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Data Centre Energy Demand

Study Report

Apollo and Stantec for

Wales and West Utilities & SGN

29 May 2025 | 373-018-GRL-RPT-0001-C

QMF64

Revisions & approvals

Revision	C	Description	Issued for use

Originated by	Check by	Approved by	Date
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Contents

1 Abbreviations

CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CNI	Critical National Infrastructure
CP30	Clean Power 2030
DC	Data Centre
DPF	Diesel Particle Filter
FLAPD	Frankfurt, London, Amsterdam, Paris, and Dublin
GDN	Gas Distribution Network
GSP	Grid Supply Point
HP	High Pressure
ICE	Internal Combustion Engine
IP	Intermediate Pressure
LTS	Local Transmission System
MCP	Medium Combustion Plant
MP	Medium Pressure
NESO	National Energy System Operator
NGT	National Gas Transmission
NSIP	Nationally Significant Infrastructure Project
NTS	National Transmission System
PRI	Pressure Reduction Installation
SCR	Selective Catalytic Reduction
SOFC	Solid Oxide Fuel Cell
UPS	Uninterruptable Power System
Whr_{el}	Watt hour of electrical energy
Whr_{th}	Watt hour of thermal energy

2 Executive summary

The fourth industrial revolution is being driven by rapid advancements in AI and cloud computing, making the global expansion of data centre capacity a strategic priority. However, power availability remains a major bottleneck, with rising demand placing strain on aging electricity grids, while new electricity network upgrade projects face permitting and supply chain challenges.

In the UK, the data centre industry is a fast-growing and nationally significant sector, playing a crucial role in the country's technological and economic ambitions. The market is shifting from a distributed model of smaller edge units to larger, hyperscale facilities, often in regions already facing severe power constraints.

While international examples across Europe and North America demonstrate the viability of providing power from alternative sources such as the gas distribution networks, this approach has not yet been pursued in the UK. However, industry stakeholders have expressed a willingness to explore these alternatives.

Our study identifies a range of potential options for different data centre archetypes within the study area, providing indicative costs, site requirements, and detailed technological solutions suitable for various scales and applications, as demonstrated in the selected case studies. The following details the key findings from this study:

Data Centre outlook

- Currently there are around 400 data centres either operational, planned, or in construction in the UK, totalling just over 1GW of operational power demand, increasing to 4.84 GWs once all are completed.
- Within the SGN and WWU supply regions, we identified 91 (87 operational and 4 planned, 75 in SGN and 16 in SGN areas) data centres, totalling 751 MW of power capacity.
- 80% of all UK DCs are located near the London M25 belt, and of all the leading European FLAPD (Frankfurt, London, Amsterdam, Paris, and Dublin) data centre clusters, London is by far the largest current market.
- Outside of the South-East key new data centre clusters are developing across the UK in Cardiff, Manchester, Newcastle, and Edinburgh. Developers are shifting their site selection priorities away from existing clusters into diverse regions with preferable power, land, or fibre availability.
- Developers and operators around the world are exploring alternative energy sources including fuel cells, natural gas fired turbines and small modular reactors. Hydrogen powered data centres outside the UK already utilise hydrogen fuel cells, including sites in California and Dublin.
- The current growth rate for data centre demand is around 10-15% per annum

Key themes from stakeholder engagement

- Data centre operators all expressed interest in this study, particularly with respect to the opportunity to reduce operational carbon emissions if utilising green hydrogen as a primary or backup power source.
- Data centre operators that are committed to net zero targets between 2030 and 2050 are currently relying on Green Power Purchase Agreements from renewable energy generators to bridge the gap in energy sustainability until the electricity grid is fully decarbonised.
- Operators also highlighted the significant barriers they are facing in their growth plans due to the constraints on procuring power, commonly facing connection dates for expanding their existing sites well in the mid-late 2030s.

- The Climate Neutral Data Centre Pact is a pledge signed by over 100 data centre operators across Europe committed to becoming climate neutral by 2030. The signatories of the pact now represent 75% of European data centre capacity.
- The M4 corridor was highlighted as a particularly constrained region that was both highly desirable for data centre siting due to customer demands but facing some of the longest connection timescales in the country, reaching out to 2039 for some sites.
- Operators emphasised how infrequently they operate their backup generation plant, only requiring 2-5 hours a year of operation for maintenance purposes rather than for explicit backup operation. Therefore, using the gas network solely for backup power is not a viable option.
- Concerns were raised about being 'first movers' in using the gas network for primary power provision. While stakeholders acknowledge the use of alternative power sources used elsewhere around the world, they are particularly wary of the regulatory and operational risks involved.
- Several operators were interested in utilising the gas supply to co-locate a peaking power plant on-site for demand flexibility or frequency response grid services as an alternative source of revenue.

Technology

- Technologies that convert natural gas to electricity are widely available and are already in use, providing power to data centres outside the UK.
- This report has focussed on the use of gas fuelled internal combustion engines and fuel cells. Gas turbines are another potential option to provide power for data centres however they have not been covered in detail in this study but could be a good option for hyperscale data centres given their greater power density compared to fuel cells and internal combustion engines.
- The natural gas solid oxide fuel cells considered in this work are capable of operating on a blend of hydrogen and natural gas. Increasing the concentration of hydrogen decreases the efficiency of the fuel cell. If the gas networks transition from 20% to 100% hydrogen, the natural gas fuel cells would have to be changed for hydrogen fuel cells to improve efficiency.
- Engagement with an internal combustion engine supplier identified that low blend (<5% hydrogen) requires no modification to the existing hydrogen ready engines. Going above a 5% blend and up to 25% would require some minor modifications to the initial engine that is still in place. Going up to 100% hydrogen will likely require a new engine or significant upgrades required to the existing engine.
- There are significant costs associated with powering data centres using fuel cells or internal combustion engines. This report has looked at two different models, the first where the fuel cells are provided on a lease basis (no CAPEX payment for the technology), and the second being a standard CAPEX cost for the internal combustion engines. The CAPEX cost for internal combustion engines is around £390,000 per MW (excluding works). There is also a fee that is required to maintain and service the engines. The CAPEX and servicing costs for the fuel cells are combined within the lease costs for the equipment which are charged on a per kWh basis.
- The utility cost (price of gas) makes up the largest percentage of the cost that a data centre would need to pay to provide power from the gas network. The high level analysis in the study has indicated that internal combustion engines are a more cost-effective method for providing power to data centres when compared against the lease model for the fuel cells. This excludes any enabling works and the potential cost differentials between the two solutions for installation.

- This work has found that fuel cells have a greater efficiency compared to internal combustion engines. This means that if the price of gas increases, the utility component of the total cost will have a more dominant impact on the total cost, potentially making fuel cells the more cost effective option.

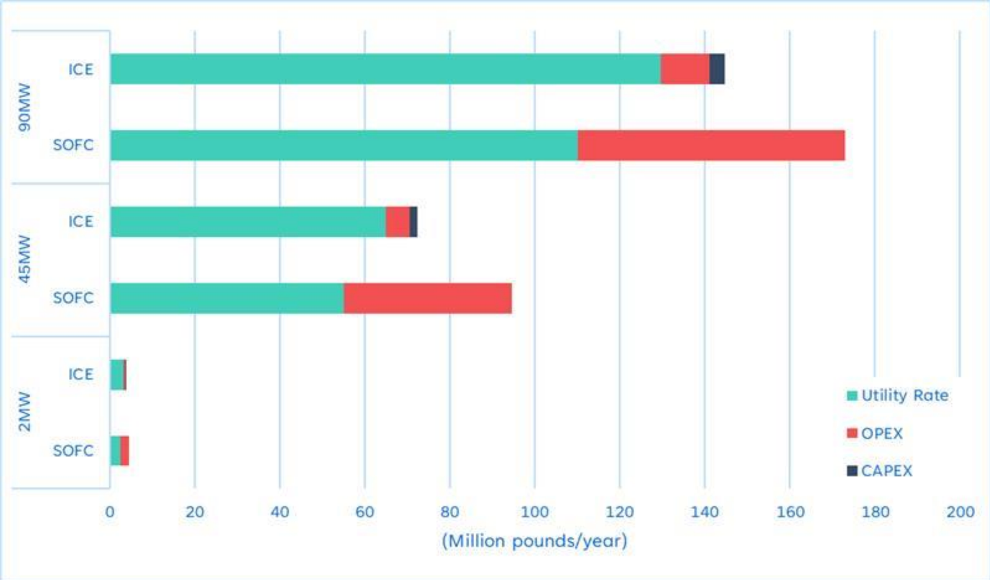

Figure 1 Annual costs comparing fuel cells and internal combustion engines

- Figure 1 compares the annual costs for different data centre power demands adopting a fuel cell or internal combustion engine solution. The CAPEX for the internal combustion engine has been spread over a ten-year period.
- If the gas networks transition to transport 100% hydrogen, it is likely that purification will be required at the data centre site if a fuel cell solution is selected. This is necessary to meet the purity requirements for the fuel cell to prevent any damage from contaminants. In comparison, assuming that the gas networks transport hydrogen at heat grade (98% purity), purification would not be required for an internal combustion engine solution.
- The additional footprint required to provide power either by fuel cell or internal combustion engine can also be significant, especially as the power demand increases. Of the two technologies considered in this work, internal combustion engines provide more power per unit of area compared to fuel cells. Internal combustion engines and fuel cell solutions are less suitable for hyperscale data centre loads due to their land requirements, and whilst suitable modular solutions can be scaled up, the land area required for these options become significant for high power demands. Gas-fired turbines can provide significant power volumes with relatively smaller footprints, but these are typically much more costly, less flexible in their output, and have lower efficiencies compared to internal combustion engines and fuel cells.

Gas network capacity

- Using the gas networks to power data centres will introduce additional demands on the networks with these becoming significant as the scale of data centres increases. The availability of the gas network to meet the individual data centre demands is very site specific and heavily driven by the rated pressure of the line selected for offtake. There are also a number of other factors that dictate the capacity of flowrate that may be provided by the selected line. These include
    - Mains diameter and layout;
    - Existing demand on system (both upstream and downstream of data centre connection);

  - Location of demands relative to supply points (offtakes, PRIs (Pressure Reduction Installation), district governors) or extremities;
  - Location of the new data centre demand being added.
- Through this study we have identified three locations where the gas networks could be used to provide power for data centres of varying scale. High level analysis performed by the gas distribution networks confirmed that the existing network has the necessary capacity to deliver the volumes of gas required to power the data centres in these locations, without the need for any significant upgrades or modifications.
- The gas distribution networks highlighted that it may be possible, in certain areas, to increase the volume of gas that could be drawn from the network due to historic high-demand users no longer utilising as much of the capacity as before, meaning the gas network could provide a much higher power provision to the data centres.
- The network operator's do not forecast a reduction in gas demand in the near-mid term (i.e. out to 2034). However, toward the middle of the century, demand on the networks may reduce as a result of increased electrification. Current estimates are that domestic gas demand could reduce to 40-50% of the current volume in some regions by 2040. This creates an opportunity to supply large volumes of gas using the freed-up capacity on the networks to power future data centre developments.
- There are a number of projects looking at the creation of dedicated hydrogen networks around the UK. Project HyLine in South Wales, the North Wales Conceptual hydrogen plan, and SGN's Project Caledonia and H2 Connect are all examples of dedicated hydrogen networks. Connecting to these 100% hydrogen networks would allow data centres to decarbonise whilst providing anchor customers to the gas distribution networks, helping to get the projects off the ground.

Recommendations and next steps

This study has indicated that it is technically and systematically viable to supply power to a data centre from the gas network, and has determined economic estimates to do so for a number of scales and forms. Global precedent, UK data centre industry appetite and growth, gas infrastructure suitability, and initial cost analysis all shows positive indications for such a solution, but there are significant questions to be answered on customer requirements, regulatory constraints, and engineering details. To explore this issue in more detail, we recommend the following:

- The gas distribution networks should continue to engage directly with data centre operators or developers and develop a detailed engineering case study for an existing or upcoming data centre development. This should include a formal modelling exercise of the nearby gas infrastructure, a detailed exploration of resilience, supply, and land requirements for the site alongside a suitable technology vendor, and engagement with the relevant planning authorities to confirm the relevant regulatory requirements to meet.
- Data centre developers should consider co-locating additional technologies such as carbon capture and storage, and waste heat recovery alongside any future on-site power generation plant to maximise local efficiencies and emissions reductions.

3 Introduction

The UK data centre market is one of the most dynamic and rapidly growing sectors in the technology industry. The adoption of cloud computing, data storage and artificial intelligence has led to an enormous increase in demand for new data centres.

One of the critical challenges currently facing the UK data centre market is electricity grid constraints. Data centres are highly energy-intensive facilities that require significant and resilient mission-critical power supplies, and their rapid expansion has led to growing pressure on the National Grid. The limited electricity grid capacity, especially in recent years, has resulted in significant electrical connection costs and long wait times for developers looking to expand their existing portfolios or build new data centres. As a result of this, operators are increasingly seeking resilient and reliable alternative solutions, such as leveraging renewable energy sources, off-grid power generation, and battery storage systems, to mitigate reliance on traditional electricity grid infrastructure.

At the same time, with the electrification of society well underway, and with mid-century net zero carbon targets for many organisations, institutions, and governments, many users are anticipated to reduce their reliance on the gas network for heating and industrial processes in exchange for low-carbon electrical sources. This is anticipated to result in a reduced national gas demand, potentially freeing up significant capacity in the existing gas distribution networks.

This report assesses the suitability of using the existing gas networks to provide suitable power to data centre users in the future. The existing data centre industry is reviewed to indicate the projected future growth of data centre developments alongside their energy requirements, relevant technologies, and geographical distribution. The status of the electricity networks' capacities and costs are outlined, the potential for the gas networks provision of power is summarised via a detailed technology review, and relevant data centre stakeholders have been engaged and interviewed to identify key issues. This study's geographical region of focus is limited to the areas supplied by the gas distribution networks 'Wales and West Utilities' (WWU) and SGN, but our findings are not specifically limited to these regions and should be widely applicable to other network operators within the UK.

The key findings of the study have been used to identify potential case study locations for assessing the feasibility of using the gas distribution network to power existing and future data centre sites. A high-level techno-economic comparison has also been provided to summarise the available opportunities and constraints.

4 Data Centre Industry Review

4.1 UK Data Centre Industry

The data centre industry is one of the most rapidly growing and capital-intensive built environment sectors in the UK, with £25bn of new investment in UK data centres announced in the second half of 2024 alone (Ref 1). Whilst what classifies as a "Data Centre" is not fixed, our research indicates that there are currently ~400 traditional data centres[1] either operational, planned, or in construction in the UK, totalling just over 1GW of operational power demand, rocketing up to 4.84 GWs once all are completed. If the growth rate of data centre demand continues at its current rate (10-15% per annum), it is anticipated that £44bn of GVA, 40,000 operational and 18,000 construction jobs, and nearly £10bn of tax revenue will be created by 2035 (Ref 2).

80% of all UK DCs are located near the London M25 belt, and of all the leading European FLAPD (Frankfurt, London, Amsterdam, Paris, and Dublin) DC clusters, London is by far the largest current market (Ref 3), with DCs historically attracted to the region due to the presence of international financial institutions, reliable power provision, and low-latency communication networks. Outside of the South-East key new DC clusters are developing across the UK in Cardiff, Manchester, Newcastle, and Edinburgh. Developers are shifting their site selection priorities away from existing clusters into diverse regions with preferable power, land, or fibre availability.

The form and business models of DCs have evolved as society's requirements for data have changed. Historically, DCs mainly existed as bespoke facilities dedicated entirely for processing and data storage use by a particular institution (e.g. banks, universities, government departments). However, the dramatic expansion of "off-site" compute and storage demands driven by on-demand streaming, application/software services, and high-performance computing (including "AI"), has resulted in multiple alternative DC operational models arising to account for the varied requirements of users. These DC forms vary depending on the ownership, proximity, resilience, and technical specifications of the end-user, with the main options outlined below and listed in order of typical size:

- Enterprise (on-premises, built, owned and operated by the organisation that requires the data resource)
- Edge (smaller distributed sites located close to the end-customer for low latency, can be co-located or Managed Hosting ownership)
- Colocation/Wholesale (providing space and power for other organisations to install and operate their servers within the building shell)
- Managed Hosting (similar to Wholesale/Colo, but leased arrangement with hardware determined by the customer)
- Cloud (similar to Wholesale/Colo, but leased arrangement with little/no IT control by the customer)
- Hyperscale (very large sites typically owned and operated by tech companies, typically offering on-demand Cloud services with ultra-high power demands and fibre speeds)

Within the SGN and WWU supply regions, we have identified 91 data centres, totalling 751MW of power capacity, as outlined in Figure 2, Figure 3, and Table 1.

[1] Self-contained facilities that primarily house computing or electrical storage infrastructure

Table 1 - Data Centre statistics in the WWU and SGN supply regions

Region	Number of data centres, by status				Total Power Capacity (MW)
	Under Construction	Planned	Operational	Total	
SGN	0	3	72	75	598
WWU	0	1	15	16	153

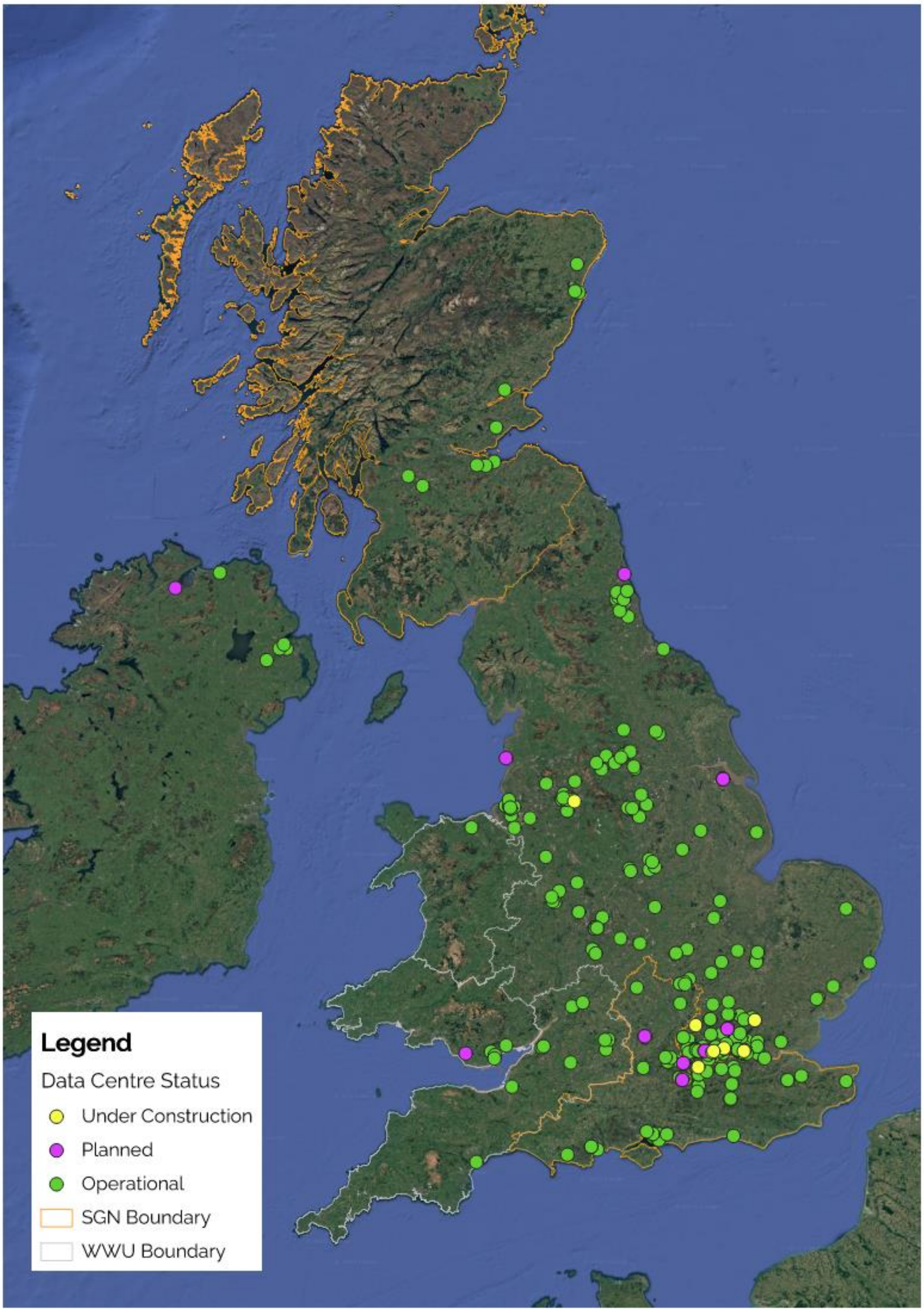

Figure 2: UK Data centre development status

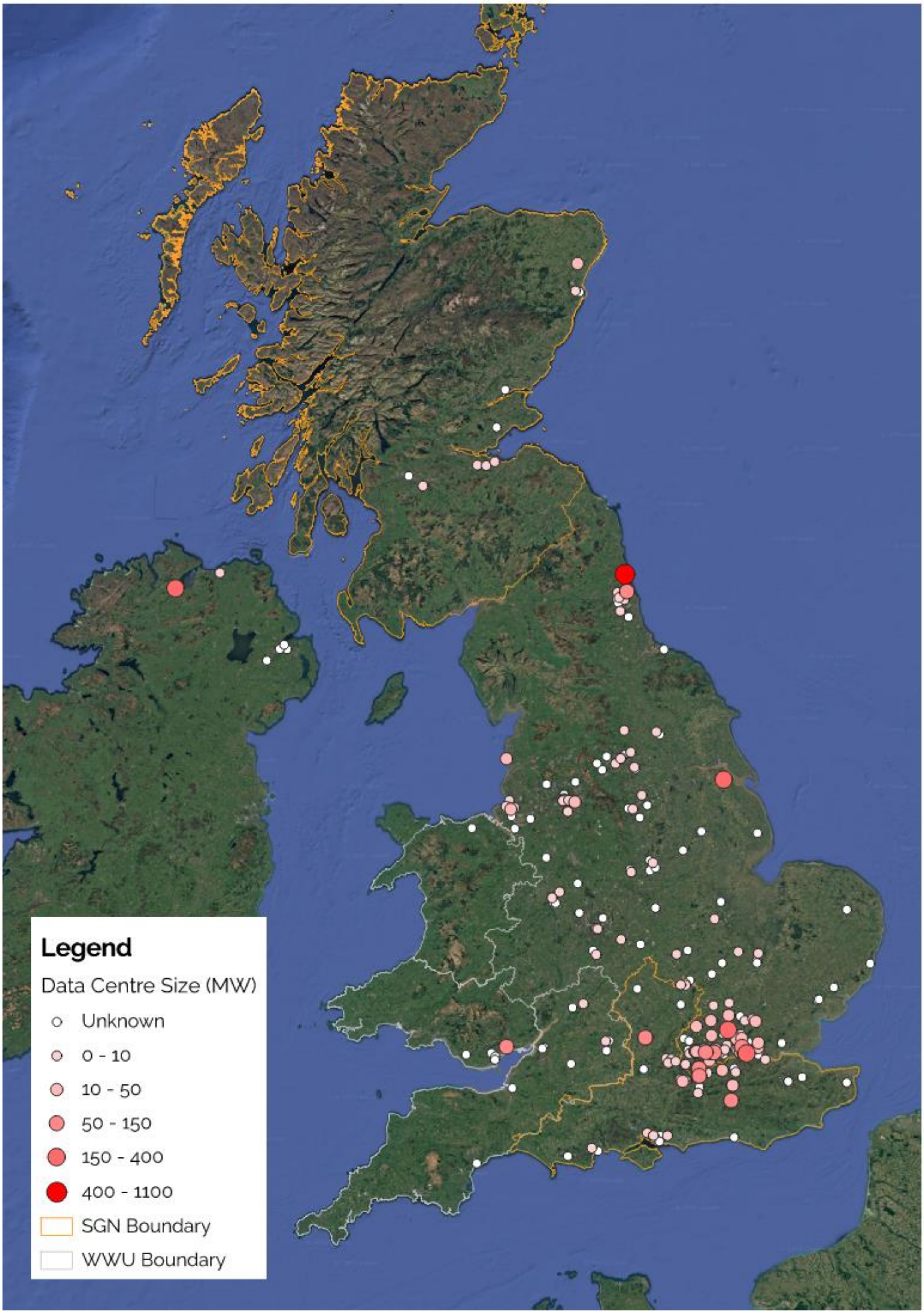

Figure 3: UK Data centre location and size (planned, in construction & operational)

4.2 Data Centre Energy Usage

Unlike other large-power or industrial users, DC power requirements are typically very stable and consistent, driven primarily by the IT computing equipment loads and the cooling equipment needed to keep the racks at optimal temperatures year-round. Whilst there are some load fluctuations throughout the year due to extreme weather conditions or specific periodic compute requirements, DC developers will typically design and operate their sites to consistently utilise as much power as they have secured for the DC 24/7/365.

The power requirement for any individual DC can vary considerably, and will depend on the particular use archetype, with hyperscale and cloud DCs typically requiring significant more load than smaller edge or enterprise facilities. The Uptime Institute classifies data centres into four Tiers based primarily on power resilience, uptime, redundancy and back up capabilities, and DC operators and customers are increasingly prioritising facilities that can guarantee a continuous power supply: with organisational data storage and computation largely being moved off-site and into DCs, loss of power can result in entire institutions and businesses losing critical operational data, with the Norwegian Data Centre Industry Association recently estimating in a report that the cost to the Norwegian economy per day in the event of an extensive power outage could be as high as NOK 1.3 billion (roughly £100 million) (Ref 4).

Power outages are therefore a significant risk to the DC industry, leading DC operators to rely on short-duration backup power facilities for periods of electricity grid outage or maintenance. These are typically in the form of on-site diesel-engine generators, sized to operate the DC at full load for several hours until the primary power provision is restored. Most commercial DCs procure "N+1" power supplies for their facilities, resulting in redundancy of incoming power infrastructure in case of electricity grid downtime. Electricity outages affecting DC operation have historically been very rare in the UK, with the network operator National Grid Electricity Distribution measuring less than one interruption per customer every two years, averaging 28 minutes of downtime in 2023-24. However, with the shift to decentralised renewable energy generation that rely on variable weather conditions, there is a concern that controlled outages may increase in frequency. The National Energy System Operator has projected that 29-56 GW of dispatchable gas and hydrogen generation will be required by 2050 to meet security of supply and ensure resilience under problematic weather conditions (Ref 5). Though not appearing to be related to upstream generation conditions, the recent Hayes substation fire that resulted in outages across West London, including Heathrow Airport, highlights the importance for critical infrastructure to ensure resilient power supplies from physically diverse parts of the network.

Although there are exceptions to the rule, DC Tiers typically align with the scale of power consumption on site (see Table 2). The vast majority of European DCs can be classified as 'Tier III', and market data procured as part of this study indicates that two thirds of all UK DCs have peak power capacities under 20MW, although demand for hyperscale-levels of power are skyrocketing, with demand for the most power-intense cloud services increasing by a factor of ten over the 2016-2022 period (Ref 3).

Table 2: Data Centre Tier Classes (The Uptime Institute)

Tier	Typical Power Consumption	Use
Tier I	50kW – 500kW	Small businesses, non-critical IT operations.
Tier II	500kW – 2MW	Mid-sized businesses, small-scale colocation providers.
Tier III	2MW – 20MW	Large enterprises, financial institutions, large colocation providers
Tier IV	10MW – 100MW+	Cloud services, big data, mission-critical operations e.g. government facilities, stock exchanges

With these huge volumes of power required for operation, DCs are therefore looking at alternative ways to more efficiently generate, utilise, and recoup on-site energy. Whilst power usage efficiencies are improving with advancements in cooling technology, denser compute structures, and scale of developments all resulting in more efficient per-site energy demands, the dramatic growth of the industry means that power-savings through on-site efficiencies are outweighed by the sheer quantity of new data centre developments, particularly when considering the growth of hyperscale facilities. DCs can be co-located adjacent to developments with high heat demands, allowing the option to provide waste-heat as a service, as in the case of DeepGreen's supply of heat to swimming pools (Ref 6). Carbon emissions from on-site fossil-fuel generation are already being captured, stored, and utilised in data centres in the US and Italy (Ref 7), and renewable energy projects are increasingly being developed primarily to directly supply hundreds of GWs of low-carbon power to DC operators (Ref 8).

4.3 Emerging Global Data Centre Trends

The high and consistent power demand of data centres is becoming a limiting factor for developers. Many suitable sites for new developments are being discounted due to insufficient power capacity on the local electricity grid. Relying on renewable energy such as solar and wind can be impractical for consistent demand requirements when those technologies rely on variable weather patterns. Developers are now looking to alternative sources of energy capable of providing a consistent level of power, such as hydrogen fuel cells, natural gas and nuclear plants. With a supply of continuous, carbon-free energy, nuclear-powered data centres are becoming more common in the US; examples include a 300MW DC owned by Amazon Web Services collocated with the Susquehanna nuclear plant (Ref 9); and a recent deal that will see new Google data centres powered by small modular reactors (SMRs) this decade (Ref 10).

Hydrogen powered data centres outside the UK already utilise hydrogen fuel cells, and recent examples include a 1MW DC in California (Ref 11) and a 250kW supply to Microsoft's data centre campus in Dublin (Ref 12).

Using natural gas as a back-up power source for data centres has been envisaged as a cleaner and more cost-effective alternative to traditional diesel generators (Ref 13), as the amount of carbon released from burning natural gas is lower compared to other fossil fuels. In countries where significant volumes of natural gas are produced domestically, such as the US and Canada, natural gas power can be cheaper than grid electricity. Lower costs, combined with widespread electricity network constraints, has led DC developers to explore sourcing their primary electricity needs from combined cycle gas turbine (CCGT) plants. In December 2024, US multi-national ExxonMobil revealed plans to build a 1.5GW CCGT plant that would generate power exclusively for DCs, and be capable of capturing and storing 90% of its CO2 emissions (Ref 14). US energy company Entergy also released plans in 2024 for a 1.5GW CCGT plant in Louisiana that will supply a new data centre (Ref 15), and DC developer Crusoe have agreed a deal to power multiple new data centres in Alberta, Canada from gas power plants (Ref 16).

The current UK Labour government passed legislation in September 2024 that classifies data centres as Critical National Infrastructure (CNI), placing the industry in the same category as many water and energy services. This designation enables more extensive government support with anticipating and recovering from "critical incidents" capable of interrupting data centre operations, such as power outages, service interruptions and cyber-attacks. The planned support includes setting up a dedicated team that will monitor and anticipate potential threats, and prioritised access to national security agencies. The government expects the designation to give reassurance to developers and hopes that it will encourage further growth in the UK data centre market (Ref 17).

In 2025 the government announced its intention to set up AI Growth Zones across the UK to encourage investment in AI-enabled data centres and associated infrastructure and services (Ref 18). In particular, the government wants to identify sites that have sufficient power, land and access to low-carbon power that can support large scale data centres above 100MW in size. Although specific incentives have not been confirmed, there is speculation they will include corporate tax incentives for data centres within the Zones (Ref 19).

The UK government is also proposing to amend the Nationally Significant Infrastructure Project (NSIP) consenting regime to explicitly include data centres (Ref 20). This change is intended to give more recognition to the importance of these projects, and greater potential for them to be given NSIP designation. The designation is designed to fast-track projects through planning and overcome obstacles within local planning committees.

As governments and the public have become more conscious of data centre energy requirements and growth trends, there is now rising pressure for the industry to decarbonise and reach net-zero targets. The Climate Neutral Data Centre Pact is a pledge signed by over 100 data centre operators across Europe committed to becoming climate neutral by 2030 (Ref 21). The signatories of the pact now represent 75% of European data centre capacity (Ref 22). Some companies have pledged their own carbon neutrality targets: Amazon Web Services (AWS) claims to have matched all of its electricity consumption with renewable energy sources in 2023, seven years ahead of its 2030 target (Ref 23); Microsoft has pledged to be carbon negative by 2030, and to have removed all its historical carbon emissions by 2050 (Ref 24); and Colt Data Centre Services has committed to sourcing 100% of its global energy needs from renewable sources by 2030 (Ref 25).

5 Stakeholder Engagement

To help assist with the formation and focus of the study, it has been crucial to ensure that key relevant stakeholders and experts in the data centre industry are involved. We have carried out structured interviews and ongoing consultation with data centre operators with facilities in the regions of study, data centre developers, energy network operators, and technology vendors to gain up-to-date information, data, and insight into the latest challenges, opportunities, and progress to date on actions relevant to the study. This has included:

- DC operators Pulsant, Ark, Clearstream, and nLighten;
- DC developer and REIT Segro;
- Innovation, Net Zero, and Network Planning teams from the gas distribution networks Wales and West Utilities (WWU), and SGN;
- Electricity Distribution Network Operators National Grid Electricity Distribution (NGED), and Scottish and Southern Electricity Networks (SSEN);

Key themes from the engagement with stakeholders is discussed below with further details provided in Appendix A.

The DC operators all expressed explicit interest in the study, particularly with respect to the opportunity to reduce operational carbon emissions if utilising green hydrogen as a primary or backup power source. As DCs currently rely on the electricity grid for their primary power provision, the carbon factor of the supplied electricity largely determines the bulk of their operational emissions, and with most DC operators committed to net zero targets between 2030 and 2050, they are currently relying on Green Power Purchase Agreements from renewable energy generators to bridge the gap in energy sustainability until the electricity grid fully decarbonises, with one operator currently utilising an agreement with an adjacent waste-to-energy plant to provide very cheap power to the DC. The operators also highlighted the significant barriers they are facing in their growth plans due to the constraints on procuring new electrical grid power, commonly facing connection dates for expanding their existing sites well in the mid-late 2030s. They also emphasised how infrequently they operate their backup generation plant, only requiring 2-5 hours a year of operation for maintenance purposes rather than for explicit backup operation. The operators of the small-medium sized DCs all shared concerns about being ‘first movers’ when considering using the gas network for their primary power provision, and although were aware of the precedent elsewhere globally, had particular concerns with overcoming the regulatory and operational risks. The larger operators were more interested in exploring the gas network for primary provision, and were interested in utilising the gas supply to co-locate a peaking power plant on-site for demand flexibility or frequency response grid services as an alternative source of revenue. It was raised that there are already significant environmental, insurance, and planning constraints when installing smaller backup generators, and it was anticipated that these would be more onerous when dealing with continuous and larger power loads for the primary power provision. A concern around the challenge/difficulty in the ability of providing diverse supplies from the gas networks for complete power supply resilience in the case of damage or outages was commonly shared.

The DC developers shared many similar concerns to the operators but emphasised the current electricity grid constraints restricting their development plans. Most notably, it was highlighted that power provision for a potential site is now considered a higher priority than procuring fibre connections or even land agreements, with examples being given of DC developers purchasing sites with existing secured connection offers with significant premiums, in some cases up to £14m per MW. The M4 corridor was highlighted as a particularly constrained region that was both highly desirable for DC siting due to customer demands but facing some of the longest connection timescales in the country, with an example of 2039 given for one site.

The ongoing engagement with WWU and SGN highlighted their ambitions and ongoing works to prepare the gas distribution networks for a hydrogen-blend in the near-term, and eventually to be suitable for a full hydrogen system. The replacement of cast iron pipework in the networks with plastic is already well-progressed, with some parts of the SGN low pressure network already seeing replacement rates above 80%, and WWU targeting 2032 for completion of their Mains Replacement Programme. This will not only result in suitability for hydrogen injection in the network but will also reduce leakage throughout the network and operational carbon emissions and increase the safety factors of the pipework. Hydrogen injected into the gas network can be produced via electrolysis, and if the electrolysis plant is powered by renewable energy, the hydrogen produced is considered "green hydrogen", that emits zero emissions when created or consumed. Early work is currently underway in the planning of SGN's "H2 Caledonia" & "H2 Connect", and WWU's "HyLine Cymru" backbone systems, able to transmit large volumes of hydrogen between industrial users in Scotland, Wales, and Southern England. The GDNs are already supporting the ongoing safety and economic assessments related to hydrogen blending, following the Government's 2023 strategic policy decision to support blending of up to 20%. Demand reduction resulting from increased electrification has not yet been identified and is not expected to be noticeable until at least 2031. Demand has, in fact, slightly increased in recent years in some areas, driven mostly by commercial/industrial users and a small increase in distributed gas peaking power plants. However, the move away from gas usage, particularly for heating, is anticipated to eventually result in a significant reduction in demand of the gas network. Current estimates are that domestic gas demand could reduce to 40-50% of the current volume in many regions by 2040 (Ref 5).

5.1 Stakeholder Engagement Results

Following the engagement, it was agreed that:

- Exploring the feasibility of providing "Primary" power to DCs via the gas networks would be of most interest and should be the focus of the study, with back-up power provision not to be considered. This primary provision could be supplying the full load required from the gas network, or a part-load to allow a larger load capacity than can possibly be supplied from the electricity grid alone.
- The operational costs, area requirement and maximum available power load of a gas-powered solution would be the most important factors to consider as part of a feasibility study.
- Sustainability and net-zero targets are important factors, so the hydrogen-gas blend ratio should be considered.
- The varied facility scales, forms, owner/operator structures, and power demands result in different requirements, and so the case study options selected should consider these variations.

6 UK Energy Networks

6.1 Electricity Networks

The UK electricity grid is comprised of two main parts; the transmission network and the distribution network. The transmission network is used to transport high volumes of energy at very high voltages across the country from generation sites to consumers and typically only connects to very large demand or generation projects such as gas-fired power plants, wind farms, and significant solar generation projects via an existing grid supply point (GSP) substation.

The distribution network is what most domestic, commercial, and industrial demand customers connect to, as well as smaller scale renewable energy generation and battery storage projects. The network's "primary" substations are where small to medium demand and generation sites typically connect, with each primary substation serving a certain number of consumers in its surrounding area.

In general, projects with a maximum power consumption under 100MW are likely to be offered a point of connection at a primary substation on the distribution network. Projects with a maximum consumption above 100MW will need to connect to the transmission network with a point of connection at a GSP. Most data centres in the UK currently fall into The Uptime Institute's Tier III category. However, there is a growing demand for Tier IV facilities, driven by the increasing need for ultra-reliable, fault-tolerant infrastructure to support cloud computing, AI, and mission-critical applications.

The rise in demand for data centres coincides with the electrification of transport and heat, and electricity grid constraints are now a major roadblock to infrastructure projects in many locations across the UK. It is increasingly difficult for developers to source and deliver electricity from the electricity grid to potential development sites. To address this issue, the UK government is aiming to invest £40 billion a year on average between 2025-2030 to upgrade electricity infrastructure and transition away from electricity generated by fossil fuels.

The connectivity requirements of data centres and the advantages of co-locating near to similar developments has led to a dense cluster of DCs in west London and along the M4 corridor (see Figure 4). This demand has led to the region's electricity network becoming heavily constrained. New developments are regularly being given connection dates in the late 2030s. Developers are now seeking sites in less-developed regions in the hopes to secure faster and cheaper electricity connections. Power availability is emerging as one of the top priorities in the selection process for data centre expansion (Ref 26).

Figure 4: Data centre location and size along M4 corridor (planned, in construction & operational)

The National Energy System Operator (NESO) is undergoing a Connections Reform aimed at improving how new energy projects are connected to the UK's electricity grid. NESO's reform seeks to prioritise and clear the current backlog of demand and generation applications by focusing on projects that are ready to progress and that are most crucial for the achievement of Clean Power 2030 (CP30) goals and meeting the UK's climate targets. It is anticipated that once the reform process has been fully implemented by the end of 2025, the wait times for connection to the transmission network should be reduced for projects that are shovel ready (i.e., those that have the necessary planning permissions, land rights, and financial backing) and needed (i.e., those that will help meet CP30 goals and are vital for electricity grid stability). This reform is anticipated to result in a significant reduction in connection timescales for both generation projects and large demand projects (such as data centres), as the reforms will remove speculative "zombie" projects that have received a connection offer but are not ready to build or required for CP30.

6.2 Gas Networks

Natural Gas is transported and distributed by a range of organisations in the UK. National Gas Transmission (NGT) is responsible for the first step in delivery, operating the network of high-pressure gas pipelines from points of entry to power stations, industrial plants, storage facilities and to the local Gas Distribution Networks (GDNs) that delivers gas into homes and businesses, as well as overseas via interconnectors. NGT must balance the supply and demand of gas in real time, ensuring enough gas is transported to the right areas of the country.

NGT's part of the network is known as the National Transmission System (NTS). At the offtake stations, gas moves into a network of lower pressure pipes operated by the GDNs.

GDNs deliver gas from offtake stations to homes, businesses and industries. Four companies fill this role in the UK: Cadent Gas, Northern Gas Networks, SGN and Wales & West Utilities. The GDNs are responsible for the high, intermediate, medium, and low-pressure pipelines that distribute gas to customers throughout the country. GDNs maintain the infrastructure and ensure safety on their networks and are regulated by OFGEM, as are the electricity networks, to ensure fair pricing, reliability and efficiency for consumers.

In the higher-pressure infrastructure operated by the GDNs, the precise pressure and volume of gas within the pipelines vary throughout the day, corresponding to fluctuating changes in regional demand. This changeable gas volume is known as 'linepack' and is carefully controlled and managed by the network operators to ensure both that the gas is maintained above minimum safe operating pressures and to effectively act as a form of flexible energy storage when required. This varying pressure means that end-customers that require a fixed gas volume output for certain industrial processes must have on-site pressure-reduction skids to fix the flow rate as required.

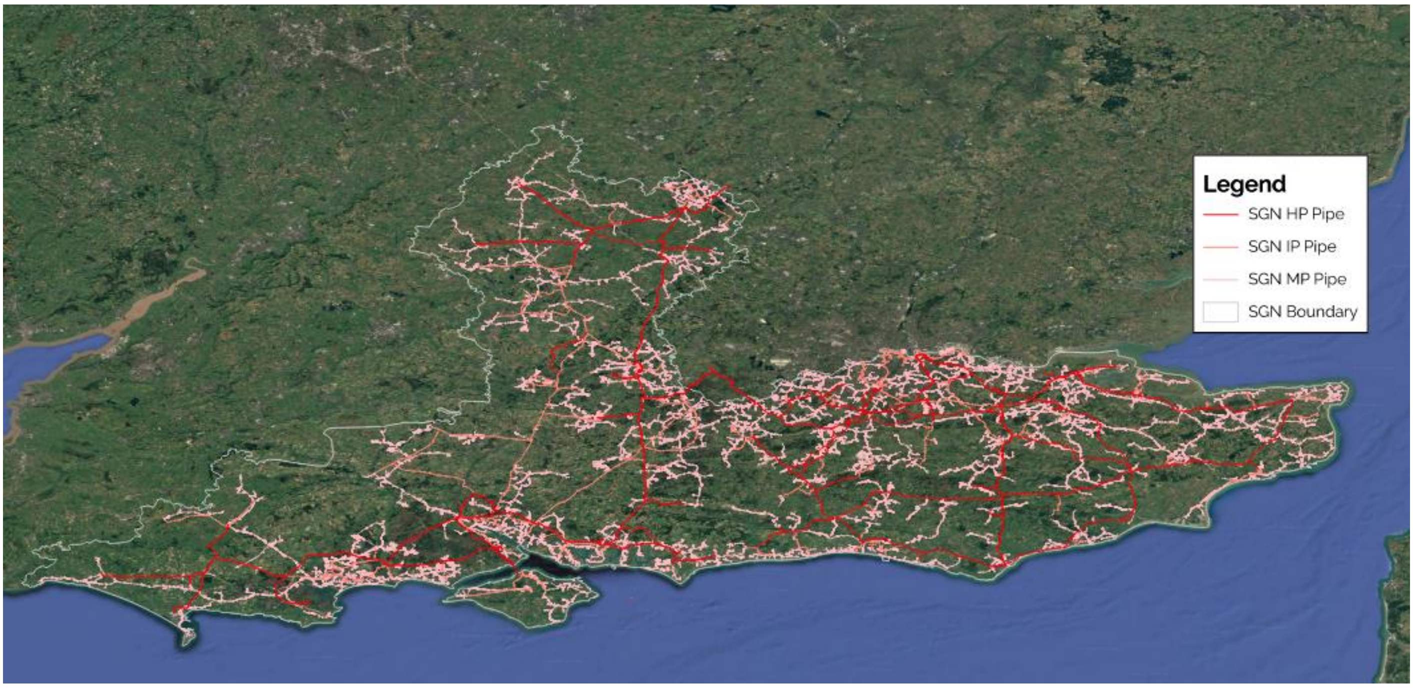

Figure 5: SGN infrastructure (England)

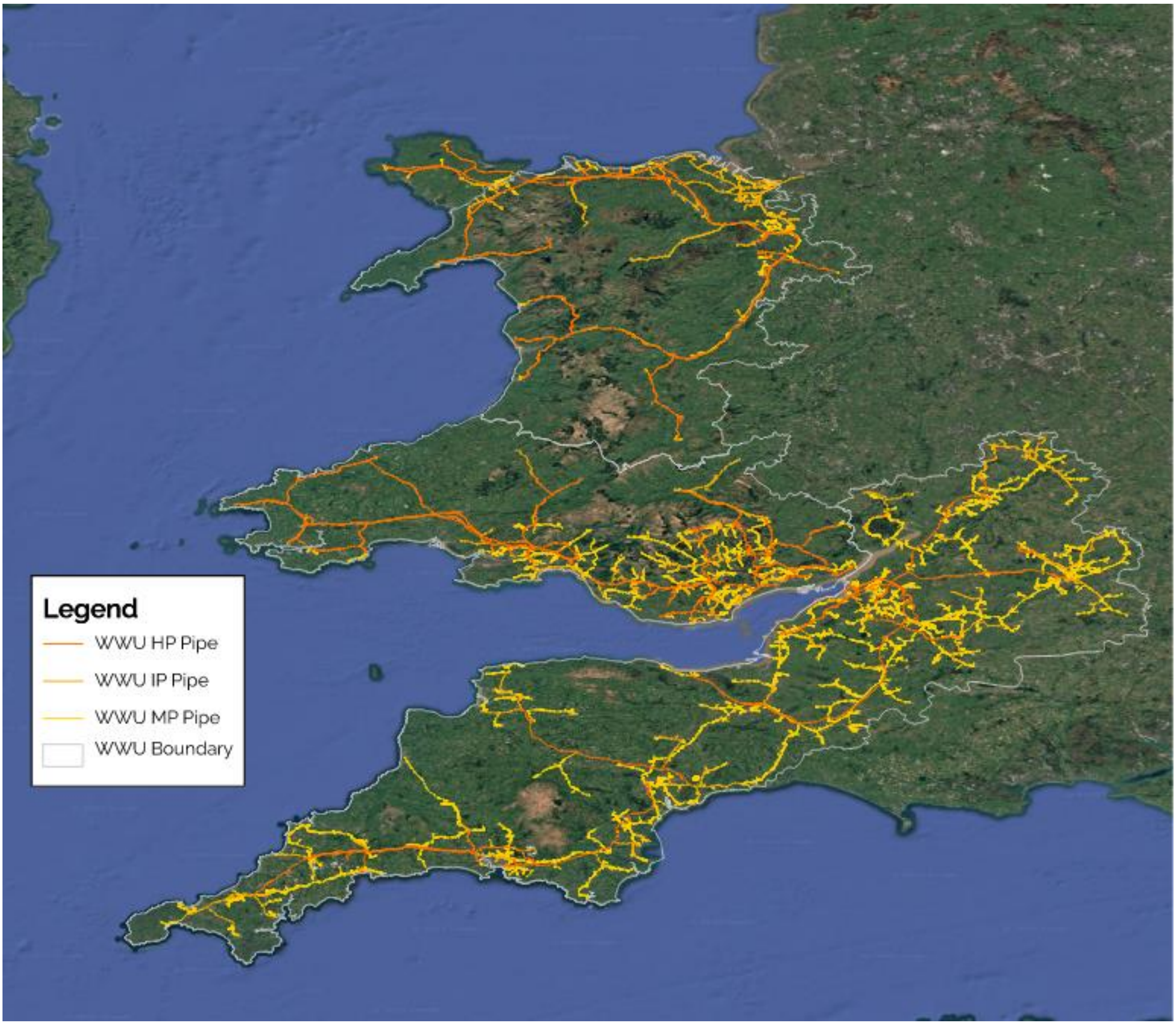

Figure 6: WWU infrastructure

6.3 Necessity of Hydrogen Blend

Blending hydrogen into the gas network as opposed to going straight to a 100% hydrogen gas network is a crucial step to ensure certainty for all relevant parties as outlined below:

- Hydrogen Producers
    - Creating early demand through blending provides a crucial early market for hydrogen, stimulating production and investment to gradually grow on the approach to a 100% hydrogen gas network.
    - It is financially a low risk entry point compared to significant investment in new hydrogen infrastructure. Producers can gradually increase production in a sustainable fashion as blending percentages rise.

    - Producers will acquire a consistent outlet for hydrogen early in their lifetime and when dedicated hydrogen infrastructure is limited.
- Gas Network Operators
    - Blending allows operators to initially leverage their existing infrastructure negating the need for significant investment to accommodate the introduction of hydrogen.
    - A gradual introduction of hydrogen allows for the operators to gain experience in handling and managing hydrogen on smaller scale before 100% hydrogen is adopted.
- End Users
    - If compatible with end use, utilising a blend from the gas network provides an immediate reduction in carbon emissions for consumers (20% blend would result in 7% reduction in carbon emissions).
    - End users can become familiar with new technologies (such as fuel cells) that are initially natural gas and H_2 ready before adopting 100% hydrogen technology equivalents if desired.

Regarding blend technologies to bridge the gap to 100% hydrogen, currently blending is anticipated to begin in 2025-2026 after the government made a strategic policy decision to support blending up to 20% in 2023. A 100% hydrogen gas network is then dependant on the success of the blended network, but if desired a 100% hydrogen gas network could be realised by the 2040s.

This timeframe of 20 years between blending and 100% hydrogen aligns with the implementation of blending technologies. These technologies have a lifespan of ~10 years (80,000 hours) running at full load before certain components need to undergo significant maintenance. This means full value will be made from an investment in blended technologies as they will likely be utilised for their entire lifespan before consideration is required for 100% hydrogen technology equivalents.

7 Technology Review

There are two major technologies to convert gas to electricity at small scale, Solid Oxide Fuel Cells (SOFC) and H_2 ready engines. Both are a matured technology and, in some cases, already utilised in data centres around the world. Gas turbines are another prevalent gas to electricity technology however these are better suited to larger power generation needs than explored in this report. As such gas turbines are not considered in detail in this report.

Discussed below are the technologies required to operate on a 5% blend of hydrogen and natural gas.

7.1 Bloom's Natural Gas/Hydrogen SOFC

A natural gas Solid Oxide Fuel Cell (SOFC) creates electricity through chemical reaction with natural gas or a blend of natural gas and hydrogen. The operation of a natural gas SOFC is shown in Figure 7 below.

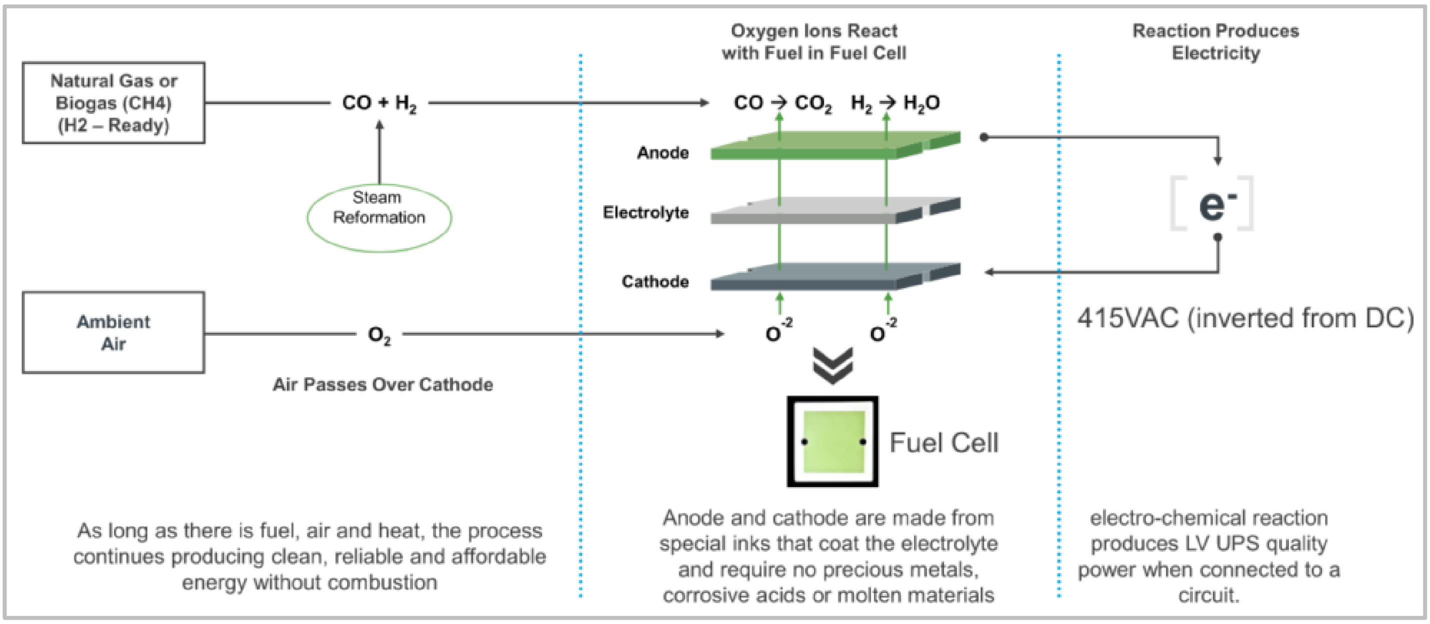

Figure 7: Natural Gas Solid Oxide Fuel Cell Operation

The fuel cells are combined to make stacks then these stacks are combined to create a server module. These modules can then be built up in a modular fashion to create large power solutions as shown in Figure 8 below.

Figure 8: A Fuel Cell Power Solution

The SOFC may utilise a Combined Heat and Power (CHP) cooling solution. A CHP utilises the significant heat produced by the fuel cell reaction with a heat recovery unit and can deliver this heat for other applications, in this case for cooling via an absorption chiller. This CHP cooling solution is illustrated in Figure 9 below.

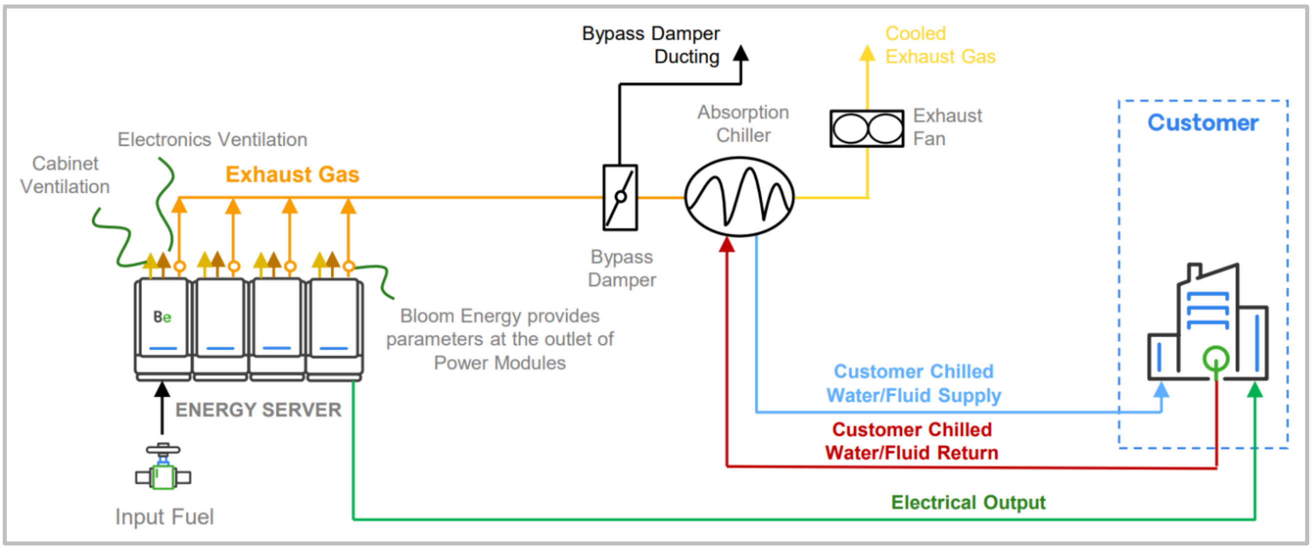

Figure 9: SOFC CHP Cooling Solution

The thermal energy in the exhaust can generate chilled water via an absorption chiller or a Vapor Absorption Machine (VAM). In addition to increasing the overall efficiency of energy conversion, VAMs do not use CFC refrigerants that are part of conventional electric chillers providing benefits beyond carbon savings and adding to the sustainability benefits.

Without the CHP solution the energy efficiency of the SOFC is ~52% but with a solution that captures heat, the energy efficiency of the SOFC increases to >90%. (Ref 27)

The energy efficiency of 52% mentioned above is termed the “electrical efficiency”. This is given as a ratio of thermal energy to electrical energy i.e. how much thermal energy is converted to electrical energy. So with 52% electrical efficiency, if $1MW_{th}$ of gas was fed into the fuel cell, it would produce $0.52MW_{el}$.

The SOFC may also utilise a Carbon Capture and Storage (CCS) solution. CCS is used to capture and contain CO_2 at the source of emission. Using natural gas with the SOFC means CO_2 is produced as a biproduct which needs to be vented to the atmosphere or the more environmentally friendly option, captured and stored. An SOFC CCS solution is illustrated in Figure 10 below, boasting a 97.5% carbon capture efficiency. Without an electricity grid connection, the parasitic load for a CCS solution will be drawn from fuel cells.

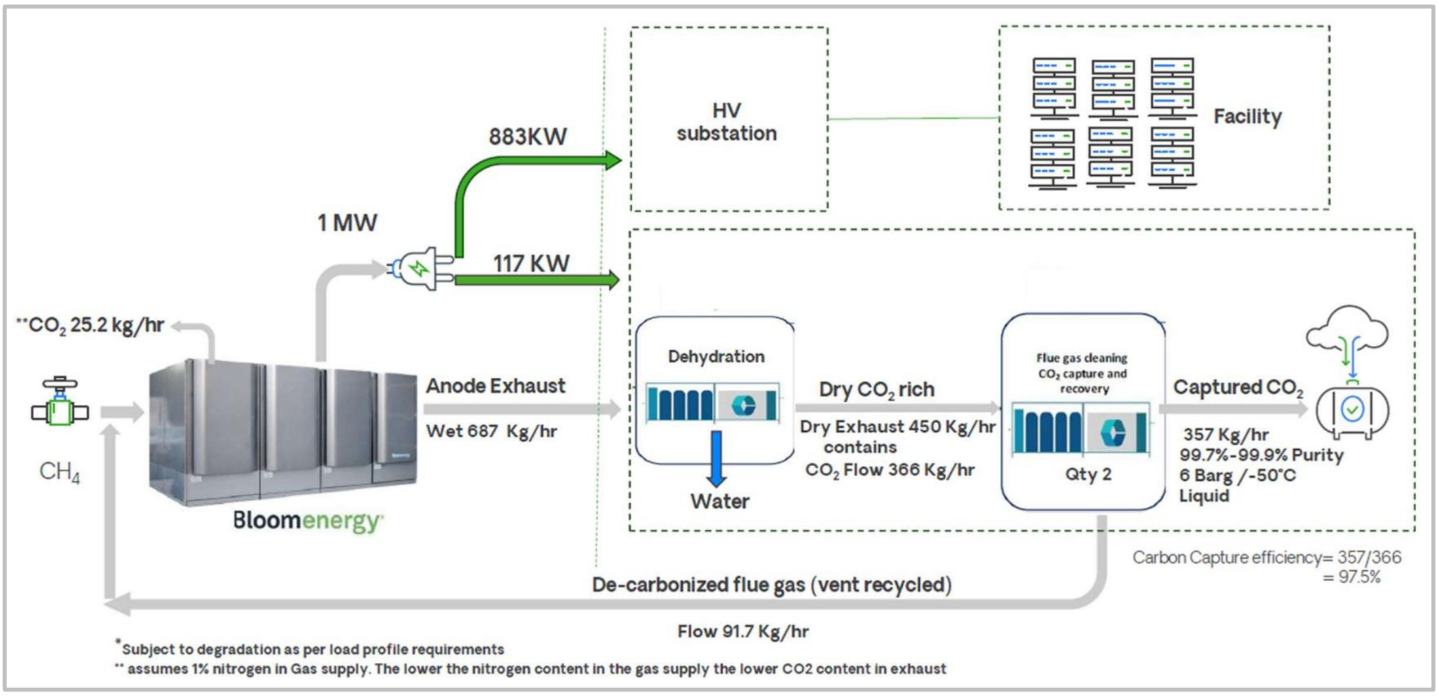

Figure 10: SOFC CCS Solution

However, it is not economical to have both the CHP and CCS solution installed as they do not complement each other operating one after another:

- If the CHP solution is used, the exhaust gas is taken from the cathode side as it is around 350°C - 380°C. However, once it has passed through the heat recovery process the flue gas will only have around 3.6% concentration of CO_2. This would make for a very inefficient CCS system if it was downstream of a CHP system.
- If the CCS solution is used, the exhaust gas is taken from the anode side as this has a very concentrated stream of CO_2, up to 60% by volume of the dried flue gas and no oxygen. However, this extraction is taken at a temperature of ~180°C which is significantly less than cathode extraction. Furthermore, the decarbonised gas containing hydrogen and CO should be recycled back to the fuel cell inlet in order to maintain efficiency as they are both required for natural gas and hydrogen blend fuel cell operation (as seen in Figure 7 & Figure 10 above).

7.1.1 Current use in Data Centre

In 2013 eBay's Salt Lake City data centre was the first in the world to switch to SOFC for primary power. The 8MW facility installed a 6MW SOFC solution and utilised natural gas as the fuel source. The remaining 2MW of the facility demand was met by a waste heat recovery solution. The waste heat is recovered 22 miles away from the pipeline compression system being used to supply the natural gas for the SOFCs on-site. (Ref 28)

Global interconnection and data centre company Equinix run a number of data centres across the US. In 2017 they partnered with Bloom to install a combined total of 37MW worth of SOFCs across twelve of their data centres. Following the success of this, in 2021 Equinix built their new facility SV11 which included 20MW of SOFC. Significantly, this will be the first time Equinix will use the SOFC system as primary generation with utility electrical grid and generators as backup sources. (Ref 29)

Intel India were the first data centre to deploy fuel cells in India & Asia in 2016. During the initial phase, the fuel cells powered the data centre through an existing Uninterruptible Power Source (UPS). An UPS is a crucial part of the backup power system that provides immediate short term power as the long term back up power system comes on line. Diesel generators are the most common long term back up power system of choice and these take a couple of minutes from start up to be operating at full load.

The high response time of the fuel cells however enabled the data centre to utilise the fuel cells without a UPS intermediary. Currently, the fuel cells serve as the primary source of power to data centre while the electricity grid serves as the backup power. (Ref 30)

American Electric Power have signed a significant agreement for a 1GW SOFC solution which begins with an initial order of 100MW. These SOFCs will be located at AI data centres to “support the installations immediate power needs”. (Ref 31)

7.2 H_2 Ready Internal Combustion Engine (ICE) (Jenbacher)

A hydrogen fuelled internal combustion engine (ICE) is a traditional combustion engine as we know it except the fuel includes hydrogen as opposed to solely diesel or natural gas. The engines of interest in this study are "H_2 ready" engines, meaning the engine is currently run on natural gas or natural gas & H_2 blend. The different variations of "H_2 ready" are illustrated in Figure 11 below with type A (red box) being most relevant to the blended scenario currently being explored in this report.

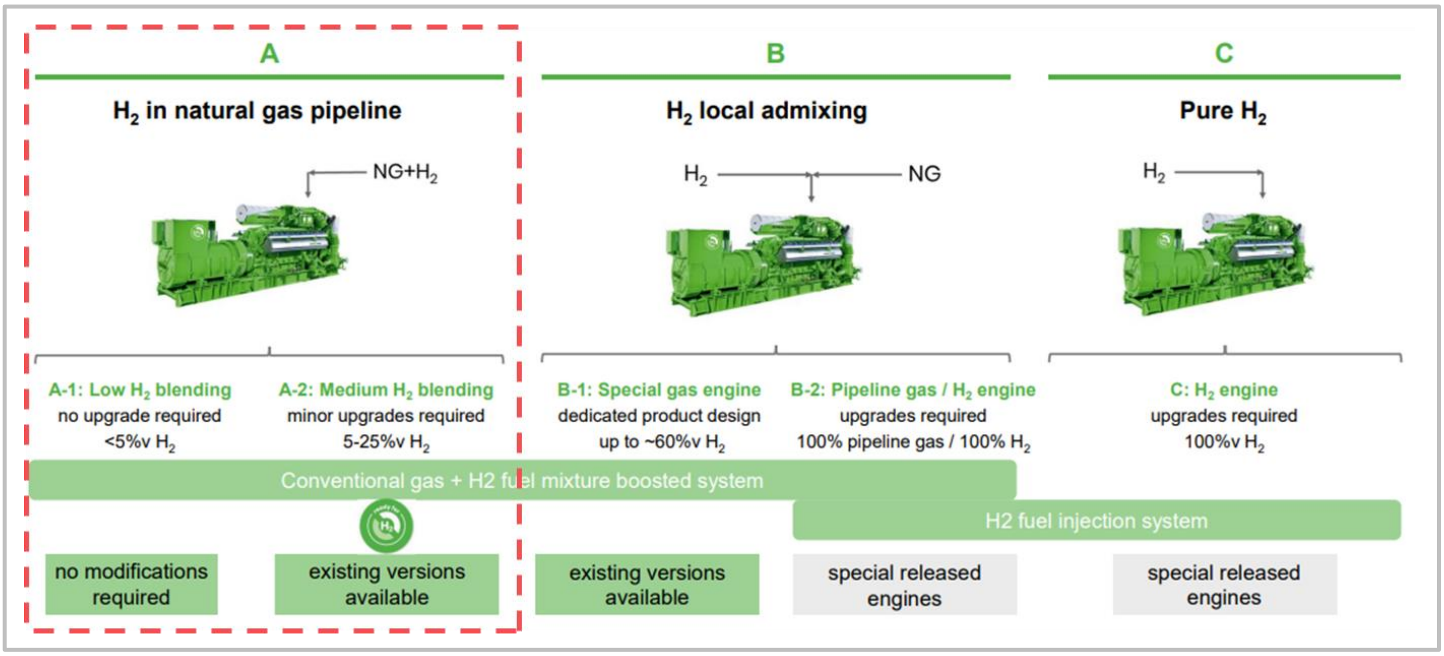

Figure 11: Jenbacher "H_2 Ready" Combustion Engine Variants

As seen above using a low blend from the network (<5%) requires no modification to the "H_2 ready" engine. Going above a 5% blend and up to 25% would require some minor modifications to the initial engine that is still in place. Going up to 100% hydrogen will likely require a new engine or significant upgrades required to the existing engine. It would be economic to align the lease/purchase of the engines with the projected introduction of 100% hydrogen to utilise the blend technologies for as much of their lifespan as practical.

Similarly to the SOFC, "H_2 ready" ICE may also be integrated with a CHP and CCS add on solution as shown in Figure 12 & Figure 13 below. The CHP solution offered with the ICE would bring up the system efficiency from 40%-45% to ~75%. Again this 40-45% electrical efficiency means if $1MW_{th}$ is fed into the ICE, $0.40MW_{el}$ - $0.45MW_{el}$ is produced. Without an electricity grid connection, the parasitic load for a CCS solution will be drawn from the ICE.

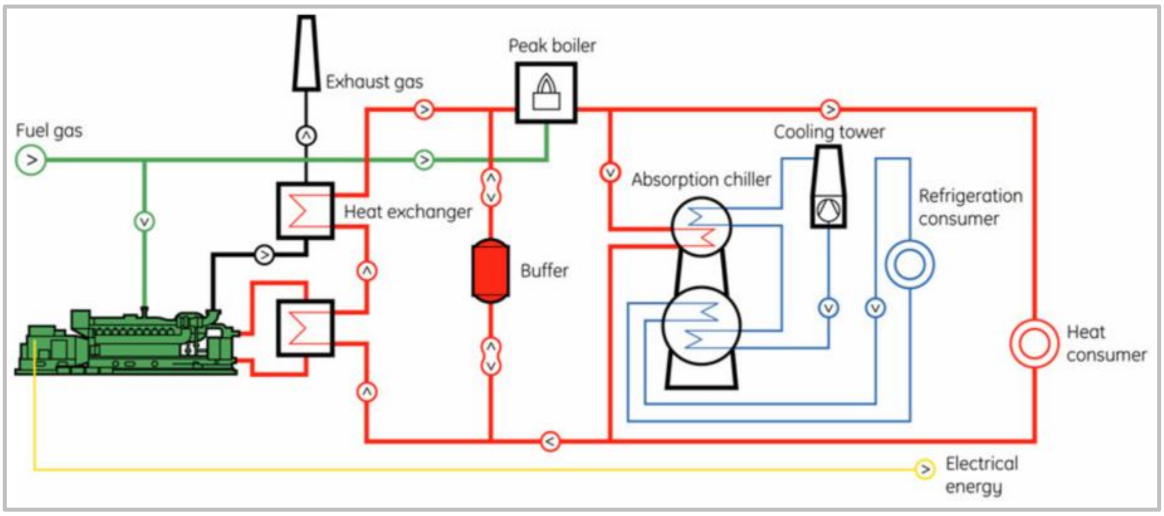

Figure 12: Jenbacher CHP Cooling Solution

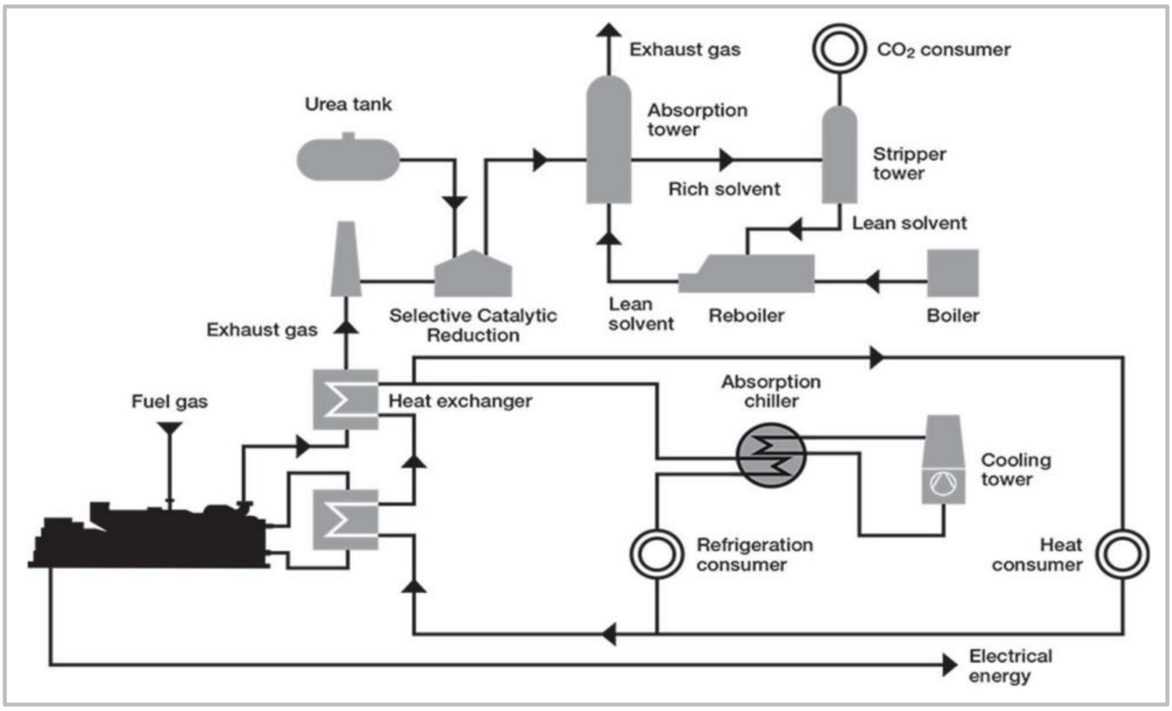

Figure 13: Jenbacher CCS Solution

A potential challenge with implementing a CCS solution is what to do with the captured carbon. Geological carbon storage is still in its infancy with a number of projects around the UK looking to become operational in the coming years. The transportation of the captured carbon is another challenge with the cost implications and lack of established infrastructure acting as a potential barrier. Non pipeline transportation of carbon by rail or road could be one option that would allow the capture CO_2 to be transported from the data centre to the storage location. Another option could be to utilise the captured carbon and use it as a potential revenue stream by selling it to industries that use it in their processes such as food and drink. This would either require co-location with the data centre or transportation links to be established, either by road, rail or pipeline.

7.2.1 Current use in Data Centre

In 2022 INNIO announced that its Jenbacher engine technology has been selected by Winthrop Technologies to power a 60MW hyperscale data centre in Dublin, Ireland. The Jenbacher engines will provide a continuous power output that is compliant with EU emission regulations. The power plant will be used for emergency backup power and electricity grid stabilisation in times of higher demand (Ref 32).

In 2015 Citibank invested in a CHP solution from Jenbacher to provide power and cooling to a UK data centre. Two 1.4MW CHP systems were installed which will generate 71% of the data centres power demand. (Ref 33)

7.3 SOFC & ICE Comparison

Both technologies discussed above offer their own pros and cons and the best solution is dependent upon the specific end user requirements. Table 3 below compares SOFC and ICE considering a natural gas and hydrogen blend. The green and red colouring denotes where one technology may be considered superior to the other for application in a data centre.

Table 3: SOFC & ICE Comparison

	Natural Gas Solid Oxide Fuel Cells (SOFC)	Internal Combustion Engines (ICE)
Efficiency	High, especially in CHP applications. Efficiency decreases over time.	Lower than SOFCs.
Fuel Consumption per MW	~191 scm/hr	~253 scm/hr
Emissions	Very low. Reduced NO_x, particulate matter. Near-zero emissions possible with high hydrogen content.	Higher emissions, including NO_x, CO, and particulate matter. Requires exhaust aftertreatment.
NG/H_2 Fuel Flexibility	High. Adaptable to various natural gas/hydrogen blends. Internal reforming capabilities. Efficiency decreases as H_2 concentration increases.	Adaptable, but modifications may be needed. Performance varies with blend ratio.
Load Flexibility	High, suited for cyclic load fluctuations.	High, suited for cyclic load fluctuations.
Technology Maturity	Commercially available but less established compared to the ICE	Mature and widely established.
Applications	Stationary power, distributed energy, potential heavy-duty transport.	Transportation, power generation, various industrial applications.
Initial Capital Cost	Higher – influenced by materials, manufacturing scale, system integration complexity	Lower - influenced by mature manufacturing processes, economies of scale, established supply chains
Maintenance Cost	Potentially lower - influenced by fewer moving parts, potentially longer lifespan	Higher - influenced by regular oil changes, filter replacements, potential for more frequent repairs
Fuel Cost	Lower (due to higher efficiency)	Higher (due to lower efficiency)
Long-Term Cost Trend	Expected to decrease with technology maturity and increased production	Relatively stable
Overall Cost Consideration	Higher upfront, potentially lower long-term cost of operation	Lower upfront, potentially higher long-term cost of operation

Note the comparison above does not consider 100% hydrogen applications which will have further nuances for each technology, some of which are discussed below. Both technologies have pros and cons but as aforementioned, both technologies are established and currently in use around the world in the data centre sector.

7.4 Hydrogen SOFC & ICE

The SOFC and ICE used for 100% hydrogen differ slightly from the natural gas equivalents that can operate on a blend of hydrogen. The blended technologies may operate on 100% hydrogen but to ensure optimised efficiency, a more bespoke variation is preferred. The SOFC operates in the same manner but without steam reformation upstream in the fuel cell. As such there are also no carbon dioxide emissions either, only water as the by product. This is illustrated in Figure 14 below.

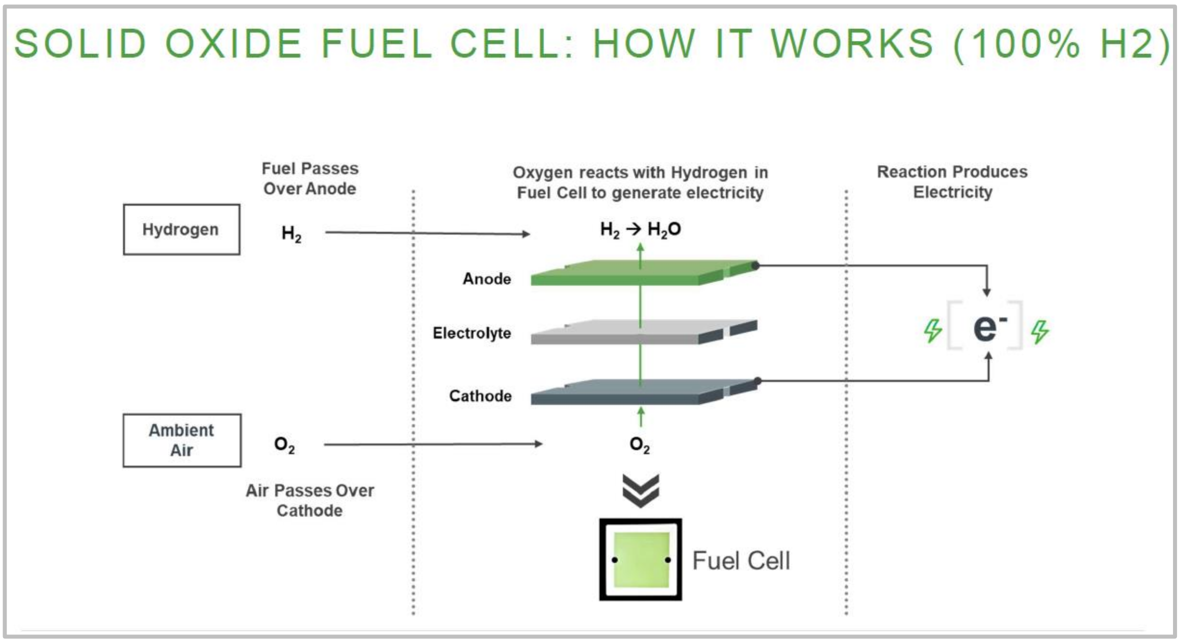

Figure 14: 100% Hydrogen SOFC

In the case of the 100% hydrogen ICE, a specialist optimised engine is used. Due to the difference in fuel, the ICE will similarly no longer emit carbon during combustion. Aside from the different emission due to the fuel, the overall combustion process in the engine is identical to the natural gas counterpart. The fuel consumption of each of the 100% hydrogen technologies are noted below:

- SOFC Fuel Consumption per MW - 58 kg/hr (Ref 34)
    - Beginning of Life consumption. As cell degradation occurs, efficiency will decrease
- ICE Fuel Consumption per MW - 77 kg/hr

A further consideration is that a 100% hydrogen gas network is anticipated to deliver 98% purity hydrogen which is suitable for combustion using ICE. However, fuel cells require 99.9% purity which will necessitate some sort of purification process like pressure swing adsorption. This is discussed further in section 14.1.

7.5 Key Criteria for Onsite Power Technology

In the 2025 Data Centre Power Report prepared by Bloom Energy (Ref 35) they found that “[Data centre] leaders are now ready to invest 50% more than seven months ago if that means they can access power faster for upcoming data centre projects”.

This willingness to pursue expedited power connections even if it comes at premium cost emphasises that being online before competitors offers a crucial strategic edge. Industry leaders understand that faster access to power is essential for establishing a dominant position in this quickly changing field and this is especially true for AI data centres. (Ref 35)

Bloom also identified when it comes to power provision, data centres now consider more than just cost and reliability. The seven key criteria now considered for choosing power provision is outlined in Table 4 below.

Table 4: Seven Key Criteria for Choosing Onsite Power Technology (Ref 35)

1	**Reliability** • Minimising outages with reliability at par or superior to the grid (at least 99.9% and sometimes up to 99.9999%)
2	**Time to Power** • Bringing a data centre online faster can provide significant economic advantages (e.g., earlier revenue opportunities) and strategic advantages (e.g., leadership in AI)
3	**Cost** • Beyond the cost of a particular technology, data centres consider value and return on investment more holistically, factoring in both economic benefits and strategic benefits
4	**Load Flexibility** • AI data centres involve greater power demands and fluctuations over short time frames, and not all power solutions can handle these load shifts (discussed below)
5	**Sustainability: Air Quality & Noise** • There is increasing scrutiny of data centres’ impact on their local communities and a need to comply with local permitting standards
6	**Sustainability: Emissions Intensity** • Data centres must comply with companies’ sustainability commitments as well as carbon emissions regulations
7	**Power Density** • Technologies with greater power density enable a more efficient use of space for revenue-generating IT equipment

7.6 AI Data Centre

The AI data centre is a significant type of data centre worth noting as it has a different load profile compared to normal data centres. AI data centres experience rapid fluctuations in power demand, ranging from ~90% to 30%, depending on whether they are training or inferring data. These variations occur over time scales from minutes to days. (Ref 36)

These rapid load fluctuations observed in AI data centres render ICE an unsuitable power solution. Fuel cells however can react effectively to handle rapid load fluctuations. The fuel cells can even be paired with fast reacting energy storage systems such as supercapacitors which also reduces the response time from the power system (Ref 36). An illustration of this fuel cell and supercapacitor system in action is shown in Figure 15 below.

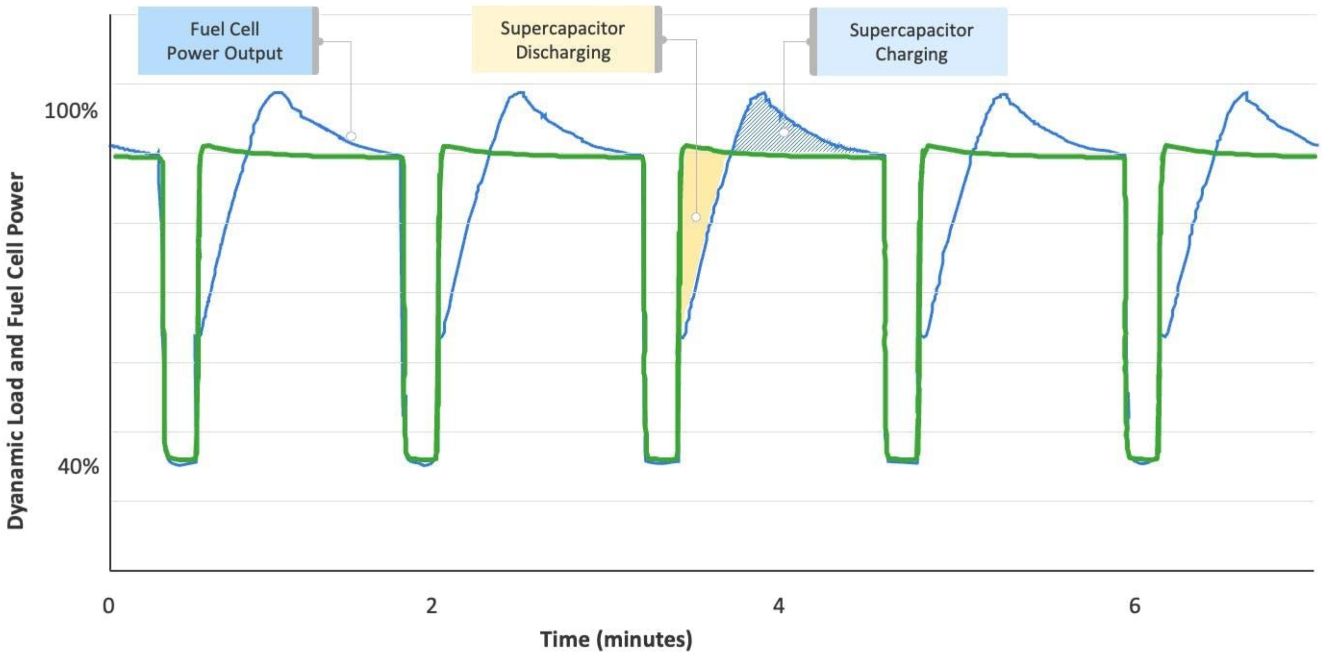

Figure 15: Fuel Cell & Supercapacitor Supporting Rapid Load Fluctuations (Ref 36)

Batteries are well suited for long-duration output such as electricity grid peak shaving. Peak shaving is when batteries (or other storage devices) are charged during low electricity demand and discharged during high demand, reducing the peak load from the electricity grid. This process lowers costs and improves electricity grid stability by smoothing out electricity usage.

Supercapacitors however are a perfect fit for rapid load fluctuations, such as AI workloads, where frequent charging and discharging occur. Advancements in material sciences have led to high-capacity supercapacitor modules that can deliver and absorb intermittent power for several minutes and sustain over 100,000 cycles. (Ref 36)

7.7 Backup Power Provision

An integral feature of data centres is the backup power source which is independent of the primary power source. This is required to keep the data centre online if the primary power is interrupted unexpectedly. Most data centres use a combination of Uninterruptible Power Supply (UPS) systems and diesel backup generators for backup power.

In the UK permitting requirements vary depending on installed capacity of the backup systems. When the aggregate thermal input of the generator is ≥1MW and <50MW, a Bespoke Medium Combustion Plant (MCP) permit is required. MCP permits focus on the air quality impacts of the generator, and aftertreatment systems such as Selective Catalytic Reduction (SCR) and Diesel Particulate Filters (DPF) may need to be implemented to reduce emissions.

For generators with an aggregate thermal input ≥50MW, a Bespoke Installation Permit is required. This permit encompasses a comprehensive assessment of potential environmental impacts including emissions to air, water and land, along with considerations for noise, dust, odour and waste generation and raw material consumption. The operator must also assess the baseline conditions of the site in order to address contamination issues at the time of decommissioning. Developers can expect higher regulatory costs and longer overall permitting times for a Bespoke Installation Permit compared to an MCP (Ref 37).

The gas network could provide backup power provision for data centres, but this would require providing a very large capacity of gas that would only be utilised by the data centre around 50 hours a year. As such backup power provision will not be considered further in this study, only the provision of primary power.

8 Cost Comparison

To best compare the associated costs of the different means of electricity generation discussed above, three electrical demands of varied size are considered. The size of these demands aligns with the case studies explored later in this report. Through stakeholder engagement, indicative costs for onsite power provision of these three electrical demands have been collated.

Three primary factors combine to calculate the onsite power cost; CAPEX, OPEX, & utility rate. The CAPEX and OPEX is dependent on the technology provider and the pricing arrangement that is agreed between them and the data centre. An indicative utility rate for the technology may be calculated as shown below.

8.1 Utility Rate

The average gas utility business rate for large businesses (65,000+ $kWhr_{th}$ per year) is as follows: (Ref 40)

- Natural Gas – 7.4p/$kWhr_{th}$

The above rate considers thermal energy so the electrical efficiency of the SOFC and the ICE can be applied. These are given as a ratio of thermal energy to electrical energy i.e. how much thermal energy is converted to electrical energy by the equipment. The SOFC and ICE electrical efficiencies are shown below. Two different ICE sizes are considered as the larger engines tend to have higher efficiencies making them well suited to build up to higher power provisions:

- SOFC – 53% (Ref 41)
- ICE (1.06MW_{el}) – 40% (Ref 42)
- ICE (4.5MW_{el}) – 45% (Ref 45)

The utility rate of consuming natural gas from the gas network to produce the electricity on site with the considered technology is therefore as shown below:

- SOFC – 14p/$kWhr_{el}$
- ICE (1.06MW_{el}) – 18.5p/$kWhr_{el}$
- ICE (4.5MW_{el}) – 16.4p/$kWhr_{el}$

The utility rate cost above considers using 100% natural gas and does not consider a 5% blend addition or full adoption of hydrogen in the gas network. This is due to the large variations in the current price of hydrogen caused by factors such as the source of the hydrogen. This makes predicting the future cost of hydrogen unreliable and it is therefore not considered in the utility rate calculation as the price of natural gas is sufficient for an indicative rate.

8.2 CAPEX & OPEX

The CAPEX and OPEX costs only consider the cost of the technology. They do not consider other onsite costs such as; civil costs, plant design cost, land acquisition costs, etc. The CAPEX accounts for the upfront cost of the technology and the OPEX considers any lease agreement pricing and associated maintenance costs (if a lease deal is acquired, maintenance will likely be included in the price of the lease).

It is recommended by both SOFC and ICE vendors to maintain suitable backup power provision as a redundancy for maintenance and downtime. Suitably sized diesel generator, battery storage, or direct electricity grid systems would still be required for onsite power downtimes (estimated one or two hours a week). Existing data centres with electricity grid connections could retain their existing infrastructure to provide the full power provision for this purpose.

8.2.1 SOFC - CAPEX & OPEX

The specific Bloom SOFC solution explored in this report has only OPEX and no CAPEX as the fuel cells are provided on a lease agreement from Bloom. The indicative lease pricing (which can be considered OPEX as it is a rolling ongoing price) for a SOFC solution for each considered demand is as follows:

- 2MW SOFC OPEX - 12p/$kWhr_{el}$
- 45MW SOFC OPEX - 10p/$kWhr_{el}$
- 90MW SOFC OPEX - 8p/$kWhr_{el}$

As seen above the price of the SOFC decreases as the capacity increases due to economies of scale. Furthermore, the price can also be reduced if the lease agreement agreed with the SOFC vendor is increased to 20 years instead of the usual 10 years.

8.2.2 ICE - CAPEX & OPEX

As aforementioned the SOFC power solutions are built up in modular fashion using multiple identical servers, however the ICE solutions are built up using different sized engines dependant on the size requirement. This is outlined below with the use of a 1.06MW_{el} engine and a 4.5MW_{el} engine:

- 2MW ICE – 2 x 1.06MW_{el} engines
- 45MW ICE – 10 x 4.5MW_{el} engines
- 90MW ICE – 20 x 4.5MW_{el} engines

As aforementioned the CAPEX below considers the equipment cost only, which represented 40% - 50% of the total installed cost. As the CAPEX are priced per engine, this leads to the following indicative CAPEX pricing for each considered demand:

- 2MW ICE CAPEX – £1.3 million (2 x 1.06MW_{el} engines @ £650,000)
- 45MW ICE CAPEX - £17.5 million (10 x 4.5MW_{el} engines @ £1,750,000)
- 90MW ICE CAPEX - £35 million (20 x 4.5MW_{el} engines @ £1,750,000)

For the OPEX, the budget considerations for ICE provided by Clarke Energy are displayed in Table 5 below.

Table 5: O&M Cost (10 year Contract) - 2MW_{el} & 4.5MW_{el} Solutions

[redacted]

These budget considerations provided lead to the following indicative OPEX pricing calculation as shown in Figure 16 below.

[redacted]

Figure 16: ICE OPEX Pricing Calculation

8.3 Total Cost Comparison

The indicative costs for both SOFC and ICE are tabulated in Table 6 below for comparison.

Table 6: SOFC & ICE Cost Comparison

[redacted]

[1] CAPEX considers the equipment cost only, which represents 40% - 50% of the total installed cost

The cost per annum is also graphically represented in Figure 17 below, with the CAPEX cost split over 10 years as previously identified as the estimated lifespan before certain components need to undergo significant maintenance.

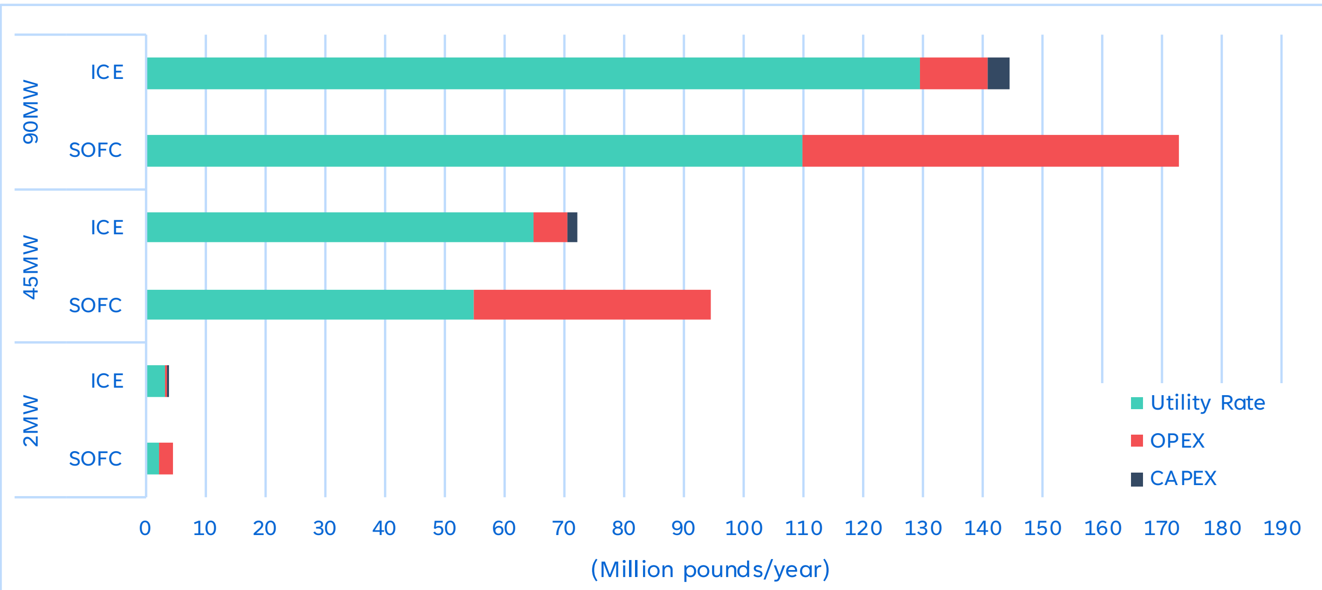

Figure 17: Utility Rate, CAPEX, & OPEX Costs Per Annum (CAPEX spread over 10 year period)

9 Gas Network Capacity

The gas network has a range of different pipelines, each transporting various amounts of gas at different pressure tiers. The pipeline and pressure tier selected to provide gas to the data centre will dictate how much electricity can be generated – the more gas that can be provided, the more electricity may be produced. Each pipeline has varying pressure and therefore varying energy density at constant temperature. This is illustrated in Figure 18 below.

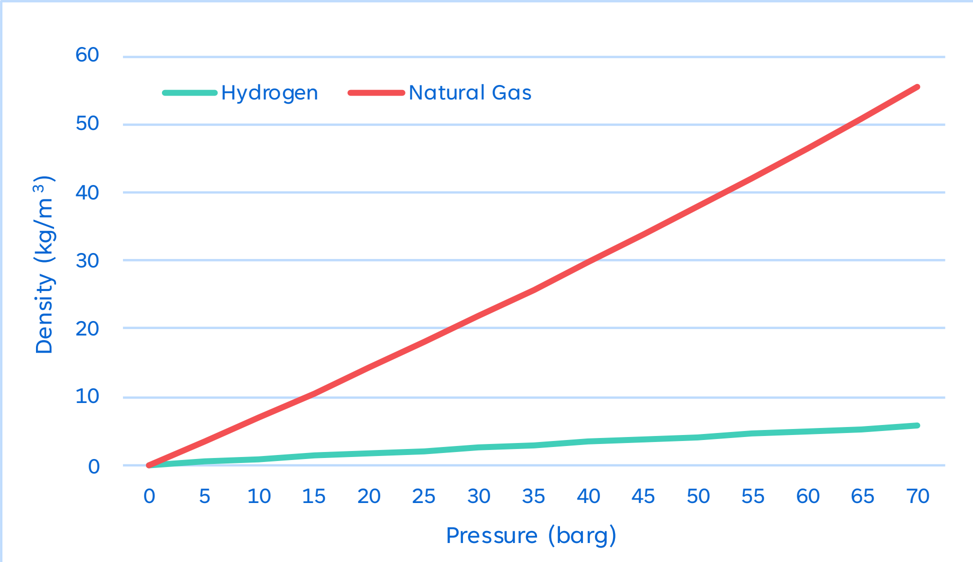

Figure 18: Density & Pressure of Hydrogen & Natural Gas at 15°C (Ref 43)

A variety of flowrates is therefore calculated to meet different desired electrical capacities and is shown in Table 7 below. This will help indicate what size of pipeline is required based on the requirement of gas at standard volume to enable the desired electrical capacity. Standard conditions taken at 1 bar and 15°C (Ref 44).

This calculation considers a 5% blend of H_2 in the gas network. The calculation of these values may be found in Appendix B and an example calculation is shown in Figure 19 below.

Table 7: Flowrate Requirement (Considering 5% H_2 Blend) for Desired Electrical Capacity

(scm/hr)	$1MW_{el}$	$2MW_{el}$	$10MW_{el}$	$20MW_{el}$	$40MW_{el}$	$60MW_{el}$	$80MW_{el}$	$100MW_{el}$
SOFC	191	382	1,909	3,819	7,637	11,456	15,274	19,093
ICE	253	506	2,530	5,060	10,119	15,179	20,239	25,298

Natural Gas Calorific Value	$NG_{CV} := 55 \frac{MJ}{kg}$	
Natural Gas Density	$NG_{\rho} := 0.67 \cdot \frac{kg}{scm}$	
Natural Gas Heating Value	$NG_{HV} := NG_{CV} \cdot NG_{\rho}$	$NG_{HV} = 36.9 \frac{MJ}{scm}$
Hydrogen Calorific Value	$H2_{CV} := 142 \frac{MJ}{kg}$	
Hydrogen Density	$H2_{\rho} := 0.08 \cdot \frac{kg}{scm}$	
Hydrogen Heating Value	$H2_{HV} := H2_{CV} \cdot H2_{\rho}$	$H2_{HV} = 11.4 \frac{MJ}{scm}$
Gas Mixture Heating Value	$GM_{HV} := (95\% \cdot NG_{HV}) + (5\% \cdot H2_{HV})$	$GM_{HV} = 35.6 \frac{MJ}{scm}$
Desired Electrical Capacity	$El_{cap} := 1\ MW$	
Beginning of Life (BOL) electrical fuel efficiency of SOFC	$SOFC_{eff} := 53\%$	
Required Flowrate	$Q := \frac{\left(\frac{1}{SOFC_{eff}} \cdot El_{cap}\right)}{GM_{HV}}$	$Q = 191 \frac{scm}{hr}$

Figure 19: Flowrate Requirement (Considering 5% H_2 Blend) for 1MW Electrical Capacity Using SOFC

The availability of the gas network to meet the individual data centre demands is site specific as eluded to above – dependant on the rated pressure of the line selected for offtake. There are also a number of other factors that dictate the capacity of flowrate that may be provided by the selected line. These include:

- Mains diameters;
- Mains layout;
- Existing demand on system (both upstream and downstream of data centre connection);
- Location of demands relative to supply points (offtakes, PRIs (Pressure Reduction Installation), district governors) or extremities;
- Location of the new data centre demand being added.

10 Case Studies

To determine the sites for the case study assessments, WWU's and SGN's gas infrastructure network GIS data (see Figure 5 and Figure 6) was mapped against the locations of all existing operational UK DCs. Several factors were considered as part of the site selection, including peak MW capacity of the DCs, DC form, proximity to the gas network, and size and pressure tier of nearby gas infrastructure.

Industry-standard conversion tables were used to convert the size and pressure of the gas pipework to a maximum "Benchmark Gas Capacity" flowrate able to be provided by the pipework. Following engagement with the WWU and SGN Network Planning teams to agree on conversion factors, these flow rates were converted into the MW_{el} power output deliverable by the SOFC and ICE engines, as outlined in Section 9. This process effectively established a benchmark MW_{el} peak power capacity for each pipe segment in the network.

It should be noted that this method should be considered as indicative and high-level only and does not constitute formal confirmation of suitable, or available, gas capacity of any part of the gas distribution networks – this can only be confirmed by the gas distribution networks themselves following a detailed network modelling study that incorporates several factors that are not considered in this study (e.g. pipework pressure variations, demand fluctuations, historic network usage etc.)

10.1 Case Study Archetypes

Optimum case study sites locations were selected based on several factors, including MW_{el} requirements, type of DC, proximity to suitable gas pipework, region of location, and engagement to date. Although 95 DCs were initially identified as being within 1km of WWU and SGN's medium-pressure infrastructure, the significant majority of these had no available gas pipework nearby able to provide the peak MW power of the facility, determined from the initial pipeline benchmarking exercise. As a result, the available case study sites were reviewed and three discrete archetypes were identified that would provide a varied output of analysis, based on the data centre form, size, gas network operator, and potential use case of a future hydrogen-based network

10.1.1 Edge Data Centre (1-2MW)

The Edge Data Centre archetype accounts for the majority of established data centres in the UK and are typically located on the edges of urban areas with good access to fibre and power. These are often in industrial or commercial centres, either hosted within retrofitted industrial units or in smaller purpose-built buildings. Peak load requirements are varied, as they typically opt to procure as much available capacity from the existing nearby electricity network, rarely having dedicated primary substations supplying them.

10.1.2 Multi-building Campus (30-50MW)

Multi-building Campuses are an increasingly common data centre archetype, with data centre developers looking to build out large, bespoke sites across purpose-built developments. Campuses are increasingly attractive sites for larger Cloud customers who require extra resilience, as the different buildings typically have multiple diverse electricity supplies to allow continued operation in the case of local building or electricity grid network failure. Campuses are largely sited near London or the M4 corridor to be geographically closer to the bulk of customer requirements, with many located within large technology parks.

10.1.3 Hyperscale support – partial power provision (30-50MW)

Whilst Hyperscale data centres typically require power loads above 100MW, several Hyperscale sites were identified near gas infrastructure that would be insufficient to provide full primary power provision, but could provide a proportion of the required load. This supporting load could be beneficial for multiple reasons: Hyperscale data centres are in very high demand, but are facing significant constraints and delays to getting the full power provision needed from the electricity grid, and having multiple sources of power provision for the data centre could increase resilience to outages compared to a single power source.

10.1.4 Future Hyperscale (100MW+)

As discussed in the Industry Review, there is already precedent for supplying Hyperscale data centres entirely separate from national electricity grids, with sites in North America currently utilising hydrogen, gas, and nuclear as their primary power source. Although there were few sections of the WWU and SGN gas networks identified in our study currently suitable to provide such volumes to existing Hyperscale sites, it is anticipated that gas network demand will be changing toward the middle of the century that would allow large-scale connections such as this to be more feasible. The potential for fully renewable green hydrogen fuel provision via the networks presents a significant opportunity for data centre operators to meet their net-zero commitments. This approach would require storage and the generation of green hydrogen from renewable sources, transferring generated electrons from one location to another in the form of molecules. By using the gas network to transport electrons as molecules, renewable energy and hydrogen can be produced at optimal locations, while the network efficiently delivers the gas to the ideal data centre sites. This also removes the need to site data centres near existing electricity infrastructure, enabling development in previously unfeasible locations, particularly in historic industrial regions.

10.2 Case Study Assumptions and Exclusions

For the case study analysis, we have provided a high-level assessment of likely costs for SOFC & ICE provision, land requirements, and gas network availability, utilising the assumptions and technology information provided in the sections above. We have not included a comprehensive assessment of all relevant factors as that would be considered site-specific (e.g. off-site works, on-site civils and site preparation works, gas pressure-reduction skids, plant controls, network diversions, HSE requirements, back-up power supplies, planning requirements etc).

An electrical-power counterfactual assessment would also be site-specific, and are discounted due to the selected case study sites already being connected to the electricity grids, and with electricity utility costs varying significantly depending on scale and location of supply. However, consideration should be given to the costs and space allowance of a new electrical connection for comparison - primary substations supplying 20-40MW typically require a 40m x 40m land parcel at a cost of ~£2m, with larger hyperscale-suitable bulk supply substations requiring 70m x 90m, at costs of £20-50m. Cable routes will also need to be considered, with buried 132kV cabling requiring 10-15m easement corridor widths potentially sanitising parts of a site. In comparison, high pressure pipelines typically require minimum 3m easement distances either side of the pipe, with significant occupied building proximity distances varying depending on building occupancy.

11 Edge Data Centre (1-2MW$_{el}$)

11.1 Pulsant - Reading East

Pulsant's 2MW "Reading East" site was considered for the 1-2MW$_{el}$ case study due to their engagement and proximity to gas network infrastructure. A 1-2MW$_{el}$ data centre running for 24 hours will consume the same amount of electricity as 9-18 average UK households consume in a year.

Through engagement with the network operator, it was confirmed this 2MW$_{el}$ connection is not considered significant and will require no additional reinforcement for connection to either the MP (medium pressure) or IP (intermediate pressure) mains nearby. As this is still in close proximity to the HP (high pressure)/IP/MP regulator, both the MP and IP mains will have the required capacity for the connection, with minimal new mains lay to the site. This is illustrated in Figure 20 below with the associated gas flowrate required in Table 8 below.

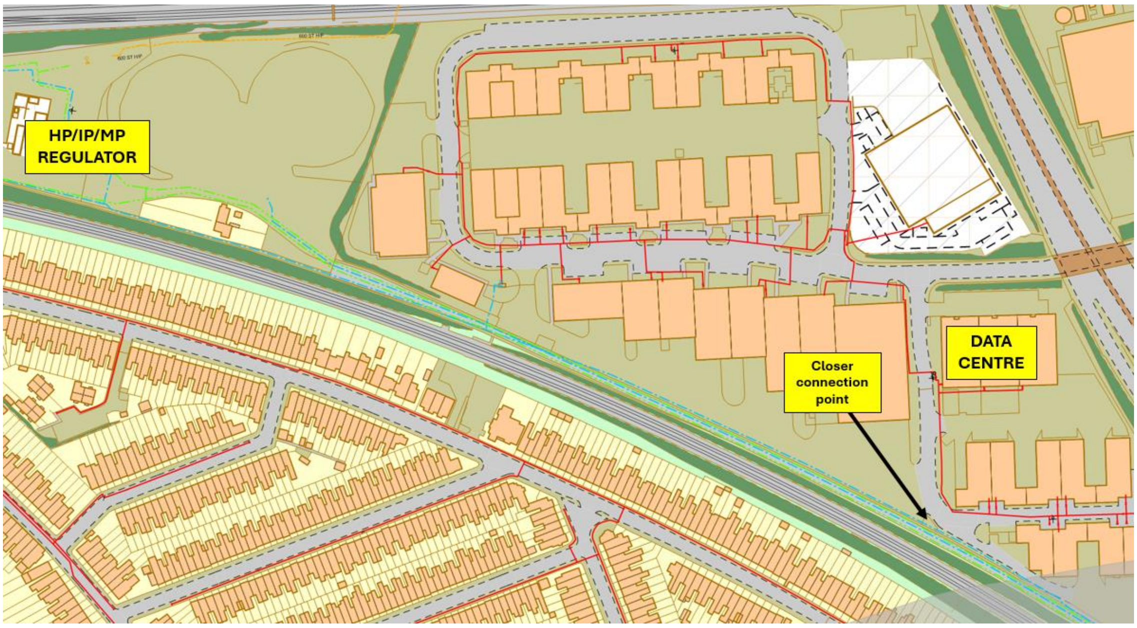

Figure 20: Pulsant Reading East Network Geography

Table 8: Flowrate Requirement (Considering 5% H_2 Blend) for 1-2MW$_{el}$

	1MW$_{el}$ (scm/hr)	2MW$_{el}$ (scm/hr)
SOFC	191	382
ICE	253	506

11.2 Primary Power

Table 9 below considers the cost to utilise SOFC and ICE for a 2MW$_{el}$ primary power solution. This does not consider the cost of a CHP or CCS solution as that would be provided by the plant designer downstream of the primary power solution.

Table 9: 2MW$_{el}$ Primary Power Cost Comparison

	CAPEX	OPEX (per annum)	Utility Rate (per annum) [3]	Whole Life Cost (10 year)
SOFC	£0 [1]	£2.1 mil	£2.4 mil [4]	£45 mil
ICE	£1.3m [2]	£0.4 mil	£3.2 mil [5]	£37.3 mil

[1] No CAPEX required for SOFC as it is a lease agreement to use the technology

[2] 2 x 1.06MW$_{el}$ engines @ £650,000 excluding works (typically the unit is 40 to 50% of the total build cost)

[3] 7.4p/kWhr$_{th}$ – Business gas rate for large business (65,000+ kWhr$_{th}$ per year) (Ref 40)

[4] 53% electrical efficiency (Ref 41)

[5] 40% electrical efficiency (Ref 42)

11.3 Land Requirements

The land requirements for an SOFC solution are very flexible. Because SOFC solutions are built up in modular fashion, each 0.65MW$_{el}$ server module can be positioned or stacked in the most space efficient manner. An illustration of how these server modules could be stacked up and arranged is shown in Figure 21, Figure 22, & Figure 23 below (units in ft and inches).

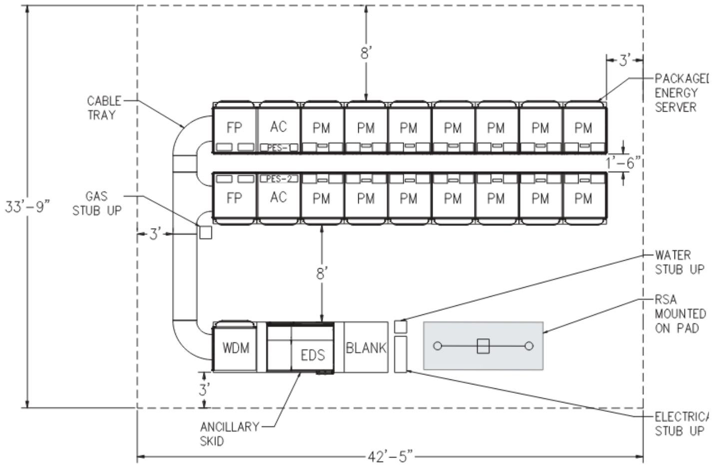

Figure 21: 0.65MW$_{el}$ Primary Power Layout

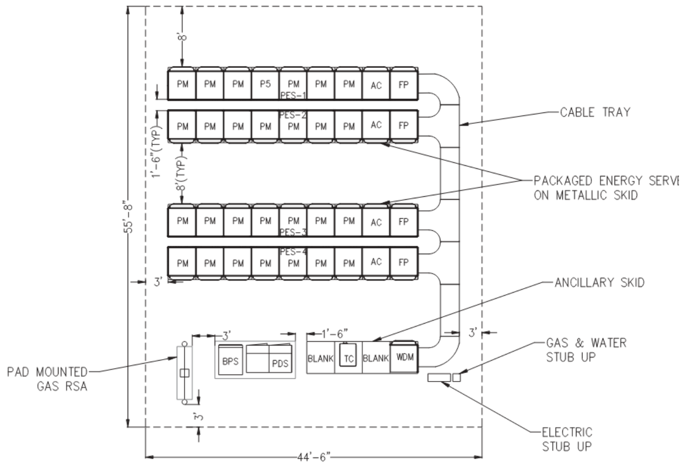

Figure 22: 1.3MW$_{el}$ Primary Power Layout

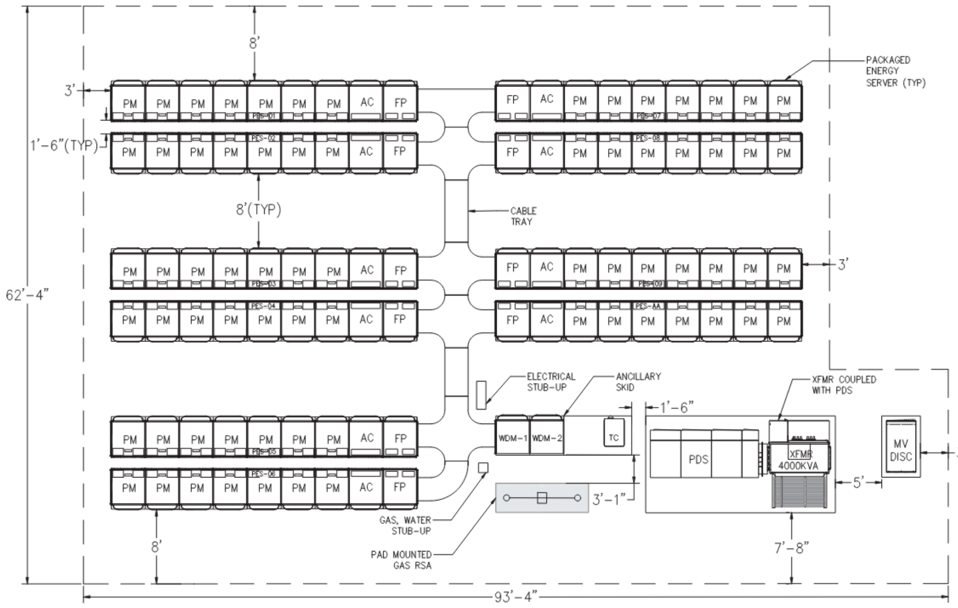

Figure 23: 3.25MW$_{el}$ Primary Power Layout

These solutions have the following footprints:

- 0.65MW$_{el}$ – 10.3m x 13m (134m^2)
- 1.3MW$_{el}$ – 17m x 13.6m (231m^2)
- 3.25MW$_{el}$ – 19m x 28.5m (542m^2)

The 2MW$_{el}$ ICE containerised solution will require a 14.8m x 4m (59m^2) footprint. An image of the containerised solution is shown in Figure 24 and full details of the containerised solution may be found in Figure 35 in Appendix C.

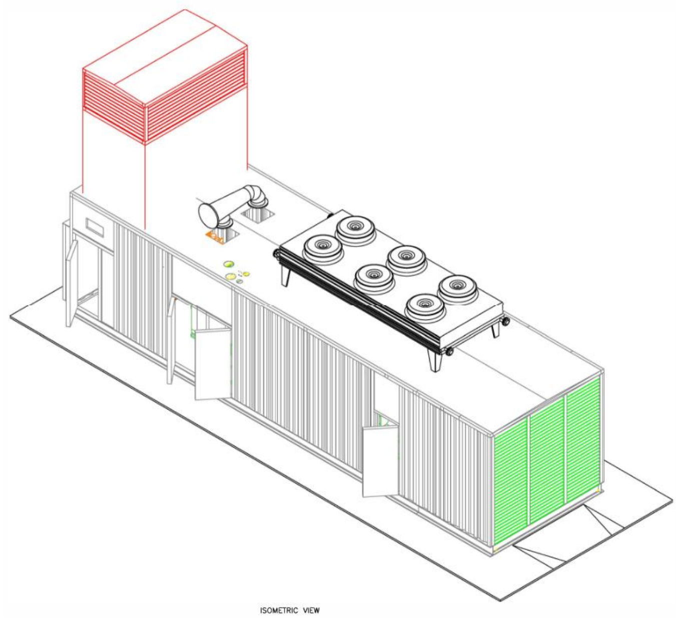

Figure 24: ICE 2MW$_{el}$ Containerised Solution

The ICE containerised solution has a smaller footprint than all of the SOFC options:

- 2MW$_{el}$ ICE containerised solution - 59m^2
- 0.65MW$_{el}$ SOFC – 134m^2 (+227%)
- 1.3MW$_{el}$ SOFC – 231m^2 (+391%)
- 3.25MW$_{el}$ SOFC – 542m^2 (+919%)

12 45MW$_{el}$ Data Centre

The Campus and Hyperscale Support archetypes have been considered simultaneously here as the on-site gas connection requirements would be similar, regardless of proximity or use case.

12.1 Digital Realty – Redhill Campus

Digital Realty's "Redhill" campus was considered for the 45MW$_{el}$ full power provision case study. This campus consists of 3no. adjacent data centres, each requiring ~15MW. A 45MW$_{el}$ data centre running for 24 hours will consume the same amount of electricity as 400 average UK households consume in a year.

Due to this being a significant demand a complete analysis would need to be complete by the gas network in order to determine the feasibility. The network operators outlined their primary considerations:

- The length of mains required for connection causes more complexity than ensuring the network has sufficient capacity (~2.5km of HP mains if connecting to HP line)
- There is a potential 24" MP connection point approx. 800m to the east (Figure 25 below)
- This is a very large connection for a MP network, but the mains here are large diameter and based on high-level modelling should be able to sustain the required demand

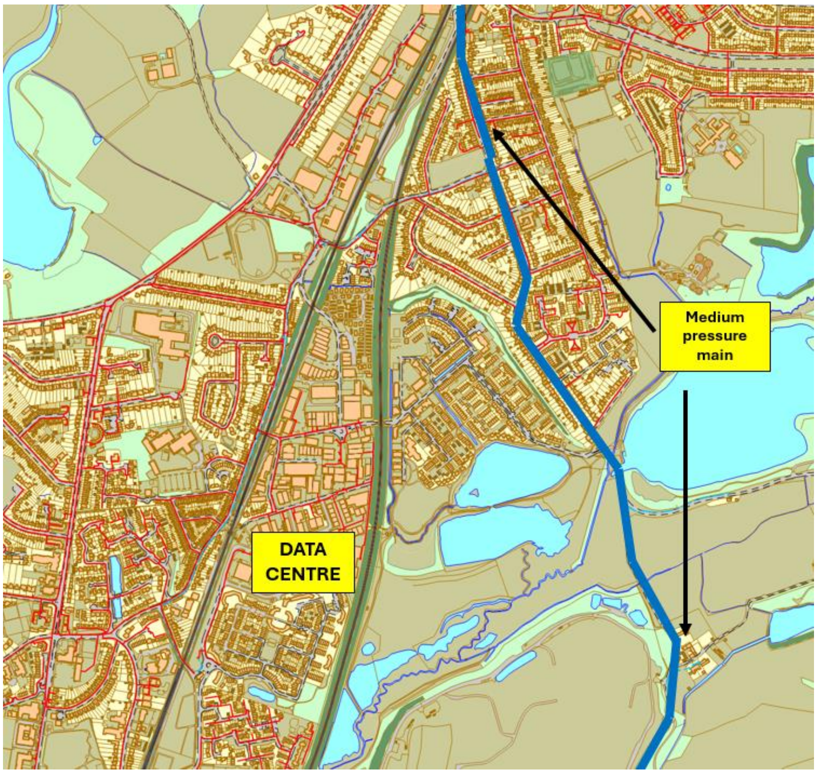

Figure 25: Digital Realty Redhill Network Geography

Table 10: Flowrate Requirement (Considering 5% H_2 Blend) for 45MW$_{el}$

	45MW$_{el}$ (scm/hr)
SOFC	8,592
ICE	10,119

12.2 Vantage – Cardiff

Vantage's "Cardiff CWL1" Hyperscale facility was considered for the $45MW_{el}$ supplementary power provision case study. This campus has a number of operational units, and is expanding with several more, connecting to newly installed electrical infrastructure for the newer units, with a total requirement of 150MW anticipated when completed. A $150MW_{el}$ data centre running for 24 hours will consume the same amount of electricity as 1,333 average UK households consume in a year.

The IP system local to the site can accommodate the demand without any major reinforcement required on the line. Following engagement with the network operator, it was noted that there is potential to increase the load due to historic nearby high-demand users no longer utilising much of the capacity on the nearby HP main, meaning the gas network could provide a much higher power provision to the data centre than would be typical for this pipe size/pressure, potentially up to ~$200MW_{el}$, but this would require further network analysis to confirm.

Figure 26 - Vantage Cardiff Network Geography

12.3 Primary Power

Table 11 below considers the cost to utilise SOFC or ICE for a $45MW_{el}$ primary power solution. This solution may be used to provide full power provision, replacing an electricity grid connection, or supplementary primary power provision to reduce the price of peak electricity demand. This does not consider the cost of a CHP or CCS.

Table 11: $45MW_{el}$ Primary Power Cost Comparison

	CAPEX	OPEX (per annum)	Utility Rate (per annum) [3]	Whole Life Cost (10 yr)
SOFC	£0 [1]	£39.4 mil	£55 mil [4]	£944 mil
ICE	£17.5m [2]	£5.7 mil	£64.9 mil [5]	£723.5 mil

[1] No CAPEX required for SOFC as it is a lease agreement to use the technology

[2] 10 x $4.5MW_{el}$ engines @ £1,750,000 excluding works (typically the unit is 40 to 50% of the total build cost)

[3] $7.4p/kWhr_{th}$ – Business gas rate for large business (65,000+ $kWhr_{th}$ per year) (Ref 40)

[4] 53% electrical efficiency (Ref 41)

[5] 45% electrical efficiency (Ref 45)

12.4 Land Requirements

An indicative footprint for a $50MW_{el}$ SOFC solution is shown in Figure 27 below. As aforementioned the SOFC footprint is very flexible, and this is demonstrated below with the multi-level arrangement allowing for a smaller footprint. The indicative footprint below has a 96m x 24m (2,304m[2]) footprint.

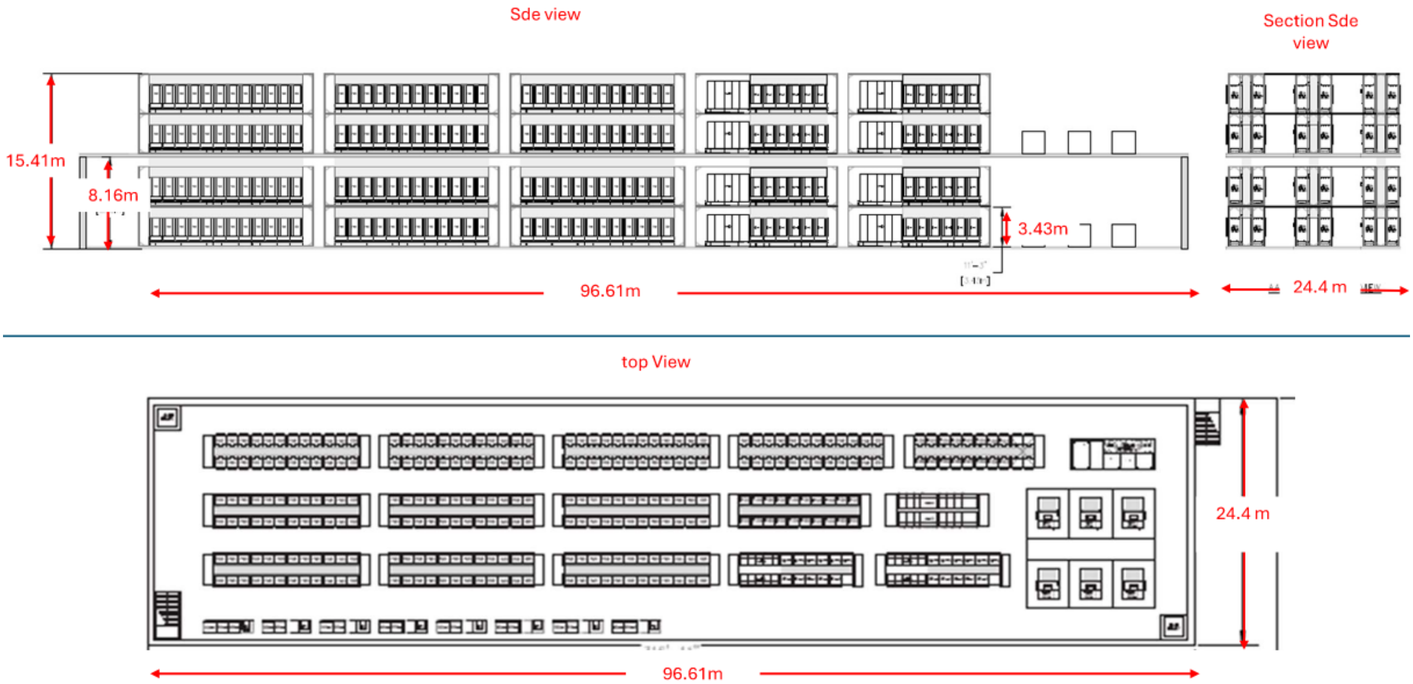

Figure 27: $50MW_{el}$ Primary Power Layout

The larger ICE solutions utilise multiple $4.5MW_{el}$ engines to build up to the desired capacity and these built up solutions are called Powerhouses. An example of two powerhouse's is shown in Figure 28 below.

Figure 28: 5 Engine Powerhouse (Top), 11 Engine Powerhouse (Bottom)

The details of a typical 5 engine 22.5MW_{el} powerhouse layout may be found in Appendix C. This typical 5 engine powerhouse may be increased in size pro-rata like shown in Figure 28 above. As such a 45MW_{el} solution would require double the number of engines of the typical 22.5MW_{el} powerhouse meaning the estimated footprint of the powerhouse would be 50m x 25m (1,250m^2). This estimate does not include surrounding areas for access roads and additional plant and/or coolers if ground mounted as illustrated in Appendix C.

Again, the Powerhouse solution has a smaller footprint than the SOFC indicative option provided:

- 45MW_{el} ICE Powerhouse – 1,250m^2
- 50MW_{el} SOFC Solution - 2,304m^2 (+184%)

Furthermore, all the engines within the powerhouse can be turned down if required by 10%-15%. As such this 45MW_{el} solution may also be used effectively to supply a 38MW_{el} - 40MW_{el} demand, without attracting low load negative effects such as: reduced efficiency, potential for component damage due to incomplete combustion, build-up of deposits on engine parts like valves and piston rings, and increased wear and tear on the engine as the combustion process becomes less controlled at low cylinder pressures.

13 Future Hyperscale Data Centre

The “Future Hyperscale” data centre archetype considers a proposed data centre situated where there is a suitable gas connection, but no electricity grid connection is possible. This gas connection could be a redundant pipeline due to a reduction of national gas users, or a purpose-built line to deliver significant amounts of power (e.g. >100MW_{el}) to a specific end user. This could be nearby gas injection sites, such as gas transmission infrastructure, LNG terminals, or hydrogen-production facilities.

With Hyperscale data centres leading the industry both as a growing sector and in terms of per-plot power demands, it is anticipated that the opportunity for feasible, accessible, resilient, low-carbon, and abundant power provision from the gas networks would be particularly attractive to future Hyperscale operator and developers.

Though the carbon, resilience, and accessibility aspects are currently reliant on resolving regulatory and gas network barriers in the long-term (e.g. upgrading the gas network to allow a 100% hydrogen blend, agreeing and ensuring power provision up-time standards and resiliency, streamlining policy for large on-site gas-fed power generation), the direction and progress in addressing these hurdles are positive both globally (with the increasing precedent of gas-powered DCs) and within the UK (with the progress the gas networks are making in their pipeline replacement programmes and hydrogen trial schemes).

In the nearer term, the aspects of feasibility and abundancy are already likely achievable. The technology needed to generate suitable large volumes of power from a gas network is already well-established, with several commercial products and vendors available to design and procure ‘off-the-shelf’ solutions with. The capacity of the gas network, unlike the electricity network, is anticipated to become more available over time as domestic and electrified-industry demand reduces, and as the physical infrastructure is already well distributed in industrial and edge-of-town regions where Hyperscale data centre developments are well-suited. As such it is anticipated that in certain areas Hyperscale facilities will not require significant civils and engineering works to connect to the existing gas networks. The Vantage case study above is evidence of this potential ease-of-accessibility, with the adjacent IP network already likely able to accommodate up to 200MW_{el} without any reinforcement works or connection to the HP network.

14 100% Hydrogen Gas Network

This study has considered H_2 ready technologies and a 5% H_2 blend to outline the feasibility of hydrogen inclusion in the gas network. A 5% H_2 blend may be considered minor as technology and infrastructure does not require significant amendments and modifications to accept the blend. 100% hydrogen adoption in the gas network would however require further considerations as explored below.

14.1 Hydrogen Purity

100% hydrogen arriving by pipeline (the gas network) will require purification to be made suitable for use in the fuel cells. This is because hydrogen will be odorised in a similar way to natural gas is and could pick up contaminants from the network. It is anticipated that hydrogen will be transported through the network at heat-grade (98% purity) which is suitable for ICE. Fuel cells however require 99.9% purity to prevent damage to the fuel cell. This is achieved using processes such as pressure swing adsorption to remove contaminants before the transported hydrogen enters the fuel cell.

Pressure swing adsorption is one method for hydrogen purification which uses adsorbent materials to selectively remove impurities from hydrogen-rich gas streams. This typically has an 85% recovery rate meaning 15% of the transported hydrogen is discarded (this 15% may be utilised for other energy generation such as CHP). This means that if using fuel cells within a 100% hydrogen gas network, this will require 15% more hydrogen compared to the ICE which can utilise 100% of the transported hydrogen without purification.

As discussed in section 8.1, the fuel cell has a higher electrical efficiency compared to the ICE, but the fuel cell can only utilise 85% of the hydrogen transported when considering 100% hydrogen due to the purification requirements. This will therefore bring the fuel cell efficiency down from 53% to 45%, which then aligns with the ICE electrical efficiency using 100% hydrogen.

There are other technologies that can be used for hydrogen purification such as polymer membranes, palladium membranes and cryogenic separation. A number of these are being developed to support potential hydrogen deblending and hydrogen fuel cell use in the future. Some of the solutions are not yet commercially available (low Technology Readiness Level). The solutions are suited to different applications based on the hydrogen content in the feed gas and the required hydrogen purity that needs to be achieved. The solutions also operate at different pressures and temperatures, some requiring the feed gas to be compressed and heated. The solutions have different hydrogen recovery rates and can be combined (e.g. membranes + PSA) to meet the needs of a specific application.

14.2 Hydrogen Energy Density

As seen in Figure 18 previously, hydrogen has a much lower density than natural gas. Subsequently hydrogen also has a lower volumetric energy density than natural gas, 11 MJ/m^3 compared to 39 MJ/m^3 respectively. This means higher volumes of gas (around 3 times more) are required to produce electricity when approaching 100% hydrogen in the gas network. This is illustrated in Figure 29 below with a sample calculation of the required flowrate for 100% hydrogen also shown in Figure 30 below.

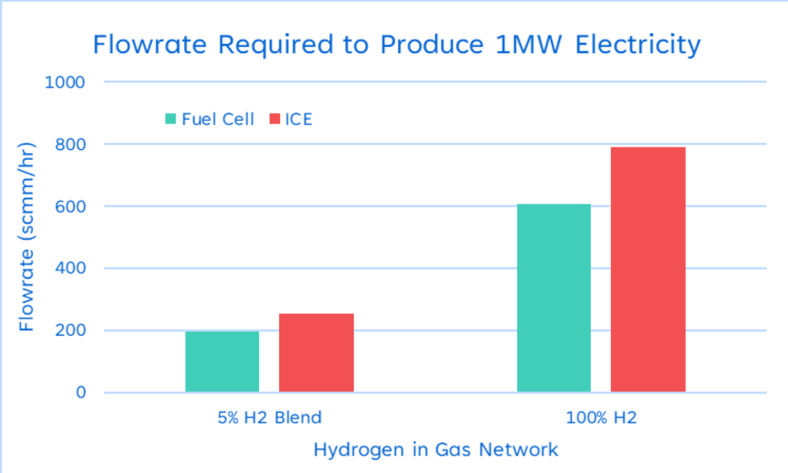

Figure 29: Discrepancy in flowrate required when introducing hydrogen to gas network

Hydrogen Heating Value	$H2_{HV} := 11 \frac{MJ}{scm}$	
Desired Electrical Capacity	$El_{cap} := 1\ MW$	
Beginning of Life (BOL) electrical fuel efficiency of SOFC	$SOFC_{eff} := 53\%$	
Required Flowrate using NG	$Q_{H2} := \frac{\left(\frac{1}{SOFC_{eff}} \cdot El_{cap}\right)}{H2_{HV}}$	$Q_{H2} = 617 \frac{scm}{hr}$

Figure 30: Sample Calculation of Flowrate Required to Produce $1MW_{el}$ using 100% Hydrogen

14.3 Cost of Hydrogen

The cost of hydrogen in the UK is a topic of much importance and discourse. There are numerous pieces of work strategising how to reduce the cost of hydrogen in the coming decade. A recent joint report by Renewable UK and Hydrogen UK sets out recommendations to utilise the large renewable energy potential in the UK to produce affordable green hydrogen. The price of electricity currently represents around 70% of the final cost of green hydrogen as illustrated in Figure 31 below, so utilising cheap renewable energy in the future will bring the cost of green hydrogen down significantly. (Ref 46, Page 8).

However ultimately, wholesale prices for hydrogen do not exist at present so the future unit pricing for the gas network once hydrogen is introduced is hard to predict.

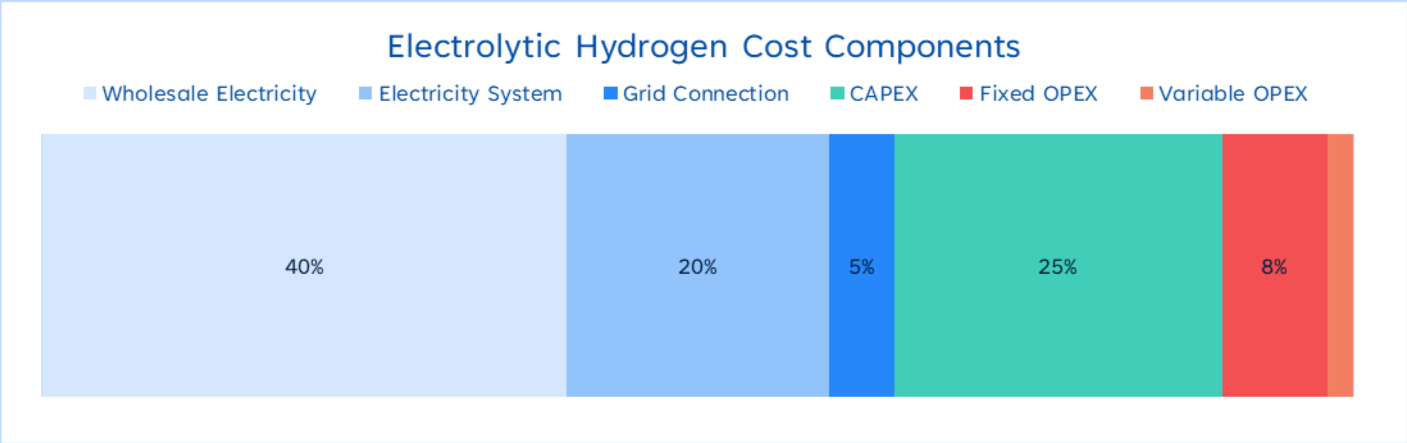

Figure 31: Electrolytic Hydrogen Cost Components (Ref 46, Page 8)

The relevance of this is the potential shift in utility rates when considering a 100% hydrogen gas network. Hydrogen may potentially be introduced at a premium compared to natural gas costs dependant to the cost landscape of hydrogen at the time. This may increase the utility rate for the end user or government subsidies and funding may offset these costs to promote the use of green hydrogen in the network.

14.4 Hydrogen End Users

If the gas network was to transition 100% hydrogen, consideration should be made to the shift in demographic of the end users. According to the Digest of UK Energy Statistics (DUKES), the sectoral consumption of natural gas in 2023 is shown in Figure 32 below.

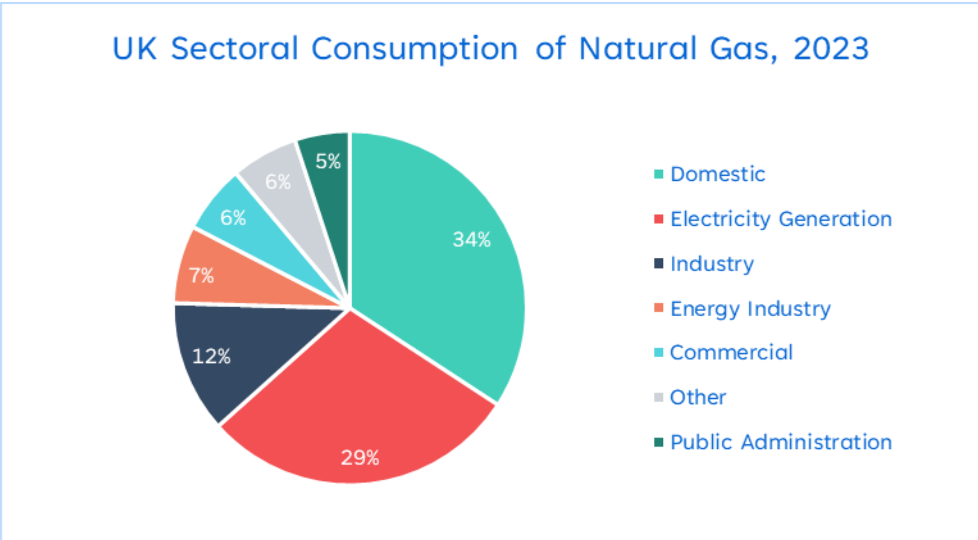

Figure 32: UK Sectoral Consumption of Natural Gas, 2023 (Ref 47, Chart 4.1)

In the UK the majority of natural gas is currently used by domestic users, closely followed by electrical generation, with industrial demand then consuming around half as much. As net zero strategies come into play, the above end users of natural gas will decrease (down to zero natural gas use in most strategies). These current end users may find other means of energy provision, electricity generation for example may be provided by offshore wind, or these end users will adapt to accept hydrogen from the gas network. As such the demographic of end users connected to a 100% hydrogen gas network will differ from a natural gas network.

The largest end users of a 100% hydrogen gas network can be extrapolated by studies conducted to forecast the biggest consumers of hydrogen if net zero strategies are followed. One such study is the Future Energy Scenarios report by the National Energy System Operator (NESO) which predicts the future low carbon hydrogen demand per sector (Ref 48).

In this report NESO focus on three potential pathways to achieving net zero emissions by 2050: (Ref 48, p20)

- **Electric Engagement**: Electrification-focused, driven by smart technologies and high renewable/nuclear capacities.
- **Holistic Transition**: Balanced approach using electrification and hydrogen, emphasising consumer engagement and gradual natural gas phase-out.
- **Hydrogen Evolution**: Hydrogen-centric, particularly for industry and heat, with significant reliance on hydrogen storage.

Using these three potential pathways NESO can present the low carbon hydrogen demand per sector for three future scenarios. This is illustrated in Figure 33 below.

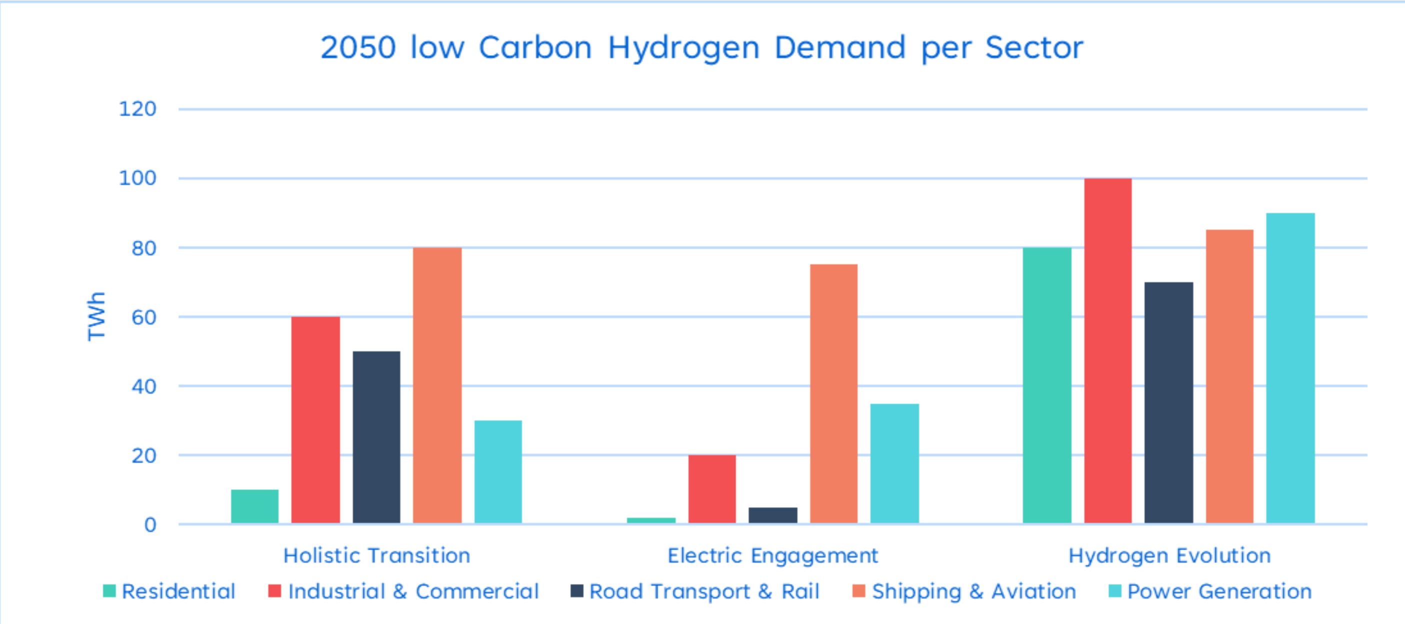

Figure 33: 2050 low Carbon Hydrogen Demand per Sector (TWh) (Ref 48, p103)

The difference between current gas network users and 100% hydrogen gas network users will likely be industrial demand becoming more dominant due to a potentially significant reduction of domestic users. This will have implications to the geographical demand on the network. Industrial users are often clustered together in industrial districts meaning the demand will be more geographically concentrated. Supplying hydrogen for transport (road, rail, marine, aviation) will also present a more concentrated demand at refuelling stations. This differs from the more discrete demand presented by domestic users.

15 Conclusion

15.1 Summary of findings

The Data Centre industry in the UK is a rapidly growing and nationally significant sector that is increasingly critical to the UK's growth and technology ambitions. The scale and form of data centres is shifting from a distributed model of smaller "edge" units to a market that demands larger and more centralised "hyperscale" facilities in regions that are facing significant electrical power constraints. Although there is international precedent for supplying data centre power primarily from alternative sources such as gas distribution networks, to date this has not been progressed in the UK, despite industry stakeholders indicating that they are willing to explore this alternative.

Our study highlights a range of possible options for different data centre archetypes within the study area, providing indicative cost and site requirements for each, as well as detailed technological solutions suitable for a variety of scales and applications, as highlighted in the selected case studies.

15.2 Opportunities and Constraints

Within the WWU and SGN regions alone, it is anticipated that there are several dozen existing data centres sites where a gas connection might be considered techno-economically suitable, and where a detailed feasibility study could be undertaken. Connection of these or future data centres to the gas network could:

- Improve timescales for energisation of new data centre facilities facing delays due to electricity network constraints;
- Allow data centre development in new regions near suitable gas infrastructure that have been limited by the availability of, proximity of, or cost to connect to the existing electricity network;
- Provide alternative industrial-scale off-takers for gas demand ahead of electrification, reducing the risk of having stranded assets;
- Utilise existing and well-established 'off-the-shelf' SOFC & ICE technologies;
- Make futureproofing allowances for replacing the incoming gas network fuel supply with a partial blend/100% hydrogen fuel mix to address operational carbon emissions;
- Co-locate the on-site gas-fired generation plant with suitable infrastructure for further carbon reduction or commercial benefits (e.g. carbon capture and storage, waste heat recovery and distribution, hydrogen electrolysis, electricity grid-balancing services).

Several items were raised as part of this study and stakeholder engagement, identifying issues that should be clarified before formally progressing with further feasibility studies of particular sites:

- The regulatory and planning landscape is very unclear, with uncertainty of how a gas connection would affect environmental impact assessments, electricity generation permitting, resilience/uptime certification, Health and Safety Executive consultation, and insurance requirements.
- The current carbon intensity of the gas network fuel is significantly higher than the electricity grid's carbon factors. Although a 100% green hydrogen fuel mix would address this, there are currently no firm plans from the gas network operators confirming when this would be completed, risking a significant increase in data centre operational emissions if carbon capture and storage plant is not incorporated.
- ICE and SOFC solutions are less suitable for Hyperscale data centre loads due to their land requirements, and whilst suitable modular solutions can be scaled up, the land area required for these options become

significant for high power demands. Gas-fired turbines can provide significant power volumes with relatively smaller footprints, but these are typically much more costly, less flexible in their output, and have lower efficiencies than ICE or SOFC solutions.

- Data centres require very stable and consistent power demands throughout the day, and so the varying linepack volumes of the gas network must be carefully managed to ensure that the required power outputs from the gas supply do not fluctuate.

15.3 Recommendations and Next Steps

This study has indicated that it is technically and systematically viable to supply power to a data centre from the gas network, and has determined economic estimates to do so for a number of scales and forms. Global precedent, UK data centre industry appetite and growth, gas infrastructure suitability, and cost analysis all shows positive indications for such a solution, but there are significant questions to be answered on customer requirements, regulatory constraints, and engineering details. To explore this issue in more detail, we recommend the following:

- The gas distribution networks should continue to engage directly with a data centre operator or developer, and develop a detailed engineering case study for an existing or upcoming data centre development. This should include a formal modelling exercise of the nearby gas infrastructure, a detailed exploration of resilience, supply, and land requirements for the site alongside a suitable technology vendor, and engagement with the relevant planning authorities to confirm the relevant regulatory requirements to meet.
- Data centre developers should consider co-locating additional technologies such as carbon capture and storage, and waste heat recovery alongside any future on-site power generation plant to maximise local efficiencies and emissions reductions.
- The gas distribution network operators should consider including data centre developments as potential large-scale industrial customers, particularly when developing new hydrogen network trials or gas injection projects such as the ongoing HyLine Cymru and H2 Caledonia schemes. This would help align the growing data centre industry trajectory alongside the gas distribution network's energy transition plans.

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Appendix A Stakeholder Engagement Register

Appendix B Pipeline Capacity Calculation

Natural Gas Calorific Value $NG_{CV} := 55 \dfrac{MJ}{kg}$

Natural Gas Density $NG_{\rho} := 0.67 \cdot \dfrac{kg}{scm}$

Natural Gas Heating Value $NG_{HV} := NG_{CV} \cdot NG_{\rho}$ $NG_{HV} = 36.9 \dfrac{MJ}{scm}$

Hydrogen Calorific Value $H2_{CV} := 142 \dfrac{MJ}{kg}$

Hydrogen Density $H2_{\rho} := 0.08 \cdot \dfrac{kg}{scm}$

Hydrogen Heating Value $H2_{HV} := H2_{CV} \cdot H2_{\rho}$ $H2_{HV} = 11.4 \dfrac{MJ}{scm}$

Gas Mixture Heating Value $GM_{HV} := (95\% \cdot NG_{HV}) + (5\% \cdot H2_{HV})$ $GM_{HV} = 35.6 \dfrac{MJ}{scm}$

Desired Electrical Capacity $El_{cap} := \begin{bmatrix} 1 & 2 & 10 & 20 & 30 & 40 & 50 & 60 & 70 & 80 & 90 & 100 \end{bmatrix} MW$

Beginning of Life (BOL) electrical fuel efficiency of SOFC $SOFC_{eff} := 53\%$

Electrical (Fuel) efficiency of ICE $ICE_{eff} := 40\%$

Required Flowrate $Q := \dfrac{\left(\dfrac{1}{\begin{bmatrix} SOFC_{eff} \\ ICE_{eff} \end{bmatrix}} \cdot El_{cap} \right)}{GM_{HV}}$

$$Q = \begin{bmatrix} 191 & 382 & 1909 & 3819 & 5728 & 7637 & 9547 & 11456 & 13365 & 15274 & 17184 & 19093 \\ 253 & 506 & 2530 & 5060 & 7589 & 10119 & 12649 & 15179 & 17709 & 20239 & 22768 & 25298 \end{bmatrix} \frac{scm}{hr}$$

Figure 34: Required Flowrate for Desired Electrical Capacities (Calculation) (40% ICE efficiency is conservative, larger engines may be more efficient)

Appendix C Power Solution Land Requirements

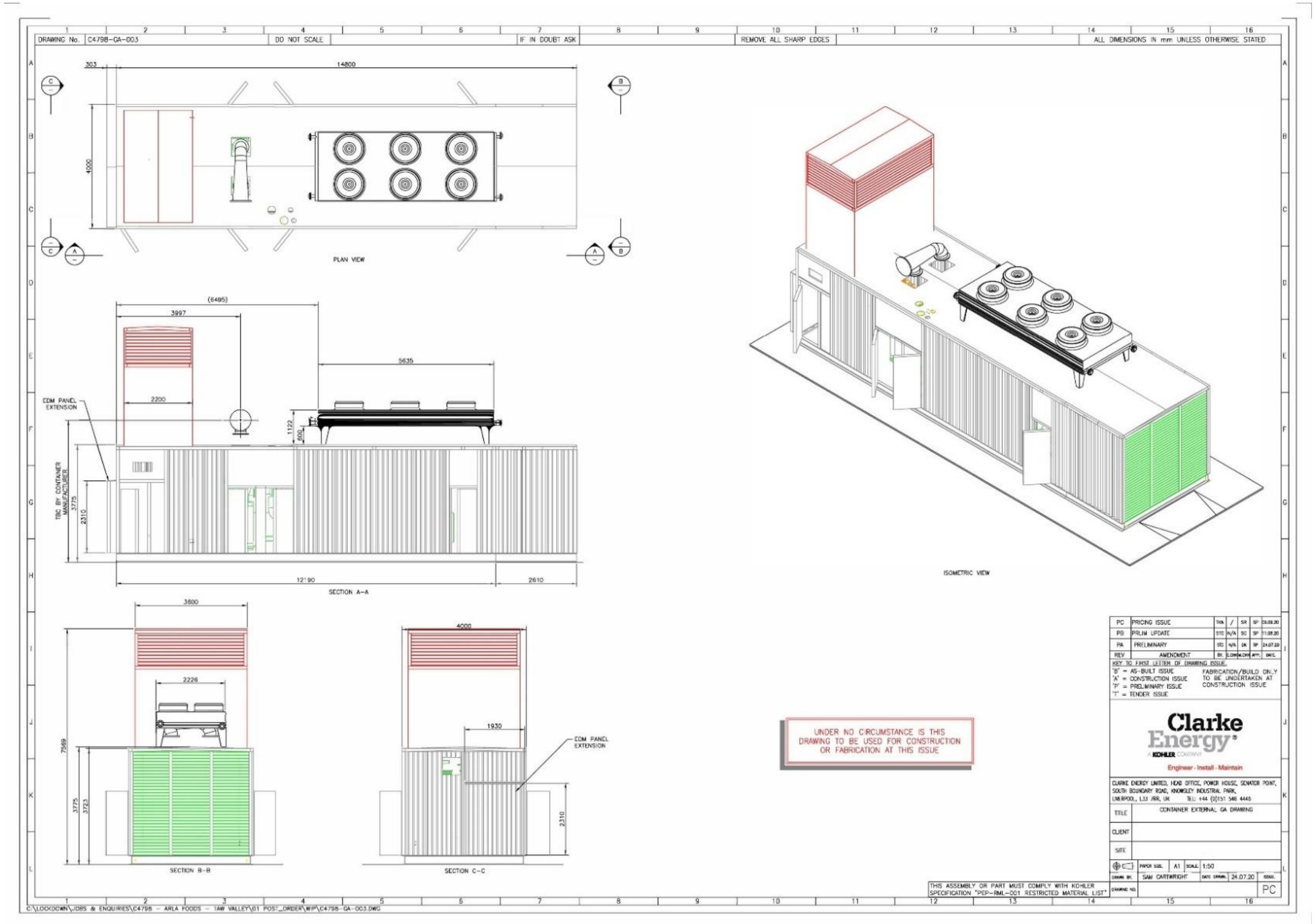

Figure 35: 2MW$_{el}$ ICE Containerised GA

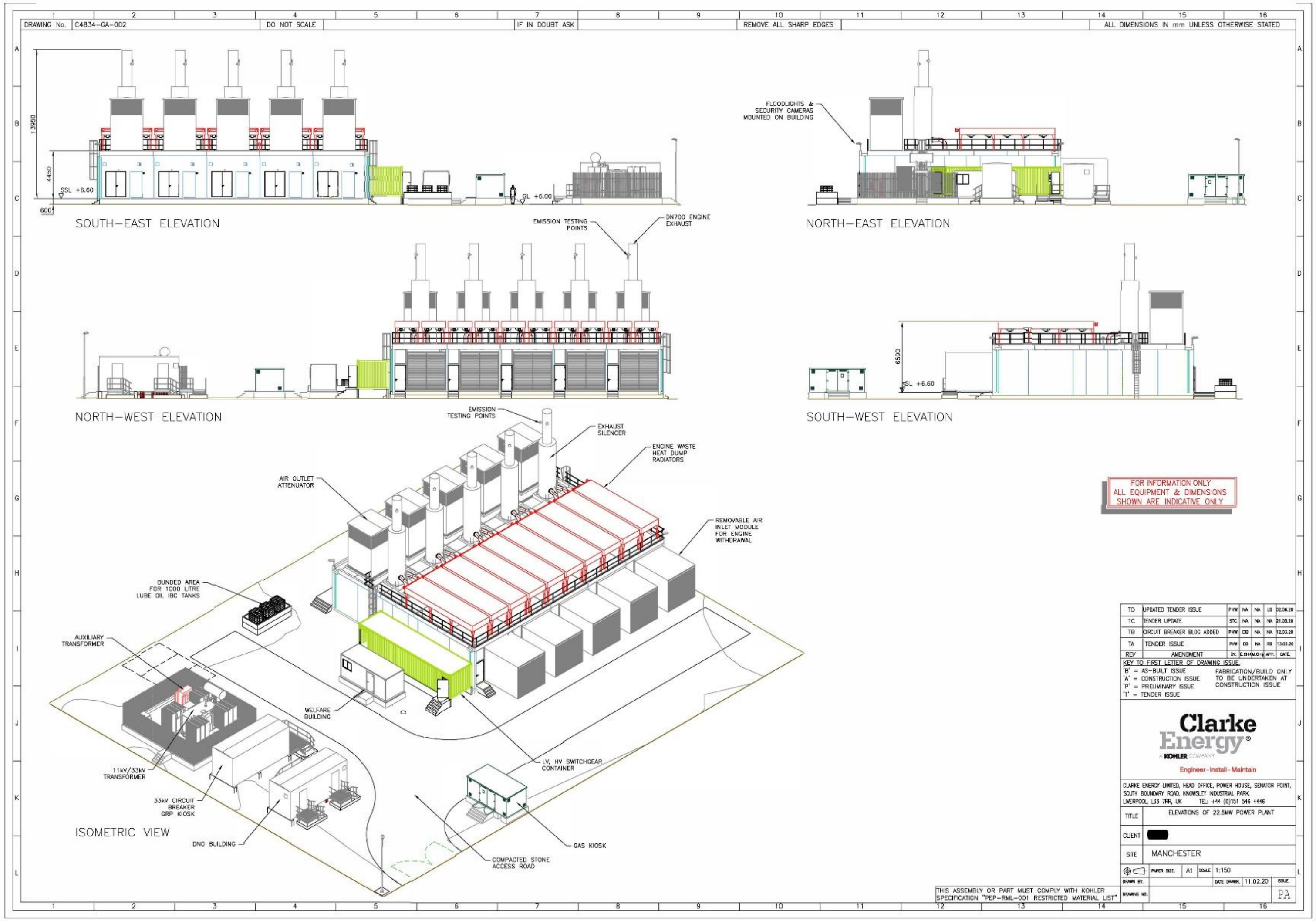

Figure 36: 22.5MW$_{el}$ Typical Powerhouse Layout

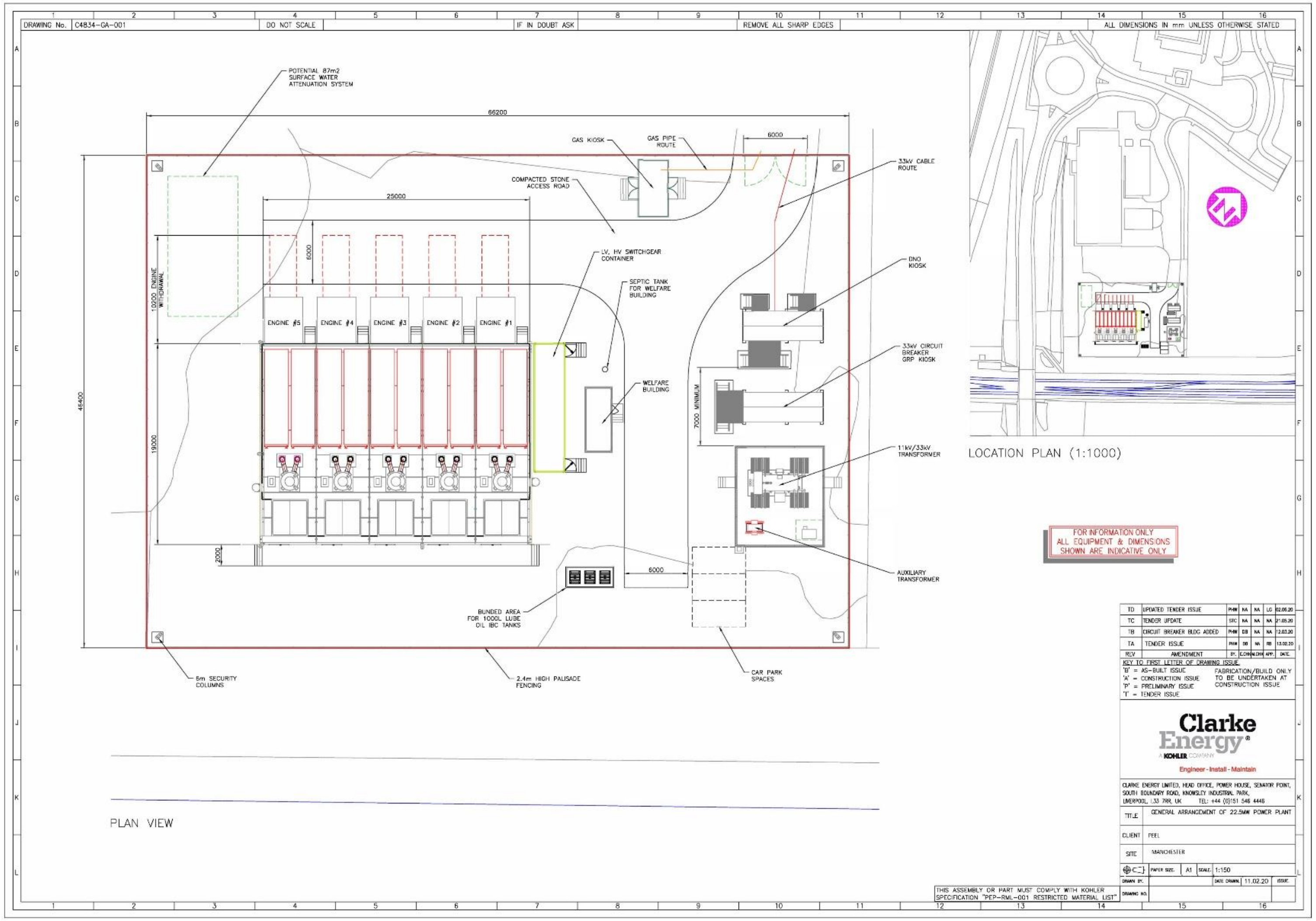

Figure 37: 22.5MW$_{el}$ Typical Powerhouse Layout - Plan

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