DATA CENTERS

This eBook will cover Gamma Technologies' extensive solutions in Thermal, Energy, and Emissions Management

eBook

Learn more

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INTRODUCTION

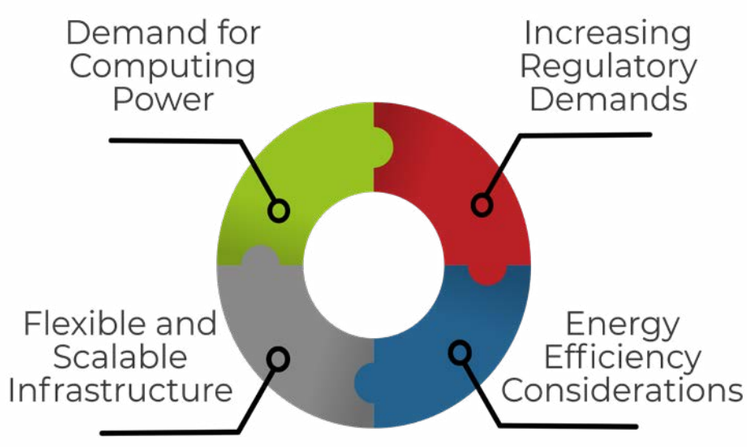
Data centers are at the heart of today's digital economy, yet their energy and cooling demands continue to rise. Engineers face growing pressure to improve efficiency, reduce Power Usage Effectiveness (PUE) and Water Usage Effectiveness (WUE), and design reliable systems that can scale with future needs. Simulation and digital twin technologies provide a practical way to explore design trade-offs, optimize cooling strategies, and evaluate reliability before implementation and during operation. This eBook highlights how GT-SUITE and GT-Play support data center engineers in modeling everything from **liquid cooling** and **HVACR systems** to **UPS batteries**, **hydrogen fuel cells**, and complete **digital twins** for predictive insights and continuous optimization.

THE DIGITAL BACKBONE: WHAT IS A DATA CENTER AND WHY IT MATTERS?

Over the past few decades, advances in technology, the growth of the internet, and the rise of cloud computing have together transformed how the world functions. Today, the explosive adoption of artificial intelligence and graphics processing unit (GPU)-driven computing is accelerating this transformation even further, pushing the boundaries of what digital infrastructure must deliver. From streaming services and e-commerce to artificial intelligence and remote collaboration, digital connectivity now underpins nearly every aspect of modern life. At the core of this transformation lies the need for powerful, reliable infrastructure, driving an unprecedented demand for data centers to store, process, and deliver information at lightning speed.

Data centers serve as the central hubs where vast amounts of information are stored, processed, and distributed. Their architecture is designed for high performance, reliability, and scalability, ensuring that data flows seamlessly across networks. By enabling continuous access to information and digital services, they play a vital role in supporting global connectivity and keeping the modern world connected.

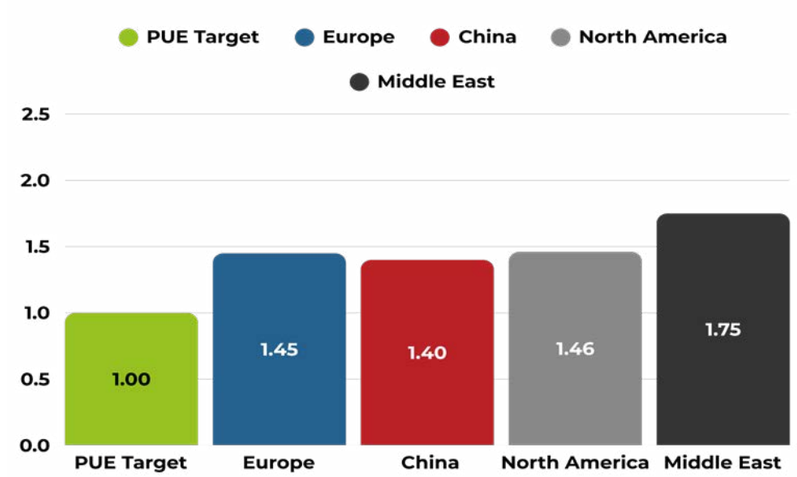
Data centers are essential assets that support a nation's economic growth by enabling digital industries, e-commerce, and advanced services. They provide the computing power needed for innovation, from developing new technologies to supporting artificial intelligence applications. By fostering a strong digital infrastructure, they help nations remain competitive in a rapidly evolving global economy.



What drives the sector's growth and development?

ENVIRONMENTAL IMPACT OF DATA CENTERS

Data centers consume vast amounts of electricity to power servers, networking equipment, and cooling systems that operate around the clock. When this energy comes from fossil fuels, it leads to significant greenhouse gas emissions. Their efficiency is often measured using Power Usage Effectiveness (PUE), with a lower value indicating better efficiency and reduced overhead energy consumption. Beyond cooling, backup power systems (such as UPS and generators) and power conversion losses also add to overhead energy use, further influencing PUE. Data centers also require substantial water resources, often for cooling processes. Managing these demands is key to reducing their environmental footprint.



Source: Uptime Institute Global Data Center Survey, 2024

PUE measurement for data center efficiency

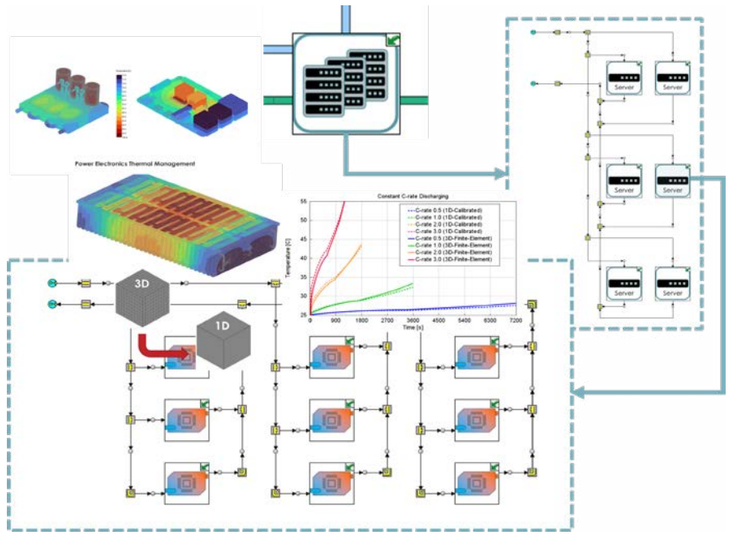
Cooling in data centers must be addressed at multiple levels. At the component level, processors, memory modules, and power units require direct heat removal to prevent localized overheating. At the system level, racks and server rows need airflow and liquid cooling solutions to maintain balanced temperatures. At the plant level, large-scale HVACR systems, chillers, and cooling towers manage heat for the entire facility. Each stage must work together efficiently to ensure reliability while minimizing energy and water use.
To address environmental challenges, data centers are increasingly adopting sustainable practices such as using renewable energy sources like solar, wind, tidal, and geothermal power, optimizing cooling efficiency, and implementing advanced heat recovery systems. Water-efficient cooling methods, energy management software, and facility designs that maximize natural airflow also help reduce resource consumption. Innovative approaches, such as deep-water data centers that use cold ocean temperatures for cooling, are also being explored. For example, Microsoft's Project Natick placed a sealed, nitrogen-filled data center on the seabed off the coast of the Orkney Islands, using naturally cold seawater for thermal management. Powered by marine renewable energy, it demonstrated significantly lower energy use and a much lower hardware failure rate compared to similar land-based facilities.

ENGINEERING SOLUTIONS FOR EFFICIENCY AND SUSTAINABILITY

Cooling strategies: component, rack, and row-level

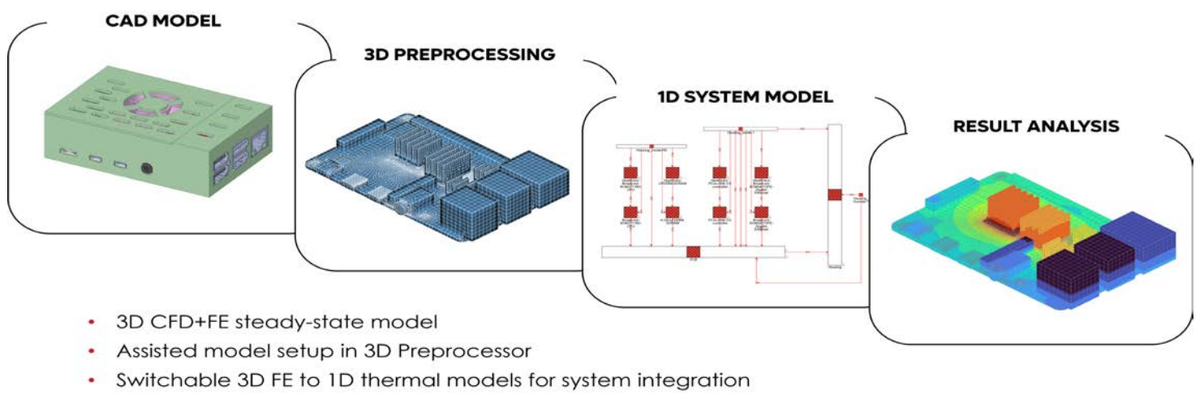
Data centers use a mix of strategies to manage heat at the component, rack, and row levels. From fans and heat sinks to liquid and in-row cooling, each method helps maintain stable operation and energy efficiency.

GT-SUITE provides fast and flexible 1D models that capture these strategies at different scales, from single boards to full racks. Engineers can quickly study system behavior, size cooling components, and design effective control strategies without the heavy computational cost of detailed 3D simulations.



Rack and server cooling with GT-SUITE

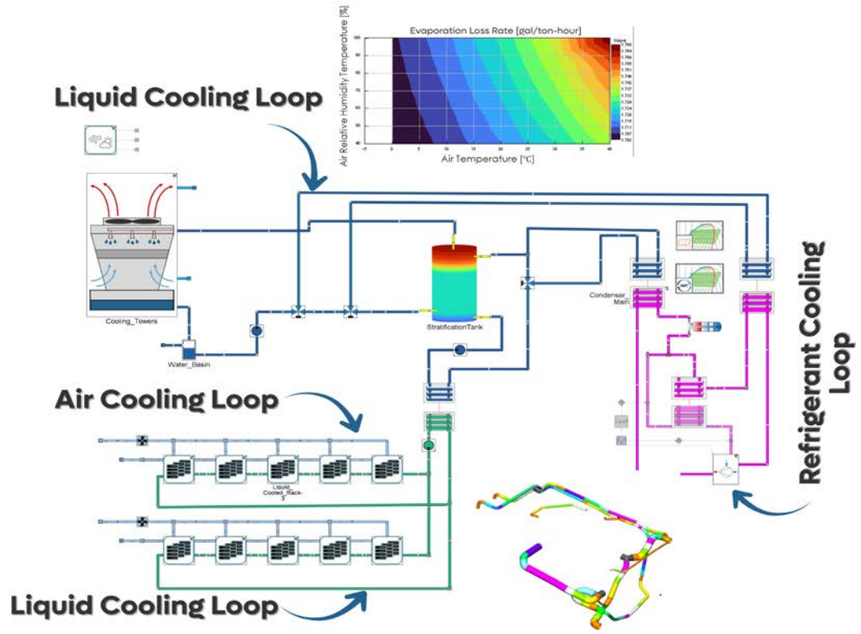
For liquid cooling, GT-SUITE can represent techniques like jet impingement or spray cooling. Two-phase refrigerant systems can also be modeled for both air-assisted and direct refrigerant cooling approaches. GT-SUITE also enables engineers to model what happens if a component such as a pump or valve fails, and how the cooling network can reroute flow to keep the data center operational. This kind of analysis relies on a fast and accurate transient system model, making it a valuable capability for designing robust data center cooling strategies. When needed, GT-SUITE also connects with internal 3D finite element models or external 3D flow tools, offering a practical 1D–3D synergy that balances speed with detail.



Synergetic 1D & 3D solution

HVACR systems and indoor climate control

HVACR systems play a crucial role in maintaining comfortable, healthy, and efficient indoor environments. By regulating temperature, humidity, and air quality, these systems ensure optimal conditions for both people and equipment. Advances in technology are enabling smarter climate control solutions that improve energy efficiency, reduce operating costs, and support sustainability goals, making HVACR a vital component of modern buildings, industrial facilities, and especially data centers.



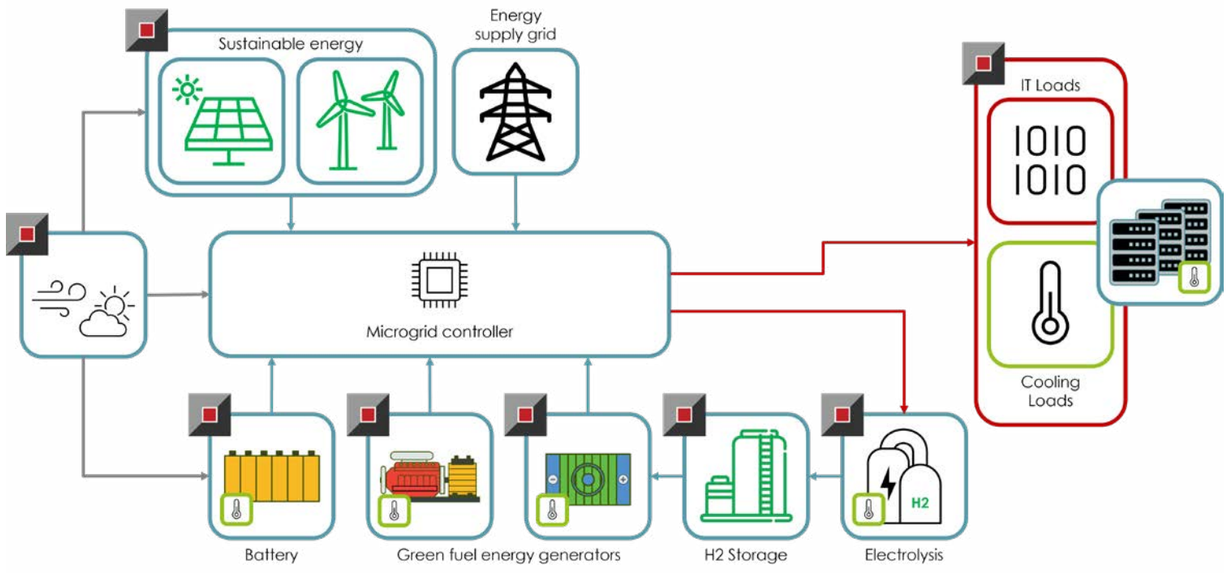
Data center system cooling in GT-SUITE

Data centers are rapidly moving beyond traditional air cooling and researching advanced cooling options such as liquid cooling systems. Unlike conventional air-based cooling, liquid HVAC systems can circulate coolant much closer to the heat source, offering significantly higher heat transfer efficiency and reduced energy use. System designs may also integrate rear door heat exchangers (RDHX) for localized air-to-liquid heat exchange, economizer cooling to take advantage of outdoor air when conditions allow, and thermal energy storage (TES) systems to balance cooling demand.

GT-SUITE supports this transition with multi-scale modeling, from building-level thermal management down to chip-level transient hot spots, allowing fidelity to be added where needed while calculating faster than real time. Engineers can size systems and components, optimize flow distribution, and evaluate a wide range of technologies including liquid direct-to-chip, jet spray, immersion, CDUs, and even waste energy recovery. The platform enables prediction of corrosion effects, selection of low-GWP refrigerants, and development of advanced active control strategies to maintain reliable operation. Integrated optimization and DOE tools deliver results in minutes, helping minimize flow variation, improve ΔT across coils, and optimize PUE. With this capability, data center engineers can confidently design safe, efficient, and future-ready HVACR solutions.

Power distribution, microgrids, and the data center powertrain

Power distribution and microgrid systems are essential for delivering reliable and efficient electricity to meet diverse operational demands. By combining grid supply with localized generation and storage, microgrids provide greater energy resilience, improved efficiency, and the ability to integrate renewable sources. These systems enable precise control over power flow, reduce dependency on centralized grids, and support sustainable energy strategies for modern facilities.



System-level simulation of power distribution and microgrids

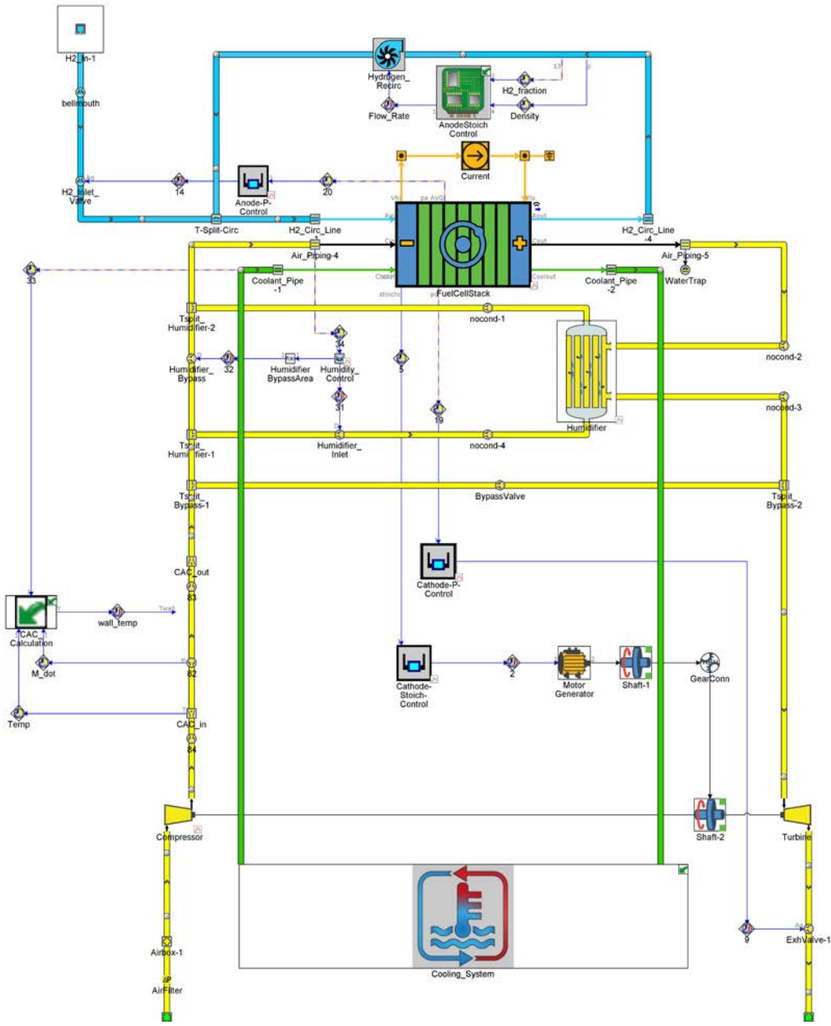
The data center powertrain builds on this concept, encompassing the full path of energy, from generation and storage, through conversion and distribution, to delivering dependable power to servers and cooling systems. Rather than treating each stage in isolation, a unified approach to powertrain design is critical for achieving reliable, efficient, and scalable performance, especially for HPC and AI workloads. Engineers and operators should focus on integrated solutions, advanced energy management systems, and lifecycle optimization.

GT-SUITE **provides a powerful platform for modeling and optimizing these integrated powertrain and microgrid systems for data centers**. As shown in the diagram, it can simulate the integration of renewable sources such as solar, wind, and green fuel generators with the main energy supply grid, all coordinated through a microgrid controller. The software can evaluate how renewable inputs, grid power, and energy storage solutions like batteries and hydrogen storage interact to meet both IT and cooling loads. It also models electrolysis processes to convert excess renewable power into hydrogen, which can be stored and later used in fuel cell generators. This comprehensive approach enables engineers to design resilient, efficient, and sustainable energy systems that reduce reliance on fossil fuels and maintain stable operation under varying demand and supply conditions.

Electrolysis and hydrogen formation for fuel cell applications

Electrolysis and hydrogen formation for fuel cell applications represent a vital pathway to clean, reliable energy. By using electricity, ideally from renewable sources, to split water into hydrogen and oxygen, this process produces green fuel that can be stored and later converted into electricity via fuel cells. This approach not only reduces reliance on fossil fuels but also enables flexible, on-demand power suitable for a range of applications, including data center microgrids.

GT-SUITE offers robust **multi-physics modeling capabilities that support both electrolysis and fuel cell systems in one unified platform**. It provides tools to simulate electrolyzer performance and fuel cell stacks with high fidelity, from electrochemistry and mass transport to thermal and electrical integration. Users can model hydrogen storage, manage humidification, predict degradation, and optimize system controls across plant-level configurations. This allows engineers to design and validate complete hydrogen power systems, from generation through storage to fuel cell conversion, with precision and efficiency.

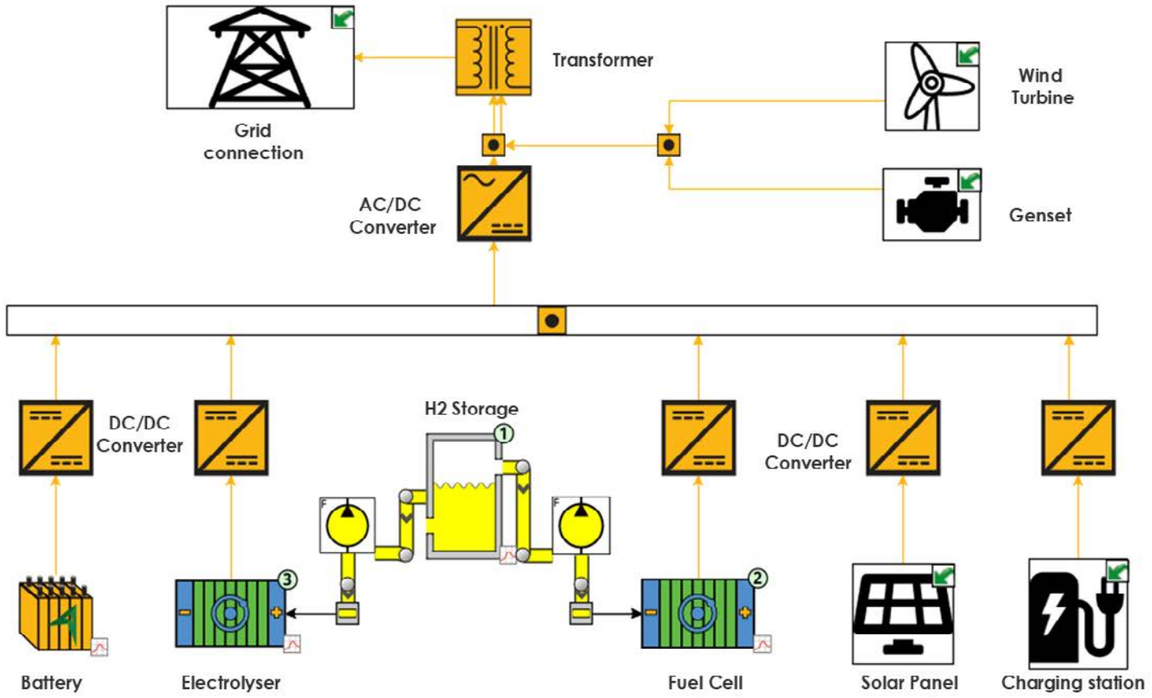


Hydrogen fuel cell model in GT-SUITE

Uninterruptible power supply (UPS)

In data centers, energy storage plays a critical role in ensuring uptime and operational resilience. Uninterruptible power supply (UPS) systems, typically powered by advanced battery technologies, provide seamless backup during grid disturbances or outages, bridging the gap until generators or alternative sources come online. Beyond reliability, modern UPS and battery energy storage systems (BESS) are also leveraged for load management, peak shaving, and supporting renewable integration, helping operators maintain stable and efficient facility performance.

GT-SUITE delivers a comprehensive multi-physics environment to model energy storage and battery systems across cell, module, and pack levels, capturing electro-thermal behavior, temperature and current distribution, real-world aging, and safety events such as thermal runaway. These models integrate seamlessly with thermal, fluid, inverter, and power conversion systems for accurate transient and steady-state predictions. Engineers can evaluate techno-economic feasibility through energy cost optimization, load shifting, and peak shaving, while reducing costs by selecting the right batteries via load profile modeling. The platform also supports safety-driven design, protects uptime with instantaneous response and switching studies, and enables optimization of advanced control strategies, empowering data centers to maximize reliability, efficiency, and lifecycle performance.

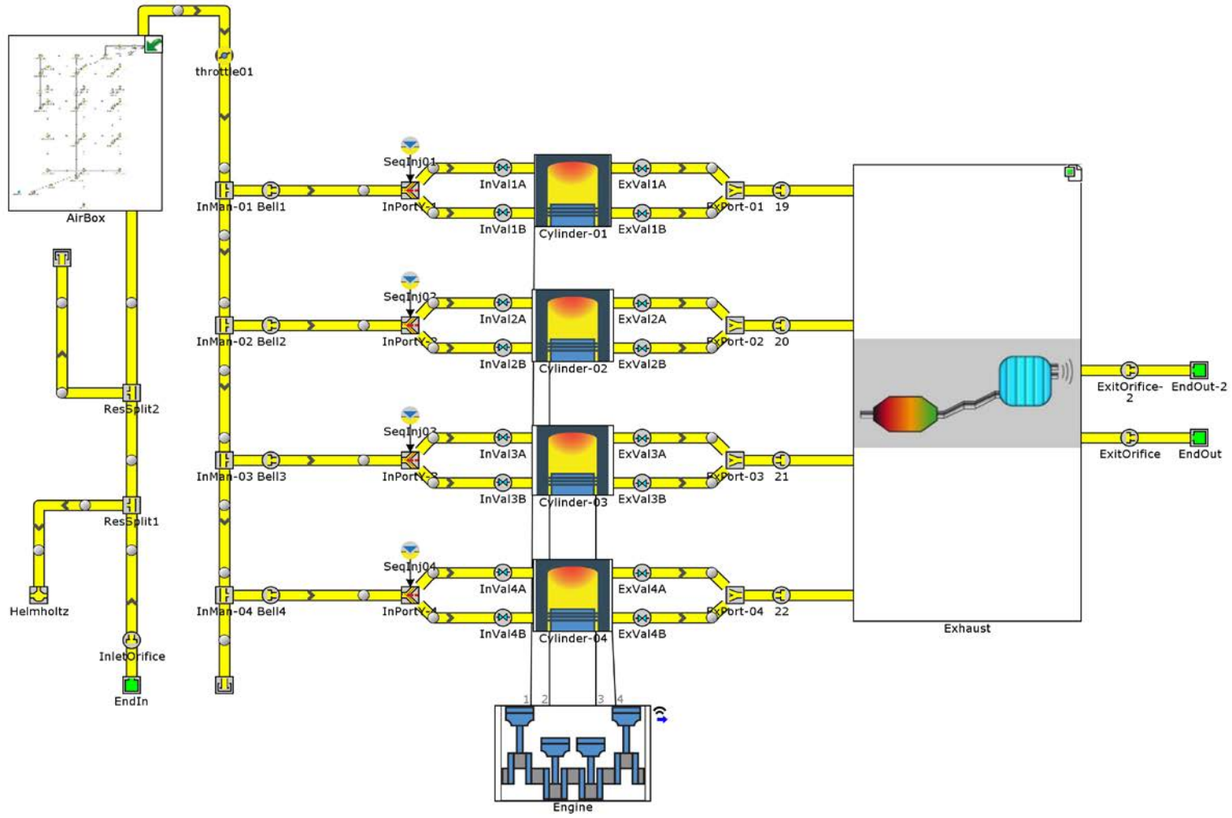


UPS modeling in GT-SUITE

Engine integration and optimization

Backup engines are essential to ensure data centers remain operational under all conditions. Their performance influences not only reliability but also fuel costs, emissions, energy consumption, and noise—key factors in meeting sustainability goals and regulatory requirements. By optimizing these power systems early in the design stage, organizations can minimize risks, improve efficiency, and strengthen long-term operational resilience.

GT-SUITE enables engineers to optimize modern power architectures for fuel savings, reduced emissions, lower energy use, noise control, and more. It supports compliance efforts by allowing teams to virtually test alternative fuels and refine control strategies before deployment. With advanced simulation workflows, decision-makers can de-risk capital expenditure by exploring component sizing, fuel types, and system configurations upfront, ensuring better ROI and informed strategic planning. In addition, validated GT-SUITE models from suppliers can be directly integrated into data center simulations, enabling faster, more accurate system-level studies that reflect real-world engine performance.



System-level simulation of engine architecture in GT-SUITE

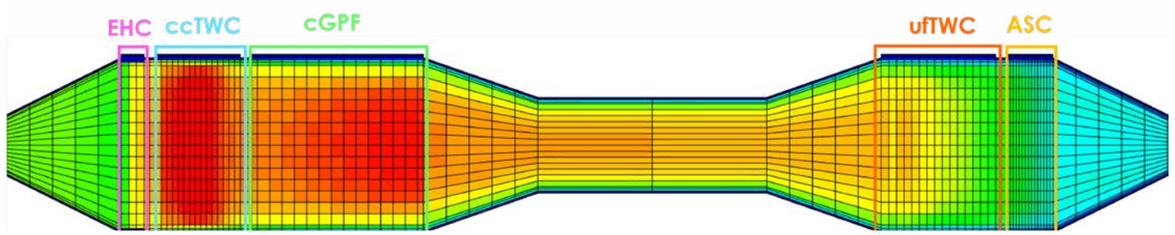
Aftertreatment systems for emissions control

For data center operators, backup power systems are mission critical. Along with reliability comes the responsibility of meeting strict emissions regulations. Aftertreatment systems ensure that diesel or gas generator sets deliver uninterruptible power during outages while staying compliant with environmental standards. By treating exhaust gases before release, they reduce pollutants, minimize environmental impact, and maintain generator efficiency across varying load conditions and supply conditions.

Gamma Technologies offers GT-SUITE, a comprehensive platform for modeling and simulating exhaust aftertreatment systems. Its advanced simulation capabilities are crucial for accurately modeling various aftertreatment systems, **including electrically heated catalysts, three-way catalysts, and advanced particulate filtration**. The tool excels in simulating intricate chemical reactions, thermal behavior, and flow non-uniformities. A critical feature is its flexible reaction mechanism templates, which allow users to define custom mechanisms or use well-calibrated examples as starting points. GT-SUITE enhances its utility by combining subsystem models into unified system-level simulations, facilitating a holistic evaluation of system interactions and trade-offs such as:

- NOx vs. PM emissions
- Thermal boundary conditions for engine control
- Control strategy optimization

With features like faster-than-real-time quasi-steady flow solvers, intuitive interfaces, and advanced post-processing, GT-SUITE provides unmatched ease and precision in aftertreatment solutions. Engineers can utilize these capabilities to optimize emission control strategies and evaluate the impact of various system interactions effectively.



Exhaust aftertreatment model

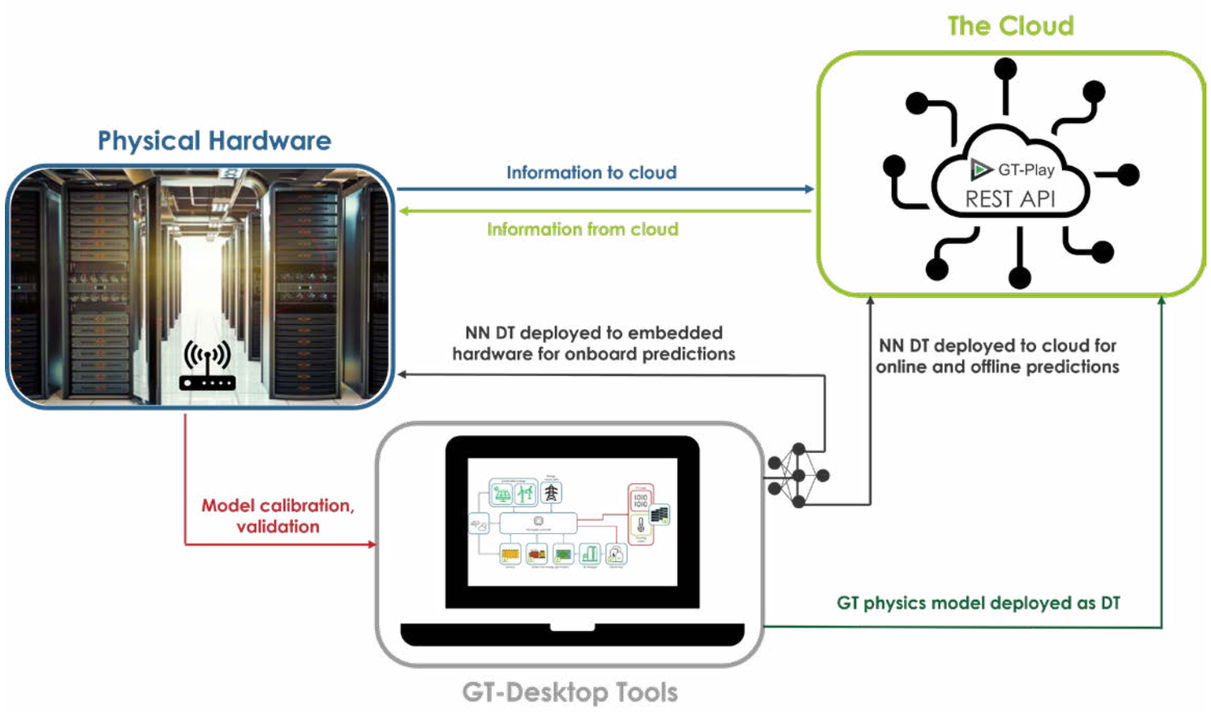
Complete digital twin and GT-Play

A complete digital twin of a data center is more than just a virtual model. It acts as a living replica of the physical facility, enabling real-time monitoring, predictive insights, anomaly detection and continuous optimization of cooling and power systems. With workloads and thermal loads changing dynamically, a digital twin helps operators anticipate issues before they occur and maintain reliable, efficient performance.

GT-SUITE enables the creation of such digital twins by combining high-fidelity multi-physics simulation with modern data science techniques. Cooling networks, HVACR systems, and even transient failure scenarios can be modeled with accuracy and speed.

Through GT-Play, these models become accessible to a much wider audience inside the organization. Facility managers, test engineers, and non-technical stakeholders can interact with simulations directly through a secure web interface without installation or advanced training. They can run parameter sweeps, explore optimization scenarios, and review results in real time. Model developers can also tailor interfaces and limit parameters, ensuring the right level of control for each user.

Together, GT-SUITE and GT-Play bring the benefits of digital twins into everyday data center operations, helping teams make smarter and faster decisions while keeping systems efficient and resilient.



Digital twin workflow

GT APPLICATIONS

GT-SUITE

GT-SUITE is the industry-leading simulation tool with capabilities and libraries aimed at a wide variety of applications and industries. It offers engineers functionalities ranging from fast concept design to detailed system or sub-system/ component analyses, design optimization, and root cause investigation.

GT-PLAY

GT-Play is Gamma Technologies' web-based platform that makes GT-SUITE simulations accessible across your organization.
It allows users of all experience levels to run models, perform parameter sweeps, and analyze results directly from any web-connected device without the need for specialized hardware or licensing. Developers can easily tailor and publish model interfaces using GT-Play's intuitive tools.

GT

CONTACT US

Power the next generation of data centers with GT-SUITE simulation solutions for thermal performance, energy optimization, and resilient design.

Gamma Technologies: 700 Oakmont Lane, Suite 300
Westmont, Illinois 60559

support@gtisoft.com

(630)325-5848

Contact Sales

GAMMA TECHNOLOGIES

www.gtisoft.com