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The Case for Natural Gas Generators

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Executive Summary

This paper provides an overview of the main factors associated with fuel selection for standby generators.

It explores the available natural gas options and the confluence of features that influence decision-making associated with a particular technology. It examines how any decision to switch to an alternative fuel standby generator requires a shift in priorities and design paradigms.

By furnishing an evaluation of the emission benefits of natural gas standby generators coupled with an appraisal of energy storage systems at the local as well as grid level the paper gives data centre operators opportunities to satisfy ambitions for a reduced GHG solution.

Content

Introduction – Why do we need standby generators?

Most data centers are designed and constructed with the goal of achieving ongoing availability of the IT equipment and services they host. Since almost every business today is highly IT-dependent, data centers are considered mission critical and vital to successful operations. Because of the need for operational continuity, data centers share common design features, notably these include uninterruptible power supply (UPS) systems and standby[1] power generators.

IT equipment - servers, storage and networking devices – are considered sensitive electronic equipment, susceptible to damage from environmental factors including ambient temperature, gaseous and particulate emissions and, importantly, the quality of the supply power.

Generally, the IT load requires a constant, uninterrupted source of electricity to reliably maintain operation. Any loss of power, whether due to a complete utility outage or drop in acceptable levels of quality (voltage and/or frequency) - even for a short duration - is typically enough to cause the loss or corruption of data. This is illustrated by the ITIC curve (Information Technology Industry Council, formerly Computer and Business Equipment Manufacturers Association – CBEMA).

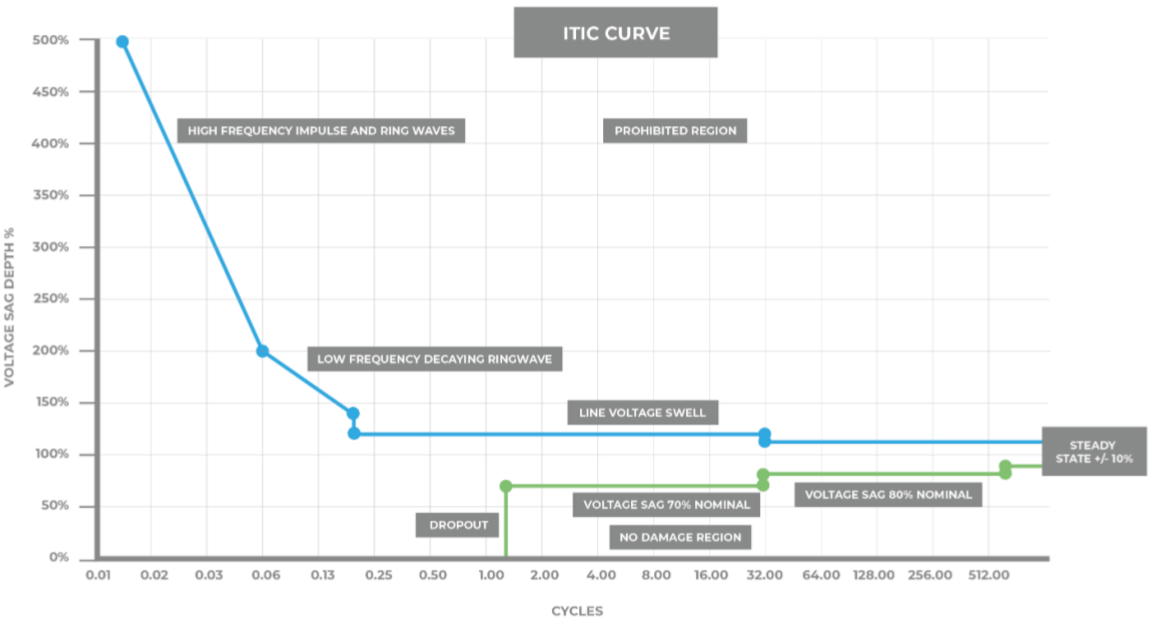

Figure 1: The ITIC Curve provides an AC Voltage boundary that IT equipment can tolerate or ride through

As can be observed from the curve, the voltage anomalies under consideration are evaluated on the basis of the duration of the event in cycles; in the US there are 60 cycles per second, a cycle is 16.67 ms. The range of acceptable operating voltages are bound between the blue and green curves (see Figure 1).

Anything above the line of the blue curve is likely to result in damage to the equipment in question, whilst anything below the green line is likely to result in unreliable operation but no damage.

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[1] In the context of this paper, we will limit our definition of standby to the most generic, widely accepted understanding of the term – a system or piece of equipment that is required to assume load only upon the failure of a primary system or piece of equipment.

Critical IT loads are therefore served from UPS system which both conditions the power as well as providing ride-through capability in the event of unacceptable line (source) conditions. Depending on the type of UPS, static or dynamic, the duration of the ride-though capability can range from seconds to minutes. If the utility power is relatively reliable, theoretically UPS systems are sufficient to assure proper operation of IT loads for the majority of events that fall outside of the ITIC acceptable ranges.

However, there are challenges when the power event is of a longer duration (i.e., beyond the ride-through capability) or when the utility is unreliable. Further, UPS systems themselves need to be maintained and serviced without jeopardizing the critical load. During these conditions, the load is assumed by standby power generators, which handle more severe power events of longer duration and facilitate maintenance under controlled conditions (please see Figure 2).

Standby power generators are able to supply a reliable source of energy for a predetermined duration, providing an economical alternative to UPS systems for prolonged energy storage and supply. Once the requirement exceeds minutes, UPS and batteries are neither economical nor practical. However, in most data center electrical system designs, the UPS provides the ability for the critical loads to ride-through the transition from the failed or failing primary source (utility) to an alternative source - the standby power generator.

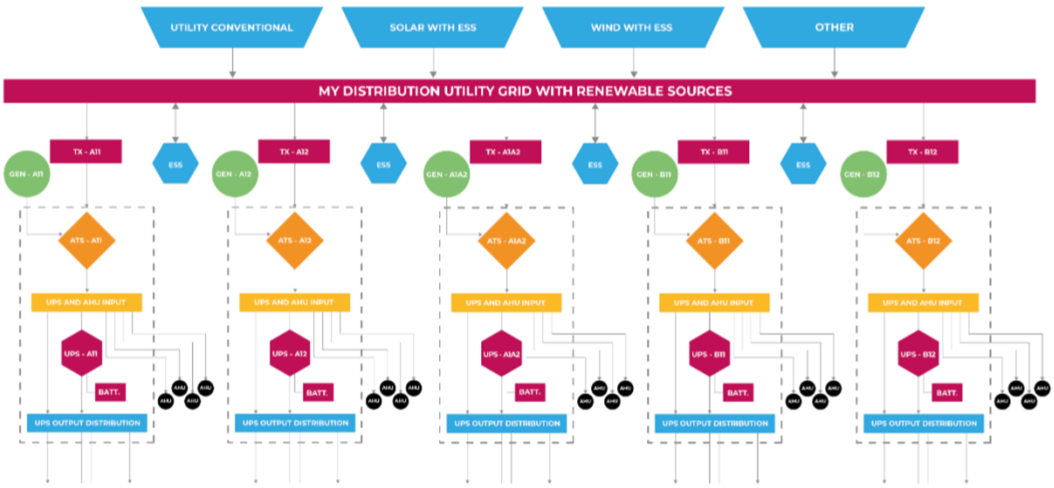

Figure 2: Typical Data Center One Line

The issue of energy storage technologies and their comparative features will be the topic of future papers but for the purposes of this paper, the engine generator provides the necessary, long term energy storage needed for reliable data center operation.

Historical perspective – Why diesel?

For the engine generator to be beneficial and meet its intended purpose, it must start-up and assume the load within the ride-through time provided by the UPS. The ride-through time provided by most static UPS (the predominant UPS topology) is typically measured in minutes. However, most data center standby generators are designed to start and assume the load within seconds. It is because of the availability of generators designed for use in life safety systems, per the National Fire Protection Association (NFPA) code, that generators designed to start and assume load in 10 seconds or less (type 10), were probably specified in early data center designs.

While startup times for generators have been relaxed for data center applications to account for, e.g., paralleling of systems, they are still typically designed to be able to start and assume the load in a matter of seconds. This, combined with the need for the emergency power supply system (EPSS) to run for 120 minutes per NFPA 110 (generally requiring onsite fuel storage), or longer for most data center operators, has resulted in the selection of diesel engine generators as the primary and most common choice of back-up energy for critical systems. The typical topology consists of different combinations and levels of redundancy of UPS backed up by diesel generators with 12 to 72 hours or more of onsite fuel storage.

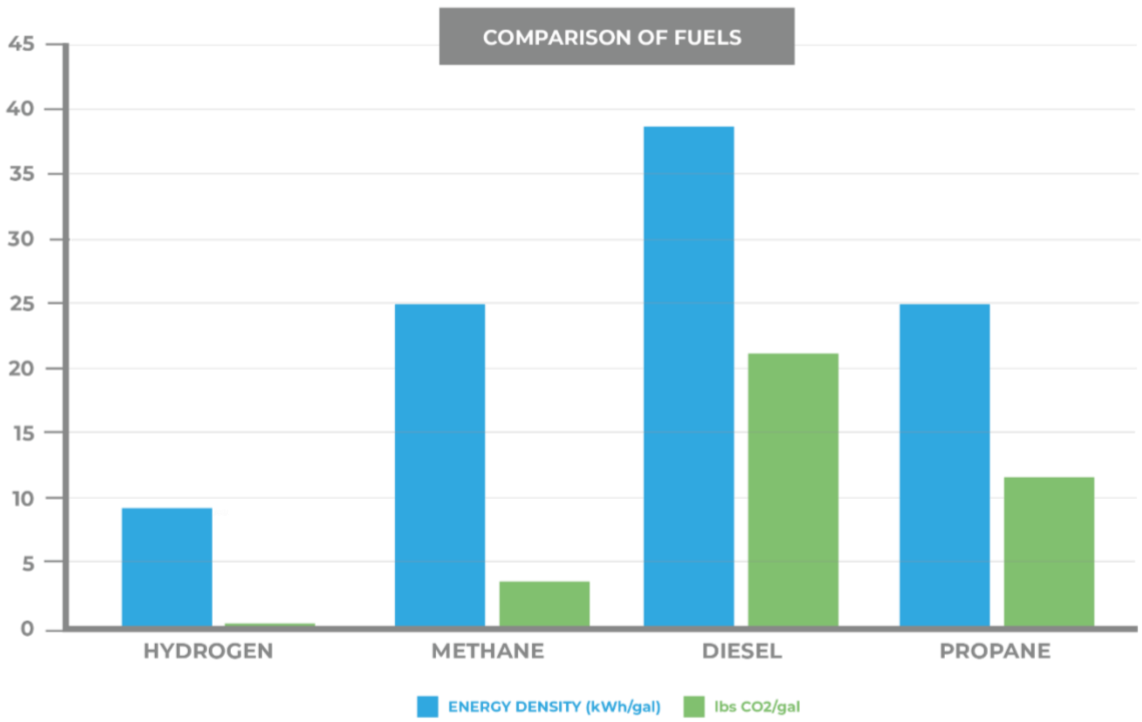

Figure 3: Energy Density and Carbon Impact of Fuels

With its high energy density per unit volume (Figure 3), diesel has been the optimum choice of fuel-type to meet the traditional requirements for load assumption and cost-efficient onsite fuel storage.

The case for natural gas

As discussed in our previous paper "*Infrastructure Sustainability Options and Revenue Opportunities for Data Centres*", today's data center owners are having to consider the impact of their businesses on climate change, and most have announced goals to reduce their greenhouse gas (GHG) emissions over the course of the coming years. Therefore, in order to be able to achieve these goals, existing design paradigms need to be carefully examined and changes in approach considered.

One of the first steps should be to evaluate the use of the largest direct source of GHG emissions for data centers, diesel generators. Operating diesel generators for back-up and maintenance operations is incongruent with the goal of reducing GHG emissions and carbon footprint. Additionally, there are severe regulatory restrictions on run-time for emissions.

In terms of its future as a standby source of power for data centers, the road map for diesel looks like one of increasing restrictions on use, tougher tax regimes, permitting, lower emissions targets, improved air quality requirements and lower noise regulations.

Emissions benefits of natural gas engines; a comparison with diesel

Natural gas (NG) engines have better emission profiles compared to same size diesel engine generators. Depending on the type of ignition system utilized, NG generators in the higher power ratings range are typically either:

- Lean burn- the air to fuel ratio is higher than the stoichiometric air-to-fuel ratio (16:1) which results in a lower combustion temperature that minimizes NO_x emissions.
- Rich burn, where the air-to-fuel ratio is lower.

The trade-off in the type of combustion selection nominally boils down to two competing considerations; while the lean burn engine has a better emission profile and efficiency, it does not have the block loading or load assumption capability of the rich burning engine. This explains why historically, rich burn engines have been preferred to lean burn engines for standby operation.

In comparison to Tier 2 (US Federal exhaust emissions) diesel generators, both lean burn and rich burn NG generators produce less NO_x and CO_2 per kW but have a higher initial cost. However, current US emission requirements for Tier 4 final certified engines adds significant cost to diesel generators, although this also lowers their emission levels closer to their NG counterparts. On the basis of emissions only, this narrows the advantage of NG generators, but it still makes them more cost competitive with diesel generators while maintaining a better emission profile.

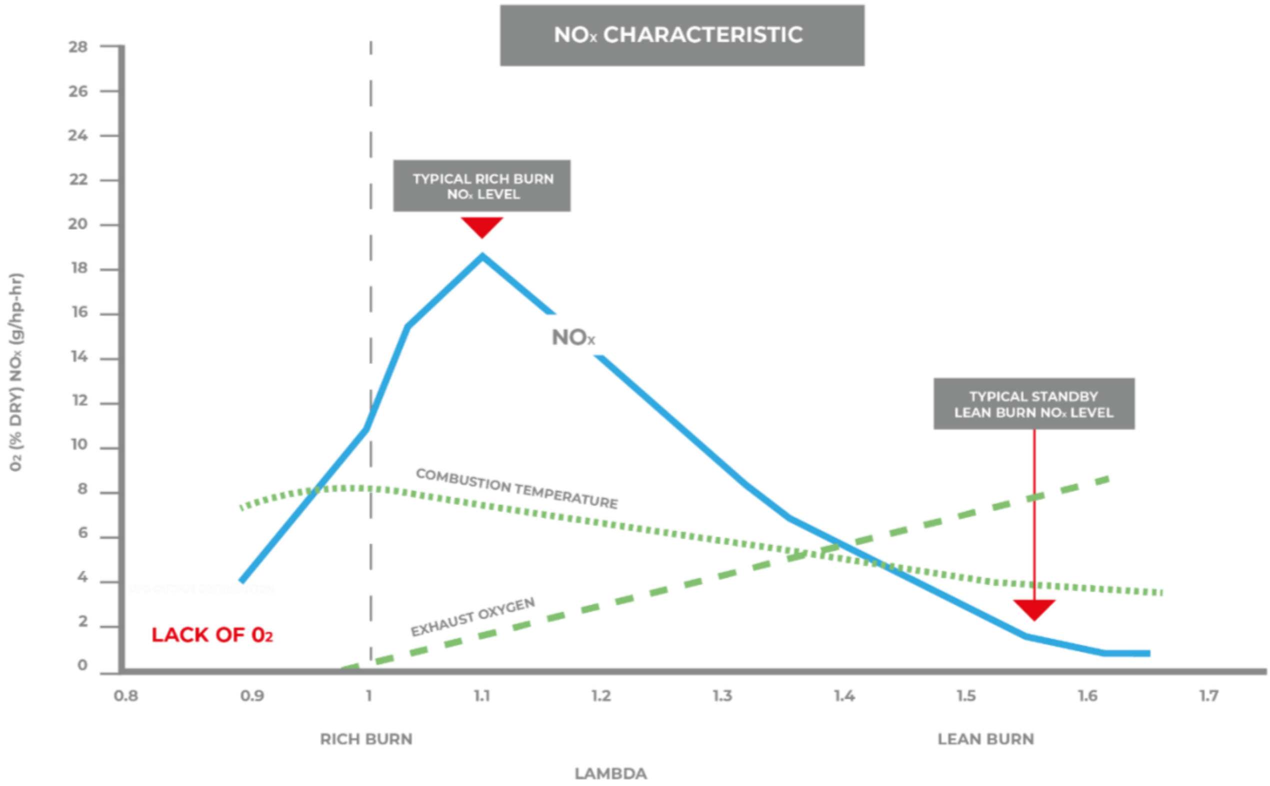

Figure 4: NOx emissions profiles of Lean Burn and Rich Burn Natural Gas NG) Engines

With further advances in both combustion controls as well as post-combustion emissions mitigation, the emissions differences between lean burn and rich burn NG engines have also narrowed. Therefore, the decision between NG technologies, is predominantly based of desired performance criteria (load assumption capability) and hours of operation.

Performance characteristics of diesel vs natural gas

As discussed above, diesel generators have superior start-up and load assumption capabilities for a wider range of generator ratings. It is commonplace for diesel generators 2MW and larger to have 100% block loading capability and start-up times of 10 to 15 seconds or less. By comparison, at these ratings NG generators cannot achieve a similar level of block loading (see Figure 6) or start-up capability regardless of the type of combustion utilized.

Smaller rich burn engines <1.2MW, can achieve 10 to 15 second start-up times, which make them suitable for standby operations for smaller loads, but typical modern data centers require the higher backup power capacities which are economical with larger generators. This is true even with modular, scalable, data centers where the typical critical load block might be 2MW - which would require a 2.5 to 3MW generator.

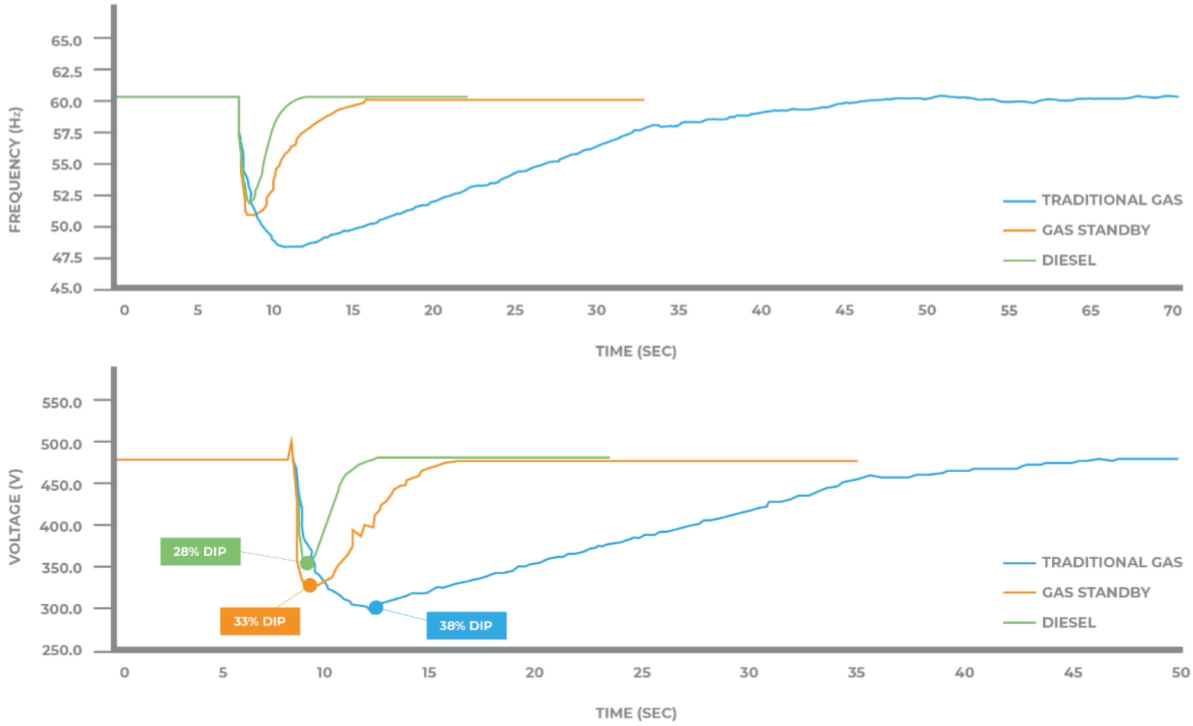

Figure 5: Block Load Response of Generators by Fuel Type [1]

Given the changing landscape of the electrical utility grid with the requisite battery energy storage systems being incorporated to account for the varying degrees of renewable energy supplies (RES) as well as the inherent energy storage on the data center side in the form of UPS, the need for quick load acceptance of the generator plant should be re-evaluated. Further, given that all modern UPS typically have an adjustable walk-in time and that all mechanical loads are typically variable frequency drive (VFD) controlled, there is little to no load that requires block load acceptance capability.

Finally, if the data center itself is part of a microgrid which incorporates RES of some form, there is also likely to be large-scale energy storage of some form that could be used to provide ride-through capability to the data center in the event of a utility outage. This would also alleviate the need for rapid start-up and load acceptance of the data center generator plant.

Design considerations for natural gas-based backup power

Given the advances in NG generator designs and capabilities as well as their favorable emissions profiles when compared to diesel generators, the decision to incorporate them into the power plant for the data center demands further design considerations to be taken into account. NG generators cannot simply be substituted for their diesel counterparts in most designs.

As discussed above, the load acceptance profile of NG generators requires a careful evaluation of the design topology and the interaction of the various loads with the generators. Given that over the last few years most data center UPS battery plants have been optimized for shorter and shorter run-time, sometimes as low as 1 to 3 minutes, it is necessary to evaluate this based on the decision to incorporate lean or rich burn engines. UPS walk-in times, as well as an evaluation of the mechanical load start-up profile, should be aligned with the load acceptance profile of the NG generator selected.

Then there is the question of onsite fuel storage. This has historically been one of the major stumbling blocks for the use of NG generators in emergency operations, since it requires onsite fuel storage in an amount which is challenging with most codes. Even if the generators are not required by regulation to have onsite fuel storage, there is the Uptime Institute's continuous operation requirements for their Tier 3 and Tier 4 data centers, that nominally requires onsite storage of fuel for a minimum of 12 hours standby operation if the data center is to gain Tier certification.

Even if a facility is not to be Tier certified, most operators will not be comfortable with no onsite fuel storage. This is another issue that will require careful analysis of the supply source of both utilities, the substantial costs associated with multiple utility connections and their relative reliability.

The argument has been made that the natural gas distribution system is inherently reliable, principally because it is almost entirely underground and also because it is a mesh-based system. However, this is not always so, as evidenced with the failure of the natural gas supply during the Texas power outage of the winter of 2021.

Although the general consensus was that this was a rare anomaly, the perception of the reliability of the natural gas distribution system has been damaged to some degree.

In a report on the comparison of fuel sources for generators, the authors state "…We estimate that the higher reliability of the natural gas fuel supply compared to that of diesel fuel for long outages makes natural gas generators more reliable options than diesel generators…"[2] Also, in comparison to the United States, the natural gas supply networks of Europe and many Nordic states are extremely reliable. In any case, best practice suggests an evaluation of the reliability of both utilities to the site should be performed and considered in the design. In addition, the risk of a concurrent failure of both utility supplies should be assessed, and the inherent "storage" provided by the volume of the gas held in the supply pipe system to the site calculated.

It's important to note that onsite diesel storage has challenges associated with maintaining the quality of the fuel as well, which typically requires fuel polishing. Further, in the event of a major event disrupting the electrical grid, reliable replenishment of diesel fuel can also prove to be highly susceptible, as observed in numerous natural disasters such as hurricane Sandy. [3]

Looking ahead, dual fuel engines

In the context of minimizing GHG emissions, the use of fossil fuel-based generators cannot be considered viable as the ultimate solution. However, one aspect of NG generators not discussed up to this point is the potential of dual fuel generators. Currently, most NG generators with dual fuel capability include units that are optimized for emergency use with rapid start-up or onsite fuel storage solutions. They include diesel NG units, or NG with alternative onsite fuel storage such as propane.

What is more promising and offers the potential for meaningful change is the availability of dual fuel generators that utilize NG and hydrogen. It is widely considered that hydrogen holds the promise to be the ultimate source of sustainable energy - subject to the development of cost-effective, sustainable and efficient means of production for a multitude of technologies from fuel cells to generators. Whilst natural gas and hydrogen dual fuel engines have to be derated, meaning the engine has to be oversized to achieve the desired power output, the reduction in emissions they achieve means that this approach should still be evaluated.

As methods are developed for the sustainable, carbon neutral, production and storage of hydrogen, it will fundamentally change the way that energy is sourced and used globally. In the near to midterm, dual fuel generators could be stepping-stones to a more sustainable, hydrogen-based future. Overcoming the immediate hurdles for the implementation of NG generators that lead the way to dual fuel generators and ultimately to hydrogen generators, could be a road map to a near net zero future.

Additional Considerations

In the context of GHG abatement, there are additional considerations that also need to be weighed, and associated with them, additional options to evaluate. For example, for the purposes of discussion, this white paper is focused on generators for standby operation, but natural gas engines can also be utilized in combined heat and power (CHP) arrangements as a prime source of electrical power for the site. This option will be analyzed in more detail in a separate article, but it might be a particularly applicable solution in instances where natural gas supply is more readily available than electrical utility power, or if the electrical utility cannot meet the demand for the data center for any number of reasons.

A particular concern and potential benefit of onsite prime power generation would be the GHG_e of the utility company, and whether the data center generator plant could contribute to the reduction of GHG emissions in a meaningful way. Onsite natural gas generation would be counterproductive in a location where, for example, the utility has a fuel mix that is mainly hydroelectric with minimal fossil fuel generation. In principle, the generation of power in close proximity to the load could be of benefit in terms of the sheer value of the losses avoided in the transmission of the same amount of useful energy from a utility grid with remote generation, however beneficial for the reduction in GHG_e this is it is very difficult, if not impossible to quantify any economic benefit for the data center operator.

Conclusion

Data centers are energy dense consumers of resources. While they are not the largest contributors to GHG emissions globally, they present an opportunity to be significant players in its mitigation. Design approaches and technologies that allow for the transition of data centers to use more sustainable, GHG neutral solutions can be a significant step in the right direction for this industry. As more data centers are designed and constructed with these goals in mind, utilizing forward-looking technologies, their contribution to a near net zero future will be invaluable.

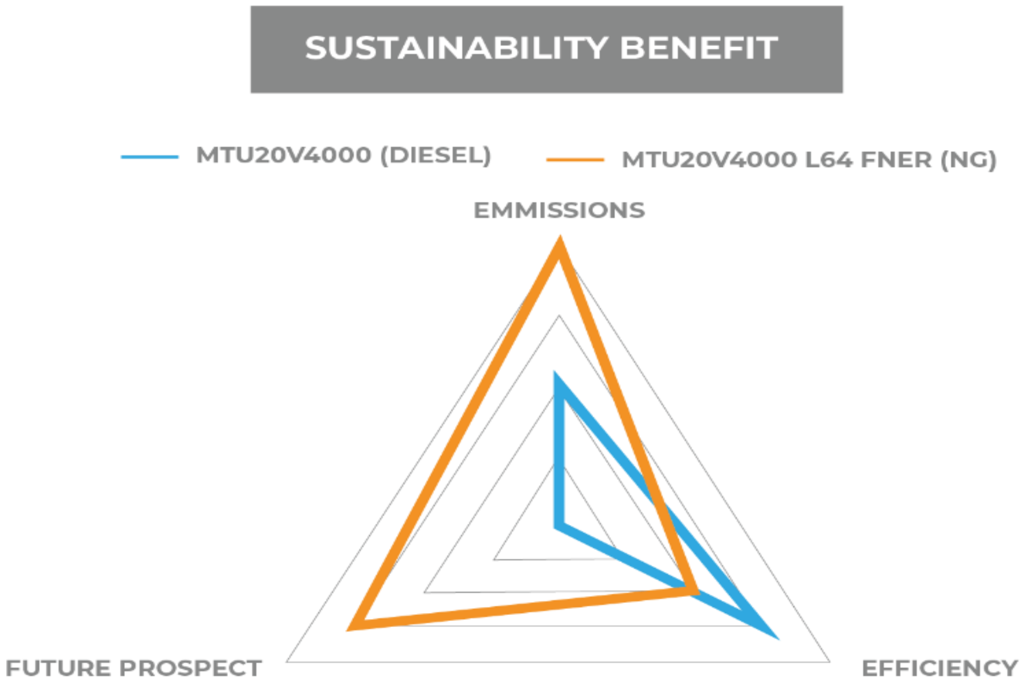

Figure 6: Sustainability Benefit Comparison

In the near term, the shift to NG generators presents an opportunity for data center owners to capitalize on the initial emissions benefits of these units that not only contribute to the reduction of GHG but also present opportunities to be able to align this goal with financial benefits. The use of NG generators makes possible the opportunity to use what are presently captive assets for reduction in operating costs or as appropriate revenue generators.

Further, the use of NG generators and their accommodation in current designs presents an opportunity - a roadmap - to the possibility of transitioning to a hydrogen-based solution that is truly net zero in the not-too-distant future. Therefore, serious consideration and evaluation of NG generators in the design of data centers today is warranted as one means to GHG abatement and a near net zero future.

References

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About the author

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Yigit has 30 years of project management and electrical engineering design experience. He is a recognized technical leader and electrical designer for data centers as well as other mission critical facilities. He is recognized in the industry and by his colleagues as an authority on electrical power distribution systems and related engineering applications for data centers and other critical facilities. He has been involved in multiple technical consulting engagements to assist clients in solving power quality issues and investigating unusual phenomena as a consequence. Yigit is one of EYP MCF's lead engineers in the development and implementation of the Flexible Data Center (FDC) product and has successfully supervised the implementation of the first FDC in the world. In addition to data center design, Yigit's experience includes the design of medium and low voltage power distribution systems, emergency systems and substations for healthcare, medical laboratory, pharmaceutical, commercial and industrial facilities.

Yigit received his MBA in Finance from the University of Baltimore in 1997 and his BS in Electrical Engineering from the University of Akron in 1986. He is a registered Professional Engineer in multiple states and an Uptime Institute Accredited Tier Designer.

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