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Flexibility in Great Britain's gas networks: analysis of linepack and linepack flexibility using hourly data

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Summary

This briefing note describes the amount of gas contained within Great Britain's gas transmission and distribution networks, and how this changes over a day to support variations in demand. The hourly data covers the 63-month period from 2013-01-01 to 2018-03-07.

The amount of gas contained within the higher-pressure tiers of Britain's gas transmission and distribution network is termed 'linepack'; literally, it is the amount of gas *packed* into the pipe*lines*[i].

Linepack is proportional to the pressure of the gas in the pipelines, increasing the pressure increases the amount of gas, and thus the energy contained therein. The amount of linepack changes throughout the day due to the varying levels of pipeline pressure. This flexing of pressure provides a method to help match the supply and demand for gas within a day.

The scale of energy that can be stored and released by varying linepack highlights its importance as a means of operational flexibility, helping to balance the changes in national primary energy demand.

The scale of the within-day flexibility currently provided by the natural gas transmission and distribution networks points to a formidable energy systems challenge; how to provide low-carbon within-day flexibility to future energy systems at a reasonable cost.

Introduction

The UK Energy Research Centre's FlexiNET project has analysed data from Britain's transmission and distribution gas networks, to provide a more complete picture of the variation of gas linepack. This is the first time this data has been presented, as hourly linepack data for the Gas Distribution Network has not previously been available at an aggregated level.

Great Britain's demand for energy varies significantly over a day and between seasons, caused by underlying patterns of consumer behaviour and activity, many of which are repeated on a daily basis. Changing the pressure in high-pressure gas pipelines varies the amount of linepack and allows Britain significant flexibility to match its gas supply and demand over a day by providing a method to store gas.

This analysis provides additional evidence to help inform the debate surrounding future energy systems by providing a better understanding of the level of within-day flexibility available to Britain's existing energy systems.

The findings add to previous work undertaken by UKERC on thermal energy storage[ii], heat incumbency[iii], and flexibility of electrical systems[iv] and provides additional impetus to focus greater levels of research and innovation on low-carbon within-day flexibility.

What is linepack and how is it calculated?

Linepack is the amount of gas contained within the higher-pressure pipelines (>7bar) of Britain's transmission and distribution gas infrastructure. Linepack is calculated by combining measurements of pressure, temperature, compressibility, specific gravity of the gas contained within pipelines and pipeline internal volume. This provides a calculated volume of linepack under high-pressure operating conditions, that is then expressed as an equivalent volumetric measure of gas in standard cubic metres at standard conditions of atmospheric pressure and ambient temperature. With additional knowledge of the calorific value of the gas, the volumetric measure can be changed into an energy equivalent measure such as GWh. The FlexiNET project has used a constant of 11 kWh (39.6 MJ) per standard cubic metre of gas for analysis.

Although linepack is defined as the total gas/energy contained within the high-pressure pipelines, it is important to point out that gas pressure and therefore the linepack has to remain above a minimum safe operating pressure. Linepack at this minimum pressure should therefore be considered as a permanent inventory of gas pipelines (even though there is a flow and constant turnover of the actual gas molecules) and should not be considered as a measure of useable energy. This is a similar concept to gas caverns that require a permanent inventory of gas (cushion gas) in the storage reservoir to provide a minimum level of pressure that can then be increased to provide the operational storage. In this briefing note, linepack is considered the total amount of gas stored within the pipelines, whilst linepack flexibility denotes how much this can be varied, in essence, a measure of the amount of useable gas storage.

Britain's gas transmission and distribution system

The majority of natural gas supplies to Britain flow into the National Transmission System at entry terminals connected to pipelines or one of the three Liquified Natural Gas facilities. The National Transmission System (NTS) for gas is owned and operated by National Grid and is used to transmit bulk amounts of gas around its 7600 km length[v]. Compression stations provide pressure increases at 24 points throughout the NTS pipelines to make gas flow in the required direction.

Major sites of natural gas demand are connected directly to the NTS such as Combined Cycle Gas Turbine (CCGT) power plants, gas storage, large industrial users and pipelines that can be used for connection to other countries. The largest annual demand for gas is from the Gas Distribution Networks that are connected to the NTS at multiple offtake points; in 2018 their demand was 72% (544 TWh) of Britain's total gas demand (less exports) of 753 TWh[vi]. This briefing note uses the terminology Local Gas Network to denote the Gas Distribution Network infrastructure between the National Transmission System and end users. Local Gas Network pipelines are about 265,000 km in length[vii] and also contain some higher-pressure pipelines that have linepack that can be varied in pressure. Gas pipelines become smaller in diameter and lower in pressure as they get closer to end users, and by the time the gas is utilised in a domestic property its operating pressure will only be slightly above atmospheric pressure.

Although hourly historical linepack data for the NTS has been available for sometime, the data for Local Gas Networks has not. The FlexiNET project collated and aggregated this proprietary hourly linepack data from the four Local Gas Networks, providing a clearer picture across Britain's combined transmission and distribution gas infrastructure for the first time.

What is linepack flexibility and how is it calculated?

This briefing note uses the terminology 'linepack flexibility' to describe the change of linepack over a defined timeframe; other terms such as linepack range, linepack swing and even linepack itself are sometimes used to describe this.

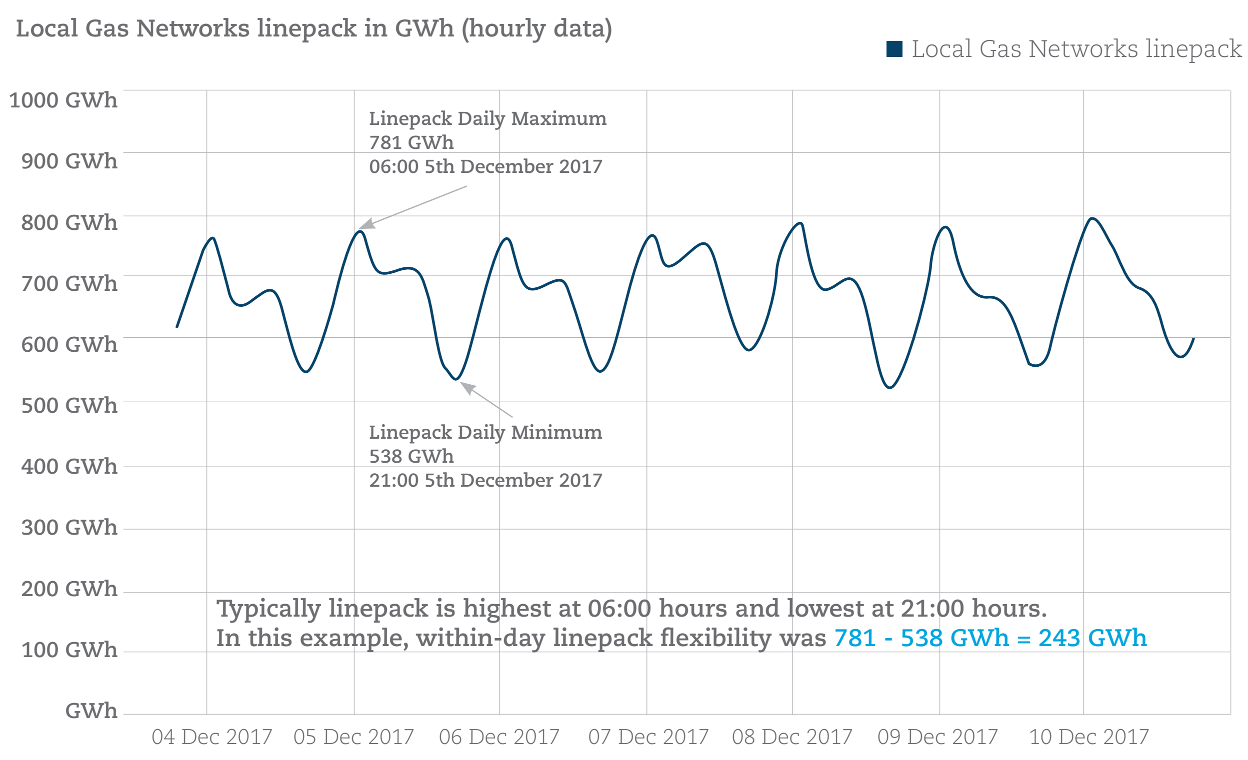
Of interest is the within-day linepack flexibility that we define as the difference between the maximum linepack in a day and the minimum linepack in the same day (a gas day runs from 05:00 until 05:00 the next day). The timeseries for the combined NTS and Local Gas Network is simply the sum of the NTS and Local Gas Network linepack values for each hour. The within-day flexibility of this series is then the maximum minus the minimum combined linepack value in the same day. As linepack variation in the NTS and Local Gas Network are not perfectly coincident, the values for the combined within-day linepack flexibility may not be the sum of their individual series.

Within-day linepack flexibility can be considered as the operational within-day storage of the gas pipelines themselves, and does not include the additional storage provided by gas caverns or LNG storage connected to the pipelines. Linepack flexibility is a measure of the storage that can be utilised as an inherent characteristic of having a gaseous energy vector contained in a high-pressure pipeline where the pressure can be varied.

Linepack is flexed over a day by the Gas Distribution Network companies in response to anticipated and actual patterns of gas demand. Typically, the amount of linepack in the pipelines is increased overnight so that additional stored energy is available, ready to accommodate the large ramp-up in demand the following morning from 5am particularly during the heating season (October to March inclusive). A major aim of managing the level of linepack throughout a day is to start the following gas day with an appropriate level to help meet the forecast demands for that following gas day. Linepack is therefore constantly monitored and adjusted dependent on changing conditions such as the weather. Figure 1 shows a week of hourly Local Gas Network linepack measurements for the week beginning Monday the 4th of December 2017. On Tuesday the 5th, the maximum linepack was 781 GWh, the minimum was 538 GWh, therefore the within-day linepack flexibility was 781-538 GWh = 243 GWh.

The ability to vary linepack between well-defined operational limits is a fundamental means that gas networks use to buffer sufficient energy to manage the changes in natural gas demand. For local gas demand alone, this change in demand was calculated to be as high as +116GW over a 3-hour period in the previous briefing note[viii] that compared local gas demand to national electrical demand.

Figure 1. Linepack for week beginning Monday the 4th of December 2017, showing maximum and minimum linepack values for Tuesday the 5th of December 2017. Within-day linepack flexibility was 781-538 GWh = 243 GWh



Summary linepack characteristics for the National Transmission System and Local Gas Network

Hourly Local Gas Network proprietary data from Cadent, Northern Gas Networks, SGN, and Wales and West Utilities was used for the analysis. It covers the 63-month period from 2013-01-01 to 2018-03-07. The NTS data is publicly available through National Grid's data explorer[ix].

Table 1 summarises various characteristics of the NTS and Local Gas Network. The average level of linepack for the NTS was 3743 GWh and for the aggregate level of the four Local Gas Networks was 662 GWh. These average values point to the Local Gas Network having less than 20% of the linepack of the NTS. This is a function of the different characteristics of the two distinct parts of the gas system, such as a significantly different internal volume (length of pipelines x diameters) and differences in operating pressures. Another measure shown in Table 1 is the drop in linepack over a 3-hour time period, which can be considered as the release of stored energy. Figure 2 presents the hourly linepack timeseries of the NTS, Local Gas Network and combined series. The Local Gas Network shows a clear seasonality for the variation in linepack with lower amounts of within-day flexibility needed in the summer in comparison to the winter.

This seasonality is due to the much greater within-day changes in gas demand during the heating season (an animation helps to show this[x]), driven primarily by demand for space heating and hot water. Larger within-day swings in demand require greater within-day flexibility to accommodate these, which can be supported by linepack flexibility as well as flexing gas supplies throughout the day.

Although the electrical network has no intrinsic equivalent of linepack and therefore linepack flexibility, a couple of related values are presented to give a sense of scale. The four pumped storage schemes in Britain have a total capacity of nearly 28 GWh[xi] and use part of this capacity to balance electrical supply and demand over a day. The highest 3-hour reduction was -7.9 GWh, starting at 2018-02-14 05:00.

Table 1: Summary of linepack from 1st January 2013 to 6th March 2018.

Data From: 2013-01-01 To: 2018-03-07	National Transmission System (NTS)	Local Gas Networks	Combined NTS and Local
Maximum hourly linepack	4146 GWh 2018-02-24 16:00	834 GWh 2013-02-10 06:00	4886 GWh 2018-02-24 16:00
Average hourly linepack	3743 GWh	662 GWh	4405 GWh
Minimum hourly linepack	3313 GWh 2016-09-05 15:00	458 GWh 2013-01-28 21:00	3841 GWh 2018-03-01 21:00
Highest 3-hour reduction in linepack (start time)	-128 GWh 2017-11-30 16:00	-164 GWh 2018-02-28 05:00	-251 GWh 2015-02-23 17:00

Within-day linepack flexibility quartile values

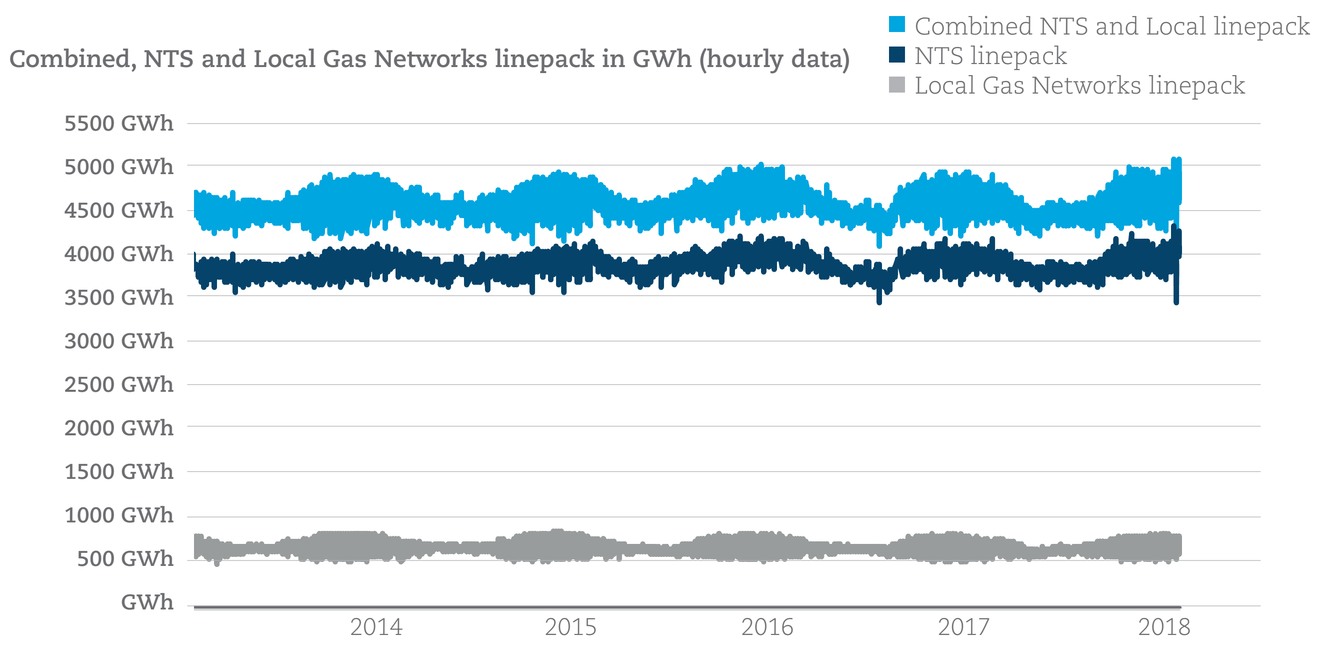
The quartile values of within-day linepack flexibility are shown in Table 2. In addition to the maximum, minimum and quartile values for the entire dataset, the within-day linepack flexibility values are shown for the October to March heating season. This gives an indication of linepack flexibility when gas demand is higher.

Of particular note is the level of within-day flexibility of the Local Gas Networks in absolute terms and in percentage terms of the average level of the linepack itself. The maximum within-day linepack flexibility was 337GWh, equivalent to just over 50% of the average linepack at 662 GWh. Local gas networks provide the majority of energy for space-heating and hot water for homes and businesses. The values in Table 2 show that Local Gas Networks provided at least 183 GWh of within-day linepack flexibility (useable gas storage) for 75% of the days over the heating season, and at least 243 GWh for 25% of the days. The related values for within-day flexibility from pumped storage are at least 10 GWh for 75% of the days over the heating season, and at least 12 GWh for 25% of the days.

The initial analysis for this briefing note has yielded a number of findings:

Firstly, the timing of variations to NTS linepack and Local Gas Network linepack are highly coincident; the increases and decreases in linepack in the distinct parts of the gas network happen at similar times. A potential reason for this is the need for flexibility in the NTS being driven by CCGT power stations as well as demand from the Local Gas Network, and the need for flexibility in the Local Gas Network being driven by space heating and hot water demand. CCGT power stations typically ramp up their gas demand in the heating season from 5am - 8am (to provide increases in electricity demand), a similar time that demand ramps up on the Local Gas Network for space heating and hot water.

Figure 2: Linepack of NTS and Local Gas System 2013-01-01 to 2018-03-07



Secondly, even though there is five to six times the amount of linepack in the NTS in comparison to the Local Gas Network, the amount of within-day linepack flexibility (the useful operational storage) is typically higher in the Local Gas Network.

Thirdly, the routine utilisation and scale of within-day linepack flexibility points to the critical role of gas infrastructure in providing flexibility to Britain's current energy systems.

Potential implications for research and innovation

The analysis illustrates the scale of the within-day flexibility currently afforded to Britain's energy systems by virtue of having a gaseous energy vector contained in an extensive high-pressure network of pipelines. In comparison, the electricity grid has no inherent means of storing electrical energy within the delivery infrastructure itself (the electrical cables).

A gas grid that transports drop-in replacements for fossil natural gas such as bio-synthetic natural gas could potentially continue to use linepack and linepack flexibility in a similar manner to today, even though overall gas demand is expected to decline. However, a gas grid that transports 100% hydrogen would require detailed network analyses to understand how much linepack that new high-pressure pipelines could be designed to hold, and the within-day flexibility of hydrogen linepack.

Reducing the need for within-day flexibility is expected to be beneficial regardless of the choice of future primary energy supplies and their associated networks that Britain implements to achieve a more ambitious net-zero target by 2050[xii]. This area should therefore be a target for increased focus across the research and innovation landscape.

Increased deployment of thermal energy storage at a district heating or at a household level could reduce the need for within-day flexibility if appropriately controlled; electric vehicles are another technology that has the potential to provide within-day storage and reduce or support the wider system needs of flexibility. Behaviour change and technology

Table 2: Maximum, minimum and quartile values for within-day linepack flexibility for all months, and the October to March heating season. All values are measured in GWh.

Within-day linepack flexibility 2013-01-01 to 2018-03-07	Local Gas Networks (October to March)	Local Gas Networks (all months)	National Transmission System (October to March)	National Transmission System (all months)	Combined NTS and Local Gas Networks (October to March)	Combined NTS and Local Gas Networks (all months)	Pumped storage (October to March)	Pumped storage (all months)
Maximum value	337	337	427	427	690	690	18	18
For 25% of the days	Greater than 243	Greater than 223	Greater than 211	Greater than 179	Greater than 442	Greater than 382	Greater than 12	Greater than 12
For 50% of the days	Greater than 220	Greater than 152	Greater than 167	Greater than 129	Greater than 377	Greater than 253	Greater than 11	Greater than 10
For 75% of the days	Greater than 183	Greater than 73	Greater than 125	Greater than 87	Greater than 301	Greater than 161	Greater than 10	Greater than 9
Minimum value	74	34	13	13	83	36	7	4

choices such as full and hybrid heat pumps also have potential to reduce the need for within-day flexibility by spreading energy demand further over the day. This would tend to smooth rather than concentrate demand, and therefore lessen the need for within-day flexibility overall. Reducing overall demand is also highly likely to reduce the need for flexibility too, and is an additional benefit from an increasing focus on energy efficiency.

Research to understand the range and limits of potential alternative low-carbon options should be a focus. How much can the need for energy system flexibility be reduced by changing behaviours that underlie the coincident demand for space heating and hot water? What are the costs, benefits and limits to the reduction in flexibility afforded by measures such as better insulated homes, smarter heating, time-of-use tariffs, flatter demand profiles from heat-pumps, or thermal energy storage in buildings on-site or at a larger scale?

The scale of current within-day flexibility is so great, that it would seem sensible to encourage several avenues of research and innovation at this point, with a view to narrowing down potential options in the future.

Conclusions

The values for within-day linepack flexibility that Britain's Local Gas Network currently provides have not previously been understood at a national level. This research therefore provides additional evidence to help inform the planning of Britain's future energy systems. The future role of Britain's gas networks in a decarbonised energy system is subject to ongoing discussion and debate which this analysis seeks to inform through a greater understanding of the existing energy system.

There is a real risk that without sufficient focus on managing and decoupling demand for space heating and hot water in particular, when considering shifting demand off the gas system (e.g. onto the electricity system), that too much of the need for within-day flexibility will be shifted across too. The existing within-day flexibility provided by pumped storage is around 1/20th of the within-day Local Gas linepack flexibility alone.

Reducing the need for the existing levels of within-day linepack flexibility in Britain is an energy system challenge that requires a substantially increased level of focus and effort in the near to medium term.

The scale of the within-day flexibility currently provided by the natural gas transmission and distribution networks points to a formidable energy systems challenge; how to provide low-carbon within-day flexibility to future energy systems at a reasonable cost.

i https://www.nationalgridgas.com/balancing/nts-linepack
ii Eames, P., Loveday, D., Haines, V. and Romanos, P. (2014) The Future Role of Thermal Energy Storage in the UK Energy System: An Assessment of the Technical Feasibility and Factors Influencing Adoption – Research Report (UKERC: London) – http://www.ukerc.ac.uk/programmes/energy-demand/the-future-role-of-thermal-energy-storage-in-the-uk-energy-system-assessment-of-technical-feasibility-and-factors-influencing-adoption.html
iii http://www.ukerc.ac.uk/publications/incumbency-in-the-heat-sector-implications-for-policy.html
iv http://www.ukerc.ac.uk/publications/security-of-electricity-supply-in-a-low-carbon-britain.html
v https://www.nationalgridgas.com/sites/gas/files/documents/Gas%20Ten%20Year%20Statement%2018_0.pdf
vi Author calculations from http://mip-prod-web.azurewebsites.net/DataItemExplorer
vii https://www.ofgem.gov.uk/system/files/docs/2018/12/riio-gd2_sector_annex_0.pdf
viii http://www.ukerc.ac.uk/publications/local-gas-demand-vs-electricity-supply.html
ix http://mip-prod-web.azurewebsites.net/DataItemExplorer
x https://www.youtube.com/watch?v=LPx9rXM0zhg
xi Table 1 https://www.sciencedirect.com/science/article/pii/S1876610214034560
xii https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

Thank you

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