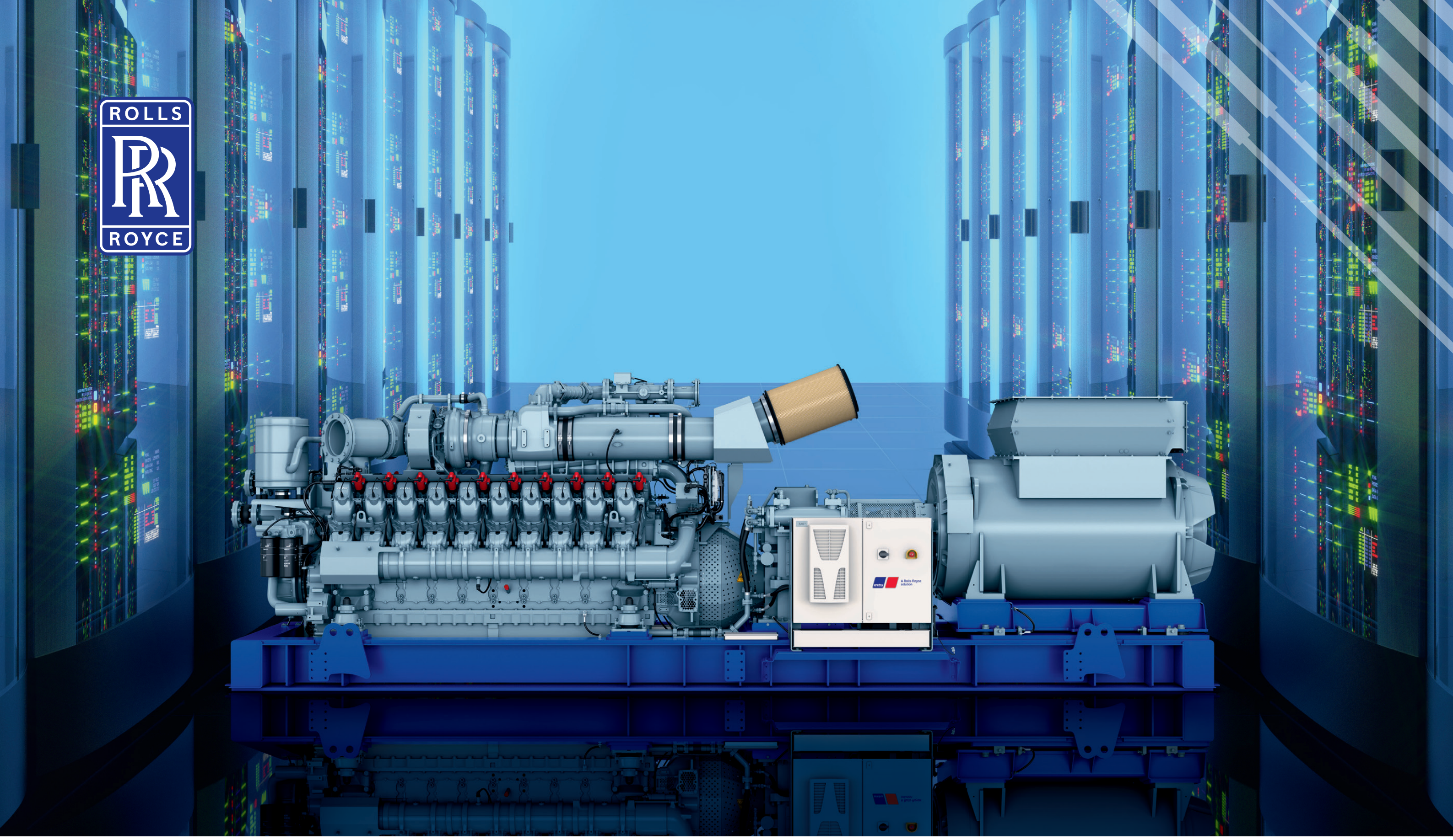

Power Generation

ENABLING DATA CENTER OPERATORS TO BRIDGE THE GRID CAPACITY GAP WITH SELF-GENERATION SOLUTIONS

The grid expansion bottleneck – When progressive data center expansion plans outpace infrastructure

Power grid capacity has become a critical resource for data centers around the globe. Be it in the US, Ireland or any of the other key locations in mainland Europe and Asia, grid operators powering more than 9,000 data centers are increasingly hitting the ceiling when attempting to provide new connections to meet ever-growing power demand. Inadequate grid capacities jeopardize investments, sideline potential site expansions, and undermine the ability to compete in AI development. [1)+2)]

Fast, flexible solutions are needed to cope with rising power demand for new technologies such as AI. While expanding high and extra-high voltage grids may take years, data centers can be up and running within a much shorter period of time. This discrepancy between infrastructure development and market demand poses enormous challenges for operators worldwide. [3)]

Dublin, Frankfurt, Amsterdam, wherever – many regional power grids are already at the limit. Forward-thinking, scalable solutions are crucial to keeping pace with market dynamics characterized by a critical reliance on a secure and capable energy infrastructure. [4)]

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A Rolls-Royce solution

The path to autonomous power – “Self-sufficiency” as an expansion strategy

Any number of versatile and efficient energy technologies have the potential to help widen existing bottlenecks (Figure 1). While promising vast capacities, complex centralized solutions still take time to plan and build – time that the dynamic data center industry often simply does not have. As a result, the focus is shifting further towards decentralized, modular approaches that enable faster and more flexible expansion of power demanding customers, i.e. data centers.

Depending on requirements for peak load, load profile, flexibility and uninterrupted operating time, technologies such as gas combustion engines and turbines play a key role. In the future, innovative technologies such as Small Modular Reactors (SMR) could also complement and further enhance these solutions.

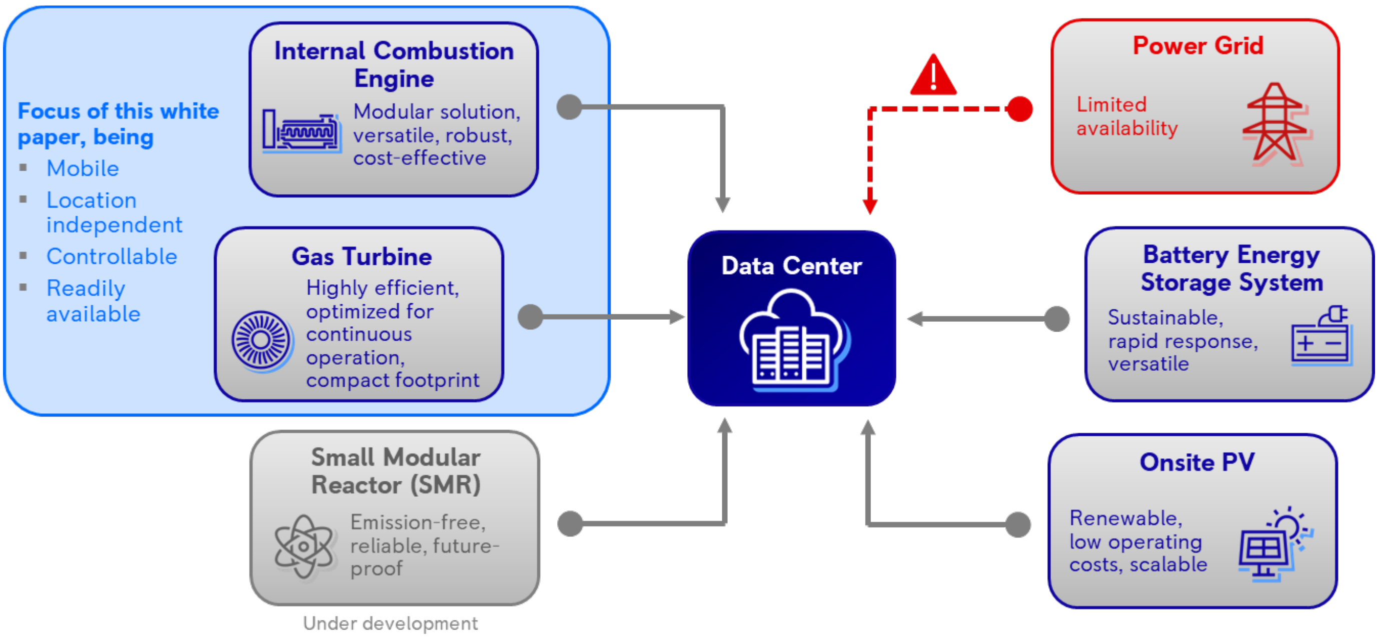

Figure 1: Grid-support or autonomous solutions for data centers

Internal combustion engine vs. gas turbine: Which technology is best suited to which baseline scenario?

Engines and turbines – Two sides of the same coin. Both act as local power generators, but what are the principal differences? Gas engines offer a versatile, efficient and economical solution to supplying data centers with short-term power. Offering notable modularity and relatively high efficiency even in partial load operation, they can be tailored to satisfy varying energy requirements and facilitate the integration of renewables. Mobility and swift deployment in modular units minimize investment cost and risks, while simultaneously bolstering the resilience of the power supply, make gas engines the ideal choice for peaker power plants. These power plants, often simply referred to as “peakers”, are generally only used when power demand is exceptionally high, and therefore often only run up around 1500 full load hours per year. In contrast, gas turbine power plants are better suited for constant base load generation being characterized by a particularly high degree of electrical efficiency by virtue of the additional steam stage.

But how do these two gas systems fare “behind the meter”? Off-grid energy systems have been analyzed on the basis of real load profiles from hyperscale data centers featuring a constant base load for the IT infrastructure and a variable load component (such as cooling, lighting, ventilation, additional changing IT loads, etc.). High-speed ***mtu*** S4000L64FNER gas engines were compared with alternative turbine solutions in terms of total cost of ownership (TCO). The simulated scenarios are summarized in Tables 1 and 2.

Table 1: Summary of parameters for simulated scenarios 1-4

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Power, heating and cooling		Power only	Power only	Power + heating + cooling	Power + heating + cooling
Technology		CCGT	***mtu*** 20V4000L64FNER	OCGT	***mtu*** 20V4000L64FNER
Installed power	**MWe**	2x 50	40x 2.5	2x 50	40x 2.5
Electrical efficiency	**%**	54	43	39	43
Thermal efficiency	**%**	–	–	47	47
Location		US	US	US	US
Gas price	**€/MWh** [5]	7.34	7.34	7.34	7.34

Trigeneration has the edge – Using electricity and waste heat in conjunction with an absorption chiller significantly reduces the levelized cost of energy

Let's first take a look at the results of these energy system simulations for the US. The differences between engine (scenario 1) and combined cycle gas turbine solutions (CCGT, scenario 2) are quite clear, with the former being 15% more cost-effective in terms of total cost of ownership (TCO) (Figure 2). This is primarily a result of favorable gas prices in the US, reflecting the significant impact of investment costs (CAPEX) on TCO. Although CCGT systems offer demonstrably lower operating costs (OPEX), the advantage is often neutralized by higher investment costs.

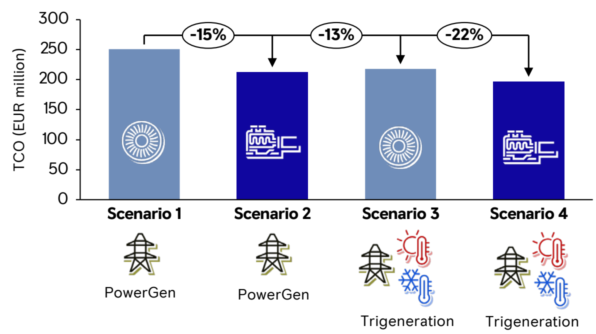

Figure 2: Result of energy system simulation for a 100 MW hyperscale data center for a US site

On top of the aforementioned cost benefit, engine-based solutions offer a number of other key gains. One major advantage of engines over turbines is their flexibility in start-up behavior, engines can reach full load in just seconds or minutes, whereas turbines require considerably more time. Engines do not require oversized configurations for high-temperature operations as turbines do, which must be over-dimensioned to mitigate performance losses due to significant derating. Additionally, the inherent modularity and versatility of engine systems enable them to operate efficiently over a broad range of load conditions, including the partial-load scenarios typical in data centers where turbine performance tends to decline. In addition, the modular design of engine systems provides enhanced redundancy and availability—crucial benefits for data center reliability—making them a far more advantageous option than designs based on one or two turbines. Another positive aspect is their mobility: following grid expansion, engine-based power plants can be simply relocated, for example, to a new data center.

Finally, engine-based power generation offers a significant advantage in terms of plant availability: while the failure of a single turbine can take out up to 50% of the total capacity, the failure of one engine in a multi-unit setup typically results in only a 2.5% loss, ensuring much higher operational resilience. For data centers in particular, gas systems also facilitate utilizing waste heat from power generation with absorption chillers to significantly moderate the energy needed for cooling. Utilizing waste heat for trigeneration rather than for the steam stage holds a significant cost-cutting potential of up to 22% for engine-based solutions (scenario 3), and savings amounting to 13% in the case of turbine power plants (scenario 4). Engine-based offerings have the edge over open-cycle gas turbines (OCGTs) by virtue of their greater electrical and thermal efficiency, and lower investment costs. They also enjoy logistical advantages such as faster delivery and easier transport, making them particularly attractive for projects with short implementation times.

Table 2: Summary of parameters for simulated scenarios 5-8

		Scenario 5	Scenario 6	Scenario 7	Scenario 8
Power, heating and cooling		Power only	Power only	Power + heating + cooling	Power + heating + cooling
Technology		CCGT	***mtu*** 20V4000L64FNER	OCGT	***mtu*** 20V4000L64FNER
Installed power	**MWe**	2x 50	40x 2.5	2x 50	40x 2.5
Electrical efficiency	**%**	54	43	39	43
Thermal efficiency	**%**	–	–	47	47
Location		Europe	Europe	Europe	Europe
Gas price	**€/MWh** [6]	35.5	35.5	35.5	35.5

Seeing as the European and US markets differ significantly – notably due to average gas prices being five times higher in 2024 (similar to those in Southeast Asia and the Middle East) – we also conducted simulations for a European hyperscale data center (Table 2).

This price structure has a considerable impact on the TCO of gas systems, resulting in a different appraisal of the various technologies (Figure 3). In Europe, fuel expenditure is the key determinant of operating cost in all scenarios, giving CCGT solutions a slim lead over engine-based power plants (scenarios 5 and 6). The electrical efficiency of the gas system becomes a decisive factor, especially for operators focusing exclusively on power generation.

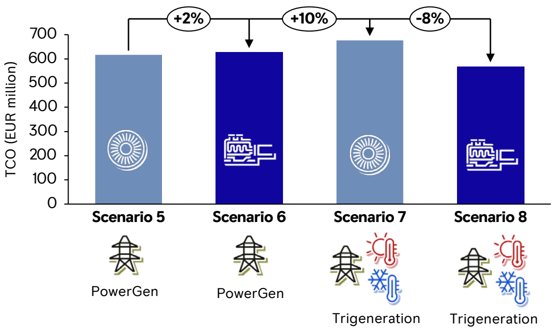

Figure 3: Result of energy system simulation for a 100 MW hyperscale data center for a European site

Further analysis indicates that transitioning from an electric-only system to a fully-integrated, energy-optimized solution, such as the trigeneration approach, also holds the promise of savings in a European setting. Cost reductions of up to 8% can be achieved with engine solutions compared to the CCGT scenario (scenario 7). Due to their lower electrical efficiency, replacing CCGTs with OCGTs (scenario 8) results in an overall increase in TCO of some 10% which, as already mentioned, is mainly attributable to higher fuel costs – despite being able to utilize waste heat, e.g. for cooling. These results clearly demonstrate that a holistic, energy-optimized strategy also promises significant savings potential in Europe, and that engine-based solutions represent an economically appealing alternative to CCGT systems.

Why internal combustion technology will remain an attractive solution for many data centers in the future

Gas engine power plants can thus be seen as a lucrative solution in terms of self-reliance. But what about sustainability? Figure 4 illustrates various decarbonization pathways that are already open to us today. Sustainable fuels such as biogas and biomethane are currently available for gas engines in continuous service, and offer an environmentally friendly solution.

Carbon capture solutions for exhaust gas aftertreatment are under development and on the verge of industrial deployment. These technologies enable up to 90% of the emitted CO_2 to be recovered and subsequently used either for carbon sequestration or recycled to synthesize e-fuel. Carbon capture technology is particularly well-suited for continuous, off-grid applications, as high runtimes enable predictable and stable revenue from selling captured CO_2, resulting in faster payback periods for such systems. Although customized plants predominate at present, widespread industrial deployment delivering reduced costs and increased efficiency is expected by the early 2030s.

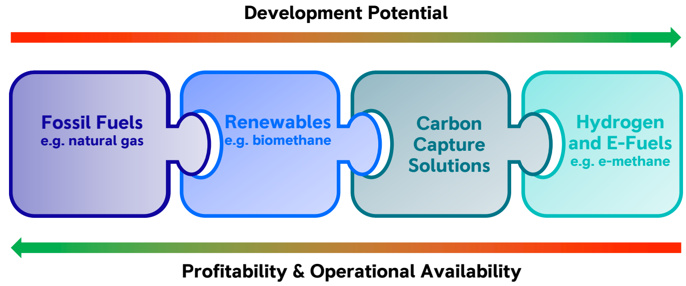

Figure 4: Decarbonization options available today and in future for ICEs and gas turbines

Looking ahead, green hydrogen and e-fuels such as e-methane could even provide gas-fueled power plants with an emission-free source of energy. Various coexisting decarbonization solutions give gas system users ample flexibility and make any investment in gas systems a sustainable and future-proof strategy for covering their own needs.

Self-generation as a strategic key: Bridging grid expansion issues and long-term potential for cost optimization and new sources of revenue

Although investing in self-generation might appear to pose a sunk cost risk at first glance, as it primarily addresses short-term grid expansion concerns, it opens up far-reaching potential in the long run, particularly when considering mobile solutions such as containerized gas systems. User-owned generation systems can serve as a strategic building block for expanding business models and tapping into new sources of revenue, e.g. by providing reserve capacity for grid-related ancillary services or capacity markets. Additionally, waste products from power production like heat and carbon can be recovered and sold to district heating networks and the food and beverage industry, respectively.

And once the grid expansion issue has been resolved, these systems can continue to feed electricity into the public grid. This allows for a continuous optimization of energy costs compared to market prices – either by covering in-house demand or marketing surpluses during periods of high prices. Self-generation capabilities therefore not only increase the resilience of the company, but also boost economic performance in the long term.

Get in touch to discover more about our energy solutions.

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