# CCS – ST FERGUS CAPABILITY AUDIT

A report to National Grid plc

5th October 2009

CCS – ST FERGUS CAPABILITY AUDIT

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# TABLE OF CONTENTS

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# EXECUTIVE SUMMARY

National Grid plc (NG) is proposing to provide Carbon Capture and Storage (CCS) transportation capacity as part of a bid for the Department of Energy and Climate Change (DECC) competition to provide a CCS demonstration project. To provide the capacity, NG has proposed that approximately 300km of the National Transmission System (NTS) be converted to transport $CO_2$ instead of natural gas (for the purposes of this document, the 'CCS proposal'). Formally, this would require National Grid Gas plc (NGG) to dispose of a part of its regulated asset, which requires the consent of the Gas and Electricity Markets Authority (GEMA).

In April 2009, the Office of Gas and Electricity Markets (Ofgem) sought the views of the industry and consulted on the proposed disposal[1]. The consultation document included an initial examination of the effects such a disposal might have on the gas industry, including reduced network capability at St. Fergus, the potential for increased buy-backs, the potential for increased compressor fuel costs and possible investments to reinstate capacity. With respect to the reduced capability of St. Fergus, Ofgem included the results of analyses undertaken by NGG (provided in November 2008), and asked consultees for their views of the capabilities. Many consultation responses requested that the capability numbers be subjected to independent scrutiny.

This document details the results of a study undertaken by Pöyry Energy Consulting examining the network analysis models used by NGG to provide the numbers used by Ofgem in the consultation. The results of this study confirm that:

- the capability of St. Fergus has not been overstated;
- the network analysis models contain and are constrained by the various technical and commercial constraints that should apply;
- the underlying supply-demand assumptions used within the network analysis models originate from data sources that are consistent with those used to produce the Ten Year Statement (TYS);
- the network models have not been created subsequent to the consultation document; and
- NGG has adopted a conservative approach to the analyses, such that the impacts to network capability of the CCS proposal are not underestimated.

We note three minor observations which, in our opinion, are not material within the context of the consultation document. The first observation consists of a minor error and inconsistent use of units, the second observation consists of the disregard of a commercial constraint within one of the models, and the third observation is concerned with a potential miscommunication between NGG and Ofgem. The observations, when properly treated, have negligible effect on reported network capabilities.

It is our conclusion that the capability figures presented in the Ofgem consultation document are appropriate within the context of that document and can be relied upon for the purposes of that consultation.

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1 'Proposed disposal of part of the NTS for Carbon Capture and Storage', Ofgem, ref. 35/09, 8th April 2009

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# 1. INTRODUCTION

## 1.1 National Grid CCS proposal and Ofgem consultation

NG is proposing to provide CCS transportation capacity as part of a bid for the DECC competition to provide a CCS demonstration project. To provide the capacity, NG has proposed that approximately 300km of the NTS be converted to transport $CO_2$ instead of natural gas. Formally, this would require NGG to dispose of a part of its regulated asset, which requires the consent of GEMA.

In April 2009, Ofgem sought the views of the industry and consulted on the proposed disposal[2]. The consultation document included an initial examination of the effects such disposal might have on the gas industry, including reduced network capability at St. Fergus, the potential for increased buy-backs, the potential for increased compressor fuel costs and possible investments to reinstate capacity. With respect to the reduced capability of St. Fergus, Ofgem included the results of analyses undertaken by NGG (provided in November 2008), and asked consultees for their view of the capabilities. Many consultation responses requested that the capability numbers be subjected to independent scrutiny.

## 1.2 Objective of the audit

Pöyry Energy Consulting was retained by NGG to provide independent reassurance to Ofgem and the wider industry that the St. Fergus capabilities presented in Ofgem's consultation document are reasonably representative of the physical network. The audit has been undertaken to enable Pöyry to confirm that both the approach and the assumptions used in the analysis were reasonable and, where relevant, consistent with normal network analyses.

The audit has also established the extent to which flow capability at St. Fergus appears to remain generally in excess of 130mcm/d, as tested against a range of appropriate conditions (in particular considering ranges of flows at Teesside and Barrow). In addition, the audit has been undertaken so that Pöyry can verify that general assertions, e.g. that capability increases with increased local demand, can be observed within the analysis.

## 1.3 About Pöyry Energy Consulting

Pöyry Energy Consulting is Europe's leading energy consultancy providing strategic, commercial, regulatory and policy advice to Europe's energy markets. Pöyry Energy Consulting merges the expertise of ILEX Energy Consulting, ECON and Convergence Utility Consultants with the management consulting arms of Electrowatt-Ekono and Verbundplan. Our team of 250 energy specialists, located across 15 European offices in 12 countries, offers unparalleled expertise in the rapidly changing energy sector.

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[2] ibid. See footnote 1.

## 1.4 Independence and impartiality of Pöyry Energy Consulting

Although we have been retained by NGG to produce this audit, in order to maintain our independence and impartiality we have:

- reserved the right to inform Ofgem directly of any findings from the audit; and
- retained full editorial control of this audit report.

We have also required unfettered access to the network analysis models.

## 1.5 Units and conventions in this document

Table 1 below provides definitions for the unit abbreviations used within this document. Where units are comprised within a quotation, the original document has been quoted verbatim and the units have not been adapted to this document's conventions.

**Table 1 – Unit definitions and conventions**

| Abbreviation | Unit | Used for | Notes |
|---|---|---|---|
| MJ/m3 | Mega-Joules per cubic metre | Calorific value (CV) of gas | Gross CV (i.e. Higher Heating Value), consistent with normal practice in the wider gas industry. |
| GWh/d | Giga-Watt-hours per day | A measurement of energy (flow) rate | One million kilowatt-hours per day, where kilowatt-hour is used within the Uniform Network Code as a measure of capacity. GWh/d is used within NGG's Gas Transporter licence to define entry capacity baselines. |
| mcm/d | million cubic metres per day | Volumetric gas flow rate | At 'standard temperature and pressure' (STP) unless otherwise stated[3].<br>A CV may or may not be quoted to enable the calculation of energy flow rate. |
| mscm/d | million standard cubic metres per day | Gas flow rate at a standard CV | Standard CV of 39MJ/m3[4]. |

Source: Pöyry Energy Consulting

[3] In the UK gas industry STP is usually used in preference to 'normal temperature and pressure' which is variously used in Europe. There is no uniform definition of STP, however, we assume 15 Celsius and 101.325 kilo-Pascal, consistent with the wider gas industry.

[4] Pöyry Energy Consulting acknowledges the changes proposed by NGG to use a standard CV of 39.6MJ/m3, but does not adopt this within this document.

# 2. AUDITING REQUIREMENTS

## 2.1 Scope

Most of the responses to the Ofgem consultation document that requested some form of scrutiny or independent verification of the network capabilities did so in response to the Ofgem consultation question, 'What is your view of the indicated capability at St. Fergus with the feeder removed, with and without additional compression?'

This audit is to verify that the indicated capabilities are accurate within the context of the consultation document, where the primary concern is that the impact of removing part of the NTS has been adequately reported. In this respect, the primary necessity for this audit to establish that the network capability should not be lower than that indicated. Secondly, this audit has examined the precision of the analyses to establish if NGG has been conservative or liberal in reporting the impact of the CCS proposal on network capability.

This audit cannot and does not provide any view as to whether the indicated capabilities are sufficient or insufficient against any particular criteria, neither does this audit consider the appropriateness or otherwise of any of the underlying supply or demand assumptions.

The analyses undertaken by NGG have all been conducted under steady-state, maximum linepack conditions. As such the audit is limited to this set of analyses. We do not consider that limiting the analyses to steady state conditions to be an inappropriate approach, and consider that detailed transient analyses might introduce spurious accuracy given the uncertainty of future within-day profiles of gas consumption and supply.

## 2.2 Modelling checks

The audit has been designed to review the network analyses undertaken by NGG, by examining the actual network models used to communicate the implications of the CCS proposal to Ofgem in November 2008.

The audit checks undertaken have included checking that:

- constraints within the models are reflective of formal network modelling assumptions, including:
  - the physical model such as pipe lengths and diameters;
  - technical parameters such as compressor operating characteristics; and
  - supply-demand assumptions (where not under the influence of the study);
- the assumptions used were appropriate at the time the analysis was undertaken;
- the analyses have not been undertaken subsequent to the submission to Ofgem; and that
- the analyses are reflective of the results presented in the consultation document.

## 2.3 Contextual checks

Pöyry has examined the effects of relaxing constraints within the model to ensure that the capability figures reported are appropriate, and also examined the range of conditions

used in the analyses in order to establish that, within reason, the lowest capability has been established. In addition, Pöyry has attempted to establish credible and reasonable higher flow levels from St. Fergus, thereby stretching the capabilities beyond that reported.

# 3. AUDIT FINDINGS

Pöyry Energy Consulting has not found any evidence that the network analyses undertaken were inappropriate within the context of the consultation document. We note three minor observations, which are detailed below, and consider that these observations are not material within the context of the consultation document.

We have set out below some general observations and the details of the specific observations. The detailed auditing log is included as Annex A.

## 3.1 General observations

Every network model that was examined as a part of this audit tested positively for further capability at St. Fergus, Teesside and/or Barrow than was stated in the Ofgem consultation document. We have therefore established that NGG has generally slightly overstated the impact of the CCS proposal on network capability (i.e. it has been conservative in estimating the capability of the revised gas network).

All underlying assumptions examined reflect the '2008 Plan Planning Assumptions' document (Planning Assumptions) and are reflective of the supply-demand forecasts in use at the time of the analysis[5].

## 3.2 Specific observations

In the process of the audit we noted three minor observations relating to calorific values, the presence of an alarm pressure, and a misreporting of the assumptions, which are described below.

### *3.2.1 Calorific values*

Paragraph 3.19 of the Ofgem consultation document states that, 'The results indicate a capability of around 132mcm/d which is equivalent to 1467GWh/d using a CV of 40MJ/m3'. A footnote is provided in the Ofgem document to explain the CV, which describes that a conversion factor of 10.833 is used to convert mcm/d to GWh/d.

The footnote appears to be erroneous. A CV of 40MJ/m3 should result in a conversion factor of 11.1 recurring (i.e. precisely 100/9). Had a conversion factor of 10.833 been used, the 'equivalent capability' (i.e. capability expressed in energy terms) would be 1429.956 GWh/d.

The confusion appears to arise from conventions used within NGG. The network analysis department, and the network analysis tool used for these capability analyses (Graphical Falcon), use a convention that a standard CV is assumed to be 39MJ/m3. This results in

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5 We would not expect that the actual supply-demand assumptions used for these analyses would be particularly material, as the analyses have sought to examine high supplies in the north of the country, at a particular demand level, balanced by reduced supplies in the south of the country. At the same demand level, a different set of demand assumptions would merely redistribute that demand around the country. Similarly, a different set of supply assumptions might redistribute the base supplies, but this would only be material in so far that changes to east-coast supplies affect capabilities (as the other supply assumptions are targeted within the study).

a conversion of 10.833 *recurring* (i.e. precisely 65/6). Upon investigation, Pöyry Energy Consulting has discovered that the results and assumptions in the consultation document are actually a mixture of gas flow rates at a standard CV of 39MJ/m3 and volumetric gas flow rates (at STP and local CV)[6].

The capability figures, reported with the appropriate CV, and restated to a standard CV of 39MJ/m3, are presented in Table 2 and Table 3 below. (For the avoidance of doubt, units of mscm/d assume a CV of 39MJ/m3, ***not*** 40MJ/m3).

**Table 2 – Restatement of Ofgem Table 1**

| | St. Fergus capability | |
|---|---|---|
| | **With current infrastructure** | **With feeder removed** |
| 310mcm demand day | 154 mscm/d | 132 mscm/d |
| 400mcm demand day | 154 mscm/d | 132 mscm/d |
| 590mcm demand day | 154 mscm/d | 138 mscm/d |

Source: Ofgem, National Grid

**Table 3 – Restatement of Ofgem Table 2**

| | | St. Fergus | | | Teesside | Barrow |
|---|---|---|---|---|---|---|
| **Scenario** | **Demand** | mcm/d @ MJ/m3 (STP) | | mscm/d | mscm/d | mscm/d |
| 1 | 310 | 131.0 | 39.7 | 133.4 | 15.3 | 6.5 |
| 2 | 310 | 133.5 | 39.7 | 136.0 | 25.0 | 25.0 |
| 3 | 395 | 131.0 | 40.3 | 135.5 | 27.6 | 23.4 |
| 4 | 400 | 132.6 | 39.8 | 135.2 | 16.7 | 10.8 |
| 5 | 400 | 130.3 | 39.8 | 133.0 | 25.0 | 25.0 |

Figures are reported to 1 decimal place

Note: Scenario 3 shows the actual flows from 30th January 2006, expressed as flows at standard CV. An appropriate flow-weighted average CV has been used to convert from volumetric flows.

Source: Pöyry Energy Consulting, Ofgem, National Grid.

In addition, Ofgem's Table 3 in paragraph 3.24 of the consultation document should be read as if the CV is 39MJ/m3.

6 We also note that the network analysis tool, Graphical Falcon, assumes STP to be 60 Fahrenheit and 14.703 pound per square inch, equivalent to 15.56 Celsius and 101.37 kiloPascal (both to two decimal places). Errors introduced by these minor differences in STP will be negligible, and have been ignored for the purposes of this audit.

In the context of the consultation document, and the impact on network capability, we consider these errors to be negligible. We note that two interpretations of the original presentation are possible, one using a conversion factor 10.833GWh/mcm (as per the footnote), the other assuming a CV of 40MJ/m3. For scenario 1, the former interpretation would imply an energy flow rate of 1419.12GWh/d, and the latter interpretation would imply an energy flow rate of 1455.56GWh/d; the correct figure should be 1444.64GWh/day.

### *3.2.2 Adherence to assumptions*

In examining the network analysis model that represented scenario 2, a minimum pressure alarm had been violated which had remained unresolved prior to extracting the network analysis result for the consultation document. However, upon further investigation, NGG was able to reconfigure the NTS very slightly (by modifying compressor operation) to overcome the alarm without any detrimental impact to supply flows (i.e. maintaining the same level of reported capability). We therefore conclude that this observation is not significant and does not invalidate the results produced.

### *3.2.3 Supply-demand assumptions*

The Ofgem consultation document states in paragraph 3.15 that NGG used the 2008 TYS forecasts, whereas NGG actually used the 2007 TYS forecasts. The 2008 TYS supply-demand assumptions may have been available to NGG at the time the analysis was undertaken; however, we note that the 2008 TYS had not been finalised at that time. We understand that this error is due to a mislabelling of the assumption by Ofgem. Because of this, and the remarks included in section 3.1 above, we do not consider this observation to be material.

## 3.3 Conclusions

The network analyses undertaken by NGG to establish the impact of the CCS proposal to the capability of St. Fergus is appropriate and thorough, and Pöyry Energy Consulting has found no evidence to suggest that the numbers presented in the Ofgem consultation are inappropriate in that context. Further, we consider that NGG has adopted a conservative approach to the modelling and that within the network models tested the St Fergus flows could be increased beyond the capabilities stated in the Ofgem document.

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# ANNEX A – AUDITING LOG

## A.1 Background material

In addition to the Ofgem consultation document (which forms the basis of this audit), NGG provided Pöyry with a spreadsheet summarising the capability results from each network model, the supply-demand 'balance sheets' for each of the three demand levels and a copy of the network analysis '2008 Plan Planning Assumptions' document. All of this information is confidential to NGG.

The summary spreadsheet detailed the results of 12 steady-state network analysis models. We examined seven of these models directly, and saw evidence that the other five models existed. During the course of these examinations, another network model was uncovered that had been created by a different analyst sometime after the original 12 models had been created. This 13th model (the eighth examined model) sought to augment the analysis of one of the original models by further increasing capability at St. Fergus.

## A.2 Network tests

This section outlines the specific observations undertaken.

### *General note regarding balancing*

A fundamental requirement of mathematics of steady-state network analysis (the analysis method used for the subject of this audit), is that the volume of gas entering the network (supply) must be equal to the volume of gas exiting the network (demand). Therefore, when examining the maximum capability of an entry point by increasing the amount flowing at that point, it is necessary to retain a balance between supply and demand by either increasing demands or decreasing other supplies. Either convention can be adopted and both have their pros and cons. A discussion of the relative merits of demand or supply balancing is beyond the scope of this document.

For examining entry point capabilities, it is Pöyry's understanding that it is usual practice for NGG to adopt the convention of decreasing supplies rather than increasing demand. In choosing where balancing actions will be undertaken, it is necessary to choose supply flows that will not have a material impact on the subject's capability. Specifically for St. Fergus, an entry point in northern Scotland, NGG has chosen to balance increased St. Fergus flows at southerly entry points – Isle of Grain, Milford Haven and Bacton. It is Pöyry's opinion that this selection is correct for the purposes of calculating St. Fergus capabilities.

### *A.2.1 Examination 1, Network 1 – baseline*

310mscm/d, base network (i.e. full NTS), base case supply flows, St. Fergus at baseline.

*Checks*

- No alarms encountered when analysed.
- Supplies checked as per balance sheet.

- St. Fergus flows increased to current baseline (154mscm/d), balanced by reducing Isle of Grain, Milford Haven and Bacton flows. Milford Haven is being controlled on a pressure constraint and there is an insignificant inflow after balancing.
- South Hook CV as per balance sheet.
- Aberdeen compressor unit utilising 29.6MW against a maximum power rating of 31.1MW.
- Aberdeen compressor operating within its operating envelope.
- Total demand 308.2 mscm/d (excluding compressor fuel).

*Capability*

- With 2mcm/d removed from Bacton flows to increase St. Fergus flows the network starts to degrade with compressors operating just outside of their operating envelopes. It would probably be possible to slightly modify the compressor control settings and/or network configuration to reinstate the feasibility of the network.
- St. Fergus capability is therefore higher than the reported capability for this network.

### *A.2.2 Examination 2, Network 2 – 'Scenario 1'*

310mscm/d, 300km Scottish feeder removed, base case supply flows, St. Fergus at capability.

*Initial checks*

- No alarms encountered when analysed.
- St. Fergus, Barrow and Teesside flows as per summary spreadsheet.
- The flow through Aberdeen compressor, compared to Network 1, is different by a similar magnitude to the flow (noted from Network 1) through the removed feeder.
- Balance has been achieved (compared to Network 1) by increasing flows at Isle of Grain and Bacton. Bacton flows have been restored to balance sheet levels.

*Capability*

- With 4mcm/d removed from Isle Of Grain, St. Fergus increases accordingly.
- Compressor envelope and minimum pressure alarms are encountered, but these are resolved through network reconfiguration.
- St. Fergus capability is therefore higher than the reported capability for this network.

*Further checks*

- Moffat, Bishop Auckland, Wooler, Aberdeen, Hatton, and Peterborough compressor powers all comply with their relevant assumption in the Planning Assumptions.
- Moffat, Bishop Auckland, Wooler, Aberdeen, Hatton, and Peterborough compressors all operating within their operating envelopes.
- Small supplies checked as per balance sheet.
- There is some gas storage injection modelled, as per balance sheet.

### *A.2.3 Examination3, Network 3 – 'Scenario 2'*

310mscm/d, 300km Scottish feeder removed, supply flows at Teesside and Barrow to approximate 30th January 2006, St. Fergus at capability.

*Observation*

On the initial running of this network model, a minimum pressure alarm was violated and therefore it could be possible that it had been left unresolved prior to extracting the network analysis result for the consultation document. However, upon further investigation, slight reconfiguration of the NTS (by modifying compressor operation) corrected the alarm without any detrimental impact to supply flows (i.e. maintaining the same level of reported capability). We therefore conclude that this observation is immaterial.

*Checks*

- St. Fergus, Barrow and Teesside flows as per summary spreadsheet.
- Easington sub-terminal flows as per balance sheet.
- Aberdeen and Kirriemuir compressor powers all comply with their relevant assumption in the Planning Assumptions, and operate within their compressor envelopes.

*Capability*

- Increased capability was achieved at St. Fergus through reducing Bacton flows and making use of Warrington compressor station.
- St. Fergus capability is therefore higher than the reported capability for this network.

### *A.2.4 Examination 4, Network 4 – reflecting Ofgem Table 1, row 1 'with feeder removed'.*

310mscm/d, 300km Scottish feeder removed, worst case supply flows at Teesside and Barrow, St. Fergus at capability.

*Checks*

- No alarms encountered when analysed.
- St. Fergus, Barrow and Teesside flows as per summary spreadsheet.
- Selected compressor powers comply with their relevant assumption in the Planning Assumptions, and compressors operate within their compressor envelopes.
- Internal diameters checked for two randomly selected pipelines.

*Capability*

- Bacton flows were decreased by 9mcm/d to increase Teesside flows.
- Pressures were restored to the South-East area by reconfiguring that part of the network for low Bacton flows.
- North to South compression increased.
- St. Fergus flows were maintained at over 132mscm/d with Teesside at these increased levels.

- Whilst not explicitly tested, St. Fergus capability may be higher than the reported capability for this network, and the reported capability appears to be very resilient.

### *A.2.5 Examination 5, Network 7 – 'Scenario 5'*

400mscm/d, 300km Scottish feeder removed, supply flows at Teesside and Barrow to approximate 30th January 2006, St. Fergus at capability.

*Checks*

- No alarms encountered when analysed.
- St. Fergus, Barrow and Teesside flows as per summary spreadsheet.
- Theddlethorpe supply flows as per balance sheet.
- A commercially driven minimum pressure constraint at a particular offtake in Scotland had been correctly applied within the model.
- Hatton compressor operating with its operating envelope.
- Three NTS-connected large demands were checked and found to be consistent with the balance sheet.
- An individual DN offtake demand was checked and the differences at this offtake between the 310mcm/d and 400mcm/d demand level appeared to be consistent with the differences in overall DN demand. (Individual DN demands are not directly specified by the balance sheet).
- A critical piece of infrastructure was removed to check that reports of infeasibility are made by the mathematics engine in the network analysis software.

*Capability*

- Increased capability was not examined.

### *A.2.6 Examination 6, Network 9 – reflecting Ofgem Table 1, row 2 'with feeder removed'*

400mscm/d, 300km Scottish feeder removed, worst case supply flows at Teesside and Barrow, St. Fergus at capability.

*Checks*

- No alarms encountered when analysed.
- St. Fergus, Barrow and Teesside flows as per summary spreadsheet.
- Selected compressor powers comply with their relevant assumption in the Planning Assumptions, and compressors operate within their compressor envelopes.
- All flow control valves, where controlling, are controlling with a minimum pressure differential of 2 bar.
- Compressor stations are flowing within the appropriate maxima as per the Planning Assumptions.
- There are no gas temperature breaches.

*Capability*

- Capability was tested by increasing Barrow flows by 2mcm/d and balancing at Isle of Grain.
- With compressor settings modified and minor network reconfiguration, alarms can be eliminated.
- Whilst not explicitly tested, St. Fergus capability may be higher than the reported capability for this network, and the reported capability appears to be resilient.

### *A.2.7 Examination 7, Network 12– reflecting Ofgem Table 3, row 1*

590mscm/d (1:20 peak), 300km Scottish feeder removed, compression added, worst case supply flows at Teesside and Barrow, St. Fergus at capability.

*Checks*

- No alarms encountered when analysed.
- St. Fergus, Barrow and Teesside flows as per summary spreadsheet.

*Capability*

Please refer to Examination 8, below.

### *A.2.8 Examination 8, Network 12a – an augmentation of Network 12*

590mscm/d (1:20 peak), 300km Scottish feeder removed, compression added, worst case supply flows at Teesside and Barrow, St. Fergus at increased capability.

*Capability*

- This network was created after the submission of data to Ofgem that originated from Network 12.
- NGG has stated that the network was created as part of a small internal audit of the figures that had previously been reported to Ofgem.
- The network analysis model had been created by an network analyst who had no involvement in the original analysis.
- Network 12a includes some minor reconfiguration and more optimal compressor settings and results in a capability in excess of the capability reported for Network 12.
- We therefore conclude that St. Fergus capability is higher than the reported capability for Network 12.

## A.3 Other examinations

We saw evidence that the balance sheets that had been provided to us had originated from a system that had been created prior to the dates that the network analyses had been undertaken, and that this system appeared to reference data that was also used to generate the 2007 TYS.

A number of the network models have been observed as being last saved prior to the date of submission of data from NGG to Ofgem. We therefore have no reason to suspect that the models have been created or modified subsequent to this date. We have also seen NGG internal email communication that support this.

The assumptions contained within the Planning Assumptions appeared to be reasonable.

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