) trial in order to explore the opportunities and environmental benefits that a wider adoption of CNG vehicles could deliver in the short and longer term.

GDNs also operate a number of company cars in support of their operations, which are a combination of a 'job need' basis or as part of an employee's terms and conditions. In an attempt to reduce their emissions, GDNs have introduced incentives to company car drivers who select the greenest of cars. GDNs intend to continue with these 'green' incentives to encourage their drivers to consider cars which are less harmful to the environment.

Interoperability

This report interprets interoperability as the interface between gas transporters, particularly between the NTS and the gas distribution networks. Greater volumes of new sources of gas connecting to the system will drive the need for a full assessment of the planning and operating environment and the associated regulatory regimes that manage these interfaces.

12.2 Gas Transmission

NGGT is required to meet specific measures for CFU. The level of CFU procured for an incentive year is set based on our Shrinkage Methodology Statement. The methodology defines that the level be determined based on forecast flows at the St Fergus terminal against a best fit curve on actual levels of CFU since 2006/7.. Figure 15 shows the current curve used to determine the 2014/15 CFU levels:

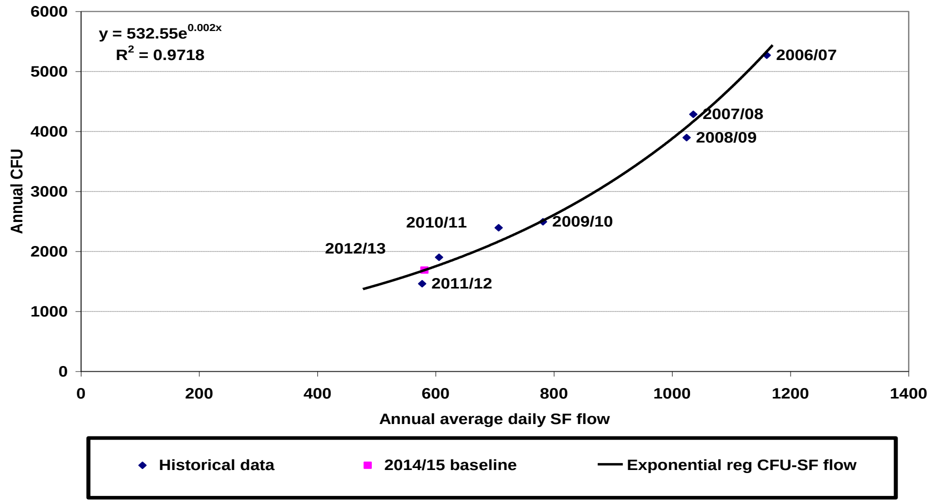

Figure 15 – Graph showing how the best fit level is determined and CFU levels

At the end of the year, the actual flow level is used to determine the associated efficient CFU level and the actual CFU is then assessed against this level. The outturn data is then added to the model to create a new best fit curve for future efficiency to be measured against. This model ensures that NGGT is penalised or rewarded against the determined efficiency criteria.

The actual levels of OUG and electricity compressor energy over the last five formula years are also provided below in Figures 16 and 17. It should be noted that, although electric units were in use in 2009-10 and 2010-11, the levels were very low and do not show up clearly in Figure 17.

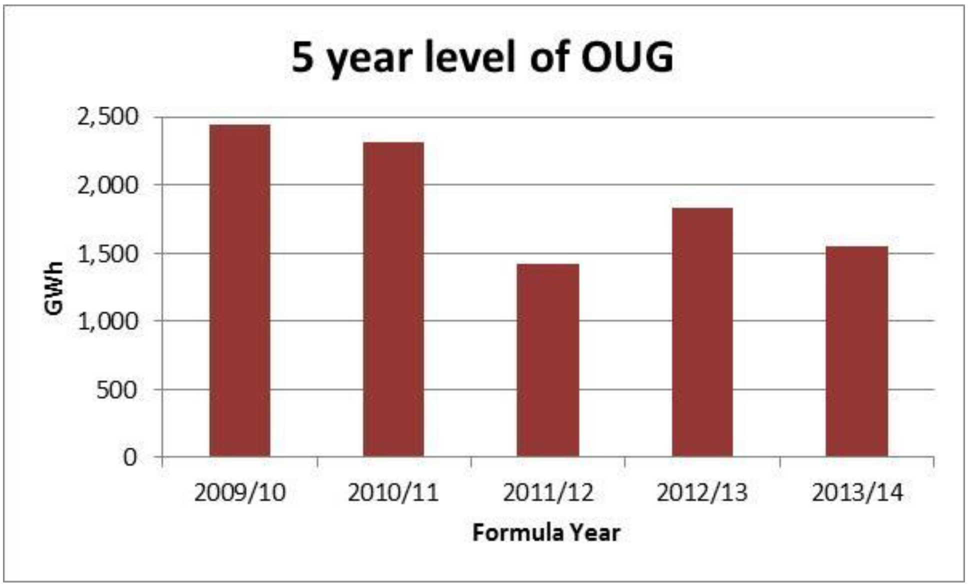

Figure 16 – Own Use Gas level for last 5 formula years

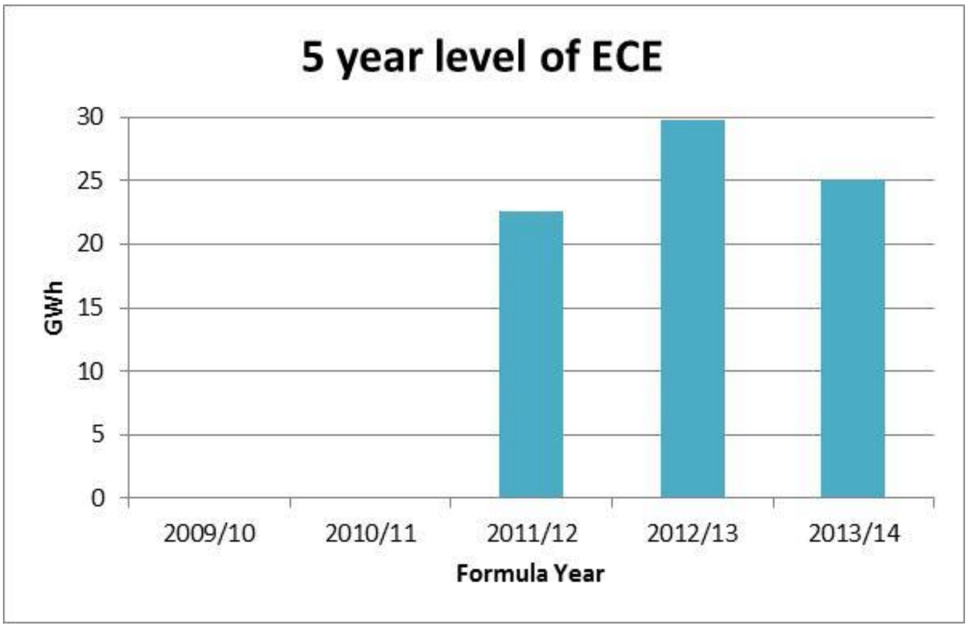

Figure 17 – Electricity Compressor Energy level for last 5 formula years

13 Innovation

The RIIO framework is intended to encourage innovation and incentivises network companies to adopt a range of innovative approaches, across all aspects of their businesses, in the delivery of network outputs. The framework includes a time-limited innovation stimulus package to fund innovation where the commercial benefits, or cost-effectiveness, may be uncertain and therefore stakeholders are unwilling to fund research and development projects speculatively. The innovation stimulus consists of the following:

- **Network Innovation Allowance (NIA)** – a set allowance that each of the RIIO network licensees will receive to fund small-scale innovative projects as part of their price control settlement.
- **Network Innovation Competition (NIC)** – an annual competition for funding larger, more complex projects which have the potential to deliver low carbon and / or wider environmental benefits to consumers.
- **Innovation Roll-out Mechanism (IRM)** – a revenue adjustment mechanism that enables companies to apply for additional funding within the price control period for the roll-out of initiatives with demonstrable and cost effective low-carbon and / or environmental benefits.

The network companies are currently developing a wide range of innovation projects that will result in environmental benefits. A list of projects which could have an impact on energy efficiency is provided iin Appendix 4.

14 Potential measures

There are many areas of potential energy efficiency improvements that network companies could focus on beyond the current price control; however this will depend upon Government and Ofgem policy surrounding the balance between sustainability and affordability.

14.1 Gas Distribution

The table below provides the potential benefits from potential future biomenthane connections and the GDNs' BCF work.

		15-16	16-17	17-18	18-19	19-20	20-21
BCF – scope 1 and scope 2	£ benefit	£25,131	£34,348	£42,514	£52,508	£67,182	£82,904
	MWh saved	0	0	0	0	0	0
Bio-methane connections	£ benefit	£2,293,487	£3,656,751	£5,158,147	£6,763,226	£8,471,986	£10,302,991
	MWh saved	2,324,673	3,156,395	3,988,117	4,819,839	5,651,561	6,483,283

Table 6 – Potential energy efficiency measures and benefits

There are several other areas of potential energy efficiency improvements that the GDNs could look to introduce in the future. These include:

Infrastructure

- Development of new innovative ways to carry out maintenance and repair on existing infrastructure (Core and Vac Innovation Project, Robotics Innovation Project)

Low Pressure Distribution Mains

- Completion of the Health and Safety Executive (HSE) mains replacement programme, and then remediation of metallic mains outside of the HSE mains replacement programme
- Investigation into the potential for internal joint repairs (CISBOT Innovation Project)
- Optimising average system pressure
- Optimising MEG saturation
- Design, development, manufacture, installation and commissioning of equipment to Improve MEG saturation (TouchSpray MEG Fogging System Innovation Project)

Medium Pressure Distribution Mains

- Completion of the HSE mains replacement programme
- Remediation of metallic mains outside of the HSE mains replacement programme
- Understanding the impact of pressure upon MP Mains leakage rates, capturing within the National Shrinkage model and then optimising average system pressure (Innovation Project)

Distribution Services

- Replacement of metallic services (Serviflex, PE Risers)

Above Ground Installations

- Understand venting and leakage rates from AGIs so reduction can be targeted (Innovation Project)
- Replacement of above ground installation control systems with equipment that reduces venting
- Remediation of leaking AGIs

Own Use Gas

- The development of more efficient gas pre-heating systems (Immersion Tube Preheating Innovation Project)
- Introduction of metering OUG

Further Development of the Shrinkage Model

To increase the intelligence of the assumptions and estimations within the model, and building upon the work already being undertaken by the Shrinkage Forum, there are several measures the GDNs are undertaking through the innovation mechanisms and a number of others that have been identified as possible improvements to the model:

- Including a pressure related MP calculation considering the relationship between pressure and leakage
- Embedding / accounting for mains remediation, as well as replacement, within model
- Accounting for proactive low pressure repair within model
- Accounting for remediation within model
- Calculation of own use gas through water bath heaters.
- Accounting for improvement in Above Ground Installation (AGI) venting volumes[29]
- Using new equipment[30] to indentify AGI leakage and Stakeholder Engagement to capture improvements

Investigating the use of Smart Meter Data

The Shrinkage Forum is also exploring new sources of data for the model, including an assessment of whether smart meter data could be used within the model. Of the key data inputs required in the shrinkage model, it is estimated that two could potentially be influenced and improved using smart metering data.

[29] These are losses in the everyday working of these assets, by understanding the volumes of losses from current equipment, working with manufacturers to identify assets with lower venting rates and by working with Stakeholders to capture within the Shrinkage and Leakage Model then leakage reductions from the distribution network could be achieved and demonstrated.

[30] Including Differential Absorption LIDAR (portmanteau of light and radar)

Average System Pressure (ASP)

Smart metering could provide usage data that might assist in the validation of network analysis models, which are used to calculate ASP. Although current network analysis validation policy already requires a high level of accuracy, smart metering could help fine tune the process, especially in small, specific areas of networks that are proving difficult to validate. To facilitate this, there would be a requirement for statistical load research to investigate the relationship between individual customer usage obtained via smart meter readings and the 'assumed fully-diversified' peak six-minute demand required by the Network Analysis modelling process.

Smart metering may also provide the opportunity to improve the pressure management of those networks operating on clocked or drawn profiles, ie. not on intelligent profile control, by providing a more accurate assessment of demand requirements, especially through off-peak periods. This could potentially allow pressure management regimes to be refined and pressures reduced during off-peak periods, both of which would result in lower ASP.

Currently, ASP is calculated using network analysis tools that assume a specified average demand across the year for all networks. Smart metering data will allow this figure to be tested and potentially allow for network specific average demand.

To fully explore some of these potential benefits, GDNs will consider the practicalities of setting up trials on specific networks to determine if smart metering data can impact on the ASP and the likely scale of any improvement. Any trial will be impacted by the smart metering rollout program and the availability of data in specific geographic areas.

Service Pipe Material Data Quality

Service pipe data is estimated using a combination of mains data and service pipe populations recorded during mains replacement activity. It may be possible during smart meter rollout to update the service type information used in the shrinkage model. This would require the support of suppliers and GDNs will raise this issue as part of supplier engagement on rollout.

There is the potential that smart metering may reduce demand, most likely during off-peak periods, allowing GDNs to operate those networks fitted with clocked or drawn profiles at lower pressures thereby reducing average system pressures which will, in turn, reduce leakage. The behaviour of customers cannot be forecast with any certainty and this will only be understood once significant volumes of smart meters are installed and a number of years of data compared.

GDNs will also investigate the opportunity to develop an improved understanding of demand patterns, following the introduction of smart metering. Smart metering may also make it easier to identify theft downstream of the Emergency Control

Valve e.g. via zero meter reads. The measure of OUG is not likely to be impacted by smart metering.

Other BCF measures, including micro-generation

Network companies have assets that experience changes in pressure and flows of pressurised gas across them, which could be used to produce clean electricity or store electricity as gas[31]. They also have a large amount of ground and roof space which could be used for locating micro-generation equipment such as wind turbines and solar arrays. Some network companies are restricted in their ability to take such measures to utilise micro-generation due to conditions within their licence. Network companies could work with DECC and Ofgem to ascertain the appetite for installing renewable micro-generation equipment on and within their assets. As a starting point network companies could undertake a desktop activity now to ascertain the potential renewable generation capability of their ground and roof space.

Gas Connections

According to research undertaken by Citizens Advice,[32] there were around 4 million households without gas for heating across England, Scotland and Wales in 2008. Of this, over 0.5 million had gas in their property but were not using it for heating, over 1.3 million were identified as being within close proximity of the gas network and 2 million were fully off grid. These households currently use other less efficient sources of energy to heat their homes and to cook with. Facilitating extension of the gas network is currently, in many scenarios, the most energy efficient, and secure, domestic heating solution. GDNs are also working with stakeholders to assess the best long term heat / energy solution seeking to achieve the right balance between consumer choice (including affordability), security of supply and energy efficiency (sustainability). Further detail on gas connections is provided in Appendix 3.

Facilitating Gas use for Transport

GDNs will work with industry stakeholders to promote and facilitate the connection of private Compressed Natural Gas (CNG) refuelling infrastructure in GB. Natural Gas vehicles have up to 28%[33] lower well-to-wheel greenhouse gas emissions, rising to 65% lower if the gas is biomethane, when compared to diesel vehicles.

The most plausible applications for CNG are for Heavy Goods Vehicles (HGVs) and fleet (buses etc.) vehicles. Whilst HGVs only account for 1.5% (550,000 vehicles) of road users, they account for 20% of road transport greenhouse gas

[31] Including Pressure to Gas http://www.smarternetworks.org/Project.aspx?ProjectID=1380
[32] http://www.consumerfocus.org.uk/files/2011/10/Off-gas-consumers.pdf
[33] http://gasrec.co.uk/biogas-transport-fuel-could-cut-hgv-emissions-by-65/

emissions.[34] Therefore, if half of all HGVs were CNG, then transport greenhouse gas emissions would reduce by between 3% and 7%, depending on the source of gas.

14.2 Gas Transmission

The largest area of energy consumption on the transmission system is through CFU from the operation of compressor fleet. The Industrial Emission Directive requires all impacted units to comply with Emissions Limit Values or be placed on a derogation. All units that are required to be replaced will then need to comply with a Best Available Technology assessment to reduce their impact on the environment as a whole.

Other areas for potential measures will be through innovation, which could be from either those projects detailed in previous sections of the report or from new projects set up through one of the innovation mechanisms. Successful projects would then be implemented into business as usual and could form the basis of future potential measures.

[34] http://naei.defra.gov.uk/data/uk

15 Overall Conclusions

In concluding this assessment, the two overriding deliverables of Regulation 6 will be revisited:

1. An assessment of the energy efficiency potentials of the gas and electricity infrastructure of Great Britain
2. A list identifying concrete measures and investments for the introduction of cost-effective energy efficiency improvements in the network infrastructure, with a timetable for their introduction.

This directive has given GB the opportunity to provide a snapshot of the losses reduction potential of GB's networks. GB's experience and strategy for improving energy efficiency on its networks through losses or shrinkage reduction can also be shared with other member states.

1. An assessment of the energy efficiency potentials of the gas and electricity infrastructure of Great Britain

A pragmatic approach has been taken to assess the energy efficiency potential of GBs networks by focusing on the area with the biggest potential; reducing network losses or shrinkage. Working groups were set up to explore this area, drawing on information that had been previously collected through GB's regulatory arrangements. This information was further developed and analysed for the purpose of this assessment.

This report has demonstrated that approaches to minimising losses or shrinkage will always be based on cost benefit analysis. Only measures that can efficiently reduce losses or shrinkage with a positive life cycle cost will be targeted. The analysis of electricity network benefit in GB has utilised the Ofgem losses calculation spreadsheet which uses £48.32 per MWh as the value for lost energy (if the CBA is positive, then the intervention will provide a benefit to the GB electricity customer). This is represented in the summary tables below. The analysis of the gas distribution network benefits has used leakage figures in 09/10 prices (based on the figures in the Transportation licence) and used carbon emissions figures in 2014 real prices (based on DECC's short term carbon values).

15.1 Electricity

For electricity, losses reduction will be achieved predominantly by utilising low loss transformers and installing larger conductors than what is needed to provide the energy. Typically this will be done when the assets have reached the end of their lives and a replacement is imminent or when new connections are being made and reinforcement is needed.

Electricity networks can be reconfigured to optimise network load flows. Where capital expenditure is required to enable reconfiguration, an assessment of cost verses benefit is undertaken to ensure that it provides long term financial and loss reduction benefit. This analysis will apply to all areas that target losses and have an associated cost. It is likely that the highest value and greatest scope approaches will be targeted first.

Network reinforcement within GB's transmission system is currently driven by customer led generation connection. While these increased power flows will tend to result in a net increase of losses across the system, losses strategies are based on considering the utilisation of lower loss conductors consistent with the capability of tower structures when designing and carrying out system reinforcement to enable generation connection.

15.2 Gas

For gas, the costs and benefits have only been quantified for measures being implemented under the current price control period. However, the report also identified innovative solutions and other future projects being investigated by the companies to identify their potential benefits and the associated costs.

Leakage comprises 94% of shrinkage on the gas distribution networks. The single biggest contributor to the GDNs achieving a reduction in leakage over the price control period is their mains replacement work. Although this is driven mainly by safety considerations, the associated reduction in leakage will significantly improve the energy efficiency of the networks and help the GDNs to meet their target of 20% reductions of shrinkage.

For NGGT, unaccounted for gas is the largest contributor to shrinkage on the NTS. However, reductions in shrinkage are achieved by correcting metering errors and don't actually contribute to the energy efficiency of the network. Instead, NGGT's cost benefit analysis has focussed on its compressor fuel usage, which is the energy used to run compressors to transport gas through the NTS. For gas driven compressors, this is Own Use Gas and for electric driven compressors this is Electric Compressor Energy.

2. A list identifying concrete measures and investments for the introduction of cost-effective energy efficiency improvements in the network infrastructure, with a timetable for their introduction.

The tables below summarise the loss savings from the concrete measures listed in this report.

15.3 Electricity

		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Replace old transformers	£m benefit	0.07	0.42	0.75	1.09	1.43	1.64	1.84	1.97
	MWh saved	1,532	8,573	15,590	22,600	29,588	33,809	38,028	40,717
Low loss transformers	£m benefit	0.7	0.42	0.75	1.09	1.43	1.64	1.84	1.97
	MWh saved	14,422	24,245	32,598	41,097	49,765	58,420	70,254	81,122
Transformer sizing	£m benefit	-	0.01	0.02	0.03	0.03	0.04	0.05	0.06
	MWh saved	0	174	346	520	694	867	1,040	1,214
Oversizing conductors	£m benefit	0.03	0.34	0.65	0.95	1.25	1.56	1.87	2.19
	MWh saved	601	7,110	13,356	19,572	25,918	32,156	38,708	45,260
Optimising conductors	£m benefit	0.33	0.51	0.64	0.79	0.95	1.12	1.39	1.64
	MWh saved	6,926	10,563	13,121	16,382	19,623	23,079	28,713	33,939
Voltage control	£m benefit	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.06
	MWh saved	164	328	492	656	820	984	1,148	1,312
Total	£m benefit	1.14	1.72	2.83	3.98	5.13	6.05	7.05	7.89
	MWh saved	23,645	50,993	75,503	100,827	126,408	149,315	177,891	203,564

Table 7 – Electricity distribution concrete measures and loss savings

		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Switch out underutilised plant	£m benefit	0.21	0.31	0.38	0.46	0.55	0.64	0.82	1
	MWh saved	4,392	6,562	8,007	9,679	11,477	13,434	17,045	20,743
Demand Side Response	£m benefit	0.12	0.17	0.21	0.26	0.31	0.36	0.46	0.55
	MWh saved	2,470	3,619	4,467	5,428	6,459	7,572	9,485	11,450
Total	£m benefit	0.33	0.48	0.59	0.72	0.86	1	1.28	1.55
	MWh saved	6,862	10,181	12,474	15,107	17,936	21,006	26,530	32,193

Table 8 – Electricity distribution potential measures and loss savings

15.4 Gas

		15-16	16-17	17-18	18-19	19-20	20-21
Mains replacement	£ benefit	£32,940,248	£39,998,151	£47,340,817	£54,527,008	£61,888,267	£69,413,851
	MWh saved	95,304	98,984	93,755	94,793	91,654	92,659
Services relaid and transferred	£ benefit	£8,206,327	£10,002,385	£11,805,287	£13,524,393	£15,240,634	£16,951,748
	MWh saved	18,086	18,606	16,835	16,697	15,736	15,631
Fuel poor connections	£ benefit	£420,348	£567,018	£731,740	£904,413	£1,083,705	£1,273,049
	MWh saved	0	0	0	0	0	0

Table 9 – Gas distribution concrete measures

		15-16	16-17	17-18	18-19	19-20	20-21
BCF – scope 1 and scope 2	£ benefit	£25,131	£34,348	£42,514	£52,508	£67,182	£82,904
	MWh saved	0	0	0	0	0	0
Bio-methane connections	£ benefit	£2,293,487	£3,656,751	£5,158,147	£6,763,226	£8,471,986	£10,302,991
	MWh saved	2,324,673	3,156,395	3,988,117	4,819,839	5,651,561	6,483,283

Table 10 – Gas distribution potential measures

		15-16	16-17	17-18	18-19	19-20	20-21
Direct Combustion of Natural Gas – NGGT transports natural gas through the NTS by means of compressors. The drive units for the compressors are prodominately gas turbines, and natural gas is used for their fuel. This energy is the total used by the gas turbine driven units	£m benefit	1.60	1.63	1.66	1.69	1.42	4.07
	MWh saved	132,888.81	133,250.07	133,490.91	133,640.18	110,123.83	311,491.42
Indirect Emissions from Electricity Usage – A number of the compressors are driven by electric motors. This energy is the total used by the electrically driven units	£m benefit	(8.79)	(8.92)	(8.97)	(9.11)	(11.33)	(13.06)
	MWh saved	(429,564)	(456,091)	(475,972)	(503,086)	(727,662)	(999,685)
Indirect Emissions from Electricity Usage – this energy is the total electricity used by compressor sites for control systems, lighting, small electrically driven equipment and domestic usage	£m benefit	-	(0.009)	(0.018)	(0.027)	(0.037)	(0.047)
	MWh saved	-	(296.46)	(592.92)	(889.38)	(1,185.84)	(1,482.3)

Table 11 – Gas Transmission measures for compressors

Appendix 1 – Electricity Networks Innovation

The contribution of innovation is uncertain but acts as a cornerstone in tackling the issues explored in this report. Relevant innovation projects, such as those funded through Ofgem Innovation funding programmes should be presented. Its cost effectiveness, potential ability to reduce losses etc. should be explored.

Project Name	Description
Smart Network Trial - Pontypool	Equipped all HV/LV pole and ground mounted distribution substations fed from one 132/66/11 kV primary substation, with measurement facilities to capture loading information and communicate back into WPD corporate systems including SCADA. Provided the data required for site specific cost benefit analysis of loss reduction measures, such as early replacement of higher loss distribution transformers. Provided monitoring of voltage, power factor and harmonic.
Optimising System Design for Performance and Losses	Working with Imperial College the project provided an optimising tool, which can consider both performance and system losses of alternative networks under different degrees of distribution generation penetration.
Voltage Unbalance in Distribution Networks	Voltage unbalance can cause damage to equipment, increase system losses, reduce network capacity, and prevent optimal feeding arrangements. A number of monitors on a meshed HV network were installed, where it was known that Voltage unbalance existed. The effect on performance and losses was evaluated.
Strategic Technology Programme (STP) Project into Energy Efficient Substations	Project (STP reference S5195_2) investigated aspects of Network Losses within the substation environment. This included network equipment and substation facilities.
Power Networks Research Academy Reactive Power Dispatch Using Distributed Generation	Queens University, Belfast carried out a detailed study of voltage profile and loss evaluation. The PhD student produced a paper and report into the use of DG in the reduction of power losses on the IEEE 13 Bus Model.
Technical Losses	Carried out by Imperial College and SOHN Associates this work developed further the research from the DPCR4 "Optimising

Review	System Design for Performance and Losses" project. It used the models previously developed to carry out a desktop cost benefit analysis of addressing losses on networks.
Carbon Tracing	The Carbon Tracing project developed a methodology to disaggregate the CO2 and kWh elements of network losses. The methodology allows a DNO to draw a distinction between "green losses" from connecting additional distributed generation and those more normally created by demand. The project also developed a number of additional innovative metrics by with to measure the carbon impact of losses including "electricity kilometres". A follow on demonstration project is planned which will take lives feeds of network analogue data.
Voltage Optimisation – 11kV Network	The study aimed to see if it was possible to operate the whole network at a reduced target voltage, but still remain within statutory limits. It set out to identify if there were any significant energy savings to customers by operating in this fashion. This project involved reducing the voltage by 2% and monitoring the voltage and load data at both the primary and secondary substations along the feeders. The study produced some encouraging results and gives confidence that there may be benefit of demonstrating the techniques on a wider scale.
Investigating Balancing of LV Networks	Determined the benefits of LV balancing by the development of a model to optimize inclusion of interconnected star transformers (static balancers) in to typical rural and urban network designs. One of the objectives was to develop techniques to ensure that LV networks are balanced. This would allow increased LV network utilization and deliver reduced network losses.
Phasor Measurement Trial	This project aimed to demonstrate the use of field Phasor identification equipment on 33kV, 11kV and LV networks, to identify operational and safety issues and equipment limitations. The stated benefits of the project included ensuring networks are balanced to maximise utilisation, avoid circulating current and reduce losses.
Harmonic Detection and Analysis	Use of disturbance recorder information to determine harmonic levels on a rural 33kV network with a large penetration of cable connected intermittent distributed generation. Harmonic voltage distortion has been recognised as a cause of increased losses in circuits and equipment.
HV Imbalance and power factor	DNOs are developing a project with a solar generation customer that will investigate the feasibility of addressing imbalance and power factor issues on the 33kV network. It will also use local storage to set the generated power per phase to reduce overall network imbalance. The storage can also be used to manage the

	overall utilisation of the network.
LV Imbalance	A project is being developed which will investigate and assess methods for correcting imbalance on the low voltage network. The project will look at the relative costs and benefits of methods such as the service-by-service rebalancing of customers or the less granular approach of rebalancing whole sections of the network between joint positions.
Revenue Protection	DNOs are currently working on an IFI project to establish if it is possible to detect the presence of heat lamps used for the cultivation of drugs such as cannabis using the specific electrical harmonic signature created by the heat lamps. This activity is often linked with illegal abstraction.
ACCC overhead conductor (Project: IFIT 2010_01)	One company has completed the assessment and trial installation of an Aluminium Conductor Composite Core (ACCC) conductor on a 132kV wood pole transmission line. The design of the ACCC maximises the area of conductive material in the conductor, providing the same power-carrying capacity at a lower operating temperature than in conventional conductor designs. The lower comparative operating temperature leads to reduced losses, as well as a high current-carrying capacity that can defer or avoid the requirement for more costly conventional network reinforcement. They are currently undertaking analysis of the trial results prior to potential transfer to business-as-usual in RIIO-T1.
Conductors	In conjunction with the University of Manchester, EPL Composite Solutions and SSE, National Grid has undertaken a research and development project to develop and trial the application of new materials to replace existing 275kV overhead line conductor insulation and supporting arms with a composite insulated supporting arm capable of 400kV operation. The new arrangement will allow the option of upgrading of existing 275kV overhead line routes to 400kV operation, to increase system capacity without the requirement to build new OHL routes. If successful, this innovation has the additional benefit to reduce circuit transmission losses by 20% to 40% depending on circuit loading, for routes which can justify this investment. The research and development project is now complete, but awaiting a suitable scheme for consideration as a development option.
Capacity to Customers (C2C)	Aim is to release capacity in the network, provided for supply security, for new connections on a non-firm basis. An integral part of this project is optimisation for the network operating configuration for its loading condition. Typically, ENWL operates its HV and LV circuits in a radial configuration with alternative supply facilitated via adjacent circuits connected via a

	circuit breaker in the open state. The C2C project aims to reduce like-for-like power losses by 'meshing' the HV and LV networks through the closure of the normally open circuit breakers. Theoretical analysis indicates a losses reduction in the order of 0.1%. The C2C project aims to provide empirical evidence for this losses reduction technique.
The Lincolnshire Low Carbon Hub	The project evaluates reduction of losses from 33kV meshing and increase in "green losses" due to higher network utilisation.
FlexDGrid	FlexDGrid explores the saving in losses from closing bus section circuit breakers in central Birmingham to share transformer loading . This will be made possible by the FlexDGrid Fault Level modelling, measurement and mitigation techniques.
SoLa BRISTOL	Elements of SoLa BRISTOL are losses related (but on the customer side of the meter primarily) looking at round trip efficiency of eliminating AC/DC convertors within the home, schools and businesses. The project will also use the micro-grid control strategy to achieve network balancing and peak reduction using a crowd sourcing approach to battery despatch.
FALCON	The FALCON Scenario Investment Model (SIM) will include an estimation of network losses in its Cost Benefit Analysis decision tree algorithm. The SIM parameters for technique efficiency will be informed by the six engineering and commercial trials.
LV Network Templates	LV Templates investigated the impact of LV voltage reduction on technical losses. As part of the project close down a paper was produced quantifying the benefits of reducing distribution voltages within UK and EU existing standards. The project also estimated and made recommendations on the opportunities for transformer losses reduction.
Solent: Achieving Value through Efficiency (SAVE)	This project focuses on engagement with customers in order to specify energy efficiency measures which could be implemented to solve network capacity problems while saving customers money on the cost of energy and reducing network losses.
Low Energy Automated Networks (LEAN)	As previously stated this project considers the benefits case to switching out of a transformer at dual transformer Primary substations. If successful could pay back the equipment cost between 5-10 years.
My Electric Avenue	This is only currently being used to manage constraint peaks, it can also be re-tasked to reduce peaks even when there are no capacity constraints to reduce losses – further investigation required in this area.
Thames Valley	A key element of the project is looking distributed energy

Vision	storage on the LV network with devices that can balance phases and hence reduce losses associated with network imbalance.
Low Carbon London	Some 1,100 domestic consumers are participating in the trial and each consumer has a smart meter which enables the project team to record their half-hourly time-series consumption. The tariff is a critical peak price tariff with three price bands. The price bands are not fixed to specific periods of the day; instead consumers are notified one day ahead of the prices and time bands that will apply over the following day. Given that a 19% increase in electricity consumption due to electric vehicles and heat pumps could give rise to a 40% increase in variable losses, the benefits of effective peak demand reduction in terms of avoided investment in network capacity and reduced distribution network losses could be considerable.
Flexible Networks for a Low Carbon Future	Aim is to provide 20% increase in network capacity headroom through a variety of innovative network solutions, including more sophisticated data analysis and network characterisation techniques, dynamic rating of overhead lines and transformers, network automation and energy efficiency measures. A key element of the flexible network control is how network reconfiguration should be done to reach a suitable compromise between losses and reliability.
Multi-terminal test environment for HVDC systems (Project: SSEEN01)	One TO is proposing to establish a collaborative facility which will enable the planning and optimisation of future HVDC systems in GB. This proposal was submitted to Ofgem in August 2013 for consideration as part of the Electricity Network Innovation Competition (NIC). This facility is known as the Multi-Terminal Test Environment (MTTE). It would allow detailed study of the interaction between new HVDC and existing AC networks as well as modelling of operational approaches to optimise DC and AC system performance, potentially leading to reduced losses. The outputs of the MTTE could potentially contribute to reducing losses in the latter years of RIIO-T1.
Maximising the use of existing infrastructure through new technologies: 132kV Crossarm Trial	One company is trialling innovative insulated crossarms on the towers of an operational 132kV circuit. The purpose of crossarms is to hold the wires clear of the tower body. Retrofitting the innovative crossarms to existing towers can enable the upgrading of existing lines to a higher voltage to enable higher power flows as well as reduce losses. This avoids the higher cost and greater environmental impact of rebuilding the affected lines to provide additional capacity. We are currently undertaking analysis of the trial results prior to potential transfer to business-as-usual in RIIO-T1.

Appendix 2 – Status of losses on the Transmission Network

SHE Transmission

The methodology used to assess the impact of the reinforcement projects on transmission losses was based on a single interval of the network performance at winter peak demand. Power losses at peak demand in a year were compared to losses in the following year, based on the ETYS years' format of year 1,2,3,4,5,7 and 10. The PSS/E network models used for the studies were the ETYS 2013 models from year 2013-14 to 2022-23 based on the Gone Green scenario.

The study results are shown in the table below where a negative change represents a reduction in transmission power losses at peak demand compared to previous year. Note, these are the ETYS 2013 'Gone Green' base case dates.

	Name of reinforcement	Description	Total Power Losses at Peak Demand (MW)	% Change in losses
2014	**Beauly – Denny 400/275kV OHL (part)**	Replace 132kV double circuit line Beauly – Fasnakyle – Fort Augustus – Errochty – Braco – Bonnybridge with a double circuit line Beauly – Fasnakyle – Fort Augustus – Tummel – Denny. The line to be insulated at 400kV but operating with one circuit at 400kV and another one at 275kV.	**150.3**	**-**
2015	**Beauly – Denny 400/275kV OHL (part)**	As above	**111.0**	**-26.1%**
	Beauly – Blackhillock – Kintore 275kV OHL Reconductoring	Reconductor existing 275kV double circuit overhead line between Beauly, Knocknagael, Blackhillock and Kintore substations with higher capacity conductors.		
	Fort Augustus – Skye 132kV Reconfiguration	Construct a new 132kV OHL from Fort Augustus substation to Skye Tee. This will offload the 132kV double circuit line from Fort Augustus to Fort William.		
	Keith – Macduff 132kV Reinforcement	Upgrade the existing 132kV single circuit overhead line from Keith to Macduff to a 132kV double circuit overhead line.		

2016	**Beauly – Denny 400/275kV OHL (part)**	As above	**76.9**	**-30.7%**
	Kintyre 132kV Reinforcement & Crossaig – Hunterston subsea cables	Establish a new 132 kV substation at Crossaig in Kintyre and install a subsea link between Crossaig and Hunterston (SPT). This will comprise of two 240MVA land/subsea cable circuits, connecting to two 240MVA 132/220kV transformer substation at Crossaig, and two 240MVA 220/400kV transformer substation at Hunterston. Rebuild the existing 132 kV double circuit line between Crossaig and Carradale. Install two Quadrature Booster transformers at Crossaig on the 132kV double circuit OHL to Port Ann.		
	Foyers – Knocknagael 275kV OHL Upgrade	Upgrade the existing 275kV double circuit overhead line from Foyers to Knocknagael to a higher capacity.		
	Carradale – Crossaig 132kV OHL Upgrade	Upgrade the existing 132kV double circuit overhead line from Carradale to Crossaig to a higher capacity.		
2017	**Beauly – Mossford 132kV OHL Upgrade**	Rebuild the existing 132kV double circuit overhead line from Beauly to Corriemoillie near Mossford with a higher capacity to replace the existing 2 x 132kV circuits.	**85.4**	**+11.1%**
2018	**Blackhillock Quad Boosters on the Blackhillock – Knocknagael 275kV OHL**	Install 2 x 865MVA 275kV quadrature boosters with bypass on the Blackhillock – Knocknagael 275kV circuits.	**96.1**	**+12.5%**
	Loch Buidhe 275/132kV Substation	Construct a new 2 x 240MVA 275/132kV transformer substation near Loch Buidhe, at the crossing point of the existing Beauly –Dounreay 275kV and Shin – Mybster 132kV double circuit overhead lines		
	Beauly – Loch Buidhe 275kV OHL Reconductoring	Reconductor circuit FYL1/BFY1 of the 275kV double circuit overhead line between Beauly, Fyrish and Loch Buidhe substations with higher		

		capacity conductor.		
2020	**Errochty 132kV Network Reconfiguration**	Split the 132kV busbars at Errochty into two separate busbar layouts and reconfigure the circuits to separate the Killin, Clunie and Burghmuir/Abernethy 132kV circuits from the rest of the 132kV circuits at Errochty substation, which are left connected to the 275kV system.	**130.1**	**+35.4%**
	Lairg – Loch Buidhe 132kV Reinforcement	Establish a new 132kV double busbar arrangement at Lairg (adjacent to Lairg GSP) and construct 20km of new 132kV double circuit overhead tower line between Lairg and Loch Buidhe.		
	Loch Buidhe – Dounreay 275kV circuit Reconductoring	Reconductor circuit DU1 of the 275kV double circuit overhead line between Loch Buidhe and Dounreay substations with higher capacity conductor.		
2023	**Beauly – Loch Buidhe 275kV OHL Reinforcement**	Upgrade the existing Beauly, Shin to Loch Buidhe 132kV double circuit overhead line with a higher capacity 275kV double circuit overhead line.	**169.6**	**+30.4%**

The SHE Transmission studies show that generally the transmission reinforcement projects helped to reduce the transmission power losses at winter peak demand in the early years. However beyond year 3, the losses increased year on year due to an increase in renewable generation connected to the network.

National Grid

Each development outlined in this section is accompanied by an estimate of its impact on total transmission losses across the transmission networks - in sections 1- 6, the impact of losses are reported for key incremental wider works schemes.

For sections 1-6, percentage loss figures outlined in the tables below are not directly comparable. The loss impact of each individual development has been assessed by considering the background pre- and post-investment. However, as developments are incrementally staged, the background against which losses are assessed continually evolves with each incremental investment. Whilst this provides an accurate reflection of transmission network development, it does not provide a consistent base for direct comparison of losses figures established at different stages of transmission network reinforcement.

1. Scotland – SHE Transmission to NGET

ETYS 2013 Gone Green base case date	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2020	**Eastern HVDC One**	A new ~2GW submarine HVDC cable route from Peterhead to Hawthorne Pit with associated AC network reinforcement works on both ends. The three onshore TOs will continue to work together during 2014 to determine the most economic and efficient design solution for the Eastern HVDC link.	**46,758**	**+0.59%**

2. Scotland – SP Transmission to NGET

ETYS 2013 Gone Green base case date	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2014	**B6 NGET series and shunt compensation**	Series compensation to be installed in the Harker – Hutton, Eccles – Stella West and Strathaven – Harker routes. Strathaven – Smeaton route uprated to 400kV and the cables at Torness uprated. Reduces the impedance of the Anglo--Scottish circuits improving the loading	**3.17**	**+0.55%**

		capability of the circuits.		
2016	**Western HVDC Link**	A new 2.45 GW (short term rating) submarine HVDC cable route from Deeside to Hunterston with associated AC network reinforcement works on both ends.	**21.42**	**+3.15%**
2024	**Eastern HVDC Two**	A new ~2GW submarine HVDC cable route between Torness and North East England with associated AC network reinforcement works on both ends.	**11,055**	**-0.12%**

3. North England

ETYS 2013 Gone Green base case date	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2014	**Penwortham Quad Boosters**	Install a pair of 2750MVA Quadrature Boosters (QBs) on the double circuits which run from Penwortham to Padiham and Daines at the Penwortham 400kV substation. They will improve the capability to control the north to south power flows on the circuits connecting the North Midlands	**0.21**	**+0.04%**

		and the West Midlands, and hence improve the transport of excess generation from the north to demand centres in the south.		
2016	**Kirkby and Rainhill substation upgrade**	Replace circuit breakers and equipment at Rainhill so that Kirkby and Rainhill can be changed to a two-way split configuration. This will divert more power to flow into the Kirkby – Rainhill – Fiddlers Ferry route from the Kirkby – Lister Drive – Birkenhead route; as a result, loading on the Kirkby to Lister Drive circuits will be better shared. Improved utilisation of the existing 275kV Mersey ring will significantly increase the capability of the network to handle north to south power flows.	**4.74**	**+0.72%**
2020	**Yorkshire lines re-conductor (Norton – Osbaldwick hotwiring and re-conductor & Lackenby–Norton re-conductor)**	Re-conductor sections of the Lackenby – Norton 400kV circuit with higher-rated conductor and up rate the cross-site cable at Lackenby 400kV	**5.18**	**+0.56%**

		substation to a similar or higher rating. Re-conductor a small section and hotwire the remainder of the existing 400kV double circuits which run from Norton to Osbaldwick. This will help ensure the circuits will provide sufficient thermal capacity to transport the excess generation from Scotland to southern demand.		
2020	**Penwortham – Padiham & Penwortham – Carrington re-conductor & Kirkby – Penwortham upgrade (Mersey Ring stage 1a)**	Up rate the 275kV double circuit overhead lines from Kirkby to Penwortham to operate at 400kV and carry out associated work (including construction of Kirkby 400kV substation and a new Washway Farm 400/132kV substation with two 400/132kV 240MVA SGTs). Uprate the limiting sections of the Penwortham - Carrington and Penwortham Padiham double circuit to improve overall transmission capability. This will improve the capability of the network to handle the heavy	**4.93**	**+0.53%**

		north to south power flows from the large amount of expected generation connection in Scotland.		
2020	**Lister Drive Quad Booster Installation**	Replace the existing series reactor at Lister Drive with a Quad Booster (QB). The Quad Booster will enable flexibility to control power flows through the circuit south of Lister Drive.	**3.86**	**-0.37**

4. East England

ETYS 2013 Gone Green base case date	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2022	**Bramford – Twinstead Tee**	Re-conductor the existing Pelham – Braintree – Rayleigh Main circuit, and construct a new transmission route from Bramford to the Twinstead tee-point, creating double circuits which run between Bramford – Pelham and Bramford – Braintree – Rayleigh Main. These works will result in two transmission routes for power to flow south from the East Anglia area and	**1.92**	**+0.21%**

		hence increase the capability of the network to export excess generation from the area significantly.		
2014	**Rayleigh – Coryton South – Tilbury re-conductor**	Re-conductor the existing Rayleigh Main – Coryton South – Tilbury circuits with higher-rated conductor. This will help ensure the circuits will provide sufficient thermal capacity to transport the excess generation from the East Anglia area to the south east demand, as an increasing amount of future wind and nuclear generation is expected to connect in the area.	**2.55**	**+0.26%**
2026	**East Anglia MSC**	Install a 225MVAr MSC to provide voltage support to the East Anglia area. The MSC will help ensure voltage compliance for local faults where power is diverted through a longer transmission route.	**1.51**	**+0.12%**

5. South England

ETYS 2013 Gone Green base case date	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2018	**Wymondley turn-in**	Modify the existing circuit which runs from Pelham to Sundon; turn in the circuit at Wymondley to create two separate circuits which run from Pelham to Wymondley and Wymondley to Sundon. This will improve the balance of the power flows on the North London circuits, and increase the capability of the network to import power into London from the north transmission routes.	**-0.26**	**-0.04%**
2014	**Barking – Lakeside Tee new double circuits**	Construct a new 400kV transmission route from Barking to the Lakeside tee-point on the existing transmission route from Tilbury - Littlebrook. This will divert some power flows from the heavily loaded North London circuits to the south east transmission route to supply	**-0.31**	**-0.05%**

		London demand; as a result the networks capability to import power into London will improve.		
2022	**Hackney – Tottenham – Waltham Cross up-rate**	Uprate and reconductor the Hackney – Tottenham – Brimsdown – Waltham Cross 275kV transmission route with higher-rated conductor to operate at 400kV, and reconductor the Pelham - Rye House double circuits with higher-rated conductor. Carry out associated work including construction of a new Waltham Cross 400kV substation, modification to Tottenham substation and installation of two new transformers	**1.39**	**+0.12%**
2019	**Wymondley Quad Boosters**	Install a pair of 2750MVA Quadrature Boosters (QBs) on the Wymondley to Pelham double circuits at the Wymondley 400kV substation. The pair of QBs will improve the capability to control the power flows on the North London	**0.03**	**+0.01%**

		circuits, and significantly improve the capability of the network to import power into London from the north transmission routes.		

6. West England and Wales

ETYS 2013 Gone Green base case date	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2023	**Wylfa – Pentir second transmission route**	Construct a second 400kV transmission route from Wylfa to Pentir, with associated work including the modification to the Wylfa 400kV substation and extension of Pentir 400kV substation. This extra transmission route will allow the connection of generation at Wylfa beyond the infeed loss risk criterion (currently 1320MW and changing to 1800MW from April 2014). The capability of the network to export power from Wylfa into the main transmission system will be improved significantly.	**-0.84**	**-0.08%**

2020	**Pentir – Trawsfynydd second circuit**	A second circuit is created by using one side of a route currently occupied by an SP-MANWEB 132kV circuit. A large single core per phase cable section is required across Glaslyn where no overhead line currently exists. A single 400/132kV transformer is teed off the new circuit to provide a connection to SP-MANWEB at Four Crosses to replace its circuit.	**2,867**	**+0.04%**
2014	**Trawsfynydd – Treuddyn Tee re-conductor**	Reconductoring the ZK route double circuit to GAP forms the first part of a suite of anticipatory investments in North Wales, designed to deliver increased transmission capacity in readiness for the first stages nuclear and wind farm generation connecting in North Wales. It is planned in 2014 as a result of asset condition drivers.	**3,711**	**+0.07%**
2021	**Bredbury – South Manchester re-conductor**	The work includes replacement of Bredbury substation cables and Bredbury to South Manchester transmission cable with two parallel single	**11.66**	**+1.14%**

		core per phase XLPE 2500mm2. The busbars, circuit breakers and cable tower termination shall also be replaced. The reinforcement, enhances the Midlands to South power flows and ultimately, supporting the networks ability to transfer more power from the north to the south.		
2022	**Cellarhead – Drakelow re-conductor**	Re-conductor the existing double circuits which run from Cellarhead to Drakelow with higher-rated conductor. Together with other West Midlands reinforcements, this will further increase the thermal capability from Midlands to South, supporting the networks ability to transfer more power from north to south.	**26.97**	**+2.36%**
2021	**Pentir – Trawsfynydd 1 single core per phase**	The existing cable sections of the Pentir – Trawsfynydd 1 are replaced by large single core per phase cable sections.	**3,037**	**+0.03%**
2021	**Pentir – Trawsfynydd 2 single core per phase**	The cable sections across both existing circuit and new circuit connecting Pentir to Trawsfynydd including the long	**13,374**	**+0.13%**

		sections across the Glaslyn estuary are paralleled with additional large single core per phase. The OHL will be the limiting component after this reinforcement is constructed.		
2019	**Running Carrington 400kV substation solid and Daines 400kV rationalisation**	Having both Carrington and Daines 400kV substations split limits the boundary transfer and overloads one of the Carrington to South Manchester circuit due to poor load sharing. This is solved by running Carrington 400kV substation solid and tee-in circuits coming into Daines 400kV substation subsequent decommissioning. The scope of the project also involves extension of the Carrington 400kV that will accommodate new generation connection in the future. This reinforcement shall improve the power transfer from north to south and relaxes the thermal stress on west region boundary circuits.	**-76,483**	**-0.96%**

Scottish Power Transmission

To provide an indication of how transmission system losses are expected to change in future, the table below shows losses in the SPT network at the time of winter peak for a number of future years. These are power loss figures (for one point in time) based on analysis carried out with the 2014 ETYS model, which is based on the Gone Green planning scenario. Note that the change in losses at the time of winter peak is not only a function of the stated network reinforcements, but also of generation dispatch and demand, which can vary considerably from year to year.

To make an estimate of an annual lost energy volume is significantly more complex as it would require the construction of a significant number of network conditions (generation dispatch, demand and outages) to approximate the year-round operation of the network. By evaluating the losses for each such condition and considering the length of time it is expected to last, an annual loss estimate could be made. We are currently considering methods to make such a loss estimate.

It is difficult to estimate the impact of individual network reinforcement projects on losses as these are often related to generation connections, which tend to lead to higher network transfers and, in turn, increased losses.

The study results are shown in the table below where a negative change represents a reduction in transmission power losses at peak demand compared to previous year.

ETYS 2013 Gone Green base case date	Name of key reinforcements	Description	Total Power Losses at Peak Demand (MW)	% Change in losses
2014	**Inverkip Disconnection**	Reconfiguration of the 400kV network associated with the Western HVDC Link will facilitate the decommissioning of Inverkip 400kV substation and the future rationalisation of the local overhead line network.	**101**	**-**
2015	**Beauly – Denny 400/275kV OHL**	The Beauly to Denny reinforcement extends from Beauly in the north to Denny. Replace the existing Beauly–Fort Augustus–Errochty–Bonnybridge 132kV overhead lines with a new 400kV tower construction which terminates at a new substation near Denny in SP Transmission's area, and carry out associated AC substation works. One of the circuits will be operated at 400kV and the other at 275kV.	**127**	**+25.6%**

	Series Compensation	Install series compensation in the Harker–Hutton, Eccles–Stella West and Strathaven–Harker routes. Two 225MVar MSCs to be installed at Harker, one at Hutton, two at Stella West and one at Cockenzie. This effectively reduces the impedance of the Anglo-Scottish circuits improving their loading capability.		
2016	**Western Link HVDC**	This is a new 2.4 GW (short-term rating) submarine HVDC cable route from Deeside to Hunterston with associated AC network reinforcement works on both ends. At the northern end it will include construction of a Hunterston East 400kV GIS substation.	**105**	**-17.2%**
	East – West 400kV Upgrade	Uprate the Strathaven–Smeaton route to 400kV and uprate the cables at Torness		
2017			**104**	**-1.1%**
2018			**110**	**+5.3%**
2020	**East Coast Upgrade**	A joint SHE Transmission and SP Transmission project to upgrade the existing east coast overhead line between Blackhillock and Kincardine. Includes new substations at Rothienorman, Alyth and an extension of the existing substations at Kintore and Kincardine.	**169**	**+53.6%**
2023	**Eastern HVDC Link**	A new 2GW submarine HVDC cable route between Torness and North East England with associated AC network reinforcement works on both ends.	**212**	**+25.4%**
	Denny – Wishaw 400kV Upgrade	The Central 400kV Uprate uses existing infrastructure between Denny and Bonnybridge, Wishaw and Newarthill along with a portion of an existing double circuit overhead line		

		between Newarthill and Easterhouse. A new section of double circuit overhead line is required from the Bonnybridge area to the existing Newarthill/Easterhouse route. Together with modifications to substation sites, this reinforcement will create two new north to south circuits through the central belt: a 275kV Denny/Wishaw circuit and a 400kV Denny/Wishaw circuit, thereby significantly increasing B5 capability.		
	Dumfries & Galloway Upgrade	The transmission network in the Dumfries and Galloway Region is provided by an interconnected single 132kV circuit between Dumfries and Coylton. This circuit has a summer rating of 106MVA and was constructed in 1936 to connect the Galloway Hydro scheme. The Dumfries & Galloway Upgrade comprises the construction of a new overhead line to serve the main demand blocks, existing generation portfolios and facilitate the connection of new renewable generation in the Dumfries and Galloway region.		

The timetable for measures reductions are presented in the tables with each concrete measure and cover the covers the current price control period to 2023.

Appendix 3 – Household CO2 Emissions Assumptions

This annex presents a methodology to estimate the CO2e saved as a result of a consumer being connected to the gas distribution system and switching from an alternative fuel source. This estimate can be used to identify the potential CO2e savings from the Fuel Poor Connections programme and for extending the gas distribution network in general.

According to research undertaken by Consumer Focus there were around 4 million households without gas for heating across England, Scotland and Wales in 2008. Of this over 0.5 million had gas in their property but were not using it for heating, over 1.3 million were identified as being within close proximity of the gas network (within the same post code) and 2 million were fully off grid. These figures are presented in the table below.

Access to Gas	Properties (m)[35]			GB properties without Gas Heating
	England	Scotland	Wales	
Gas in property but not for heating	0.489	0.053	0.026	14%
Gas within same Post Code	1.096	0.171	0.053	34%
Off Gas Grid	1.535	0.317	0.190	52%

These households currently use other less efficient sources of energy to heat their homes and to cook with, as shown in the table below. By connecting, or facilitating the connection of, these consumers to gas distribution networks it would reduce their carbon footprints and in many cases would reduce their energy bills.

[35] http://www.consumerfocus.org.uk/files/2011/10/Off-gas-consumers.pdf

Fuel	Properties (m)[36]			GB properties without Gas Heating
	England	Scotland	Wales	
Oil	0.828	0.135	0.143	28%
LPG	0.128	0.018	0.025	4%
Coal / Solid Fuel	0.240	0.033	0.037	8%
Electricity	1.919	0.354	0.063	60%

The table below shows the different fuels that consumers may switch from and the carbon dioxide factor for each fuel and the carbon dioxide savings that would be achieved if they switched to gas. This is calculated as:

% savings = 1 – (Gas Carbon Dioxide Factor / Alternative Source Carbon Dioxide Factor)

Fuel	Carbon dioxide factor (kgCO2/kWh)[37]	Carbon Dioxide Savings if switched to gas (%)
Oil	0.246	25%
LPG	0.214	14%
Coal / Solid Fuel	0.296	38%
Electricity	0.480	62%
Gas	0.184	0%

Therefore, assuming a household would use the same amount of energy before and after fuel switching (14,800kWh38), then switching from oil to gas would save 918 kgCO2 pa, LPG to gas would save 444 kgCO2 pa, coal / solid fuel to gas 1,658 kgCO2 pa and Electricity to Gas 4,381 kgCO2 pa.

[36] http://www.consumerfocus.org.uk/files/2011/10/Off-gas-consumers.pdf
[37] http://www.energysavingtrust.org.uk/domestic/content/our-calculations.pdf
[38] Assumption that all properties use 14,800kWh pa DECC Gas Domestic Consumption Figure (table 3.07) as used by Ofgem in their Supply Market Indicator (p20)Supply Market Indicator (p20)

Fuel	Calculation	Emissions (kg/CO2 pa)
Oil	14,800 x 0.246	3,641
LPG	14,800 x 0.214	3,167
Coal / Solid Fuel	14,800 x 0.296	4,381
Electricity	14,800 x 0.480	7,104
Gas	14,800 x 0.184	2,723

If we assume that:

1. the 1.32 million properties currently without gas but within close proximity of the gas network have the same current fuel split as seen across the whole population with no gas for heating;
2. each property uses 14,800kWh of energy for heating with their current fuel; and
3. they would continue to use the same if they switched to gas then almost 4MtCO2 could be saved each year if they were switched to gas for heating. This is set out in the following table

Fuel	**Properties (m)**[39]	**Average Household Consumption (kWh)**[40]	**Carbon Dioxide Emissions (MtCO2)**[41]	**Carbon Dioxide Emission Savings if switched to gas (MtCO2)**
Oil	0.37	14,800	1.35	0.34
LPG	0.05	14,800	0.16	0.02
Coal / Solid Fuel	0.11	14,800	0.05	0.02
Electricity	0.79	14,800	5.61	3.48

[39] Based on assumptions provided within text
[40] Assumption that all properties use 14,800kWh pa DECC Gas Domestic Consumption Figure (table 3.07) as used by Ofgem in their Supply Market Indicator (p20)Supply Market Indicator (p20)
[41] Properties *X* Average Household Consumption *X* Carbon Dioxide Factor

As such it could be estimated that on average switching to Gas from another fuel source <u>saves c. 3,000 kgCO2 pa for each household</u>, *based on those households identified as being within close proximity (same post code) of the gas network*,as shown in the calculations below. Note consumption is assumed to be 14,800kWh.

Fuel	Carbon Disoxide factor (kgCO2/kWh)	Carbon Dioxide Emissions (kgCO2) per household	Properties	Total Carbon Dioxide Emissions (kgCO2)
Oil	0.246	3,641	372,144	1,354,901,029
LPG	0.214	3,167	57,538	182,233,083
Coal / Solid Fuel	0.296	4,381	104,308	456,952,169
Electricity	0.480	7,104	786,011	5,583,820,056
Average Household[42]	**<u>0.388</u>**	**<u>5,741</u>**	1,320,000	7,577,906,337

Facilitating extension of the gas network is currently, in many scenarios, the most energy efficient, and secure, domestic heating solution, GDNs are also working with stakeholders to assess the best long term heat / energy solution seeking to achieve the right balance between consumer choice (including affordability), security of supply and energy efficiency (sustainability).

[42] Average off-gas but within close proximity to gas network property

Appendix 4 – Gas Networks Innovation

Project Name	Description
Low Carbon Gas Preheating[43]	The objective of this project is to trial the potential of two 'alternative' preheating technologies aimed at accelerating the development of alternative technologies and increasing the level of competition in the preheating technology market. The project will provide data to allow networks to optimise investment decisions, including reducing the BCF of preheating. The project data will also be used to assess the accuracy of current estimates of GDNs' own use gas within the current shrinkage estimates, reducing whole life costs of preheating installations. (Project end date – 31/12/2017)
TouchSpray MEG Fogging System[44]	The overall aim of the MEG improvement initiative is to design, develop, manufacture, install and commission a TouchSpray MEG Fogging system for use on the Gas Distribution network, in order to achieve a major improvement in MEG saturation levels across the network, which will result in a reduction in leakage from metallic mains within thethe networks. This project will assess the practical and financial feasibility of the technology offered by the Project Partner, The Technlology Partnership (TTP) to significantly improve the effectiveness of the current Gas Conditioning process under Phase 2B[45] of the project. It.I is to produce the conceptual design of a TouchSpray MEG Fogger, produce the test capability, and understand the droplet size dynamics in the pipe flow. Under Phase 2C[46] of the project, is to enhance the TTP air based facility built as part of Phase 2B ahead of droplet size testing occurring. (Project end date – 01/09/2014)

43 http://www.smarternetworks.org/Project.aspx?ProjectID=1319
44 http://www.smarternetworks.org/Project.aspx?ProjectID=1276
45 http://www.smarternetworks.org/Project.aspx?ProjectID=1407

46 http://www.smarternetworks.org/Project.aspx?ProjectID=1496

Robotics[47]	This innovative and world-leading project has the potential to allow extensive work to be carried out on the gas network without the associated disruptive road works. Its objective is to develop new robotic technologies which operate inside the live gas main which can not only remotely repair leaking joints, but support thethe pipe fracture risk management process through enhanced inspection in larger our diameter pipes. (Project end date – 01/12/15)
AGI Venting and Leakage[48]	This one stage research project seeks to undertake a practical study to gain a better insight on the actual leakage rates from selected venting controllers. This study will be used to inform a potential further piece of work to develop an extended modelling approach to predict the emission rates on a regional basis and to quantify the emission savings through venting controller replacement. The expected benefits of this work will be reduced losses of natural gas at Above Ground Installations (AGIs) and reduced carbon footprint for AGI site operations related to valve positioners and controllers. (Project end date – 01/09/2013)
Cured in Place Pipe[49]	The CIPP technique is a method whereby a host pipe is lined with a flexible tube which is impregnated with a thermosetting resin, which produces a tough pipe lining after resin cure. The scope of this project is to demonstrate 'fitness for purpose' of CIPP lining technologies for Gas distribution mains, focusing on iron mains of 8" diameter and above operating up to 2 bar pressure, as a potential alternative to pipeline replacement. (Project end date – 01/04/15)
Cast Iron Joint Sealing Robot[50]	The scope of this project is was carry out a detailed technical assessment and field trial of the joint sealing robot 'Large CISBOT', which has the potential to repair or rehabilitate a number of cast iron joints under live conditions in a more cost effective manner than existing methods. The project evaluated the effectiveness of the

[47] http://www.smarternetworks.org/Project.aspx?ProjectID=1321
http://www.smarternetworks.org/Project.aspx?ProjectID=1321

[48] http://www.smarternetworks.org/Project.aspx?ProjectID=1281
[49] http://www.smarternetworks.org/Project.aspx?ProjectID=1222
[50] http://www.smarternetworks.org/Project.aspx?ProjectID=1245

	repair technique and associated inspection method to determine extension to asset life and to understand the potential cost benefit. This project was implemented in July 2014.
Optomole[51]	To develop a mobile, optical methane sensing system that gas distribution companies can utilise to quickly and accurately detect the location of natural gas leaks in ducts. (Project end date – 01/10/15)
Seeker Particle[52]	To carry out a conceptual study of the development of discrete particles that intelligently locates and repair leaks within the gas distribution network and various methods of introducing them into the gas network. (Stage 2 end date 01/06/15)
Opening up the Gas Market[53]	The objective of this Project is to demonstrate that gas which meets the European specification but sits outside of the characteristics of gas specified within Gas Safety (Management) Regulations 1996 can be distributed and utilised safely and efficiently in GB. For this demonstration, there is a unique opportunity an isolated network in a remote part of Scotland. This Project is based on the principles of increasing competition for network entry, improving energy security, reducing the cost of gas for customers through opening up the market to new sources and reducing the requirement for expensive processing in the future. (Project end date 27/02/16)
Pressure to Gas[54]	The proposal is to replace the existing pressure reduction equipment with an integrated energy recovery and hydrogen electrolysis equipment package. The hydrogen gas will be generated from the power generated and immediately injected into the gas grid. The main elements to this technology are: Pre-heat (if required), Turbo expanders, Hydrogen electrolysis and Gas analysis and injection. (Project end date – 01/09/2014)

[51] http://www.smarternetworks.org/Project.aspx?ProjectID=1230
[52] http://www.smarternetworks.org/Project.aspx?ProjectID=1231
[53] http://www.smarternetworks.org/Project.aspx?ProjectID=1320
[54] http://www.smarternetworks.org/Project.aspx?ProjectID=1380

In Line Robotic Inspection of High Pressure Installations[55]	This project is to develop in-line inspection of below ground pipework at AGIs operating above 2 barg. Current methods of inspection for below ground pipework AGIs involve visual inspection via excavation, which is both financially and environmentally expensive. As such, it does not regularly take place and reliance on survey techniques to target excavations is favoured. This project would allow NGGT to implement an intelligent and proactive asset management strategy, reducing the requirement for inefficient and expensive excavations, extending the life of assets and reducing the likelihood of an asset failure at a high pressure installation thereby securing our national resilience. The benefits that could be provided are estimated at a saving of around 2,145 tonnes CO_2e per year. The project has a target completion/implementation date of November 2018.
Renewable Power Trial and Demonstration[56]	There are over 200 block valve sites and 39 Exit Points which have locally operated valves and would require staff to visit site. During a proceeding NIA project it was ascertained that it is feasible to provide the electrical power for existing or new National Grid installations from just renewable power sources such as PV cells and/or wind turbines. This project is to demonstrate the technology in a simulated environment reviewing the factors that would determine the most practicable solution for an individual site. The project has a target completion/implementation date of February 2016.

[55] http://www.smarternetworks.org/Project.aspx?ProjectID=1613
http://www.smarternetworks.org/Project.aspx?ProjectID=1613
[56] http://www.smarternetworks.org/Project.aspx?ProjectID=1577