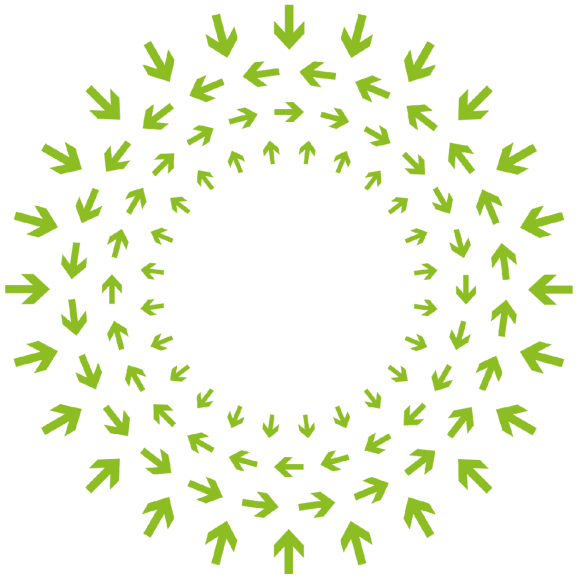


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Compute Project

DCF-Sustainability-Project: Clean Backup Power Technologies

Title: Clean Backup Power Technology Requirements

Version 0.3

Base Specification

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1. License

1.1. Open Web Foundation (OWF) CLA

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Company names: Google, Microsoft

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1.2. Acknowledgements

The Contributors of this Specification would like to acknowledge the following companies for their feedback:

- Net Zero Innovation Hub (NZIH)
- Google
- Microsoft
- Verrus

2. Compliance with OCP Tenets

2.1. Openness

Accessibility and Collaboration: The specification is provided openly to collaboratively facilitate the development of clean backup generator technologies that can be used by the data center industry. Providing this set of specifications will guide consistency in the supply of clean backup power generation technologies.

An objective of this specification is to collect end to end industry feedback and alignment on clean backup requirements that can be shared throughout the industry including with colocation providers.

2.2. Efficiency

This specification outlines standardized efficiency requirements for data center clean standby power generators. This ensures that any new technology developed continues to meet or exceed the data center industries high end to end power efficiency standards.

2.3. Impact

Aligning on clean backup requirements for data centers has a transformative impact on the industry by accelerating the development and time-to-market of these technologies. This specification will serve as an enabler to the data center industry and suppliers in the transition to clean standby power generators.

2.4. Scale

Clean standby generators specified through this base specification should have the ability to be modularized and be deployed at any scale, with minimal intervention. Aligning on a broad set of common requirements within the industry directly supports achieving at scale deployments faster.

2.5. Sustainability

Clean standby generators directly support OCPs sustainability tennet. This specification provides the emissions guardrails to suppliers who are designing and producing clean backup generators. The format is technology agnostic and flexible enough to accommodate a wide range of clean backup technologies.

3. Overview

3.1. Introduction to clean backup technologies

This Data Center Industry Standard Specification is a performance based, technology agnostic specification, designed to provide a comprehensive and authoritative guide for the selection, design, implementation, and operation of **Zero-Carbon and Low-Carbon Transition** backup power technologies within data center environments. Its primary purpose is to guide technology providers to support the data center industry goals of high levels of reliability and uptime while simultaneously minimizing environmental impact and optimizing energy efficiency.

Traditional diesel generators offer robust, high-reliability emergency power. However, their emissions profile—especially NOx, PM2.5, and CO_2—is no longer compatible with decarbonization goals or environmental regulations in many jurisdictions.

This specification enables vendors to offer alternative clean backup power generator solutions such as (but not limited to):

- Fuel Cells (Proton Exchange Membrane - PEM)
- Clean fueled Generators (e.g., renewable natural gas, e-fuels, hydrogen, green methanol)
- Energy storage systems (ESS) including Long duration energy storage (LDES)

3.2. Technology Agnosticism and Focus

This is a performance based specification and does not mandate a single technology path. It instead provides the criteria by which alternative generation and energy storage technologies should be evaluated to ensure they meet mission critical requirements.

3.3. Definition of Clean

For the purposes of this specification clean refers to zero-carbon and Low-carbon Transition technologies. These technologies either eliminate local emissions entirely or significantly reduce carbon intensity compared to Tier 2 diesel baseline emissions.

Zero-carbon is defined as a system that produces **zero Scope 1 emissions** (CO2, NOx, SOx, PM) at the point of use during steady-state operation. **Low Carbon Transition** defines systems that produce

considerably lower Scope 1 emissions (CO2, NOx, SOx, PM), when compared with Tier 2 diesel generator emissions without after treatment controls, at the point of use during steady-state operation. **Low Carbon Transition** technologies may utilize fuel sources with carbon intensity that is measurably reduced compared with traditional diesel fuel.

3.4. Technology Evaluation Methodology and Baseline

When evaluating **zero carbon** and **low carbon transition** backup technologies, establishing a standardized point of comparison is crucial. The backup technologies in terms of emissions should be compared against diesel engines with 1742 lbs/MWh CO2 emission. Ideally, reducing this value to less than 10th percent without NOx and SOx can be an ideal target. The technologies from the highest to the lowest emission are diesel engines. diesel engine with SCR, natural gas engines, natural gas with SCR, hydrogen engines, and PEM which can take us to near zero emission. Energy storage if used in backup use cases should be used in combination with other technologies to meet the availability requirements of the facility.

Key comparative metrics include:

- Volumetric & Gravimetric Power Density (kW/m² and kW/kg) compared to high-density Li-Ion packaging.
- Duration
- Capital Expenditure (CAPEX) & Levelized Cost of Storage/Energy (LCOS/LCOE) compared to prevailing Li-Ion market rates.
- Degradation Rates & Augmentation Requirements mapped against standard Li-Ion degradation curves.
- Transient Response & Step-Load Capabilities benchmarked against inverter-based BESS response times.

Conventionally backup technologies are “generation” where the unit can run indefinitely as long as it has fuel. Data center designers target enough storage to make sure in case of long outages they can refuel the unit. Energy storage units (like BESS, etc.) for the same reason should be put in a different category. They can only be used where there is a short outage and the grid operator guarantees the outage will never exceed that duration.

3.5. Emissions Reduction Methodology and Technology Eligibility

Clean backup technology can be classified according to system performance. Since all backup generators feature electrical backup capabilities, the technology is categorized by:

- Fuel or energy source,
- Energy conversion process
- Electrical interface.

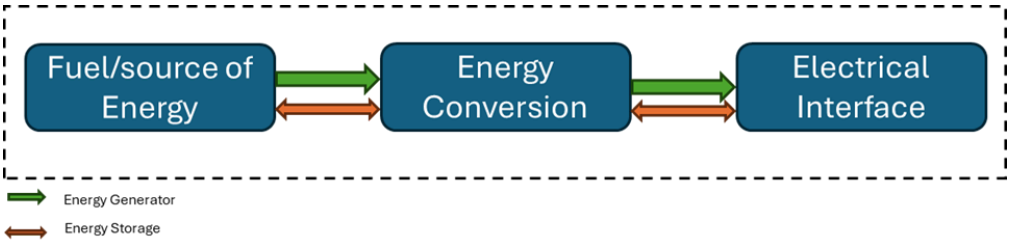


Figure 1: Clean backup technology classification showing the relationship between storage, generation and electrical interface

The electrical interface primarily determines characteristics relevant to a data center. These interfaces can be:

- Inverter-based
- Non-inverter-based

Inverter-based interfaces provide both AC and DC power output, whereas non-inverter-based interfaces supply AC power (50/60 Hz).

Energy conversion technologies include chemical, thermal, mechanical, and electrochemical processes. The majority of engine generators and fuel cell systems fall under chemical energy conversion; battery technologies fall under electrochemical processes, while emerging long-duration energy storage solutions are often categorized as chemical, electrochemical and mechanical storage.

Fuel or energy sources may come from the grid (for energy storage) or from stored fuels, such as various carbon-based or non-carbon-based types. Clean energy backup typically refers to the fuel source, and due to the method of power conversion, these technologies can produce NOx and CO_2 emissions.

The type of fuel and power conversion largely determines the energy density of the technology, while the electrical interface governs the characteristics of the solutions.

One or a combination of the following approved methodologies to achieve the performance and sustainability targets defined in this specification may be used.

- Direct Energy Storage (Elimination)
    - Lithium-Ion,
    - Sodium-Ion,
    - Flow Batteries,
    - Flywheels
- Electrochemical Conversion (Substitution)
    - Fuel Cells (PEM)
    - Metal Air
    - Linear Generators
    - Alternative Generators
- Low-Carbon Combustion (Engineering Control)
    - Hydrogen ICE,
    - Bio-Methanol Turbines,
    - Renewable Natural Gas (RNG) Generators,
    - HVO generators
    - After Treatment (SCRs)
- Carbon Capture Technologies
    - Point Source Carbon Capture

Sustainability Classification

- Target Architecture: Zero Carbon and Zero Emissions
- Bridging Architecture: Low Carbon Transition

3.6. Definitions

ESG (Environmental, Social, and Governance):
Refers to a set of standards for a company's operations that socially conscious investors use to screen potential investments.

- Environmental criteria consider how a company performs as a steward of nature. This includes, but is not limited to, energy use, waste, pollution, natural resource conservation, and treatment of animals.
- Social criteria examine how it manages relationships with employees, suppliers, customers, and the communities where it operates. This

includes, but is not limited to, labor standards, health and safety, diversity and inclusion, and community relations.
- Governance deals with a company's leadership, executive pay, audits, internal controls, and shareholder rights.

GHG (Greenhouse Gas):
Any of the gases that absorb infrared radiation in the atmosphere, contributing to the greenhouse effect. For the purposes of this specification, GHGs shall include, at a minimum, Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), and Sulphur Oxides (SOx). All GHG emissions should be reported in metric tons of CO2 equivalent (CO2e), calculated using the Global Warming Potential (GWP) values from the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) with a 100-year time horizon.

LDES (Long Duration Energy Storage):
An energy storage system capable of discharging at its rated power for a sustained period, typically defined as 10 hours or longer. These systems are intended to provide grid stability, support renewable energy integration, and ensure power availability during extended outages.

Scope 1 Emissions:
Direct greenhouse gas (GHG) emissions that occur from sources that are owned or controlled by the company. For the purposes of this specification, this includes, but is not limited to:
- Emissions from the combustion of fuel in stationary sources, such as backup generators
- Fugitive emissions from the leakage of refrigerants from cooling systems.

Scope 3 Emissions:
All indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, both upstream and downstream. For the purposes of this specification, this includes, but is not limited to:
- Embodied emissions from the sourcing, production, and transportation of fuel.
- Embodied emissions from the manufacturing and transportation of the backup power equipment.
- Emissions from the disposal and end-of-life treatment of the backup power system.

Availability:

The percentage of time that a system is operational and able to perform its intended function. It is typically calculated as:

$$Availability = (TotalTime - Downtime)/TotalTime * 100\%$$

e-fuels:

Synthetic fuels that are produced using renewable or decarbonized electricity to split water into hydrogen and oxygen (electrolysis), and then combining the hydrogen with a carbon source (like captured CO2) to create a liquid fuel. These fuels are considered a type of drop-in fuel, meaning they can be used in existing infrastructure without significant modification.

Reliability

Reliability is the probability that a power system performs its intended function without failure for a specified time under defined operating conditions, as defined in IEEE 493.

Microgrid:

A microgrid is a group of interconnected loads and distributed energy resources (DERs) within clearly defined electrical boundaries that acts as a controllable entity with respect to the grid, and that can operate in either grid-connected or islanded mode. If a datacenter backup system is capable of operating in either grid-connected or islanded mode, it is considered a microgrid.

3.5 Referenced Codes and Standards

- NFPA 68 - Standard for Explosion Protection by Deflagration Venting
- NFPA 69 - Standard for Explosion Prevention Systems
- NFPA 72 - National fire alarm and signaling codes
- NFPA 70 - National Electric Code
- NFPA 855 Standard for the Installation of Stationary Energy Storage Systems
- NFPA 110: Standard for Emergency and Standby Power Systems
- IFC International Fire Code
- UL 1642 Standard for Lithium Batteries
- UL 1973 Batteries for Use in Light Electric Rail Applications and Stationary Applications
- UL 9540 Energy Storage Systems and Equipment
- UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

- ASHRAE 21-2022 Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications
- IEEE 1547 Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electrical 1 Power System Interfaces
- IEEE 2030.2 Guide for the Interoperability of Energy Systems Integrated with the Electric Power Infrastructure
- UL 1741 and (Supplements A and B) Standard for Stative Inverters and Charge, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
- UL 62109-1 Safety of power converters for use in photovoltaic power systems – Part 1 General requirements
- UL 2200: Stationary Engine Generator Assemblies
- UL 9540: Energy Storage Systems (ESS) and Equipment
- Stationary and Portable Fuel Cell Systems Codes and Standards
- NFPA 2 Hydrogen Technologies Code Requirements
- Hydrogen Technologies Safety Guide
- ISO 8528-5: Reciprocating Internal Combustion Engine Driven Alternating Current Generating Sets
- ISO 14064-1: GHG emissions reporting
- IEC 62282-2 (fuel cell safety and performance)
- NEMA MG-1 (generator design)
- IEEE 2800 Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnection with Associated Transmission Electric Power Systems

4. Detailed Specifications

4.1 Technical Viability and Reliability

Table 1: Clean backup technology Technical Viability and Reliability requirements

Requirement	Specification
System Topology	Must be a self-contained, grid-forming (GFM) energy source capable of isolating from the utility.
Start-up Time	≤ 10 seconds from signal to power delivery

Seamless Transfer	Detect utility loss and transition to island mode in **<8ms** (quarter cycle)
Continuous Power Rating	Must provide [X] MW continuous output at a power factor of 0.8 lagging to 0.9 leading.
Overload Capability	Support **110% for 60 seconds** and **150% for 3 seconds**.
Block Load Acceptance	Capable of accepting a **100% block load step instantly**.
Voltage Deviation (Transient)	a) Upon load steps the backup generation should meet the ISO8528-5 G3 transient response requirements. b) The requirements are different for the energy storage units if they are used as a back up source.
Frequency Regulation (Steady-state)	Maintain frequency within **±0.5%** of nominal (e.g., 60Hz).
Waveform Quality (THD)	Shall not exceed **5%** at full load in compliance with IEEE 519.
Grid Interactivity/Certification	Must comply with IEEE 2800 (Voltage Ride-Through) and be certified to **IEE1547-2018** (Interconnection Standard).
Output (AC)	**480 VAC, 3-phase, 60 Hz (±1%)**. Performance guarantee at **13.8kV**.
Output (DC)	**0-800 VDC (±2%)**

4.2 Scope, Scale, Reliability and Operating Environment

Table 2: Clean backup technology Scope, Scale, Reliability and Operating Environment requirements

Requirement	Specification
Target Scale	Support data center demands of **40 to 50 MW**, scalable to **300 MW–1 GW**.

Module Size	Back-up module size of **2–10 MW is preferred**
Technology Readiness	Target **TRL of 8 or above**
Availability/Reliability	Ensure high level of uptime, typically **99.99% availability** or more for the backup system with N+m to achieve 99.999% at the datacenter system level. **MTBF and MTTR** of individual units must be provided.[1]
Maintenance	All components of the backup system should be concurrently maintained.
Backup Duration	**Indefinite duration**, with the ability to refuel.
Fuel	Any fuel fulfilling the **Net-Zero emissions requirement**. On-site storage solution must be integral to the design and sized for refueling time.[1]
Footprint/Form Factor	Preferred deployment is **containerized or skid based** (road transportable). Typical footprint **2.5 m × 6.0 m**.
Weight	Weight **< 12,000 kg** (including fuel or battery modules).
Energy Density	The vendor must specify the power and energy density (m^2/MW, m^2/MWh).
Operating Temperature	**–20 °C to +50 °C**.
Safety Compliance	**NFPA 110 Level 1 compliant**. Explosion-proof enclosures required for hydrogen or e-gas systems.

4.3 Sustainability and Emissions Requirements

Compliance with emissions and lifecycle standards is mandatory for technology eligibility.

Table 3: Clean backup technologies: Sustainability and Emissions requirements

Requirement	Specification
Zero Carbon Goal (Scope 1)	Produce **0.0 g/kWh** of direct CO2e emissions and **zero criteria pollutants** (NOx, SOx, PM2.5/PM10, VOcs) at the point of use during operation
Low Carbon Transition (Scope 1)	Criteria pollutants must be **equal to or lower than EPA Tier IV requirements**.
Hydrogen NOx Emissions	For generators using hydrogen as a fuel, NOx must be controlled to **<0.02 g/bhp-hr** via Selective Catalytic Reduction (SCR).
Embodied Carbon (Scope 3)	Vendor must provide a **Type III Environmental Product Declaration (EPD)** verified by a third party (e.g., UL, NSF) in accordance with ISO 14025. If an EPD is not available, a timeline for its development must be provided.
Carbon Intensity Cap	The total embodied carbon of the energy storage and conversion system shall not exceed [X]kg CO2e per kW of installed capacity.
Circular Economy Strategy:	The vendor shall provide a documented **End-of-life (EOL) management Plan** prioritizing reuse and recycling over disposal.
Material Recovery Rate	For chemical storage systems, guarantee a recovery rate of **>95%** for critical minerals (lithium, Cobalt, Nickel).
Noise Pollution	Sound pressure levels shall not exceed **75 dBA at 1 meter** from the enclosure.
Prohibited Materials	Lead, cadmium, mercury, hexavalent chromium (per RoHS).

4.4 Testing, Management, and Lifecycle

These define how the product must be verified, controlled, and supported over its lifespan.

Table 4: Clean backup requirements Testing, Management and Lifecycle requirements

Requirement	Specification
Factory Acceptance Testing (FAT)	Required, including **Hardware-in-the-Loop (HIL) simulation** for controller logic and Round-Trip Efficiency validation. This test must demonstrate the controller's response to simulated grid faults (such as voltage sags and frequency steps) and critical mode transitions (grid-tied to island mode) without requiring the physical battery assets to be fully assembled
Round-Trip Efficiency Validation	A sub-scale module test must be performed to validate the vendor's DC-to-AC-to-DC efficiency claim, including the accounting of HVAC and auxiliary losses.
Safety System Integration	For Battery Energy Storage Systems (BESS), the Battery Management System (BMS) logic must be verified, specifically confirming the "Stop charge/Discharge" commands function when thermal or voltage limits are breached
Site Acceptance Testing (SAT)	Required, including **Black Start Simulation** and **Step Load Response** verification.
Integration	The power generation system must integrate seamlessly with the data center's UPS and Power Distribution Unit (PDU)
System Lifetime	**≥ 15 years** with midlife refurbishment.
Spare Parts Availability	**≥ 10 years** post-EOL.
Management System	System interface must natively support **DNP3 or IEC 61850** for utility communications and **OpenADR 2.0b** for automated demand response signals.
Maintenance Plan	Vendor must provide a preventative maintenance schedule (e.g., every 200–400 hours). An **End-of-life recycling/reclamation plan** is required.

Module Servicing	Modules must be Hot-swappable or field replaceable.

4.4.1 Site Acceptance Testing (SAT)

These tests verify dynamic performance under realistic conditions.

Table 4: Clean backup technologies: Site Acceptance Testing requirements

Test Category	Key Requirement	Pass Criteria
Black Start Simulation	Must detect outage, disconnect the utility breaker, and form the islanded microgrid voltage reference.[1]	Critical load must be supported within **<8ms** (the specified transfer time) with **zero human intervention**.
Energy Capacity Test	Discharge the system at 100% rated kW load from 100% State of Charge (SoC) down to the manufacturer's minimum SoC.[1]	Total energy delivered (kWh) measured at the output meter must **equal or exceed** the rated nameplate capacity.
Functional Performance Test (FPT)	Apply 0% → 50% → 100% load steps.[1]	Verify voltage recovery times (**<500ms**) and frequency slew rates (**<2Hz/s**) match the performance requirements.
Thermal Management	Conduct infrared (IR) scanning during the 100% continuous load event.	HVAC/Liquid Cooling systems must maintain cell temperatures within the optimal range (e.g., 23 ℃) and prevent any component from exceeding its rated temperature limits.
Interoperability	Simulate a Utility Demand Response event and verify Anti-Islanding Safety.	System must respond to the signal command within the specified latency (e.g., **<5 seconds**) and correctly

		disconnect from the grid in compliance with **IEEE 1547.1**.

5. Compliance

Table 5: Specification Compliance Requirements

Item	Requirement	Reference	Mandatory
1	Technical Viability and Reliability	Section 4.1	Yes
2	Scope, Scale, Reliability and Operating Environment	Section 4.2	Yes
3	Sustainability and Emissions Requirements	Section 4.3	Yes
4	Testing, Management, and Lifecycle	Section	4.4

5.1. Repository Location

Not Applicable

5.2. Prescribed Materials

List any prescribed materials included in your contribution, such as specific components that are referenced but not contributed.

- *All references to external codes and standards are not contributed here*

5.3. References

See Section 3.5