Natural Gas' Role in Reaching Net Zero

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The United Kingdom (UK) was the first country to make use of fossil fuels in industrialisation and is now a world leader in reducing greenhouse gas emissions and its effect on climate change. This long history has led the UK into becoming heavily reliant on natural gas. This report aims to utilise various datasets, looking at the United Kingdom's energy usage, predominantly between the years 1998 and 2023 to find how natural gas usage has varied to the present day.

Natural gas consumption was found to have decreased since 1998, but this decrease was found to be due to a drop in demand rather than moving away from natural gas as a fuel source. This dependence on natural gas is thought to undermine the UK's energy security, although its effect is limited by the use of large scale gas storage. Hydrogen gas is considered as a replacement for natural gas in the current system, however difficulties with production and transportation will hamper is progress too much that it is not expected to be widely adopted.

1.1 Introduction

The United Kingdom (UK) was the first country to make use of fossil fuels in industrialisation and is now a world leader in reducing greenhouse gas emissions and its effect on climate change, committed to becoming a net zero economy by the year 2050 [1]. The largest barrier to achieving this is the UK's current dependence on natural gas as a fuel source. This report aims to quantify this dependence on natural gas as a main source of electricity and understand how this may contribute to its energy security. Then explore if hydrogen could be a viable alternative and answer if natural gas is really needed in the UK's transition to a clean energy grid and net zero by 2050.

This report is split up into multiple sections; section 1 details the context, background information and theory behind the report. Section 2 contains the methodology for how the research and data analysis for this report was carried out. Section 3 presents the plots from any data discussed in this report and section 4 analyses and discusses them. Finally, section 5 gives the conclusions of the report and suggests actions to take in the future.

1.2 Natural Gas

Natural gas is a fossil fuel used for energy generation; it is an umbrella term that encompasses different gaseous compounds, mostly hydrocarbons [2]. Up to 97% of natural gas is made up from methane, which is four hydrogen atoms bonded to a single carbon atom (CH_4), the remaining 3% is composed of other short chain hydrocarbons like ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}), as well as other gases such as carbon dioxide (CO_2) and Nitrogen (N_2) [3].

The energy stored in natural gas comes from the carbon-hydrogen bonds, this energy can be released by burning the gas with oxygen, undergoing a combustion reaction [4],

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 891kJ \quad (1)$$

The process releases 891kJ of energy for every mole of methane burned [4]. With this energy being released as heat that can be used to rotate a turbine, which in turn can power a generator to produce electricity [5].

Natural gas has many benefits for use in energy production, for example, it produces less CO_2 when burned than other fossil fuels like coal or oil [6]. Power plants that run on natural gas are very flexible, meaning they can start or stop generating electricity quickly to cope with the change in demand throughout the day [6]. This ease of use has led natural gas to make up 33.7% of the UK's total energy generation in 2023 [6]. Other uses for natural gas in the UK include space heating, cooking using gas hobs, with 56% of all natural gas used in the UK in 2023 being consumed in residential areas [6].

This reliance on natural gas as one of the UK's main energy sources has the potential to negatively impact its energy security, which is defined as the reliable and affordable access to all fuels and energy sources [7]. And is generally affected by destabilising events, such as conflicts and harsh weather events [8].

1.3 Background

The history of natural gas use for electricity production in the UK starts largely in the 1970s, with oil and gas extraction in the North Sea [9]. Initially the main use of this natural gas was as a replacement for town gas in streetlights and residential heating [10], town gas was produced from burning coal, causing it to be heavily polluting and poisonous, making natural gas a much cleaner and safer alternative [11].

Production of natural gas in the North Sea continued to increase with time, but in the 1980s consumption rose at a higher rate than the UK's domestic production, so gas was imported to meet this demand, since then, almost every year the UK has been a net importer of natural gas [9]. Just over twenty years since natural gas started being used for electricity production, in 1993, it overtook coal as the UK's primary energy source, accounting for 29% of the UK's total energy consumption compared to 25% for coal [9].

Production continued to increase up until the mid-2000s, where natural gas' share of the UK's energy mix stagnated [9]. Rising operation costs and lower investment in the discovery and extraction of oil and gas from the North Sea combined to significantly drop the domestic production of natural gas from 126 TWh in 2000 to just 42 TWh in 2022, with growing imports supplying the extra gas needed to satisfy demand [9].

As coal and oil produce more pollutants than natural gas [6], they have so far been the biggest priorities when it comes to reducing greenhouse gas emissions, but with the closure of the UK's last coal fired power station, at Ratcliffe-on-Soar in 2024 [12], natural gas is now the fossil fuel that needs to be cut from the UK's energy mix in order to reach its climate targets [13].

1.4 Hydrogen

Hydrogen gas (H_2) is a potential candidate for replacing natural gas for the UK's energy production, similarly to methane, it is able to store energy within its bonds and that energy can be released through combustion [14],

$$2H_2 + O_2 \rightarrow H_2O + 572kJ \quad (2)$$

The reaction produces less energy per mole burnt than methane, see eq.(1), however less fuel is burned, and no carbon is involved in the process, so no carbon dioxide is produced. This only holds true if the method used to produce the hydrogen gas is also carbon neutral, hydrogen gas is commonly labelled with a "colour" that refers to its method of production.

The colour represents the process the hydrogen was produced with, for example electrolysis, steam methane reforming (derived from natural gas), or being found naturally, as well as the energy source used in the production itself [15]. The label "green" hydrogen means it was produced using electrolysis powered by renewable energy, resulting in no carbon emissions, whereas "grey" hydrogen generates H_2 from natural gas, producing carbon dioxide in the process [15]. Over 90% of hydrogen gas that was produced in 2020 was made using fossil fuels [16], removing any benefit gained from the combustion reaction itself as carbon dioxide had already been emitted during the production process.

Currently, the biggest challenges hydrogen needs to overcome in order to be considered a viable energy source are its high production costs and low supply, especially for more renewable "colours" [17]. Storage and other related infrastructure are needed specifically for hydrogen, due to its low energy density and high reactivity [17]. And safety concerns need to be addressed because of its high flammability [17].

2. Methodology

This report aims to use quantitative data provided by governmental sources, to plot and find trends in past and present energy usage. And combine this with qualitative data from government published reviews, scientific journals and news articles to find the driving forces for any changes that are observed.

The main datasets, all published by UK governmental departments, used in this report are:

- Digest of UK Energy Statistics (DUKES) Chapter 4: Statistics on supply and demand for natural gas [18]
- Energy Consumption in the UK 2021 [19]
- Energy Trends: UK Electricity [20]

Specific data tables, from these sources, used in any plot presented in this report are referenced in the figure or table caption. By sourcing quantitative report data directly from the UK government, no bias should be present in any trends found from the data. Any qualitative data used is sourced from respected journals and sites as well as being cross-referenced with adjacent sources to ensure no bias effects the findings of this report.

3. Results

This section presents graphs and tables produced from the datasets. Key details from each figure are briefly discussed in this section, but the information they provide is later explained in the discussion section of this report.

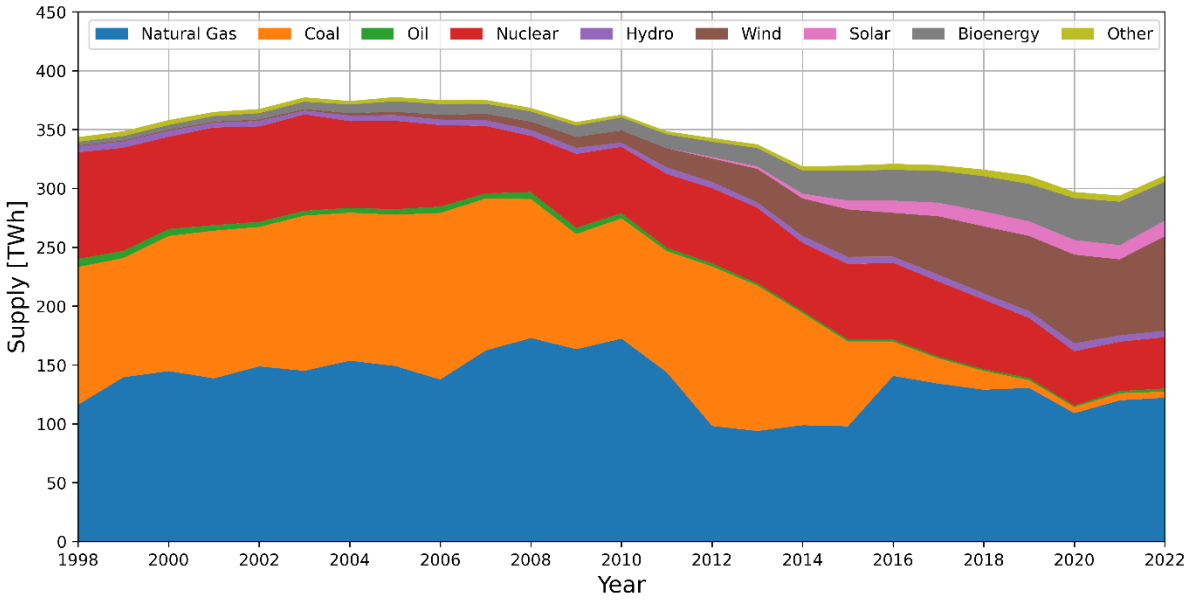

Figure 1: Composition of supplied energy in the UK between 1998 and 2022. Considering only electricity generation. Plotted using data from 'Energy Trends: UK Electricity 5.1, Fuel used in electricity generation and electricity supplied' [20]

Figure 1 shows a general downward trend in the UK's energy consumption per year since 2005, while also splitting the total energy supplied to consumers, over a 24-year period, by the source that was used to generate it. The largest single source of electricity in the UK, during this time, has consistently been natural gas, with it accounting for 33% (116 TWh) of all electricity supplied in 1998 and overall increasing to 40% (122 TWh) of total electricity supplied in 2022. Figure 1 also shows the eventual phase out of coal as a power source in the UK's energy mix; falling from 33% (116 TWh) of all electricity supplied in 1998, to <2% (5 TWh) in 2022. As well as the rise of renewable energy sources such as wind and solar power, with wind energy making up 26% (80 TWh) of all supplied electricity in 2022, increasing from <1% (<1 TWh) in 1998.

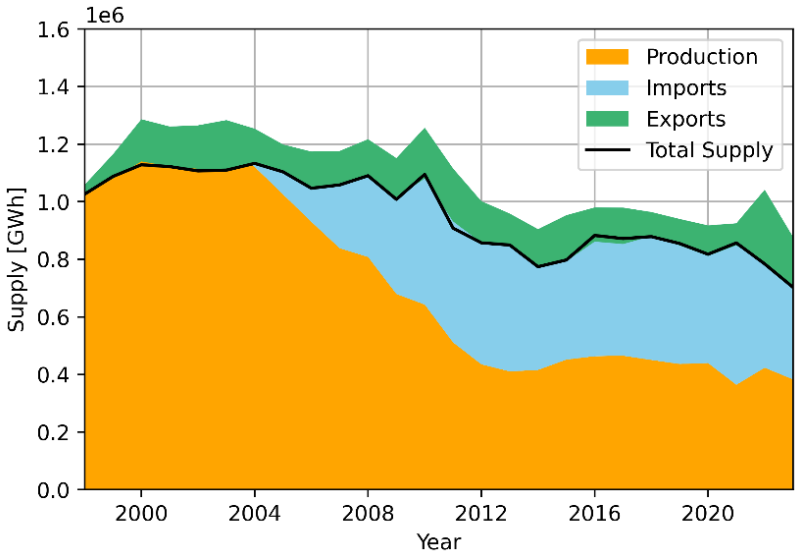

Figure 2: Supply of the UK's natural gas between 1998 and 2023. Plotted using data from 'DUKES chapter 4.1, Commodity balances' [18]

Figure 2 also shows a downward trend in the UK's supply of natural gas year-on-year. Between 2004 and 2012, the UK significantly reduced its domestic production of natural gas, falling by 61%, from 1120 TWh in 2004 to 435 TWh in 2012, where it plateaued. Before this decline in production, the UK was self-sufficient with regard to fuelling its own natural gas consumption, being an overall exporter of natural gas. However, after the decline in production, the UK started to import natural gas and since 2011 has imported more natural gas than it produced itself, with the most recent data, in 2023, showing that the UK imported 56% of its total supply of natural gas.

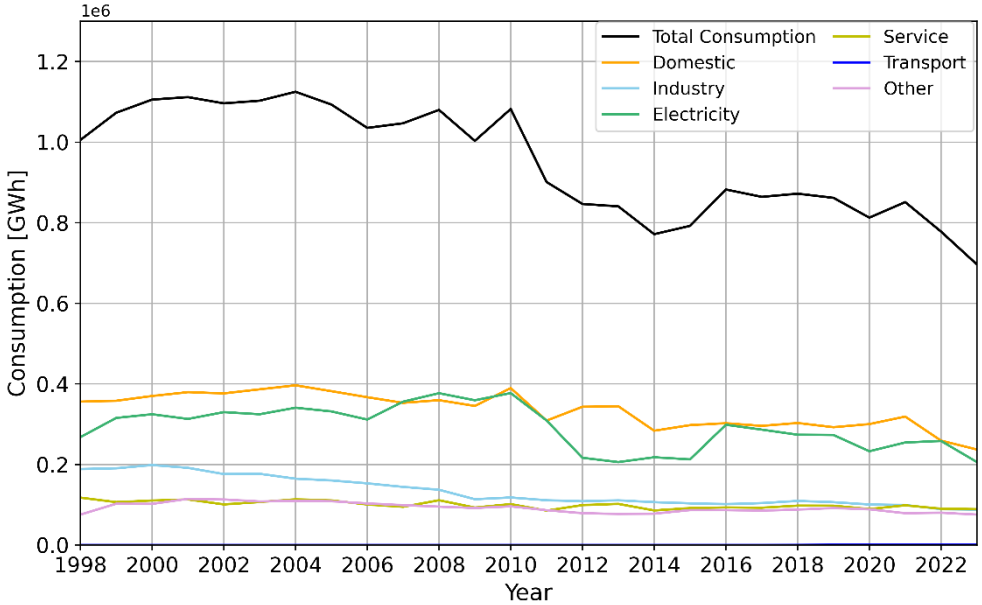

Figure 3: Composition of how natural gas is consumed in the UK between 1998 and 2023. Plotted using data from 'DUKES chapter 4.1.1, Natural gas and colliery methane production and consumption' [18]

Figure 3 plots the total natural gas consumption between 1998 and 2023, as seen in figure 2, and separates it out into the different sectors it was used in, each year. From this

plot, it can be seen that domestic use of natural gas, meaning gas that was burned for space and water heating, typically consumes slightly more natural gas than electricity production does in a year, in 2023 accounting for 34% of total natural gas consumption [18]. However, since 1998 both domestic and electrical usage of natural gas has fallen, with domestic use of natural gas falling by 33% between 1998 and 2023. Industry use of natural gas more than halved between 1998 and 2023, decreasing by 53% in 25 years, while services such as commercial businesses and agriculture have maintained relatively constant consumption in the same time period.

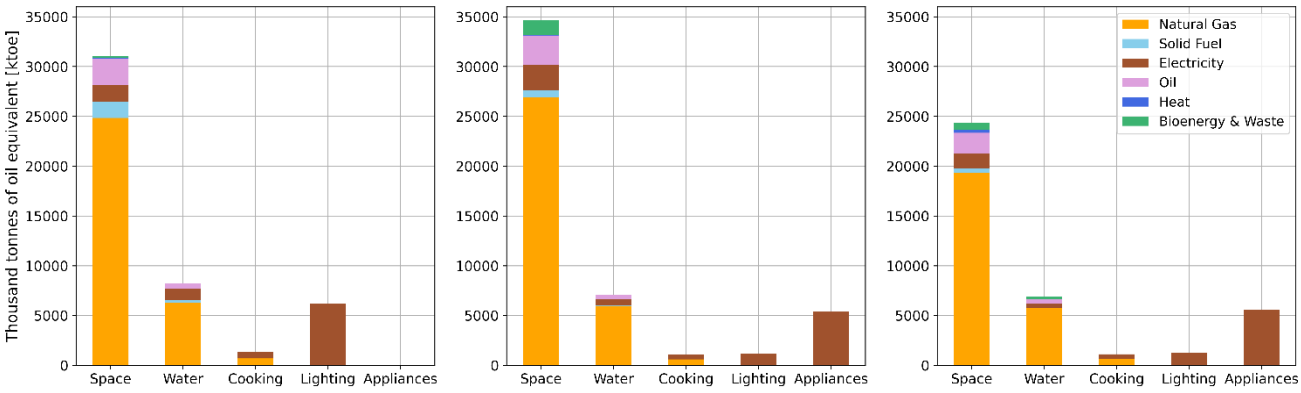

Figure 4: Domestic consumption of energy in the years 2000 [left], 2010 [middle] and 2020 [right], measured by the end use and fuel. Note: Data regarding appliances was not collected until after the year 2000, so it is not included in the relevant plot. Plotted using data from 'Energy Consumption in the UK 2021, End uses data tables' [19]

From figure 4, it can be seen that, historically, the majority of energy used in a home is put towards space heating and most of this is provided through the use of natural gas. Water heating is the second highest end use for energy provided to a household and is also shown to be heavily reliant on natural gas. Cooking is the final end use that makes use of natural gas, although its consumption is minimal when compared to either space or water heating.

The relevant trends in figure 4 are the 30% decrease in energy required for space heating between 2010 and 2020; with all sources of energy, apart from heat, which is heat directly delivered to homes through insulated pipes from a central source, decreasing in quantity. Water heating is consistent in its total energy usage, especially between the years 2010 and 2020. And power needed to light homes also decreased significantly between 2000 and 2020.

Table 1: Countries that the UK imported the most natural gas from in 2023, accounting for both pipeline and liquified natural gas imports. Data from 'DUKES chapter 4.5, Natural gas imports and exports' [18]

Country	Natural Gas Import [GWh]	Percentage [%]
Norway	288,185	58.2
USA	128,490	26.0
Qatar	29,842	6.0
Peru	19,595	4.0
Other	28,806	5.8

Table 1 gives the biggest contributors to the UK's natural gas imports with both a numerical and percentage figure, showing that the UK imports more natural gas from Norway than any other country combined, most of this is imported using submarine gas pipelines. Followed by the USA, importing liquified natural gas that has been shipped from overseas.

4. Discussion

Natural gas' contribution to the UK's electricity network, as seen in figure 1, has been relatively constant for the past 24 years. With the exception between 2010 and 2016, the dip in natural gas use in this period was caused by market prices changing [21], making coal cheaper to produce energy with. Natural gas consumption later increased in 2016, see figure 1, to cover some of the demand left by coal power being slowly phased out of use. However, natural gas use has never since returned to pre-2010 levels of consumption, this gap was instead filled by renewable sources like wind energy.

Following the increase in renewable energy production into the future, as more and more fossil fuel alternatives are added to the energy grid, the UK's dependence on natural gas will decline, as it is the last fossil fuel still widely used to produce electricity. However, weather dependent energy sources like wind and solar are not flexible enough to cope with the changing energy demand throughout each day, and currently natural gas is used to keep the lights on during times of low renewable output [22]. Until alternative technologies, for example batteries [22] or a wider geographical diversity from renewable sources [23], are able to cover this flexibility issue, natural gas remains the best option for the UK to ensure it can balance the supply and demand of electricity.

Another area where the UK is highly dependent on natural gas is in domestic use cases, specifically space and water heating of people's homes, see figures 3 and 4. The drop in energy needed for space heating between 2010 and 2020, from figure 4, showed all the main sources of energy dropping in consumption, this implies that in this time, the overall demand for energy in order to heat homes has decreased. Likely being caused by government programmes to install smart meters in homes [24] as well as insulate older and less energy efficient buildings [25,26]. Overall helping the public keep track of, and reduce, their energy consumption. However, while energy consumption in this area has decreased, figure 4 shows that natural gas is still the dominant energy source for space and water heating, due to the continued use of gas boilers. Since 2007, new gas boilers in the UK must have an efficiency of 90% or more [27]. Making further progress in improving their efficiencies difficult, so in order to reduce the usage of natural gas in heating systems, other alternatives need to be considered. Such as replacing natural gas, at least in part, with hydrogen gas. Or replacing boilers with a low carbon alternative, like a heat pump.

Electricity generation and space heating are the two largest areas of natural gas consumption in the UK, with both having a large dependence on natural gas with very little alternatives available currently. This dependence, in combination with high levels of gas imports, see figure 2, has the potential to destabilise the UK's energy security. Energy prices in the UK are highly dependent on the global price of natural gas because energy is priced by the most expensive unit that was produced, and this is usually natural gas [28]. This relation can be directly seen from the affect the Ukraine-Russia war had on electricity and gas prices in the UK, being a contributing factor to the energy crisis in 2022 [8]. This is despite Russia only accounting for 6.2% of total UK natural gas imports the year before the war in 2021 [18]. This level of impact signals that the UK's current domestic natural gas production in the

North Sea is not significant enough to protect the country from volatile global gas markets. Because the UK imports more natural gas than it produces itself, 56% of its total supply was imported in 2023, as seen in figure 2, its domestic production has little impact on the UK's energy security [28].

This does not necessarily mean that the UK needs to increase its domestic production of natural gas to meet concerns regarding energy security. Increasing renewable energy production instead, can also have a positive impact on energy security; by reducing the UK's dependence on natural gas, less will need to be imported to cover the demand [29]. Eventually, demand will be reduced enough so that domestic production can satisfy the majority of the UK's needs, with little natural gas imports leading to a stronger energy security for the country.

It is important to express the role large scale natural gas storage can play in energy security; the fluctuating supply and demand of natural gas inherently can weaken energy security, but large scale storage, such as the UK's eight gas storage sites [30], offers more flexibility to the supply of natural gas, allowing gas to be stockpiled in times of low use, for example over the summer, to later provide another source to tap into in times of high demand, usually over winter [30]. Storage can also smooth out any volatility the UK might experience from importing natural gas from the global market, as it would be capable of stockpiling more gas when it is cheaper, avoiding having to buy natural gas at higher prices, aiding in its energy security [30].

Not all sectors that make use of natural gas can simply be converted to make use of electricity, in these cases the best candidate to supersede natural gas is hydrogen [31]. Its main uses are expected to be in transport, manufacturing and space heating [31], with the latter being most relevant to the topic of this report. Hydrogen gas has the potential to make use of current natural gas infrastructure to operate, possibly removing this barrier to entry for the energy source. In the short term, hydrogen could be mixed with natural gas; blends of 15% hydrogen have already been tested to be safe, with newer appliances in the UK being able to safely accommodate blends of up to 23% hydrogen, at the cost of some efficiency [32]. Blending hydrogen and natural gas can immediately reduce the concentration of natural gas that is being used in power plants and boilers, while still receiving the same amount of energy in return, offering a quick way to reduce carbon emissions in some of the largest contributing areas to greenhouse gas emissions, seen from figure 3 [22]. Despite this, hydrogen gas is expected to only have a small contribution to decarbonising space heating, due to limitations like its high costs of production, safety concerns in transport, and low supply from renewable production methods, which other technologies competing in the same space, such as heat pumps, do not possess [31]. Further research and development are required in this area, and even though hydrogen gas could work as a clean alternative to natural gas, it requires more time to build up, become cheaper and a more feasible competitor in the space, but this may be too long for the UK's target of 2050.

5. Conclusion

Overall, natural gas usage in the UK has declined, mainly due to the decreasing demand from households as legislation has enforced higher efficiency standards for new builds and appliances, in addition to schemes aiming to insulate older houses [25,26]. However, the UK remains highly dependent on natural gas for its electricity production and space and water heating, causing it to have low energy security due to its high reliance, but

this can be displaced through the use of large scale gas storage. This reliance is expected to decrease in the coming years as renewable energy continues to scale up and electrical alternatives to domestic natural gas uses, like heat pumps, become more widely available.

Hydrogen gas, while theoretically viable to replace natural gas, currently has too many limitations holding it back. More research is required into this area, but this delay will likely limit its use in the UK's transition to net zero by 2050 as more readily available alternatives will fill the space. Hydrogen gas, instead, will likely replace fossil fuels in the transport and manufacturing industries [31], as electrification is much harder in these areas.

For the United Kingdom to meet its target of being net zero by 2050, natural gas is the next fossil fuel that needs to be phased out. The UK has already started this, but natural gas is deeply embedded in its energy production, making it challenging to move away from and cannot be phased out entirely. To meet the 2050 deadline, decarbonisation efforts need to increase in scale, legislation and government schemes have already shown to work from the trends found in this report, so should be the main method of change in the future [32].

6. References

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