Greenhouse Gas Investigation Mechanism – Final Statement

Field validation of a novel, near real-time methane monitoring system for vent and leak detection

Submission Date	22nd December 2017
Purpose of Report	Final Statement related to Special Condition 8J of the NTS Gas Transporter License which requires the licensee to undertake GHG investigation activities, most notably related to venting.

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1 Executive Summary

Background

In accordance with the National Transmission System (NTS) Gas Transporter Licence, Special Conditions 8J and 3D.47, National Grid Gas plc (NGG) are required to undertake and report on greenhouse gas investigation activities by 31 December 2017.

The Greenhouse Gas Investigation Mechanism (GHGIM) was introduced in the Gas System Operator Incentive Review 2015-18. It required NGG to undertake activities to improve understanding of venting, identify ways to increase transparency through accurate measurement of venting and identify ways to deliver long-term carbon benefits through cost effective mitigation of venting within its control.

We submitted a business plan dated 28 July 2016 to Ofgem, setting out the activities we would undertake, which was approved by Ofgem on 27 September 2016.

What we did

NGG, along with its third party partner National Physical Laboratory, designed and trialled a technique across two NTS AGI's ([redacted] and [redacted]) to use a highly accurate and sensitive real-time gas analyser to monitor methane at an array of sample points from locations within and around the boundary fence of an above ground installation (AGI). This combined real time measurements with a continuously updated reverse dispersion model to provide hourly emission measurements and enabled the scale of leaks to be located and quantified.

The continuous monitoring has provided a more accurate picture and understanding of total site fugitive emissions and has detected natural gas leaks from pipework, flanges and valves that have previously not been accessible via the ground level walk over surveys. In addition it was possible to validate the fugitive emission estimates from the monitoring system using approved industry methodologies.

The monitoring has positively identified hotspots for more detailed investigation by operational site staff. This is an improvement over the current 4 yearly walk over surveys, which are carried out on one day and is just a snapshot of leaks at a point in time.

What we found

The project identified and quantified fugitive leaks and vents within the boundary of two compressor stations. At one station repairing these has saved 13.7 tonnes of GHG emissions per annum. For each 10 tonnes saved this equates to a saving of £17,926 (using wholesale value plus untraded carbon cost for 2017) that can be reliably assigned as a benefit of operating the system. Throughout this Final Statement all savings calculations will be based on a 10 tonne saving of GHG emissions as a result of operating the system. The project also identified leaks in neighbouring facilities, which were reported to the operator and repaired by them.

Continuous monitoring also allowed the investigation of different valve configurations, process sequences and isolations. From this we have identified and isolated leaks and will continue to monitor this site to better understand the profile and reasons for fugitive and venting emissions.

Part of this project was to validate the "portable" nature of the equipment. We have demonstrated that the equipment is suitable to be transferred between sites. In this project we have sucessfully moved the equipment from [redacted] to [redacted] compressor stations within a 4 week time frame within budget. We recognise that the equipment was only in place for 4 weeks at [redacted] and with this limited data set to validate conclusions and therefore we have only utilised the [redacted] data with respect to cost benefit.

External Dissemination

We have spoken on the improved understanding and cost-effective mitigation of GHG venting at industry events, such as the Industrial Methane Measurement Conference in November 2017 in Antwerp and at MarcoGaz meeting in November. We have also shared our research with the Distribution Networks and with National Grid's US business. Through attendance at industry events and engagement with customers at industry working groups NGG has shared the benefits of the investigation activities. Overall we have received positive feedback and interest in the detailed results and how this is being taken forward.

Future Work

We believe there is real benefit to be gained from continuing with this monitoring programme. Reducing fugitive emissions is beneficial to climate change, and ultimately reduces operating costs for consumers.

The project has identified that the business plan estimates of the potential emissions savings of 109 tonnes/year, which were based on 2008/10 walk over surveys, were very conservative. We now estimate that if this monitoring was extended to all 23 compressor sites, there may be a potential 265 tonnes/year of GHG fugitive emission and venting that could be avoided which equates to £478,261 (using wholesale value plus untraded carbon cost for 2017), if all leaks are identified and fixed.

The monitoring system would deliver benefits in the following ways:

- Improved understanding and quantification of the emissions, to enable a better cost/benefit analysis for repair and replacement planning. This is an area where it has always been difficult to factor in the cost of emissions, as walk over surveys cannot quantify the quantity of leakage.

- Support better operating strategies to minimise leakage during operations and maintenance – eg. by changing routes of gas through a compressor station, valve configurations, process sequences and isolations.

- Further improvements in the portability of the equipment would allow NGG to begin to characterise fugitive emissions from other AGI's and temporary pipeline operations.

- During planned maintenance, the system can be set up and monitoring carried out before, during and after planned work to demonstrate the value of maintenance activity to reduce GHG emissions.

The project costs incurred to date to fulfil the requirements in the approved business plan are £207,815.

NGG is therefore seeking the award of GHGIM (in accordance with Special Condition 3D.48) of £207,815 to reimburse the costs incurred to date.

In addition, based on the encouraging results to date, we would like to discuss with you at our meeting on the 30 January 2018 how we take the investigation activities forward. Our current thoughts are that we would like to access some of the remaining funds to continue the work at [redacted] with the challenges of topography and weather, as well as considering a further programme of works. In Section 3.5 we outline potential roll out programmes that could be considered in RIIO T2 if the next stages of the project are successful.

2 Section A: Summary of activities undertaken

2.1 Title

Field validation of a novel, near real-time methane monitoring system for vent and leak detection

2.2 Total cost (projected)

The 14 month project included the purchase, assembly, factory test, installation, operation and measurement costs of a near real-time methane monitoring system. Associated costs are summarised below, with a full description in Section 4.7 Actual Project Costs.

Instrumentation and equipment	£85,401
Project running costs	£122,414
Total (excluding VAT)	**£207,815**

2.3 Aim

The NTS Gas Transporter Licence Greenhouse Gas Investigation Mechanism special condition 8J was introduced to incentivise research into new techniques to enable National Grid Gas (NGG) to improve understanding and transparency, and allow for cost-effective mitigation, of greenhouse gas (GHG) venting on the National Transmission System (NTS).

Within the Business Plan submitted on the 28 July 2016 NGG estimated that there is at least 109 tonnes of methane per annum across the 23 compressor sites that is emitted, and this represents 'controllable' emissions that can be targeted for improved environmental performance. The estimate comes from the 2008-2010 baseline of 4 yearly fugitive emission walkover surveys. However, the current rolling 4 yearly programme of fugitive[1] emission surveys only provide a 'snap-shot' of emissions, and are limited to accessible pipework, flanges and valves. In addition, long term boundary fence-line methane monitoring alone cannot be used to locate sources of emissions.

The aim of this project was to enhance the current 4 yearly programme and develop a cost-effective methodology to enable NGG to monitor and control fugitive emissions from above ground installations (AGI) on the NTS, and to understand both planned and unplanned venting events. The project trialled a continuous fugitive emission monitoring method over a 9 month period to assess its practicality, performance and cost effectiveness. In addition, the "portability" of the equipment was tested to have the potential to expand the application beyond AGIs.

2.4 Technique

The technique trialled demonstrated the use of a continuous fugitive emission monitoring system comprising a highly accurate and sensitive real-time gas analyser to monitor methane at an array of sample points from locations within and around the boundary fence of an AGI. The design combined real time measurements with a continuously updated reverse dispersion model to provide hourly emission estimates for the facility. In addition, during the period of operation any detected fugitive emissions were validated using sniffing by flame ionisation detector and, where available optical gas imaging (OGI), and quantified using a high-flow sampler. This enabled the scale of any leaks to be quantified.

[1] In the context of this report a fugitive emission is a leak of natural gas from an asset where under normal operations there should be none, e.g. a leaking valve stem or valve seal leak.

The following chart outlines the project timeline:

Activity	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Bishop Auckland												
Site Visit	✓											
Install equipment		×	✓									
Monitoring system operation (1st campaign)			✓	✓	✓	✓	✓	✓	✓			
Move to Moffat									×	✓		
Moffat												
Site Visit						✓						
Install equipment								×		✓		
Monitoring system operation (2nd campaign)									×		✓	

Figure 1: Project timeline

Due to its bespoke design, the project encountered initial delays due to procurement and design of monitoring equipment and enhanced pre-installation testing, which delayed commencement of monitoring activities at [redacted] by one month.

To test the portability the monitoring equipment was moved to [redacted] compressor station. The commencement of monitoring was delayed because a scheduled outage overran, preventing the pressurisation of the compressor site. The monitoring system was successfully moved and recommissioned.

2.5 Benefits

Due to continuous monitoring, the system has provided a more accurate picture and understanding of site fugitive emissions. The system has shown the ability to detect natural gas leaks from pipework, flanges and valves which have not been previously accessible from ground level surveys, and has positively identified hotspots for more detailed investigation by site staff.

It has been possible to validate the fugitive emission estimates from the monitoring system using approved and available industry methodologies and the monitoring system has demonstrated that the potential methane emission reductions are much higher than estimated in the original business plan.

Continuous monitoring has allowed the investigation of different valve configurations, process sequences and isolations to minimise emissions whilst operating and maintaining the equipment, while maintaining availability of compressor units.

The improved understanding and quantification of the emissions obtained from the operation of the monitoring system will enable a better cost/benefit analysis for investment plans for areas such as asset health and defect remediation. This is an area where it has always been difficult to factor in the cost of emissions both from a resource loss and an environmental impact perspective, as they have previously not been fully identified or costs fully quantified.

2.6 Deliverables

In accordance with the submitted business plan on the 28 July 2016 and Ofgem's 'The Greenhouse Gas Investigation Mechanism: Guidance on Submissions', these are the projects planned deliverables and how these have been achieved:

- *Increased understanding of the source of methane emissions from the test installation(s) and the quantification of those emissions*

  Whole site methane emission estimates has been achieved for two compressor stations on the NTS. These estimates have identified the main sources of fugitive emissions;

  1. [redacted] emissions from the whole shared site (including assets not owned or operated by NGG) prior to intervention were estimated at 61.5 ± 7.7 tonnes per year.

This was reduced by 50% following intervention; the majority of the remaining emissions were shown to be from assets not owned or operated by NGG.

2. [redacted] emissions prior to intervention were estimated at 213.5 ± 97.4 tonnes per year.

- *Validation of the operational use of the near real-time methane monitoring system on the NTS*

  The monitoring system methane emission estimates have been validated at [redacted] by conducting a fugitive emission walk over survey during the monitoring campaign. The walk over survey used for validation identifies leaking components with a flame ionisation detector and then quantifies those above a threshold with a hi-flow sampler. For example a leaking valve was identified at walk over survey emitting 11.7 ± 1.2 tonnes per year, which compares well with modelled emissions of 12.0 ± 0.9 tonnes per year.

- *Validation of the "portability" of the equipment to ensure that it can be utilised across the NTS for both installation and operation monitoring and assessment.*

  The monitoring system was installed and operated at one compressor site for seven months. It was then decommissioned, sample pipework capped off for future use and the monitoring equipment moved to a second compressor site. The monitoring system was then successfully recommissioned and monitoring continued for a further month.

- *Production of quantified methane emissions map for the test installation(s).*

  The monitoring system has been developed over the eight month measurement period to deliver site mass emission estimates of fugitive emissions with associated probability contour maps showing the likely source areas of those emissions (see Technical Appendix)

- *Production of a costed remediation report that can be used to inform investment strategy.*

  The modelled fugitive and vent emissions have been monetised using the 2017 non-traded value for carbon and the 2016/17 System Average Price (SAP), which reflects the same methodology as in Section C of the original submitted business plan. This methodology can be used for future investment papers or strategy for asset replacement when these are shown to be a high source of emissions.

3 Section B: Statement Description

3.1 Overview – high level description

Traditionally, boundary fence style long-term sampling methods, e.g. diffusion tubes, have been used to assess the impact of industrial processes on the local community. While these methods are low cost and well validated, they provide no useful emission quantification data due to the long-term sampling period. Over the sampling period the meteorological conditions, especially wind direction, have extreme variability meaning that the long-term samplers are not measuring source plumes directly, but are making long term averages of the concentrations at individual sampling points. This makes it very difficult to differentiate between likely sources of emissions.

By performing real-time sampling from different sampling locations, it is possible to link measured concentrations to specific wind directions and speeds and hence determine specific emission sources or areas.

In the last nine months NGG has installed the methane monitoring system at two compressor stations on the NTS delivering near real-time measurements of methane at up to 16 locations around the fence line of the facilities along with (at one of the two sites) measurements from the site's main vent stack. The vent stack monitoring captured emissions from all process and emergency venting activities.

By combining distributed methane measurements with wind speed and direction measurements and reverse dispersion modelling techniques, it has been possible to make an estimate of total site mass emission of methane and construct probability maps highlighting the likely sources of those emissions.

The sources can either be known regulated emissions or unknown fugitive emissions. Possible fugitive emission locations have then been further investigated with a gas sniffer (flame ionisation detector) and, where available, optical gas imaging (OGI), and suspected emission sources quantified using a hi-flow hydrocarbons analyser. The quantification of specific emission sources has allowed an emission inventory of the site to be established along with a method to demonstrate the impact of remedial work to reduce fugitive emissions.

The measurement system has increased the visibility of planned or unplanned venting events and fugitive emissions, which will drive environmental performance improvement, enhancing existing policies and procedures.

More accurate quantification of emissions from leaking assets allows an estimate of the carbon benefit of replacement to be factored into the investment process. This aligns with National Grid Group policy to introduce carbon pricing into all major investment decisions.

3.2 Findings from the investigation activities

The monitoring phase of the investigation was conducted at two compressor stations;

1. [redacted], for a period of seven months and
2. [redacted], for a period of one month.

The sites were selected on the basis of previous work to characterise fugitive emissions. The existing survey work saved initial investigation setup costs as the sample point locations were already identified.

The monitoring at [redacted] continued into a scheduled site outage, which enabled the impact of maintenance activities on fugitive and vent emissions to be quantified. The delay in the move to [redacted] enabled this to take place.

[redacted] compressor was chosen as the site had recently undergone a four yearly walk over survey and had known potential site sampling locations thus saving costs in pre-installation work to identify the high emission source areas. As per the business plan the site was a high emission site and had a known leak from a compressor isolation valve.

[redacted]

Following an extended period of factory testing, the monitoring system was installed at [redacted] in early March 2017, with the monitoring commencing from 17 March 2017, the first two weeks of monitoring were used to characterise the sites baseline level of fugitive emission, which were 61.5 ± 7.7 tonnes per year of methane.

This baseline assessment quickly established that assets not owned or operated by NGG but within the shared site boundary of the installation, were almost 50% of the overall site emission.

Continued monitoring of total site fugitive emission into April and May 2017 established the likely source of the emissions in the area of the site not owned or operated by NGG to be from the water bath heaters and one above ground valve. Detection of emissions from the water bath heaters is not surprising; this is most likely to be unburnt hydrocarbon in the exhaust gas due to incomplete combustion.

On 3 May 2017 a walk over fugitive emission survey was conducted at the site where all above ground valves and pipework were surveyed. The survey results gave a total site emission of 41.4 ± 4.1 tonnes per year. The discrepancy between the fugitive emission survey and the monitoring system was not unexpected as the monitoring system captures all fugitive emissions, such as that from valve pits which the walk over survey does not.

The walk over survey additionally gave a direct measurement of the leaking above ground valve picked up by the monitoring system in the area of the site not owned or operated by NGG. The measured result of 11.7 ± 1.3 tonnes per year compared well with the modelled emission of 12.0 ± 0.9 tonnes per year; this gave confidence to the modelled emission output and a source of emission to focus on for reduction. The walk over survey also identified leaks within the areas of the pig traps, again the modelled emissions correlated well with the measured emissions.

Following the walk over fugitive emission survey, NGG began a programme to address the leaks identified and also engaged with the owner and operator of the leaking above ground valve. Over the period during June and July, emission rates were monitored to detect reductions following repair. Once repaired, leaks in the pig trap area and the leaking above ground valve were reduced to zero. During this time, however, compressor utilisation at the site increased significantly and it became apparent that detecting reductions in fugitive emissions as a result of interventions by NGG staff would be challenging as compressors were brought on or offline and NTS demand changed.

From week commencing 17 July 2017, vent monitoring points were installed on both compressor cabs at the installation. These monitoring points detected designed gas turbine and compressor purges at start up, shut down and from seal leakage. Emission estimates in the range of 4.1 to 6.0 tonnes per year were modelled from these monitoring points. From the inception of the project it had been anticipated it would be possible to install monitoring points on the main station and unit vent stacks however safety considerations and operational restrictions to access the vents prevented installation.

Monitoring continued until 10 October 2017, at which point the system was decommissioned and moved to [redacted] compressor station. On removal total site emissions (vent and fugitive) were estimated at 30 ± 2.4 tonnes per year, with 81% of emissions coming as fugitive emission from the area of the site not owned and operated by NGG. Reductions in emissions to 5.7 ± 1.6 tonnes per year (82% reduction) were achieved from the NGG owned and operated part of the site. Table 1 summarises the monitoring period at [redacted] compressor station.

Table 1: Summary of [redacted] monitoring periods and emission estimates (Source areas defined in Technical Annex)

All in tonnes/yr		NGG Assets				Non owned /operated assets		
Period		PIG trap (N)	PIG trap (W)	Comp	NGG Total	Sp11 Valve	Heaters	Other Total
17/03/17	31/03/17	15.5±3.8	16.4±3.3	0.0	**31.9±5.1**	7.6±2.7	22.1±5.2	**29.6±5.8**
01/04/17	31/05/17	6.3±0.9	5.4±1.0	0.0	**11.7±1.3**	11.4±0.8	0.0	**11.4±0.8**
31/05/17	06/06/17	2.5±0.8	0.0	4.1±2.6	**6.6±2.7**	12.9±1.6	19.6±2.5	**32.5±3.0**
08/06/17	07/07/17	2.8±0.8	0.0	0.0	**2.8±0.8**	0.0	19.9±2.1	**19.9±2.1**
08/07/17	03/09/17	0.0	0.0	6.0±1.3	**6.0±1.3**	5.7±0.7	22.4±1.3	**28.1±1.4**
04/09/17	10/10/17	0.0	0.0	5.7±1.6	**5.7±1.6**	3.8±0.8	20.5±1.6	**24.3±1.8**

[redacted]

The monitoring system was commissioned on 25 October 2017 at Moffat compressor station. Twelve sample locations were established inside the boundary fence, the positions of which were established from previous knowledge of the likely sources of emissions. A baseline level of fugitive emissions was established for the installation in the first two weeks with emission estimates in week one of 213.5 ± 97.4 tonnes per year and in week two of 334.6 ± 97.4 tonnes per year.

The first two weeks of monitoring identified that the [redacted] above ground installation (AGI) within the boundary of the compressor station was a significant source of fugitive emissions. This was verified by operational staff as being from a remotely operated flow control valve (FCV).

The monitoring system successfully detected compressor vents and compressor starts/stops on a number of occasions during the monitoring period and additionally from 24 November 2017 elevated concentrations of methane from the station and unit vent stacks. The station and unit vent monitoring could not be installed until 24 November 2017 because the station was required by the Gas Network Control Centre (GNCC); an outage was required to install the monitoring points which for operational reasons could not take place.

On 24 November 2017, in addition to the vent monitoring being installed, the remote FCV in the [redacted] AGI was switched off in an attempt to reduce emissions however on initial analysis this appears to have had the opposite effect with emissions from the AGI increasing.

The monitoring system remains in place and operational at [redacted], despite no longer being required for Special Condition 8J. Analysis of the output of the monitoring system will continue to better understand the reasons behind the trends in emissions. Table 2 summarises 4 weeks of emission estimates from [redacted] compressor station.

Table 2: Summary of [redacted] monitoring periods and emission estimates (Source areas defined in Technical Annex)

Period		AGI - North, t/yr	AGI - West, t/yr	AGI - South, t/yr	Compressors, t/yr	South, t/yr	East, t/yr	Total, t/yr
25/10/2017	03/11/2017	85.5 ± 68.6	128.0 ± 57.0	0.0	0.0	0.0	0.0	**213.5 ± 97.4**
04/11/2017	13/11/2017	0.0	206.6 ± 68.8	0.0	0.0	0.0	128.0 ± 68.9	**334.6 ± 97.4**
14/11/2017	20/11/2017	149.8 ± 80.0	0.0	0.0	0.0	0.0	0.0	**149.8 ± 80.0**
21/11/2017	24/11/2017	0.0	106.9 ± 66.9	76.0 ± 53.7	103.4 ± 51.6	0.0	56.1 ± 42.7	**342.5 ± 108.8**

3.3 Output Interpretation

NGG has achieved the deliverables set out in the business plan on the 28 July 2016 which gives NGG a better understanding of venting and fugitive emissions. However to demonstrate value of the continuous monitoring system to consumers we want to be able to evidence how interventions to minimise venting and leakage have saved greenhouse gas (GHG) emissions caused as a result of NGG operations.

[redacted]

The weekly mass emission of methane from [redacted] compressor station has been calculated for the three source areas defined in the reverse dispersion model were PIG traps, AGI and Compressors.

On initial analysis of data it appeared that following beginning of interventions that the mass emission from the compressor area greatly increased. However at this moment compressor utilisation at the site greatly increased and the vent monitoring points on the compressor cabs were installed. It is therefore not appropriate to include the compressor area in estimates of the value of interventions in reducing GHG emissions as we are not comparing the same vent and leak points pre and post intervention. This is not to say that intervention has not had an effect but it is difficult to detect over a short monitoring period with changing operational conditions and additional monitoring points added half way through the monitoring period.

To obtain a better estimate of the benefit of the interventions undertaken at [redacted], we have removed the amounts detected from the compressors. The benefit of the monitoring system, and the interventions taken as a result of that, in reducing fugitive emission and venting can be illustrated in figure 2 by the difference between the yellow line (the cumulative emisions pre-intervention, extrapolated to the end of the monitoring period) and the purple line (the actual cumulative mass emission to the end of the monitoring period).

This shows a benefit, on an annualised basis, of 13.7 tonnes/year however a figure of 10 tonnes per year will be used within the business caseto estimate the cost benefit of two potential roll out scenarios.

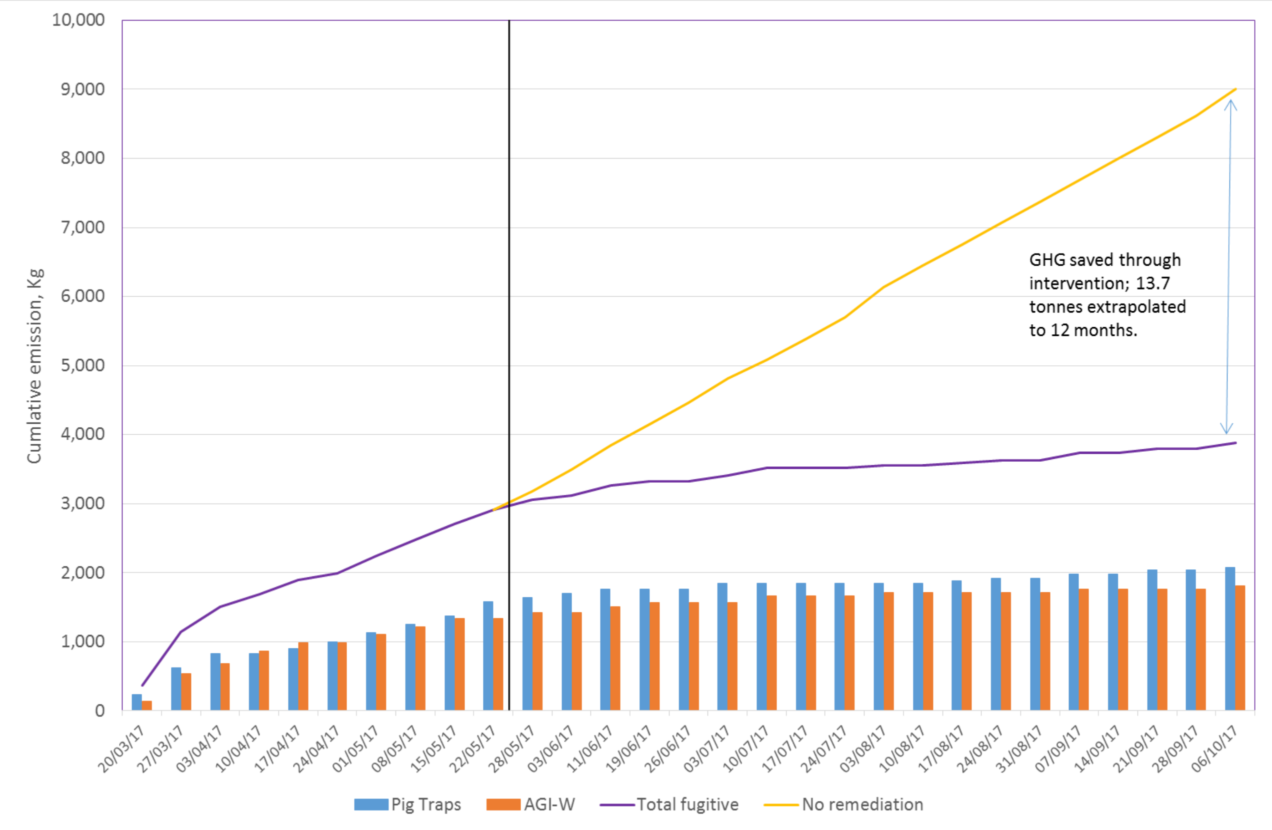

Figure 2: [redacted] ***fugitive emissions***

[redacted]

The monitoring results from the one month study at [redacted] have been significantly more challenging to interpret and correlate with the site operations. There are two principle reasons, the first being the topography surrounding the [redacted] site means that the reverse dispersion modelling has much greater uncertainty. The topography, it would appear, has a tunnelling effect on wind which makes it difficult to model emission plumes with a consequential increase in the uncertainty from ~12% of modelled mass emission at [redacted] to >50% at [redacted] for some periods.

In Figure 3 below, the bars show the weekly mass emission for the [redacted] site while the line shows the cumulative mass emission.

Although the chart does not show the reduction in mass emission following intervention on the 24 November 2017 the monitoring system shows its value in that it has detected a change in profile which had the system not been operated would have gone undetected. The chart also shows that prior to intervention at the AGI that mass emission rates were consistent which gives confidence in the modelled mass emission rates. When you compare figures 2 and 3 it is clear that a much longer period of monitoring gives greater understanding of the profile of mass emission and quantification of the impact of intervention. As a result of this the monitoring results at [redacted] will not be used in the updated cost/benefit analysis of operating the monitoring system.

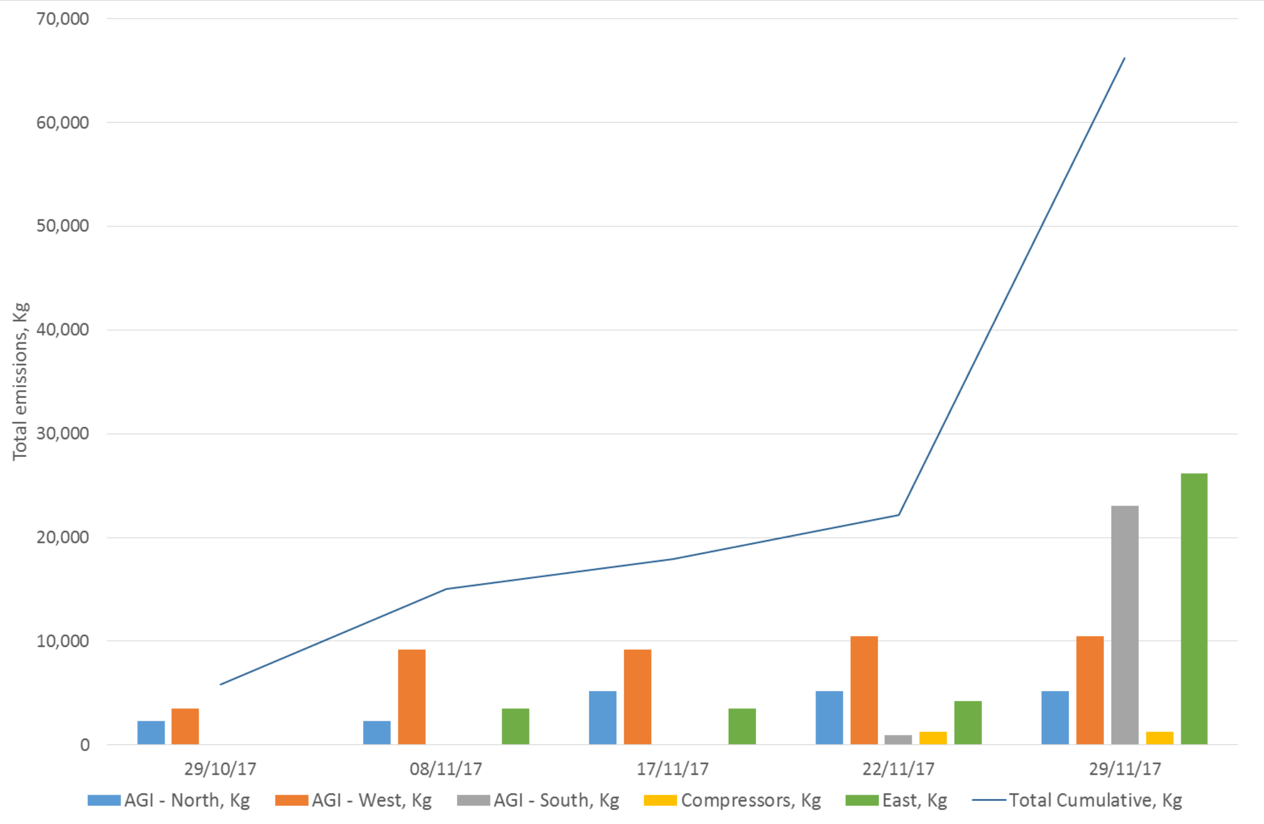

Figure 3:* [redacted] *fugitive emissions

3.4 Lessons learnt

A learning log was kept to record issues and their resolutions for future implementations of this project; reducing delivery costs and increasing efficiency within the project. These can be found in the Technical Annex.

3.5 Future projects schemes of works

Continuous fugitive leak detection and repair combined with improved understanding of the causes of venting has as part of this project demonstrated a reduction in GHG emissions and deliver long term carbon saving benefits due to reduced fugitive and vented emissions. The scale of any roll out of the monitoring system across NGG assets will depend on estimates of GHG emission savings that can be achieved compared to the cost of investment. NGG would be looking to include a proposal for any roll out in the RIIO T2 negotiation process.

The scale of the GHG emission savings that could theoretically be achieved based on the experience to date gained from the investigation activities are detailed in the updated business plan and worked up cost benefit in Section C. If the project continues we will obtain more learning and update the cost benefit and scenarios as appropriate.

The roll out scenarios do not include the cost of rectification only the wholesale product cost and carbon saving of the GHG emissions.

Scenario 1

- Install sample pipework at all 23 compressor stations on the NTS.
- Use eight trailers (ie procure 7 additional trailers) with methane sampling and weather monitoring equipment.
- Monitoring equipment hardware owned and operated by NGG.

- The reverse dispersion model “Airviro Receptor” from the Swedish Meteorological and Hydrological Institute (SMHI) operated under licence by the National Physical Laboratory (NPL).
- NPL under contract to NGG to provide fugitive emission and vent modelling measurement service.

This scenario would allow each compressor site to be visited annually, with a three month monitoring period. It allows for three months downtime per trailer per year to allow for setup and commissioning between sites.

The frequent monitoring will allow areas of high emission to be addressed quicker than existing four yearly fugitive emissions walk over survey, where the potential exists for leaks to remain undetected for up to four years. It would also capture fugitive emission and vents that were previously undetectable in the walk over surveys.

1st year cost	**£1,620,527**
Cost of additional instrumentation	825,842
Running cost	268,266
Installation at 21 new sites	526,419
Total cost over 4 years	**£3,157,822**
Cost of additional instrumentation	825,842
Running cost	1,073,065
Installation at 21 new sites	526,419
Move trailers between 23 sites	732,497

The projected savings due to the reduction of fugitive leaks would be £433k in the first year and £1,733k over the 4 year project. This assumes a 10 tonne per compressor site year saving at each site visited and this saving continues over the 4 year project ie. by running the system you continue to save the 10 tonnes saved in year 1 as continuous monitoring once a year prevents re-occurrence. The likelihood however is that additional leaks would be found during years 2, 3 and 4 which could be rectified in increasing the natural gas saved over and above the 10 tonnes saved in year 1.

In addition to this saving there would be the reduced cost of routine walkover surveys of £184k over 4 years. Walkover surveys would only occur when a leak could not be identified by operational staff or the leak rate required characterisation to monetise the impact on the environment to inform investment decisions.

Overall, over the 4 year period, the cost of **£3,158k** significantly higher than the overall benefit of **£1,917k**.

Scenario 2

- Install sample pipework at all 23 compressor stations on the NTS.
- Use two trailers (ie procure one additional trailer) with methane sampling and weather monitoring equipment.
- Monitoring equipment hardware owned and operated by NGG.
- The reverse dispersion model “Airviro Receptor” from the Swedish Meteorological and Hydrological Institute (SMHI) operated under licence by the National Physical Laboratory (NPL).
- NPL under contract to NGG to provide fugitive emission and vent modelling measurement service.

This scenario would allow each site to be visited once every four years, with a three month monitoring period. In this scenario the potential exists for fugitive emissions and vents to go undetected for three years longer than Scenario 1. In both scenarios monitoring and maintenance activities would be planned concurrently to maximise the potential GHG reductions from leak detection and repair.

1st year cost	**£406,104**
Cost of additional instrumentation	129,163
Running cost	70,575
Installation at 6 new sites	158,020
Move trailers between 6 sites	48,347
Total cost over 4 years	**£1,149,860**
Cost of additional instrumentation	129,163
Running cost	282,300
Installation at 21 new sites	553,069
Move trailers between 23 sites	185,329

The projected savings due to reduction of fugitive leaks would be £113k in the first year and £1,111k over the 4 year project. Again as in Scenario 1 this assumes a 10 tonne per year saving at each site visited and this saving continues over the 4 year project. In addition to this saving, there would be the reduced cost of routine walkover surveys as in Scenario 1.

Overall, over the 4 year period, the cost of **£1,150k** is slight less than the overall benefit of **£1,295k**.

Applications other than compressor stations

The portability of the monitoring system was tested during the monitoring phase of the project by decommissioning and moving the system between compressor stations and then restarting continuous monitoring. Sample pipework was capped off for future use at the first monitoring location.

This activity proved the portability of the monitoring equipment and potentially opens up new opportunities for NGG to characterise fugitive emissions from AGIs and temporary pipeline operations, hence further increasing its understanding of emissions. However, the current sample pipe material is not suitable for transport and re-use. Until such time as re-usable sample pipe material or wireless methane sensors are available and tested, this is not a viable undertaking. This is a potential area of future innovation under the Network Innovation Allowance.

3.6 Technical description of the measurement system

See technical annex attached.

4 Section C: Updated Business Case

4.1 How NGG has met its Obligations under Special Condition 8J

This updated business plan relates to Special Condition 8J of the Gas Transporter License which requires the licensee to undertake GHG investigation activities, most notably related to venting. The aims of Special Condition 8J are stated below, together with an outline of how the investigation undertaken by NGG delivered on the business plan submitted to Ofgem on the 28 July 2016.

(i) Increasing the Licensee's understanding of venting (including the causes and driving factors of venting) which are within and outside of the control of the Licensee.

Venting emissions from compressor installations is a significant contributor to NGG's total emissions. This project has delivered near real-time measurements of methane at up to 16 locations around the fence line of two NGG compressor facilities, along with measurements from one site's main vent stack. Combining distributed methane measurements with wind speed and direction measurements has enabled emission maps to be constructed at up to an hourly frequency highlighting likely sources. Possible fugitive emission locations have then been investigated with a gas sniffer and where required emission sources quantified using a hi-flow hydrocarbons analyser. The quantification of specific emission sources has allowed an emission inventory of the two sites to be established along with demonstrable impact of remedial work to reduce fugitive emissions.

The emission maps produced by the monitoring system have been analysed alongside the site operational logs. This has enabled verification that the monitoring system has picked up known emission events, for example the start/stop of a compressor or an emergency shut down event. By picking up known events it has given confidence in the ability of the system to detect other fugitive leaks such as that from the above ground valve not owned and operated by NGG at [redacted], which potentially could have gone undetected.

The [redacted] station and unit vent monitoring points have detected elevated levels of natural gas during normal operation. Unless a vent of compressor is required for operational reasons or an emergency shut down has occurred, there should be ambient concentrations of natural gas at these sample points. The elevated levels detected are indicative of valve seal leakage; for example when a compressor is pressurised and the suction/discharge valves are closed. Measurements from the station and unit vent stacks have never before been attempted, therefore further investigation will be required to understand and minimise the source of the seal leakage.

(ii) Identifying ways to increase transparency through accurate measurement of venting.

The system used for this investigation was developed by the National Physical Laboratory (NPL). NPL is a world-leading centre in the development and field application of highly accurate measurement techniques. As the UK's National Measurement Institute, NPL underpins the national measurement system, ensuring consistency and traceability of measurements throughout the UK and guarantees international comparability. By utilising NPL's knowledge and experience in measurement, NGG has ensured the greatest possible confidence in the measurements being undertaken.

The accurate measurement of compressor seal leakage at [redacted] and potential suction/discharge valve leakage at [redacted] raises the visibility and therefore increases the transparency of this previously invisible consequence of operations.

(iii) Identifying ways to deliver long-term carbon benefits through cost effective mitigation of venting within the control of the Licensee.

Continuous monitoring of fugitive emissions and vents has facilitated targeted fugitive leak detection and repair combined with an improved understanding of the causes of venting; this has delivered demonstrable carbon savings at [redacted]. Performing repairs of fugitive leaks in a timely manner and on a prioritised cost/benefit basis when significant intervention is required will help reduce overall site emissions compared to NGG's current 4 yearly inspection and repair programme.

Currently this 4 yearly programme only inspects and tests ground level emission points. The NPL system has demonstrated the capability to detect leaks from above ground level accessible pipework and thus emissions were higher at [redacted] from the monitoring system compared to the walk over survey by ~30%. This is not unsurprising and represents an opportunity for NGG to address previously unknown fugitive leaks and minimise venting.

The portability of the core measurement system in the trailer has been proven with the move from [redacted] to [redacted] compressor stations. The sample pipework has been capped off and left at [redacted] for future use, thus minimising expense to carry out further periods of monitoring at a later date. The sample pipework, once installed, cannot be disassembled and re-used. This is not a problem for fixed large AGI's such as compressor stations, but should NGG wish to explore the use of the system on temporary pipeline operations, a portable pipework system will need to be developed, or wait for developments in wireless methane sensor technology.

The monitoring system has proven its potential to save 13.7 tonnes of methane per year at [redacted] compressor station. If replicated at other sites, and there is no reason to think otherwise, then a targeted roll out following one of the scenarios in Section 3.5 would remove the need for the current four yearly inspection regime saving £184k over four years.

The three month monitoring period for each site in the two roll out scenarios in Section 3.5 would be carefully scheduled around planned maintenance at site so that NGG can clearly demonstrate to customers and end users the reduction in emissions that can be achieved and so the value of the monitoring system and proactive rather than reactive intervention. Reducing fugitive emissions is beneficial to the climate and reduces operating costs, which is beneficial to consumers.

4.2 Additional Environmental and Wider Benefits

The monitoring system has demonstrated its ability to detect sources of fugitive emission and venting occurrences. By doing so this raises the visibility of this previously invisible consequence of NGG's operations and gives the opportunity to contribute to UK Government carbon reduction targets. However, by proving a measurement methodology to estimate fugitive emission from gas transmission in the natural gas supply chain there is a risk that previous estimates may need to be revised. Improvements however in estimates of leakage from the transmission system (1B2b4: Natural Gas – transmission leakage) has been identified by the UN following expert review of the UK's Greenhouse Gas Inventory, 1990 to 2015 submission.

By reducing carbon from fugitive emissions NGG will increase operational efficiency and lower the cost of operating the NTS. This will benefit consumers, consistent with the goals of balancing sustainability and affordability.

Additionally by quantifying fugitive emissions on a continuous basis, NGG has opened up the ability to reduce emissions levels by ensuring targeted, proportional investments, underpinned by supportable business plans and appropriate funding arrangements. NGG is developing a revised methodology for Network Output Measures where the 'volume of emissions' is taken into account when prioritising asset replacement; more detail on the methodology is given in Section 4.5

This project has demonstrated a potential to create a legacy in the field of carbon emissions reductions, contributing to the UK Government's targets to mitigate the impact of climate change, and delivering long-term societal benefits.

4.3 Innovation

The measurement protocol trialled to assess site emissions goes far beyond current business-as-usual approaches, and any current commercially available monitoring solutions. As such, this innovative approach has produced many benefits:

- A clearer understanding of the emissions profiles of two NGG sites and the delivery of potential for emission reductions.
- The ability to undertake targeted maintenance and repair coupled with evidence that emissions have reduced as a result of the action taken (through continued measurement after the maintenance period).
- Ability to detect emissions from all above ground emission sources, not just ground level sources which are inspected through the existing 4 yearly maintenance and repair programme.
- Potential for greater than expected emission reductions and improved maintenance procedures. Monitoring of emissions from [redacted] would suggest that current four yearly emission surveys may underestimate total site emission by ~30%.

The environmental benefits from operating this continuous fugitive emission monitoring system stem from intervention to reduce detected methane emissions, which is a potent GHG. The effect of a gas upon our climate is described by its global warming potential (GWP) - a relative measure of how much heat a GHG traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question (in this case methane) to the amount of heat trapped by a similar mass of carbon dioxide. GWP values are frequently reassessed, with an authoritative view provided by the Intergovernmental Panel on Climate Change (IPCC). The IPCC's 5th assessment report gives the following GWP data for methane:

	GWP over 20 years (t CO2 equivalent / t gas)	GWP over 100 years (t CO2 equivalent / t gas)
Methane (without climate-carbon feedback)	84	28
Methane (including climate-carbon feedback)	86	34

Table 1: GWP for methane. Taken from the following source:
http://www.climatechange2013.org/images/uploads/WGIAR5_WGI-12Doc2b_FinalDraft_All.pdf
8.7.1.4 Uncertainties and Limitations related to GWP and GTP, Table 8.7

Therefore, depending upon the time horizon you are considering, and the methodology used, the GWP for methane can vary widely. For the purposes of this Final Statement and to be consistent with the previously submitted business plan, we will use the GWP of methane as published for the Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland 1990-2014, June 2016 – namely a GWP of 25* (assuming a 100 year horizon).
http://naei.defra.gov.uk/reports/reports?report_id=894

The level of methane emissions from NGG compressor sites are currently estimated using data from fugitive emission surveys. The results from 23 compressor sites are shown in Figure 5.

(- current recognised 100 year global warming potential for methane which may be different to NGG internal figure - IPCC (Intergovernmental Panel on Climate Change) - https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html)*

[redacted]

Figure 4: 2008/10 and latest 4 yearly fugitive emission surveys from NGG compressor sites.

The 2008/10 data indicates that the total fugitive emissions from these sites are 178 tonnes/year of methane. Including the most up to date data for sites following implementation of a 4 yearly fugitive emission survey programme raises this to 257 tonnes. Not all sites in figure 4 have had a fugitive emission survey since the 2008/10 baseline; the four yearly programme was implemented in 2015.

Combining this data from fugitive emission surveys, and our operational experience; NGG estimated that a reasonable level of fugitive emissions per compressor would be 1 tonne per year. This estimation remains as a reasonable target however the fugitive emission monitoring system would indicate total site emission may be 30% higher than that from the walk over survey.

On average each site has 3 compressors, and therefore across 23 sites we would propose that 69 tonnes of methane per year remains a reasonable target level of fugitive emissions across this portfolio.

Emissions above this level represent ‘controllable’ emissions and therefore a target for improved environmental performance. Taking the data above and assuming a 30% underestimation of total site fugitive emission from walkover surveys, this means that we now calculate that 265 tonnes of fugitive methane emissions could be avoided per year ((257*1.3)-69=265 tonnes).

This compares to the initial business plan estimate of 178 – 69 = 109 tonnes per year

The potential carbon benefit of interventions to reduce controllable fugitive emission would be 6,628 CO_2e per year if rolled out across all 23 compressor sites. For consistency with the previously submitted business plan a GWP of methane of 25 has been used however it is possible that future editions of the DEFRA inventory could update their guidance in line with IPCC findings, and increase the GWP of methane to 28-34, which would imply an even greater carbon benefit from intervention.

This represents a theoretical target for reducing fugitive emission; the following sections monetise this saving based on the wholesale value and carbon cost of the gas saved. The costs presented should be viewed as the potential for greenhouse gas reduction; the scenarios and cost benefit of roll out in Section 3.5 are based on a 10 tonne reduction per year in emissions that has been demonstrated during the period of the trial at [redacted].

4.4 Cost Benefit analysis

This project has enabled an evaluation of the value of rectification and provided a focus for works to minimise fugitive emissions. Additionally it has been able to quantify fugitive emission leakage from components which could feed more detailed cost benefit analysis in NGG's revised Network Output Measure methodology. The leakage amount can be monetised, to potentially raise the replacement of leaking components up the asset replacement prioritisation. Any roll out of one of the two scenarios in Section 3.5 would be planned to coincide with existing planned maintenance, asset health and equipment replacement strategies, to achieve greatest possible efficiency.

The following updated cost benefit analysis has been produced based on the current view of fugitive emissions from compressor stations with the additionally learning which has been gained from operating the continuous fugitive emission monitoring system at [redacted] and [redacted] compressor stations.

Updated Fugitive Emissions View Cost Benefit

The ultimate aim of this project was to support future investment plans that enable carbon emission reductions. If achieved, this would have environmental and societal benefits. A cost benefit analysis for this proposal relies on assigning a value to the 'controllable' methane emissions, estimated above as 265 tonnes per year across all 23 sites (including the additional learning that current walk over surveys underestimate fugitive emissions by 30%). The value of the gaseous emissions from the site arises in two ways:

1. The wholesale value of the natural gas as a product
2. The non-traded cost of carbon assigned to the associated methane emissions.

Natural gas is primarily composed of methane. For the purposes of these calculations 1 tonne of methane is assumed to be equivalent to 1 tonne of natural gas.

Wholesale value of natural gas

Wholesale natural gas is traded in therms. Therefore, we must convert tonnes into therms to calculate the value of the gas.

- 1 tonne of natural gas is 1000kg
- 1000 kg is 1408.45 m^3 (using natural gas density of 0.71 kg/m^3)
  http://unitrove.com/engineering/tools/gas/natural-gas-density
- NGG uses a calorific value of natural gas of 39.6 MJ/m^3
  Therefore 1 tonne of natural gas equates to 1408.45 x 39.6 = 55774.62 MJ
- One therm is equal to 105.5 MJ (Unit of Measurement Regulations 1995)
  www.legislation.gov.uk/uksi/1995/1804/contents/made
  55774.62 MJ converts to 55574.62/105.5 = 528.67 therms
- The 2016/17 System Average Price (SAP) for 1 therm was 38.7p

1 tonne of natural gas = 529 x 38.7 = 20472.3p

Therefore, 1 tonne of natural gas has a wholesale price of £204.72, based on the 2016/17 SAP. **Assuming 265 tonnes of methane emissions are avoided, this give a cost benefit of £54,251 per annum following implementation of the process at all 23 sites.**

Non-traded cost of carbon
The introduction of binding carbon budgets across the UK economy means that a robust approach to valuing carbon emissions is vital, to ensure that Government takes full account of climate change impacts in appraising and evaluating public policies and projects. Government concluded a major review of the carbon valuation approach to be used in UK policy appraisal in July 2009. The revised approach moves away from a valuation based on the damages associated with impacts, instead using as its basis the cost of mitigation. The EU Climate and Energy Package (December 2008) introduced separate emissions reduction targets for the traded sector (i.e. emissions covered by the EU Emission Trading System) and for the non-traded sector (i.e. emissions outside the EU Emission Trading System). The emissions considered here fall into the non-traded sector.

Using BEIS guidance, a reasonable 2017 non-traded value for carbon would be £64 per tonne *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/602657/5._Data_tables_1-19_supporting_the_toolkit_and_the_guidance_2016.xlsx; Table 3: Carbon prices and sensitivities 2010-2100 for appraisal, 2016 £/tCO2e*

Assuming 265 tonnes methane saved across all sites, the GWP of methane as 25, and cost of carbon as £64/tonne, **gives a value of the avoided emissions of £424,000 per annum.**

Cost Benefit Evaluation
The examples above demonstrate a simple methodology to assign a value to the benefits achieved from implementing the monitoring system across the full portfolio of 23 sites in one year and achieving the maximum possible greenhouse gas reductions. However, achieving these benefits takes time; the total of **£478,251** is improbable and as such the roll out scenarios in Section 3.5 are based on a reduction of 10 tonnes per year.

The costs of the roll out scenarios in Section 3.5 and the savings in greenhouse gas emissions that could be achieved determine that the most cost efficient roll out is Scenario 2, whereby one additional monitoring system is purchased along with sampling materials for all 23 compressor stations. The scenario gives payback in greenhouse gas reductions within 4 years of investment. Additionally a conservative roll out of the technology makes commercial sense with the likely development in the medium term of low cost methane sensors.

This however does not quantify the added benefits of operating the monitoring system to quantify and better inform investment decisions. How data from the system will be input into this decision making process will now be explained.

4.5 Network Output Measures Project

NGG's gas transmission network ensures the safe and reliable transportation of gas to 23.2 million industrial, commercial and domestic customers (via the Distribution Networks) around Great Britain, and our customers are asking it to do more. We are ensuring the network can meet the flexible needs of our customers, so it can manage the changing flows within day and physically across the network. We are also responding to external drivers for change that directly affect our assets such as emissions legislation.

Understanding how our assets are performing and that the investments we are making to maintain the safety and services required by our stakeholders is key in demonstrating our asset management capabilities. Through our proposed methodology for Network Output Measures ("the

Methodology") we aim to be able to quantify the level of performance that our assets are delivering for customer whilst providing additional justification for the expenditure needed to maintain and / or improve our safety, reliability and environmental performance across our network.

The Methodology enables the evaluation of:

- the Network Asset Condition Measure – current condition, expected reliability and predicted rate of deterioration in condition of the Network Assets;
- the Network Risk Measure – the overall level of risk to the reliability of the NTS based on the condition of the Network Assets and the interdependencies between Network Assets;
- the Network Performance Measure – the technical performance of the NTS that have a direct impact on the reliability and cost of services provided as part of the transportation activities;
- the Network Capability Measure – the current level of capability and utilisation of the NTS at Entry Points and Exit Points together with compressor asset utilization; and
- the Network Replacement Outputs – a method that will facilitate the establishment of an asset management performance measure for NGG.

The foundation of the methodology is the Service Risk Framework (SRF). This consists of a set of measures that in totality describe the service performance requirements of the asset base from the perspective of NGG and its stakeholders. All assets either directly or indirectly contribute to the delivery of one or more of the measures within the SRF. The impact of an asset on one or more of the measures within the SRF provides a consistent method of assessing and articulating the consequence of assets and ultimately its monetised risk value.

Category	Service Risk Measure
Safety	Health and Safety of the General Public and Employees
	Compliance with Health and Safety Legislation
Environment	Environmental Incidents
	Compliance with Environmental Legislation and Permits
	Volume of Emissions
	Noise Pollution
Availability and Reliability	Impact on Network Constraints
	Compensation for Failure to Supply
Financial	Shrinkage
	Impact on Operating Costs
Societal and Company	Property Damage
	Transport Disruption
	Reputation

The Environmental elements of the SRF include our compliance with environmental legislation and the environmental permits we hold for some of our sites. The category also covers any environmental incidents or noise pollution caused by our assets as well as the volume of greenhouse and other gases that we emit.

The failure modes identified to impact emissions relate to:

- Emergency Shut Down (ESD) venting which have been identified to occur with unit or system trips
- Major and minor leaks

The data that the continuous fugitive emission monitoring system provides can be input directly into the monetized risk model or alternatively highlights the leaking component requiring more detailed inspection and measurement to quantify the leak.

Emissions are then valued summing the wholesale value of the natural gas lost and the non-traded carbon value of that gas. The value of that gas year on year if it was left to leak can then be compared to the cost of replacement in order to better inform that investment decision taking account of the environment impact for the first time.

A continuous fugitive emission monitoring system such as that trialed would provide an environmental cost estimate for the saved gas on replacement. The monitoring system allows NGG to apportion environmental impact cost considerations to the overall cost benefit of, inclusion in and prioritization of repair/replacement programmes. The Network Output Measures Project is an effort to incorporate environmental considerations into asset replacement decision making.

4.6 Actual Project Costs

The project was divided into a number of discrete work packages, as described below.

WP1 – Procurement and planning (2 months)

- Initial emissions assessment – Already performed by earlier DIAL measurements
- Initial site visit
- Procurement, of equipment for near real-time methane fence line measurement system.

WP2a – Installation and commissioning at [redacted] (1 Month)

- Installation and commissioning of near real-time methane fence line measurement system.

WP2b – Procurement of additional sampling system, installation and commissioning at [redacted] (1 Month)

- Procurement of additional sampling system
- Installation and commissioning of near real-time methane fence line measurement system.

WP3 – Continuous surveillance and reporting (9 months)

- Continuous surveillance of emissions with monthly reports on concentrations measured and resulting emission map
- Quarterly presentation of progress and results to NGG
- Annual report on emissions and effects of remedial work to reduce fugitive emissions
- Improved knowledge of emission sources and calculations of emissions savings
- Production of a Statement to Ofgem in line with GHGIM guidance.

The costs associated with the work packages are summarised in Table 3 below, together with NGG's own costs. Costs detailed are up to the end of November 2017 for WP1, WP2 and WP3.

Work package	**Activity**	**Core Project, £**	**Instrumentation Equipment (NGG to own), £**
WP1	Initial emissions assessment	5,352	
	Fast response analyser		39,982
	Sample selection system		7,743
	Meteorological equipment		1,300
	Mobile setup (trailer etc.)		28,633
WP2a	Installation and commissioning of distributed sampling and real-time analyser system at [redacted]	23,206	
WP2b	Installation and commissioning of distributed sampling and real-time analyser system at [redacted]	24,556	
	Sample selection system		7,743
WP3	9 month operation + reporting	22,431	
	9 month model set up and operation	14,670	
NGG Project Costs			
	GTO project management, safety assessments, reporting and governance	11,968	
	GTO Operations site management, safe control of operations, commissioning support	8,662	
	GTO Operations minor equipment (electrical supplies and cherry picker hire)	6,986	
	GSO project input, cost management, regulatory governance and reporting including Final Statement	4,583	
Total		£122,414	£85,401
Project total		**£207,815**	

Table 3: Full project costs.

The was no additional CAPEX at [redacted] just OPEX cost of additional maintenance work.

4.7 Conclusion

NGG has successfully completed the investigation deliverables by

- Increasing understanding of the source of methane emissions from the test installation(s) and the quantification of those emissions.
- Validated the operational use of the near real-time methane monitoring system on the NTS.

- Proven the “portability” of the equipment to ensure that it can be utilised across the NTS for both installation and operation monitoring and assessment.
- Produced a quantified methane emissions map for two test installations.
- Proposed a future roll out of the technology and with additional trialling we would be able to better influence the priority and investment strategy and repair/replacement activities.

5 Technical Annex

See attached Technical Annex