JENBACHER

HYDROGEN-BASED POWER GENERATION

I. A Net-Zero Backup Solution for Data Centers

This white paper is the first in a series dedicated to the use of hydrogen generators. This paper's focus is on data centers, where hydrogen generators can be used to decarbonize the backup power supply. By outlining the techno-economic specifications of this technology in general and INNIO Group's solutions in particular, the paper is aimed at data center operators and project planners as well as planning offices for decentralized energy solutions. It is intended to be used as a decision-making aid for the transformation path towards net-zero data centers.

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INTRODUCTION

1. INTRODUCTION

As a low-carbon energy carrier, hydrogen shows significant potential in various sectors, serving as a crucial element for advancing the worldwide journey towards net zero by 2050. This white paper comprehensively illustrates the numerous technical and economic advantages behind adopting hydrogen within decentralized energy solutions tailored for data center backup power.

1.1 Global electricity demand for data centers

In this era of digital transformation, data centers have emerged as the backbone of our increasingly connected world. These facilities are responsible for storing, processing, and delivering massive amounts of data, supporting everything from cloud computing and artificial intelligence to online commerce and social media. However, the rapid expansion of data centers has raised concerns about their substantial electricity demand and its impact on global energy consumption.

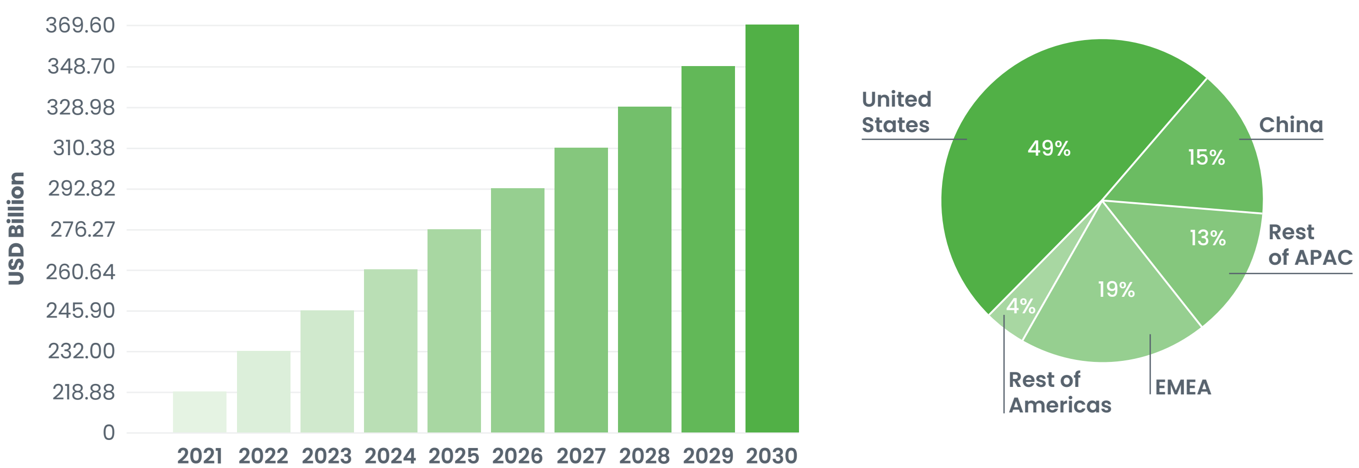


Figure 1: Left, data center construction market size forecast; and right, regional distribution of data center capacities (Precedence Research)

Data centers are notorious for their substantial electricity requirements. The proliferation of data-driven applications and the explosive growth of data-intensive technologies have led to an exponential increase in the demand for computing power and storage capacity. As a result, data centers have become one of the largest consumers of electricity globally. Several factors contribute to the electricity demand of data centers:

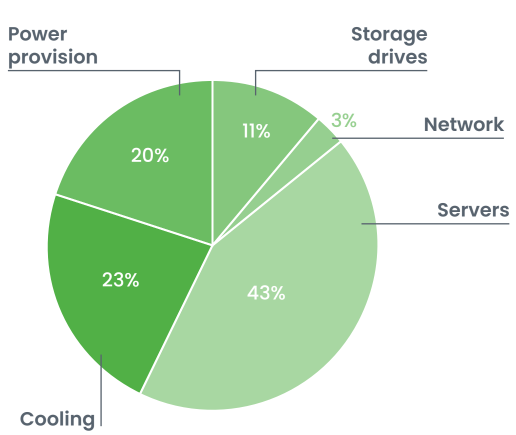


Figure 2: Breakdown of electricity consumption by different components of a data center (Shehabi; 2016, assuming PUE = 1.3)

1. **Computing infrastructure:** The scale and complexity of data center infrastructure, including servers, storage systems, networking equipment, and cooling systems, require significant power to operate efficiently.

2. **Cooling and ventilation:** Data centers generate substantial heat due to constant server operation. Cooling and ventilation systems are crucial for maintaining optimal temperatures, but they consume a significant amount of electricity.

3. **Redundancy and backup systems:** Data centers prior-itize reliability and uninterrupted operations. Redundant power systems, backup generators, and uninterruptible power supplies (UPS) are essential components, but they contribute to the overall power demand.

1.2 Demand for decarbonization

Data center emissions have only grown modestly within the last decade, despite increasing demand for digital services, largely thanks to more energy-efficient products, practices, and renewable energy purchases. However, these emissions must drop 50% by 2030 to avert the worst effects of climate change.

For data center operators, there are many additional reasons to embark on this decarbonization path:

Improve energy efficiency for costs savings

The prospect of overhauling existing infrastructure can pose a major challenge. Nonetheless, technology continues to evolve, encompassing hardware, software, and energy- efficient systems, including power and cooling equipment. Through strategic investments in innovative energy-efficient equipment, the energy expenses likely will decline over time.

Stay one step ahead of industry regulations

The IEA's ambitious global roadmap to achieve net-zero emissions by 2050 presents a significant challenge. Although existing policies frequently fall short, there is an inevitable trend toward increasing stringency, broader adoption, and greater ambition as global climate concerns intensify. Data center operators can proactively prepare and maintain a competitive edge by exploring the concept of decarbonization and embracing climate-friendly policies today.

Decarbonization must be a multifaceted, concentrated effort addressing various fields of action:

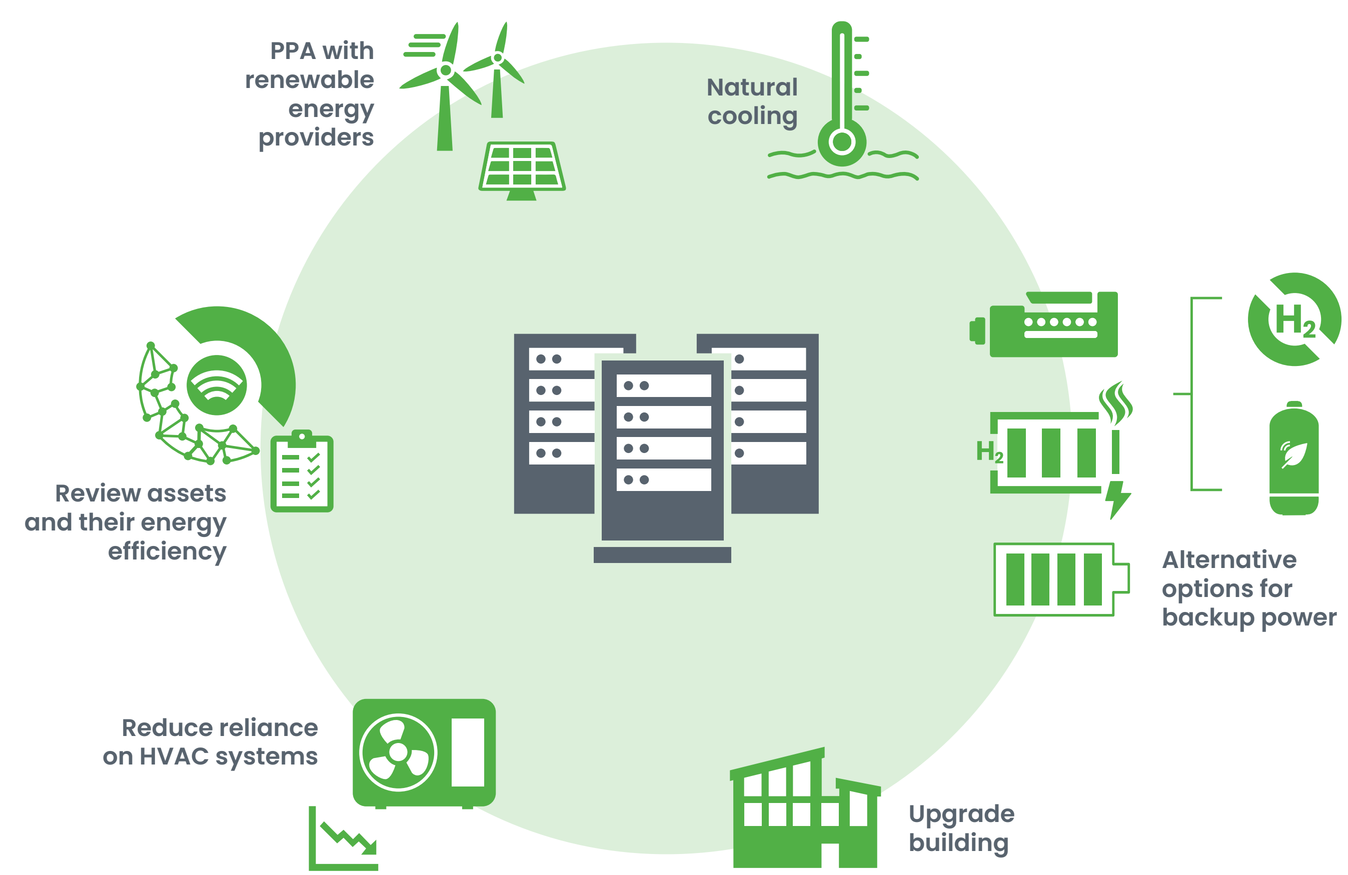


Figure 3: Fields of action for the decarbonization of data centers

Establish power purchase agreements with renewable energy providers. The first step on the path to decarbonization involves shifting to sustainable energy sources. Wind and solar power stand out as the most prevalent alternatives, although the suitability of geothermal energy or hydroelectricity can be equally important, contingent upon their local accessibility.

Upgrade buildings: While numerous data center operators emphasize enhancing energy efficiency within the data center itself, the construction of the data center building presents significant untapped potential for greenhouse gas reduction. Every aspect, from the production of cement, steel, and raw materials to the utilization of construction machinery in erecting the data center, can have an impact on its overall carbon footprint.

Use natural cooling: Servers emit a substantial amount of heat, necessitating substantial cooling measures to sustain optimal temperatures and prevent overheating. Certain data centers explore innovative approaches like natural or liquid cooling to reduce temperatures, such as incorporating external air or seawater to efficiently manage equipment temperature. The choice of location plays a pivotal role, making it advantageous to establish data centers in colder climates whenever possible.

Reduce reliance on heating, ventilation and air conditioning (HVAC) systems: HVAC systems represent a major source of energy consumption within data centers. These systems may suffer from obsolescence or inefficient management due to inadequate monitoring tools. In the contemporary landscape, advanced control systems harness the power of AI-based models to forecast and optimize HVAC operations, resulting in a substantial reduction in energy consumption.

Review assets and their energy efficiency: Cutting-edge data center infrastructure management software provides data center administrators with a holistic view of the energy consumption of each hardware component, from network equipment and servers to cooling systems and more. These analytics and insights empower administrators to continuously optimize resource allocation and asset configuration for enhanced daily efficiency. This proactive approach plays a pivotal role in significantly reducing the operational carbon footprint.

Assess alternative options for backup power: Most data centers today rely on diesel generators and fuel as a backup to avoid downtime from potential power outages. However, the increasing demand for decarbonization requires net zero alternatives, which will be addressed in this paper.

1.3 Hydrogen generators to decarbonize backup power

Hydrogen engines have emerged as a promising technology for backup power in data centers due to their high energy density, reduced environmental impact, and potential for long-duration power generation. The main advantages of using hydrogen engines as backup power solutions for data centers are:

1. **High energy density:** Hydrogen has a high mass-specific energy density, making it an efficient fuel source for backup power generation. Hydrogen engines can provide a large amount of energy, allowing for longer-duration power supply during outages.

2. **Environmental sustainability:** Hydrogen is a clean and renewable energy source when produced through sustainable methods such as electrolysis using renewable electricity. Besides low levels of nitrogen oxides (NO_x), hydrogen engines emit only water vapor as a byproduct, contributing to reduced greenhouse gas emissions and mitigating the environmental impact of data center operations.

3. **Fast response time:** Hydrogen engines can provide fast backup power during grid outages. This quick response time in conjunction with UPS enables disruption-free data center operations and helps maintain the integrity and availability of critical systems and services.

4. **Scalability and modularity:** Hydrogen backup power solutions offer scalability and modularity, allowing data centers to customize their backup systems according to their specific power requirements. Additional hydrogen storage tanks and engines, typically in a containerized setup, can be added as needed, providing flexibility in capacity expansion.

The main challenges when considering using hydrogen engines as backup power solutions for data centers are:

1. **Hydrogen infrastructure:** The widespread adoption of hydrogen engines as backup power solutions requires a robust hydrogen infrastructure, including production, storage, and distribution facilities. Developing an extensive network of hydrogen is crucial to ensuring a reliable supply of hydrogen fuel.

2. **Safety measures:** While hydrogen is a safe fuel when handled properly, certain safety considerations must be addressed. Power houses for data centers must implement stringent safety protocols, including proper storage, handling, and ventilation systems to mitigate any potential risks associated with hydrogen storage and utilization.

3. **Cost and efficiency:** The initial cost of implementing hydrogen backup power systems can be higher compared to traditional backup solutions. However, advancements in technology and economies of scale are driving down costs.

4. **Hydrogen production:** The method of hydrogen production greatly impacts the overall environmental benefits of hydrogen engines. To reach their sustainability goals, data centers should consider purchasing green hydrogen based on renewable energy sources, such as wind or solar power, enabling a truly clean energy solution.

Hydrogen engines offer an attractive alternative for backup power solutions in data centers, combining high energy density, environmental sustainability, and fast response times. As the demand for reliable and net zero backup power grows, hydrogen-based systems present an opportunity to enhance the resilience and environmental performance of data center operations. However, challenges such as infrastructure development and safety considerations must be addressed for successful implementation.

1.4 Hydrogen as a future-proof energy supply option

In our transformative energy system, data centers increasingly are placed in the role of grid-serving prosumers. Emerging regulations, therefore, require data center operators to become increasingly energy self-sufficient. As a result, the role of on-site power generation is shifting from merely supplying emergency power to becoming a local power plant. In concrete terms, this goes hand in hand with higher power plant capacities and, in particular, longer operating times per year. The resulting significant increase in fuel requirements cannot be covered by the currently established concept of diesel engines with a fuel tank. At the same time, a reliable power supply remains the overarching criterion for backup systems. In this respect, gaseous energy sources have the advantage of a far-reaching and granular distribution network compared to the currently dominant diesel fuels. By converting from diesel engines to gas engines, today's data center operators can access the huge capacities of these networks as opposed to on-site diesel tanks.

An established method to quantify the reliability of energy supply infrastructure is the so-called System Average Interruption Duration Index (SAIDI). The SAIDI indicates the total sustained interruption duration for the average end user during a predefined period of time. It is commonly measured in minutes or hours of interruption. The following figure shows the significant reliability improvement that can be achieved in countries such as Germany with an established gas infrastructure.

Figure 4: SAIDI values for the German power and gas grid (for large consumers and gas power plants) over the last decade (Federal Network Agency)

In central regions such as Europe and North America, far-reaching measures already are being taken to establish an adequate supply infrastructure for hydrogen as an energy carrier.

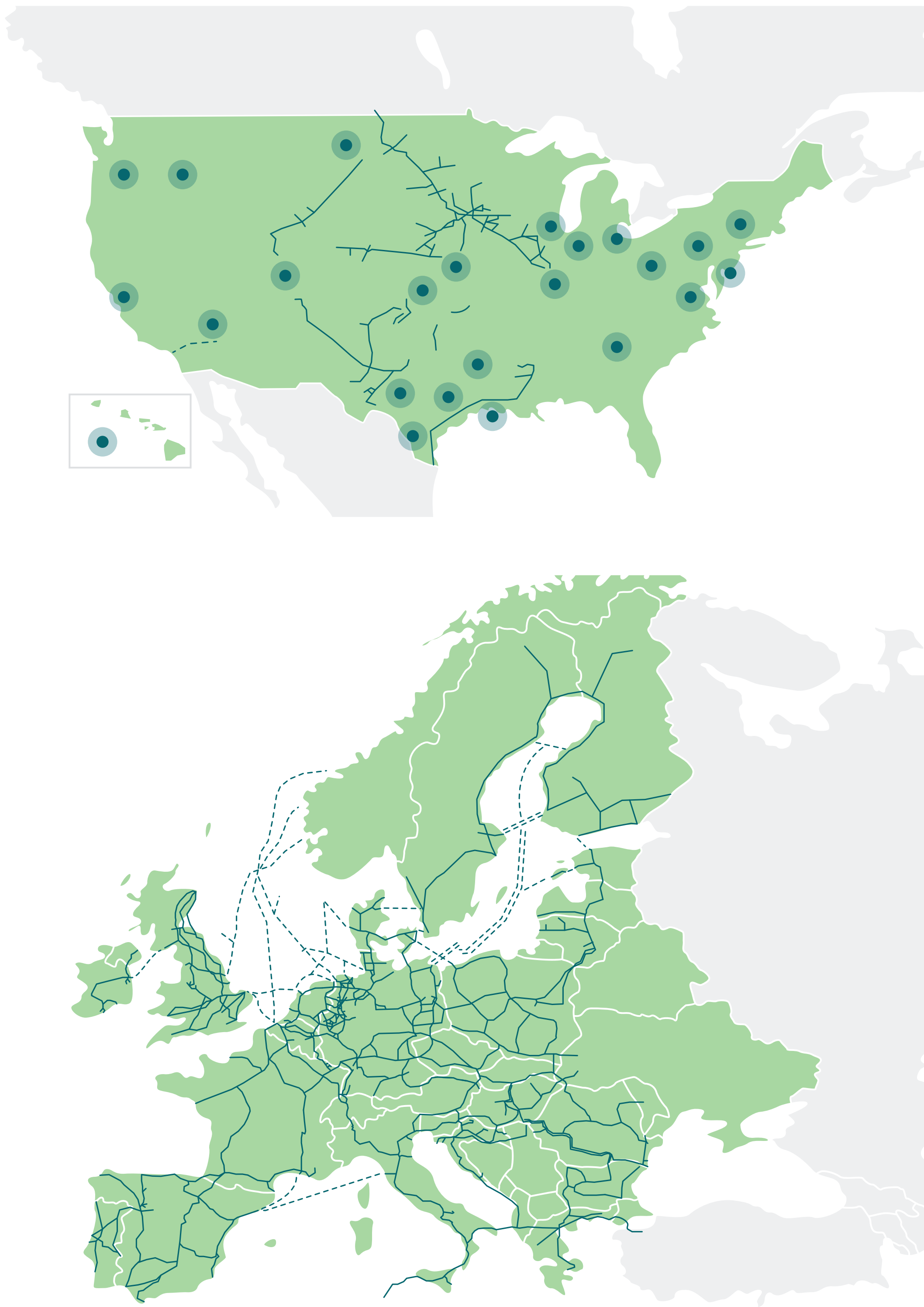


Figure 5: Top, U.S. hydrogen hub applications and infrastructure (illustration based on Hydrogen Insight, Rystad Energy, 2023); and bottom, European hydrogen backbone initiatives (illustration based on Guidehouse, 2022)

In addition to the development of hydrogen production and import capacities, these measures focus on the rededication of existing gas grids and the development of new hydrogen networks. Furthermore, a variety of trade routes for the export of large-scale hydrogen capacities will be developed on a global level in the coming years.

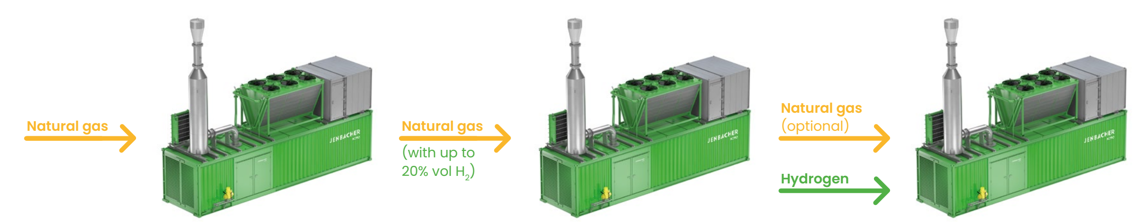
As a result, data center operators face the medium-term challenge of converting their energy supply with a heterogeneous supply infrastructure of sustainable gases. In this context, the engines from INNIO Group's Jenbacher product line offer the key advantage of fuel flexibility while protecting customers from stranded investments in their decarbonization strategy.

All new Jenbacher power plants are "Ready for H_2." In addition, engine variants with a corresponding option can be operated with up to 25% (vol) of H_2 in the pipeline gas. As hydrogen availability increases, all new plants and most of the currently installed Jenbacher natural gas-powered generators can be converted to run on 100% hydrogen.

Built as natural gas asset

Built as a "Ready for H_2" asset

Switched to a hydrogen asset



Natural gas with <5% (vol) of H_2 content
Current standard

Natural gas with up to <25% (vol) of H_2 content
Pipeline gas can have up to 20% (vol) of hydrogen content

Required:
- NO_x-sensor
- H_2 signal integrated into LeanoxPlus
- H_2-ready compensation software

Low-cost package

Hydrogen fuel (natural gas optional)
When hydrogen becomes available

Required:
- Hydrogen conversion package
- NO_x-sensor
- H_2 signal integrated into LeanoxPlus
- H_2-ready compensation software

Medium-cost package

Figure 6: Demand-oriented conversion of INNIO's Jenbacher engines to hydrogen operation

Up to 60% (vol) hydrogen content can be admixed to pipeline gas for use in specific versions of INNIO's Jenbacher Type 2, 3, 4, and 6 engines. Type 4 engines and CHP systems are available today as dual-gas-fuel solutions capable of running on 100% conventional gas, 100% hydrogen, or mixtures of pipeline gas and hydrogen.

INNIO Group is the first energy solution provider to receive an "H_2 Readiness" certificate from the world-renowned TÜV Süd for its Jenbacher H_2 power plant concept. The independent certification increases investment security for companies in the transition to net-zero.

2.

TECHNICAL REQUIREMENTS FOR BACKUP OPERATION

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2.1 Regulatory framework

The design and implementation of backup solutions for data centers must consider a wide range of region-specific regulations and standards. A summary of key standards is listed below, addressing security, reliability, and sustainability issues that commonly are referenced in the context of data center backup power for particularly relevant markets:

North America: ANSI system

- **ANSI/TIA-942: Telecommunications Infrastructure Standard for Data Centers**
  This standard provides guidelines for the design and implementation of data center infrastructure, including backup power systems. It covers various aspects such as topology, redundancy, and reliability.

- **NFPA 70: National Electrical Code (NEC)**
  The NEC is a widely adopted standard that sets the requirements for electrical installations, including backup power systems, to help ensure safety and proper operation. It covers topics such as wiring, grounding, and protection against electrical hazards.

- **UL 924: Standard for Emergency Lighting and Power Equipment**
  UL 924 specifies the requirements for emergency lighting and power equipment, which are crucial components of backup power systems in data centers. It covers topics such as emergency lighting fixtures, exit signs, and emergency power sources.

- **EPA ENERGY STAR Program Requirements for Data Center Storage**
  This program is aimed at improving energy efficiency in data centers. While it doesn't directly address backup power systems, it encourages data centers to adopt energy-efficient practices, which can include optimizing backup power infrastructure.

Europe: EN/DIN-system

- **EN 50600 Series: Information Technology Infrastructure for Data Centers**
  The EN 50600 is the first European-wide, transnational standard that provides comprehensive specifications for the planning, construction, and operation of a data center with a holistic approach. The EN 50600 series comprises a set of standards that cover various aspects of data center infrastructure, including backup power systems. These standards provide guidelines for the design, construction, and operation of data centers, emphasizing reliability, efficiency, and availability.

- **EN 50171: Central Power Supply Systems for Emergency Lighting**
  EN 50171 focuses on central power supply systems used for emergency lighting, which is an essential component of backup power systems in data centers. It provides guidelines for the design, installation, operation, and maintenance of these systems to ensure their proper functioning during power outages.

- **EN 50171: Information Technology Equipment—Safety—Part 1: General Requirements**
  This standard is part of the EN 60950 series and addresses the general safety requirements for information technology equipment, including data center backup power systems. It covers aspects such as electrical safety, protection against hazards, and proper functioning under normal and fault conditions.

- **EN 62040 Series: Uninterruptible Power Systems (UPS)**
  The EN 62040 series includes standards that cover uninterruptible power systems (UPS), which are commonly used for backup power in data centers. These standards specify the performance, safety, and environmental requirements for UPS devices, ensuring their reliability and compatibility with data center operations.

Global: IEC-/ISO-system

- **IEC 60945: Maritime Navigation and Radiocommunication Equipment and Systems**
  While primarily applicable to marine environments, this standard often is referenced for data centers located in coastal areas or on ships. It sets guidelines for the design, installation, and testing of electrical systems, including backup power, to help ensure their reliability and safety in maritime environments.

- **ISO/IEC 27001: Information Security Management System (ISMS)**
  Although not specifically focused on backup power, ISO/IEC 27001 provides guidelines for establishing and maintaining an information security management system. Data centers often consider backup power as part of their business continuity and disaster recovery plans, and adherence to this standard helps protect critical data and systems during power outages.

- **ISO 22301: Societal Security—Business Continuity Management Systems**
  While not specific to backup power systems, ISO 22301 provides guidelines for establishing and maintaining business continuity management systems. Data centers often consider backup power as part of their business continuity plans, and adherence to this standard helps ensure the availability of critical systems and services during power disruptions.

- **ISO 8528-5:2022: Reciprocating internal combustion engine-driven alternating current generating sets— Part 5: Generating sets**
  This standard is not limited to DC applications, but applies to AC generating sets driven by RIC engines for land and marine use, excluding generating sets used on aircraft, or to propel land vehicles and locomotives. The ISO 8528-5:2022 specifies design and performance criteria arising out of the combination of a reciprocating internal combustion (RIC) engine and an alternating current (AC) generator when operating as a unit. This unit can run in parallel to the grid.

It's important to note that these standards can vary across different countries and regions. Additionally, local regulations and guidelines also may apply. Data center operators should consult the specific standards and requirements applicable to their location to determine compliance and best practices for their backup power systems.

For the specific operation of a spark-ignited gas engine and an alternating current (AC) generator, operating as a unit, design and performance criteria are specified in ISO 8528-5:2022. The standard defines four design classes, G1 to G4, in which operating limits are listed with regard to voltage and frequency behavior, while data center emergency backup systems are advised to meet the highest requirements.

G1: Low requirements for voltage and frequency behavior (lighting, simple drives).

G2: Requirements on voltage and frequency behavior largely corresponding to the public network (building services equipment, fans, elevators).

G3: Higher requirements on voltage and frequency behavior and on the waveform (telecommunication equipment).

G4: Highest requirements on voltage and frequency behavior and on the waveform (EDP equipment).

Design class	G1	G2	G3	G4
Static frequency deviation	±8%	±5%	±3%	According to specific agreement
Static voltage deviation	±5%	±2.5%	±1%	According to specific agreement
Voltage regulation time	10s	6s	4s	According to specific agreement
Transient frequency after load application	≤-25%	≤-20%	≤-15%	According to specific agreement
Dynamic voltage deviation after load shedding / after load application	≤+35% / ≤-25%	≤+25% / ≤-20%	≤+20% / ≤-15%	According to specific agreement
Frequency response	10s	5s	3s	According to specific agreement

Table 1: Operating limits with regard to voltage and frequency behavior of spark-ignited gas engines according to ISO 8528-5:2022

For the classes G1 to G3, ISO 8528-5 specifies concrete operating limits for the static/dynamic stress and frequency behavior, while for class G4, no operating limits are specified. The operating limits must be determined based on the application-specific operational and technical requirements.

The substitution of existing diesel generators as a backup solution with more climate-friendly gas generators requires intensive technology development, especially in the use of hydrogen. Thanks to decades of experience in CHP operation with specialty gases, INNIO Group as a technology leader can offer reliable climate-neutral solutions in this demanding segment.

Besides these established standards and regulations, a variety of actions are being taken around energy efficiency, use of renewables, and even moratoriums on data center builds. Table 2 provides insight into present and future regulations that could impact data centers.

Countries/regions	Potential impact on data center environmental sustainability
EU	European Commission is exploring measures to improve the energy efficiency and circular economy performance in cloud computing and data centers. Existing instruments include: — Ecodesign Regulation on servers and data storage products — EU Code of Conduct on Data Center Energy Efficiency — EU Green Public Procurement criteria for data centers, server rooms, and cloud services European Commission is linking energy efficient data centers to policy and funding initiatives such as: — Proposal for a directive on energy efficiency (recast) introduces new elements to improve the energy efficiency and sustainability monitoring of data centers. — Taxonomy Regulation and its Delegated Act, adopted in July 2021, which sets the framework for investments to be qualified as sustainable and whose delegated act is being finalized, has a section on data centers. — Funding programs Horizon Europe, Connecting Europe Facility, Digital Europe program, InvestEU, and the Recovery and Resilience Facility will support the deployment of an innovative, green, and secure cloud.
US	The Inflation Reduction Act of 2022 (IRA) is a landmark United States federal law that aims to curb inflation by possibly reducing the federal government budget deficit, lowering prescription drug prices, and investing in domestic energy production while promoting clean energy. It was passed by the 117th United States Congress and signed into law by President Joe Biden on August 16, 2022. The IRA gives data centers plenty of incentives to clean up their operations far more than existing clean energy tax credits. In April 2021, Washington became the second state in the U.S., following California, to establish a comprehensive carbon pricing policy. This initiative introduces a "cap-and-invest" program designed to progressively impose stricter restrictions on carbon pollution and other greenhouse gases. Under this policy, polluters are mandated to continually reduce their emissions or procure pollution allowances.
China	The Beijing Development and Reform Commission declared in April of 2021 that the proportion of renewable energy utilization in annual energy consumption will increase by 10% every year, and 100% will be achieved by 2030.
Singapore	The Green Building Masterplan in Singapore outlines its objective to enhance the sustainability of existing buildings and encourage occupants to adopt energy-efficient practices. The aim is to ensure that, by 2030, a minimum of 80% of the total building floor area in Singapore will adhere to green building standards. In February 2021, the Ministry of Trade and Industry (MTI) conveyed in a distinct written parliamentary response its intention to establish a cluster of data centers that not only fulfill the demands of both industry and society but also excel in resource efficiency. These data centers will remain at the forefront of innovation, consistently pushing the limits of resource efficiency within a tropical climate.

Table 2: Insights that could become potential regulations on data center environmental sustainability

2.2 Safety considerations

The technical requirements for data center backup power systems can vary, depending on factors such as the size of the data center, its criticality, local regulations, and industry best practices. However, here are some common technical requirements to consider:

Redundancy and reliability:
Backup power systems should be designed to provide high levels of redundancy and reliability to enable continuous power supply during outages or disruptions. To reduce single points of failure, this often involves the use of redundant components, such as multiple generators, UPS units, and battery banks.

Capacity and scalability:
Backup power systems should be sized appropriately to meet the power demands of the data center during outages. The capacity of generators, UPS units, and batteries should be determined based on factors such as the power load, runtime requirements, and growth projections. Scalability also should be considered to accommodate future expansion or increased power demands.

Autonomy and runtime:
Backup power systems should be capable of providing sufficient runtime to support critical operations until primary power is restored or alternative arrangements are made. The required autonomy and runtime depend on factors such as the duration of potential outages, the time required for smooth shutdowns, and the availability of fuel or energy sources.

Fast switchover and transient response:
Backup power systems should have fast switchover capabilities to seamlessly transition from the primary power source to the backup source without interruption. They also should exhibit good transient response to maintain stable and reliable power during the transition and subsequent power fluctuations.

Monitoring and management:
Backup power systems should be equipped with monitoring and management capabilities to allow real-time visibility into their performance, status, and health. This includes features such as remote monitoring, alerts, reporting, and integration with data center infrastructure management systems for centralized control and oversight.

Maintenance and serviceability:
Backup power systems should be designed for ease of maintenance and serviceability. Components should be readily accessible for inspections, repairs, and replacements. Maintenance schedules, procedures, and documentation should be established and followed to reach optimal performance and longevity of the backup power equipment.

Compliance and safety:
Backup power systems must adhere to applicable electrical and safety codes and standards to enable the protection of personnel, equipment, and the environment. This includes proper grounding, electrical protection devices, ventilation, fire suppression systems, and compliance with local regulations and industry best practices.

Testing and commissioning:
Backup power systems should undergo rigorous testing and commissioning procedures to validate their performance, reliability, and functionality. This includes load testing, synchronization testing, failover testing, and documentation of test results to determine the system's readiness for real-world power disruptions.

It's important to consult relevant standards, guidelines, and experienced professionals to determine the specific technical requirements for backup power systems in your data center, as they can vary based on location, industry, and specific project considerations.

Fast switchover and transient response are crucial aspects of data center backup power systems for uninterrupted power supply during transitions and transient events. Here are some technical requirements related to fast switchover and transient response:

— **Transfer switches:** Backup power systems should incorporate automatic transfer switches (ATS) or static transfer switches (STS) to enable seamless switchover between the primary power source and the backup power source. These switches should have fast response times, typically in milliseconds, to reduce interruption to critical loads during power transfer.

— **Inverter technology:** Uninterruptible Power Supply (UPS) systems, which commonly are used in data centers for backup power, should employ high-quality inverter technology. Modern UPS systems often use double-conversion topology, where power is continuously converted from AC to DC and back to AC, ensuring a stable and clean power supply during switchover.

— **Voltage and frequency regulation:** Backup power systems should be capable of maintaining stable output voltage and frequency during switchover and transient events. Voltage and frequency regulation mechanisms, such as voltage regulators and frequency converters, should be implemented to mitigate fluctuations and enable compatibility with sensitive data center equipment.

- **Transient voltage response:**
  Backup power systems should exhibit good transient voltage response to protect connected equipment from voltage spikes, sags, and harmonics. This can be achieved via voltage regulation techniques, such as active voltage regulation, fast-reacting voltage control systems, and voltage stabilization features within UPS units.

- **Transient frequency response:**
  Backup power systems also should have a fast and accurate transient frequency response to maintain stable power supply during load changes and switchover. Frequency regulation mechanisms, such as droop control and active frequency regulation, should be employed to decrease frequency deviations and enable compatibility with data center equipment.

- **Harmonic distortion control:**
  Backup power systems should reduce harmonic distortion levels during switchover and transient events to prevent adverse effects on sensitive equipment. Harmonic filters, power conditioning units, or active power factor correction (PFC) techniques can be implemented to mitigate harmonic distortion.

- **System synchronization:**
  When multiple backup power sources, such as generators, are used in parallel, synchronization control mechanisms should be implemented for accurate synchronization during switchover. This enables smooth load transfers and avoids issues such as phase mismatches or power surges that can occur during parallel operation.

To meet these diverse safety requirements, internal combustion engines with diesel fuel have become established in recent decades due to their scalability, good dynamic behavior, robust operation, and continuous availability of the energy source.

These technical advantages offered by the internal combustion engine also can be applied to a decarbonized energy supply. By switching to natural gas generators, the carbon footprint of data centers can be reduced significantly without major technical losses. The final steps toward net zero then can be implemented with hydrogen generators as a climate-neutral energy carrier.

3.

RELIABLE BACKUP POWER AND A REDUCED CARBON FOOTPRINT WITH JENBACHER TECHNOLOGY

3. RELIABLE BACKUP POWER AND A REDUCED CARBON FOOTPRINT WITH JENBACHER TECHNOLOGY

To meet these diverse process and security requirements, INNIO Group has developed a technical concept especially for data center backup power and implemented it in the Jenbacher product portfolio.

3.1 Concept design for data centers

Based on INNIO's proven Jenbacher Type 6 design, the Jenbacher J620 natural gas solution was developed to meet specific data center requirements.

This solution delivers the following key features:

Enhanced electrical starting and fuel supply system with permanent pre-lubrication and pre-heating to make certain that the unit is always ready for operation. With technical improvements, including port injection and an advanced control management system, the fast start Jenbacher J620 natural gas genset for data centers can provide full output in less than 45 seconds (see figure 7) while supporting a single 100% load step, which is a step change compared to 180s or 300s, which are typical required start times for other gas engine power generation applications.

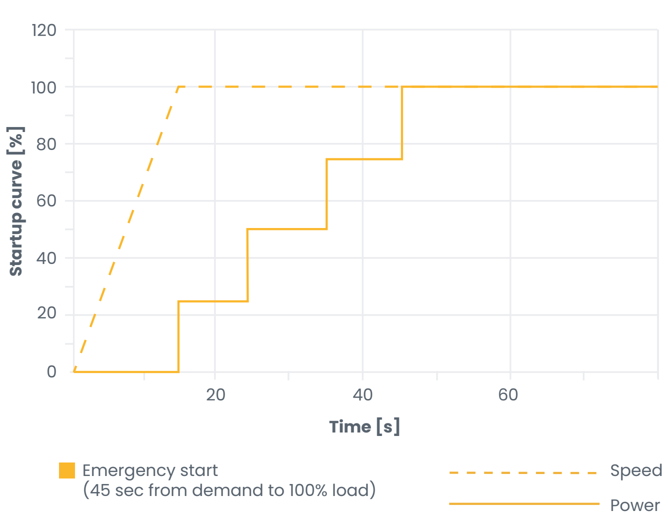

Figure 7: J620 emergency start behaviour

High reliability

- Jenbacher technology can support 99.999% data center availability
- Fast startup capability that delivers load within 15 seconds and full capacity in under 45 seconds

Enhanced fuel availability

- Stable pipeline supply
- Increased resilience
- Resilient fuel supply infrastructure compared to other energy sources

Optional: myPlant Performance remote connection and monitoring capabilities for improved engine reliability and availability.
INNIO Group's cloud-based Asset Performance Management solution enables data center operators to efficiently monitor their fleet's health in real time, securely and remotely, so they can promptly respond to its needs.

3.2 Ready for hydrogen

As a key enabler and an integral part of the energy transition, INNIO Group has launched its "Ready for H_2" portfolio, which includes 100% hydrogen-powered Jenbacher H2-Engines. INNIO's "Ready for H_2" engine portfolio is built on a long history of innovation with more than 30 years of experience and expertise in the use of renewable fuels and hydrogen-rich fuels, such as syngas and process gases for power generation.

As of today, Jenbacher Type 4 engines—with an approximate output of 600 to 1,000 kW—are available for operation with 100% hydrogen or mixtures of natural gas and hydrogen.

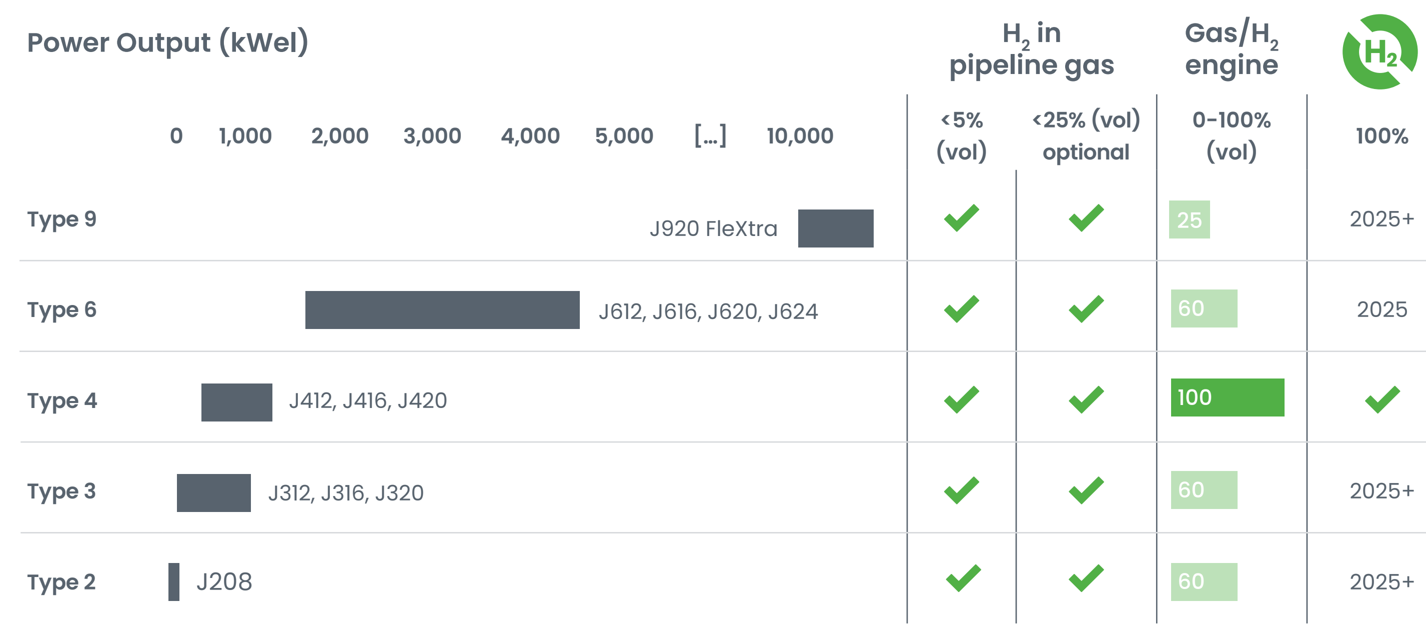

Figure 8: Jenbacher "Ready for H_2" product portfolio

4.

COMPARATIVE EVALUATION OF HYDROGEN TO ALTERNATIVE LOW-CARBON BACKUP SOLUTIONS

4. COMPARATIVE EVALUATION OF HYDROGEN TO ALTERNATIVE LOW-CARBON BACKUP SOLUTIONS

Data center operators basically have a wide range of technology solutions at their disposal for decarbonizing their backup power supply. In this section, a comparison is made with technologies that can be be seen as an alternative or supplement to hydrogen engines.

4.1 H2-Fuel cells

For hydrogen-based decentralized energy supply in almost all applications, the H2-Fuel cell and the H2-Engine represent the dominant competing technologies. In the comparative assessment, both technologies show different strengths and weaknesses.

Advantages of hydrogen engines:

- Established and flexible technology: Hydrogen engines resemble conventional internal combustion engines, making them easier to understand and maintain. They can be adapted to existing infrastructure with fewer modifications.
- CAPEX: In particular, the need for rare earths and the energy-intensive production of the electrochemical cell materials lead to significantly higher investment costs for the fuel cell compared to an internal combustion engine.
- Thermal efficiency: Due to the lower temperature level of the waste heat generated, the potential for waste heat utilization (for example in trigeneration systems) of most fuel cell technologies is significantly below that of internal combustion engines.
- High power output: Hydrogen engines can deliver high power output, making them suitable for applications where high torque and rapid acceleration are required, such as in heavy-duty vehicles or certain industrial settings.
- Flexibility: Hydrogen engines can be used with various fuels, including hydrogen produced from renewable sources or conventional fossil fuels. This flexibility allows for a transition from fossil fuels to cleaner alternatives over time.

Challenges of hydrogen engines:

- Efficency: Hydrogen engines have lower electrical energy efficency compared to most fuel cells.
- Emissions: Hydrogen engines produce emissions, primarly in the form of nitrogen oxides (NO_x). While the NO_x emissionsn are significantly reduced compared to the use of other fuels, a low amount of NO_x emissions is not avoidable.

	H2-Fuel cell		H2-Gas turbine	H2-Engine
	PEM	SOFC		
Fuel flexibility	-	○	+	+
CAPEX	-	-	-	+
Efficiency	+	++	-	++
Cold start for grid stabilization	++	--	-	+
Load flexibility	+	-	○	+
Service life	--	++	+	++

Table 3: Comparison of H2-Engines and H2-Fuel cells

Among the strengths and weaknesses of the hydrogen engine compared to the fuel cell, the significantly lower investment costs on the one hand and the lower efficiency on the other are particularly noteworthy from an economic perspective. As a result, hydrogen engines have a significantly lower levelized cost of electricity (LCOE) at lower full load hours, where efficiency does not play a significant role, while capital costs are dominating.

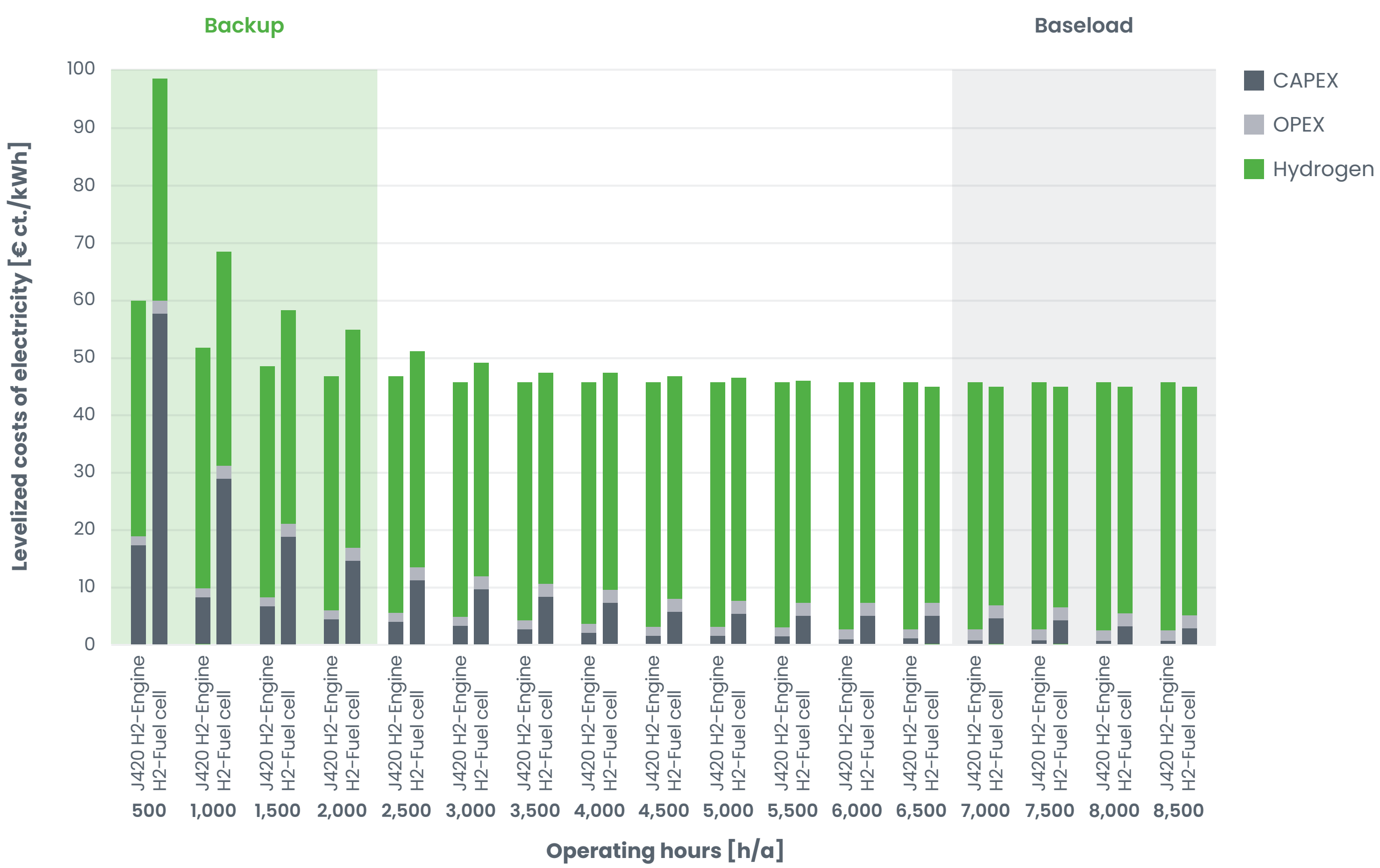

Figure 9: Levelized cost of electricity (LCOE) for H2-Engines and H2-Fuel cells

Therefore, hydrogen engines show significantly higher economic efficiencies in corresponding applications, such as backup operation.

4.2 Battery electric backup

Besides power generation with sustainable fuels, battery electric storage systems can be a promising backup solution for data centers.

Typically centered around lithium-ion (Li-Ion) batteries, BESS can switch from grid to battery operations a hundred times faster than a diesel genset. The speedy switchover between grid to battery operations is the key enabler to further cost reduction. These properties make BESS predestined for data center short-term backup power supply, flexible peaking capacity, frequency regulation, renewable integration, transmission, and distribution enhancement.

However, the main challenge of battery-electric storage systems as a sole backup solution is the comparatively high storage cost, which is the limiting factor to bridging long-term power deficits. Even today, typical BESS capacities cannot cover the average bridging times in key target segments.

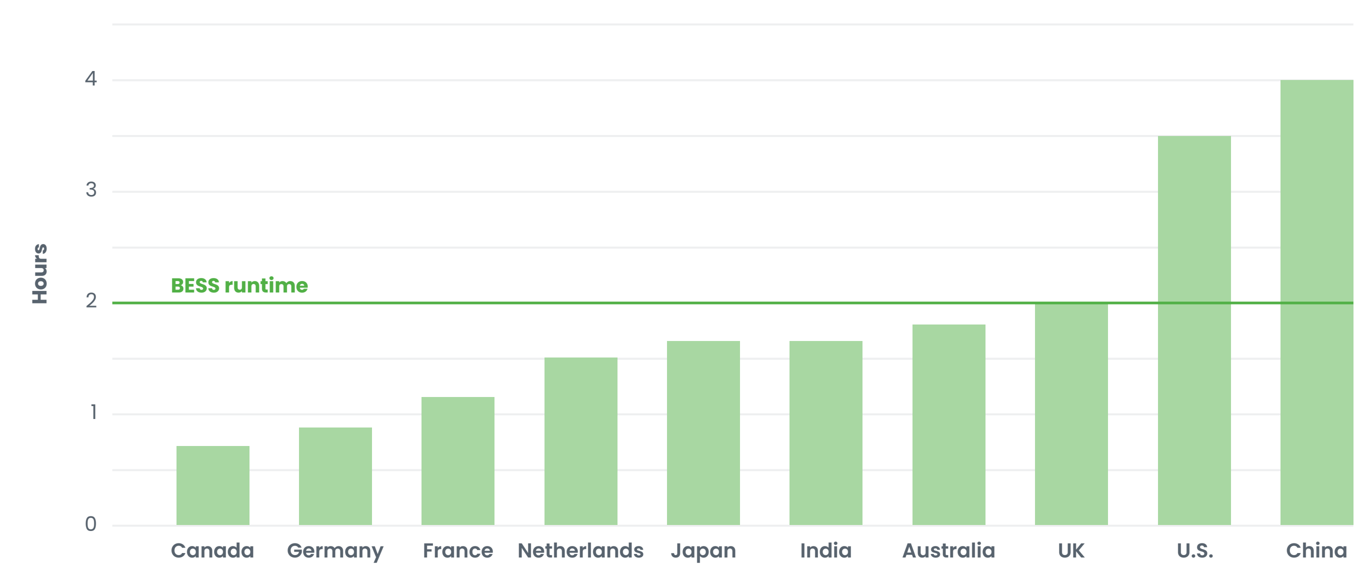

Figure 10: Customer Average Interruption Duration Index (CAIDI) compared with BESS runtime (Siemens Data Bank, 2021)

However, an increasing share of fluctuating generators in the future power system also will be accompanied by higher self-sufficiency requirements on the part of grid operators for data center operators. Engines that can be converted to hydrogen operation according to availability and therefore can rely on a secure supply infrastructure are able to provide this self-sufficiency. BESS, therefore, can be a useful supplement to gas engines but not a reliable alternative.

5.

IMPLEMENTING HYDROGEN-BASED BACKUP POWER SYSTEMS

5. IMPLEMENTING HYDROGEN-BASED BACKUP POWER SYSTEMS

5.1 Integration in existing heat and power infrastructure

Data centers have been a driving force behind positive change in climate protection over the past decade. Cloud computing platforms have done valuable pioneering work in terms of sustainable operations and the introduction of renewable energy into companies.

However, the transformation of our energy system also requires that data centers, in their new role as prosumers, also tap local efficiency and decarbonization potential through intelligent regional integration. With the increasing share of fluctuating renewable energies in the power grid, power grid operators in the future will be dependent on power-intensive consumers operating in a more energy-autonomous manner and flexibily procuring power according to the available supply. Data centers with climate-neutral backup and storage systems have the opportunity to make a valuable contribution as prosumers to a reliable climate-neutral energy supply and, in this context, generate additional revenue options.

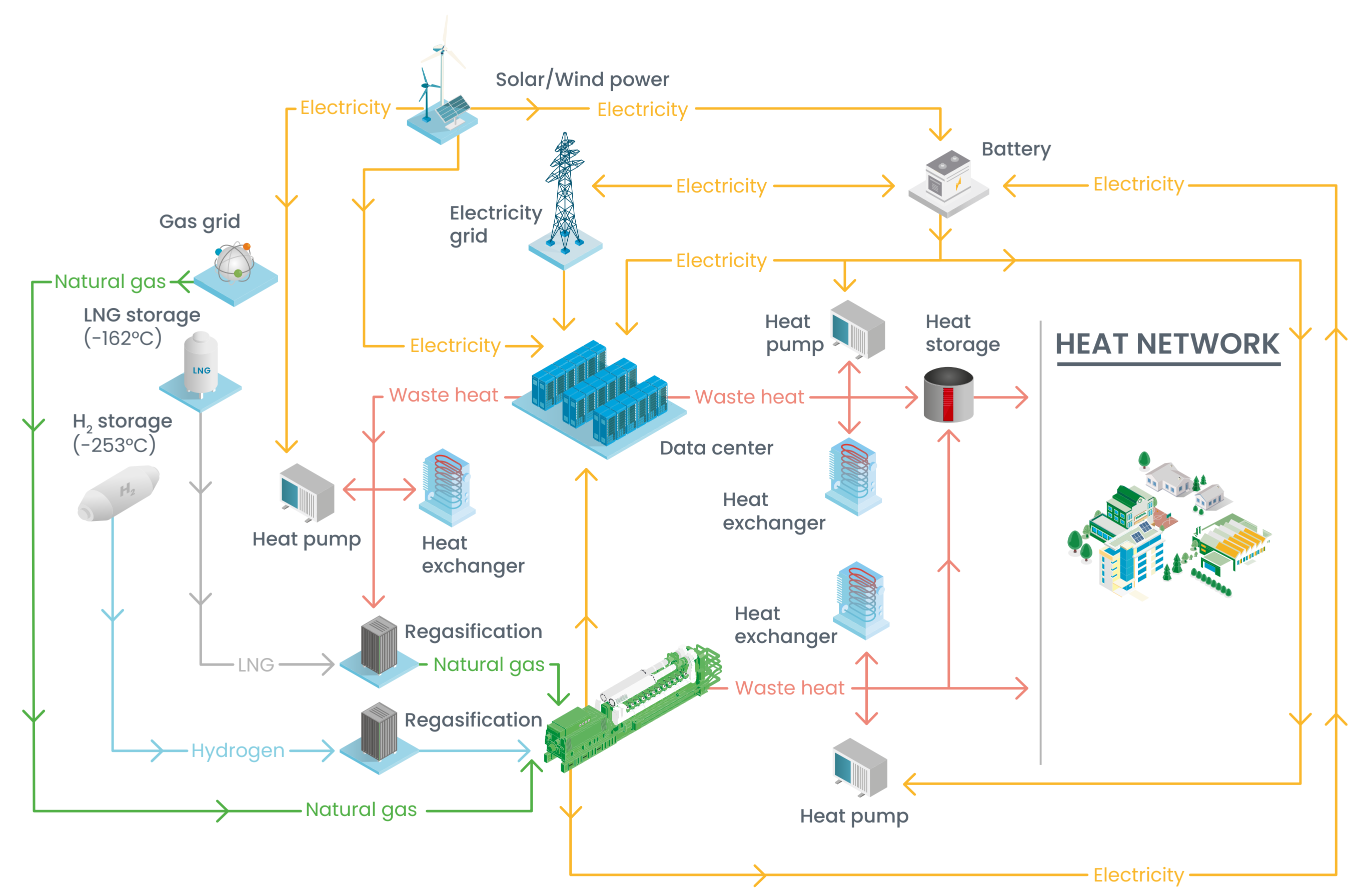

Figure 11: Regionally integrated decarbonization of data centers

In addition to the electricity sector, the heating sector offers a wide range of opportunities for the regional integration of data centers. The increasing use of heat pumps and regional heating networks as central elements for a climate-neutral heat supply in many places offers sufficient capacity for the use of waste heat, both from server cooling and from CHP-based backup systems.

To avoid stranded investments in this era of transformation, INNIO Group's fuel flexible power solutions enable data center operators to adjust the backup power system according to the changing requirements and revenue opportunities of the energy system. With an increased share of green hydrogen in the fuel supply, the engines can provide additional services, such as grid stabilization, and flexible compensation of volatile green PPA power supply.

The resulting higher operating hours and waste heat production in turn allow the implementation of waste heat recovery concepts. In particular, on-site combined cooling, heat, and power (CCHP) represents a promising concept for data center operators.

However, a high degree of automation and a resilient intelligent energy management system are needed to tap this cross-sector efficiency potential and at the same time keep a secure power supply as a top priority.

All-in-one energy management solutions for a sustainable regionally integrated energy supply

Decarbonization, decentralization, and digitalization pose major challenges for CHP plant operators today. INNIO Group recognizes the growing importance of complex energy-generating plants, especially in the context of constantly changing regulatory requirements. With the all-in-one energy management solution myPlant Optimization, INNIO offers a tailor-made tool to increase overall profitability through a directly marketed, sustainably flexible, and heat- as well as storage-oriented mode of operation in compliance with regulatory requirements. Based on precise electricity price forecasts as well as storage and heat forecasts, it enables the production and feed-in of electricity precisely when it is demanded in the grid, thus helping to improve the profitability of the plant and claim productivity gains through a high degree of automation. At the same time, precise design and mapping of the connected storage and heat networks contributes to high power generation flexibility. For this purpose, the intelligent digital solution continuously compares new information (e.g., new regulatory guidelines, current electricity and gas prices, weather data, and calculated forecasts such as emissions) and uses self-learning algorithms to create economically optimized and resource-saving operating strategies within the framework of individual specifications and operating conditions. By integrating INNIO's innovative myPlant Optimization as an all-in-one energy management solution, plant operators have the opportunity to make better operating decisions in a constantly changing environment and contribute to a sustainable heating, cooling, and power supply.

myPlant Optimization from INNIO is available in select countries.
For more information, visit: https://www.jenbacher.com/en/services/myplant-energy-management https://myplant.io/en/optimization

5.2 Combined cooling, heat, and power

Combined cooling, heat, and power (CCHP), also known as trigeneration, offers several specific advantages when applied to data centers. Since data centers consume a significant amount of energy for both computing operations and cooling, CCHP systems represent a promising approach to capturing the waste heat generated during electricity production and repurposing it.

Data centers generate a significant amount of heat due to their server operations. CCHP systems can provide consistent and efficient cooling by using waste heat for absorption chillers, ensuring that the temperature-sensitive equipment remains within safe operating limits. By simultaneously generating electricity, heating, and cooling on site, CCHP systems can substantially reduce data centers' energy costs. The reuse of waste heat for cooling diminishes the need for additional energy-intensive cooling solutions.

Furthermore, CCHP systems combine multiple energy services into a single system, freeing up valuable floor space within the data center that otherwise would be dedicated to separate power generation and cooling systems.

Data centers are sensitive to fluctuations in energy prices. By generating their own power and using waste heat for cooling, data centers can stabilize their long-term energy costs and reduce vulnerability to price hikes. While the benefits of CCHP for data centers are clear, it's important to conduct a thorough feasibility study and system design to determine that the technology is appropriately sized and integrated to meet the data center's specific needs. Factors such as local energy costs, climate, available resources, and the scalability of the system should be considered when evaluating the adoption of CCHP for data centers.

Jenbacher trigeneration plants are flexible, innovative systems offering combined cooling, heat, and power solutions.

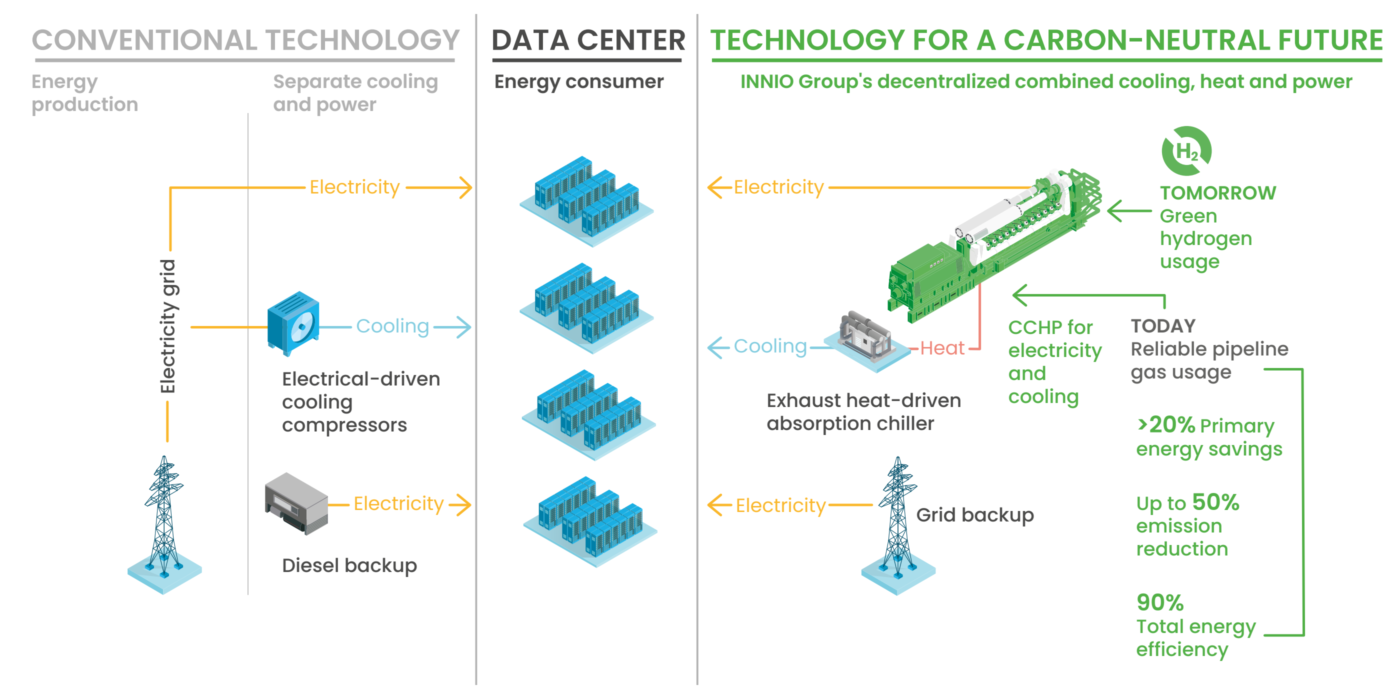

Figure 12: H_2 engine-based CCHP concept for data centers

6.

BEST PRACTICE

Figure 13: Factory acceptance test of the Jenbacher Type 4 hydrogen engine for NorthC Datacenters at INNIO Group's headquarters in Jenbach, Austria

6. BEST PRACTICE

Jenbacher solutions are sustainable technologies that can meet very different customer requirements in the data center industry. The NorthC project—with the world's first 100% hydrogen solution as a backup power supply for data centers—represents a true pioneering solution. The Winthrop project demonstrates how companies can prepare technologically for a hydrogen ramp-up. As can be seen from these two examples, Jenbacher technologies are available today that can put data centers on the transformational path to net zero.

6.1 NorthC—first hydrogen emergency backup power solution with engines worldwide

INNIO Group's Jenbacher "Ready for H_2" technology was selected by NorthC Datacenters (NorthC) to deliver an emergency backup power solution for its newest data center in Eindhoven, Netherlands. Six Jenbacher hydrogen engines will provide carbon-free emergency backup power in case of an electricity grid outage. The Jenbacher Type 4 hydrogen engines generate a total power output of 6 megawatts (MW) and will be delivered as a containerized package.

NorthC plans to be fully carbon neutral by 2030, which it will accomplish through four sustainability pillars: 100% green energy, modular construction, the efficient use of residual heat, and green hydrogen. The Eindhoven data center will be powered with solar and wind energy from the grid.

To provide additional flexibility and security to NorthC, the Jenbacher Type 4 engines are configured as dual-gas engines. In case of an electricity grid outage, they will be operated with hydrogen that is stored on site. For longer duration grid outages, NorthC has the option to switch to natural gas should the H_2 supply run short. INNIO Group's myPlant Performance cloud-based digital platform solution will provide NorthC with secure, real-time monitoring of the emergency backup solution. The project supports the Netherlands' strategy to achieve carbon neutrality by 2050.

6.2 Winthrop Technologies—preparing for a future with hydrogen

Winthrop Technologies is taking advantage of INNIO Group's technology now so it can be ready for hydrogen once that fuel is more readily available. Twenty-two containerized Jenbacher engines that can be converted to operate on hydrogen will provide 60 MW of continuous rated power output that are compliant with EU emissions regulations. The power plant will be used for emergency backup power and grid stabilization in times of higher demand and to support renewable power generation. Operating on pipeline gas, the Jenbacher engines emit up to 25% less CO_2 and up to 90% less NO_x emissions compared to traditionally used diesel generators. The fast-start and scalable Jenbacher Type 6 engines will be installed in a plug- and-play containerized configuration.

Ireland has benefited from significant amounts of foreign technology investment over the past decade that have transformed the country into one of Europe's largest hyperscale data center hubs. Today, Dublin's standing as Europe's second-largest data center hub creates a challenge for the country's energy infrastructure as server farms are increasingly integrated into the national grid. The Jenbacher island mode solution will allow the Winthrop power plant to operate independently from the national grid during peak times and support the grid during peaking power.

INNO Group also will provide Winthrop with secure, real-time monitoring of the power plant through its cloud-based digital myPlant platform. The project supports Ireland's strategy to achieve carbon neutrality by 2050.

PRESS RELEASE
INNIO and NorthC Datacenters to build First Hydrogen Emergency Backup Power Solution with Engines Globally

PRESS RELEASE
Winthrop Technologies has selected Jenbacher Engines, which can be converted to operate on Hydrogen[1] for Emergency Backup Power and Grid Stabilization to power a 60 MW Hyperscale Data Center in Ireland.

[1] Optional Scope on Demand

LITERATURE

LITERATURE

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About INNIO Group

INNIO Group is a leading energy solution and service provider that empowers industries and communities to make sustainable energy work today. With its product brands Jenbacher and Waukesha and its digital platform myPlant, INNIO offers innovative solutions for the power generation and compression segments that help industries and communities generate and manage energy sustainably while navigating the fast-changing landscape of traditional and green energy sources. INNIO is individual in scope, but global in scale. With its flexible, scalable, and resilient energy solutions and services, INNIO enables its customers to manage the energy transition along the energy value chain wherever they are in their transition journey.

INNIO is headquartered in Jenbach (Austria), with other primary operations in Waukesha (Wisconsin, U.S.) and Welland (Ontario, Canada). A team of more than 4,000 experts provides life-cycle support to INNIO's more than 55,000 delivered engines globally through a service network in more than 100 countries.

In March 2023, INNIO's ESG rating ranked first out of more than 500 companies worldwide in the machinery industry assessed by Sustainalytics.

For more information, visit the INNIO website at
www.innio.com

Follow INNIO Group and its brands on X (formerly known as Twitter) and in.

ENERGY SOLUTIONS.
EVERYWHERE, EVERY TIME.

Digital version available

In general, "Ready for H_2" Jenbacher units can be converted to operate on up to 100% hydrogen in the future. Details on the cost and timeline for a future conversion may vary and need to be clarified individually.

"Optimization/optimize" refers to the automatically generated recommendations for action by the myPlant energy management solution to improve the status quo of electricity trading and resource-efficient plant operation.

Jenbacher is part of the INNIO Group

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