WHITE PAPER

INTEGRATED POWER & COOLING

DATA CENTER SOLUTIONS

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Executive Summary

Data centers face constraints on power availability, cooling capacity, and construction timelines. Natural gas generation is often the quickest path to operation, but many campuses with access to natural gas leave valuable, clean energy on the table. When supplied by or co-sited with gas pipelines, data center operators can take advantage of pipeline pressure to supplement their energy needs. Turboexpander-generators convert pressure into electricity and usable "cold," offsetting refrigeration loads and improving power usage effectiveness (PUE) in one equipment package.

The Challenge

Data centers must bring online new server capacity while managing interconnection risk, operating expenditure (opex), and emissions exposure. Server cooling is a large component of campus auxiliary power demand, and traditional cooling technologies are both capital- and maintenance-intensive.

The Opportunity: Pressure Energy

Pipelines deliver natural gas at high pressure. Before gas can be used on-site, the pressure must be reduced with regulators or valves at pressure regulating stations. In older station designs, the pressure energy is dissipated rather than recovered. Turboexpander-generators may be integrated into the stations to improve the pressure regulating process by using the pressure energy to spin an electric generator. Turboexpanders may be installed at campuses with natural gas-fired turbines onsite and at existing pressure regulating stations in the gas pipeline network.

Proven, Mission-Critical Equipment

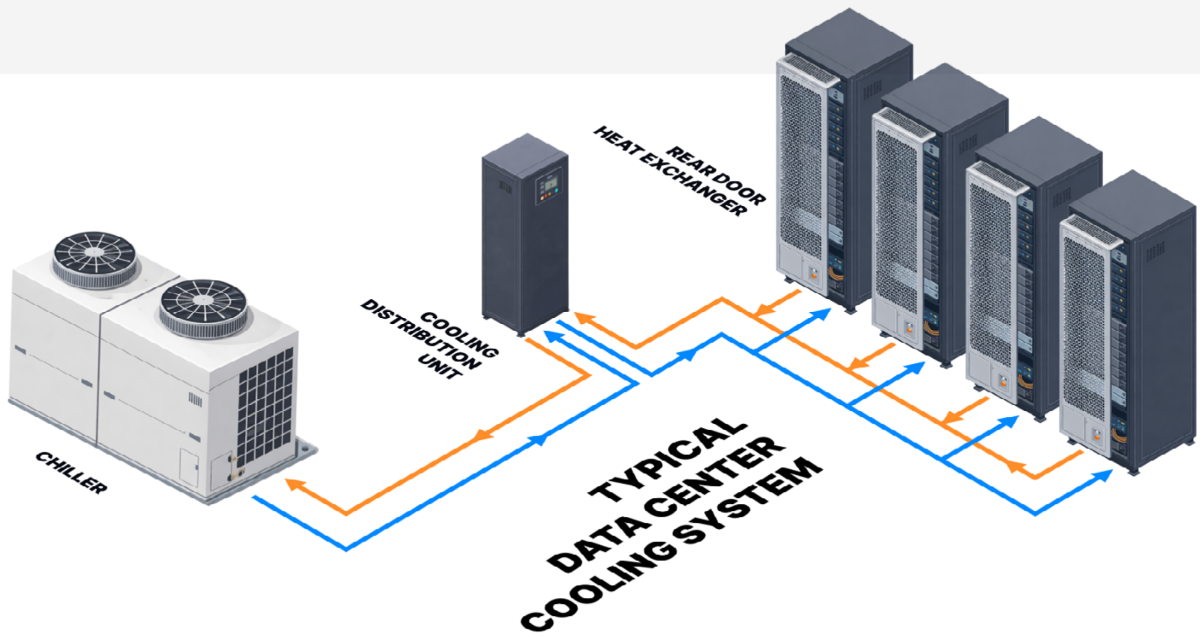
Each turboexpander-generator module is designed to output up to 300 kilowatts of clean electricity and 3.5 MMBTU per hour of cold.

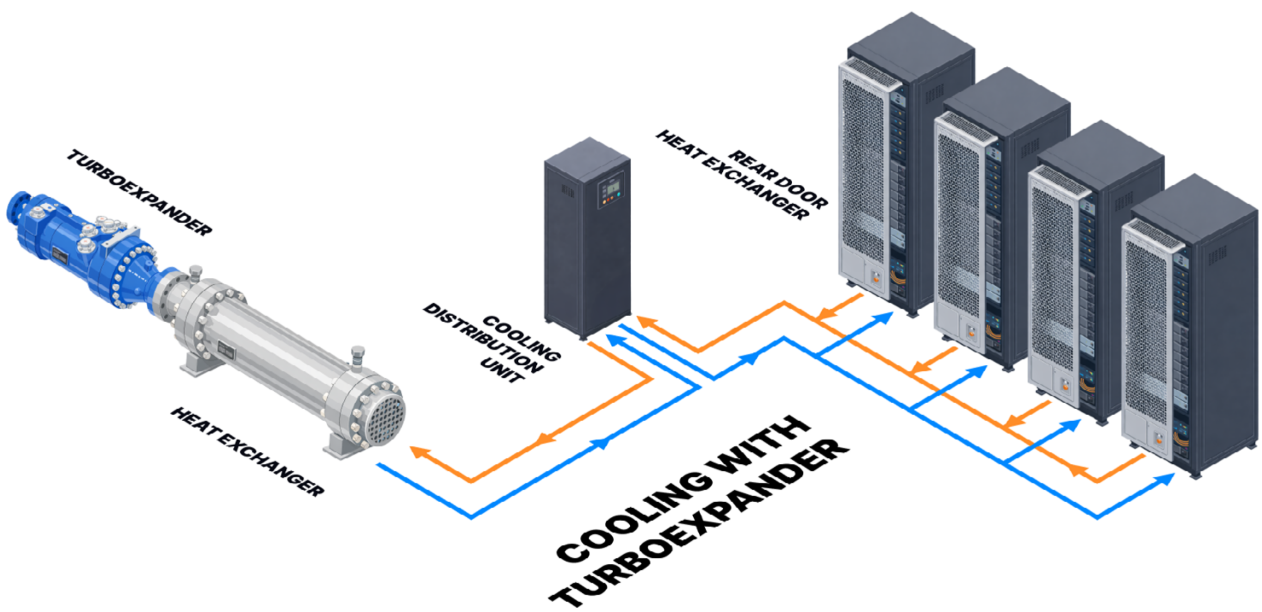
FreeSpin® was designed to the most demanding oil and gas specifications with a design life of 20+ years for major components. Mission-critical subsystems such as magnetic bearings are included to reduce maintenance and downtime compared to conventional power and cooling equipment.

Integrated Power and Cooling: How It Works

The integrated system is enabled by the installation of a turboexpander-generator at the pressure regulating station and the integration of a heat exchanger with the coolant distribution unit (CDU). As gas expands across the turboexpander, electricity is produced in the generator and the gas is instantly cooled. The generated electricity is sent to the campus power distribution center. The cold can be consumed by data center in different configurations.

A CDU manages thermal and hydraulic exchange between a building's cooling loop and its servers cooling loops. A common turboexpander cooling scheme is shown below, in which a heat exchanger is integrated with the CDU. In this configuration, the turboexpander and heat exchanger take the place of traditional chillers.





Operational Impact: Illustrative PUE Improvement

As artificial intelligence workloads push facilities toward unprecedented energy consumption, power usage effectiveness (PUE) has become the most important metric to track data center operating efficiency. PUE is calculated by comparing a facility's total energy consumption (in the numerator) to a facility's total IT load (in the denominator). High-performance chips generate large amounts of heat, and cooling requirements account for 30 to 40 percent of a data center's total energy consumption for these workloads.

The next improvements to PUE will not come from better chillers or more advanced cooling hardware. A new perspective that expands how operators think about PUE, cooling systems, and energy procurement is required to create transformational change. Rather than viewing cooling as an isolated subsystem attached to electricity opex, integrated power and cooling enables operators to take a more holistic view of campus energy consumption.

Table 1 describes the power accounting required to calculate PUE for a hypothetical campus with a 2-megawatt IT load and a traditional cooling scheme. Table 2 demonstrates how the addition of turboexpanders and integrated power and cooling eliminates the refrigeration electrical load (619 kW at COP 3.1) and reduces total campus power demand from 3.0-MW to 2.4-MW.

Integrated power and cooling enables what can be described as a "comprehensive PUE framework." Under this approach, efficiency is evaluated not only by how well mechanical cooling equipment performs but also through system-level reduction or elimination of active cooling demand. By generating electricity on-site and simultaneously providing cooling, this framework minimizes reliance on mechanical chillers and grid power while capturing and repurposing energy that would otherwise be lost. Table 3 describes the operational impact that implementation can have on IT loads up to 20-MW.

Table 1

Typical PUE Calculation	Percentage	Kilowatts
IT power		1,935
UPS	4%	77
Power conversion	6%	116
Lights	3%	58
Controls	1%	19
Refrigeration (COP 3.1)	32%	619
Fans	6%	116
Water pumps	4%	77
Total Campus Power		**3,019**

$$\text{PUE} = \frac{\text{Total Campus Power}}{\text{IT Power}} = \frac{3019\,\text{kW}}{1935\,\text{kW}} = 1.56$$

Table 2

Integrated Cooling	Percentage	Kilowatts
IT power		1,935
UPS	4%	77
Power conversion	6%	116
Lights	3%	58
Controls	1%	19
Refrigeration	0%	0
Fans	6%	116
Water pumps	4%	77
Total Campus Power		**2,400**

$$\text{PUE} = \frac{2400\,\text{kW}}{1935\,\text{kW}} = 1.24 \;\; \text{(with integrated cooling)}$$

$$\text{PUE}_c = \frac{0\,\text{kW}}{1935\,\text{kW}} = 0 \;\; \text{(with integrated power)}$$

Table 3

IT Power (kW)	Total Power at 1.55 PUE (kW)	PUE with 10 Integrated Cooling Modules	PUE with 10 Integrated Power Modules
500	825	1.25	0
1,000	1,550	1.25	0
1,935	3,019	1.25	0
2,500	3,925	1.25	0.05
5,000	7,750	1.25	0.65
7,500	11,675	1.25	0.85
10,000	15,500	1.25	0.95
15,000	23,250	1.35	1.15
20,000	31,000	1.40	1.25

AI workloads are driving unprecedented facility-level energy demand as operators face constraints on power availability, cooling capacity, and construction timelines. In this context, power usage effectiveness (PUE) is more than an operating metric; it reflects how efficiently a data center manages its energy supply chain. Integrated power and cooling delivers a step-change improvement in PUE by installing a turboexpander-generator at a natural gas pressure regulating station and coupling a heat exchanger to the coolant distribution unit (CDU) to provide both electricity and usable “cold.” In illustrative performance summaries, this system-level integration displaces mechanical refrigeration and materially reduces total campus power demand, underscoring the benefits of a more comprehensive approach to PUE improvement. Delivered as mission-critical modules with a 20-year design life and high-uptime subsystems such as magnetic bearings, FreeSpin® is a mature equipment package for integrated power and cooling applications. When evaluating projects, data center operators and developers should prioritize campuses which need to lower opex, reduce emissions exposure, or add behind-the-meter clean generation capacity.

About the Authors

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Steve is the Vice President of Engineering at Sapphire Technologies. He has extensive international experience leading technology and product development programs as well as building and maturing world leading engineering teams.

Before joining Sapphire Technologies in 2022, he was the President of Rolls-Royce High Temperature Composites Inc where he led the activity to develop a lightweight, high temperature material system and industrialize the manufacturing process. During his career with Rolls-Royce spanning nearly four decades he held a number of senior engineering and product roles including Chief Engineer, Product Director and VP of Engineering in the United Kingdom, Canada, Ohio (USA), Norway and California (USA).

Steve has a Masters in Engineering Science from Cambridge University and a MBA from the Open University (both in UK).

Jeremy Liu
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Jeremy is the Chief Product Engineer at Sapphire Technologies, playing a key role in the development of high-speed generators for gas expansion applications since the founding of the company in 2020. Jeremy joined Calnetix, Sapphire Technologies’ parent company, in 2012 and has over 19 years of experience in designing systems utilizing rotating machinery, magnetic bearings, and power electronics technologies. Before joining Calnetix, he was an Electro-Mechanical Engineer for Northrop Grumman at the Space Park Campus.

Jeremy holds a Bachelor of Science in Mechanical Engineering and Master of Science in Biomedical Engineering from the University of California, Irvine.