Data Centers

The Engineering Marvels Powering Our Modern Economy



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Data Centers: Energy and Water Consumption

Energy Consumption
The International Energy Agency (IEA) reports that data centers consumed around **415** terawatt-hours (TWh), or about 1.5% of global electricity consumption, in 2024. This demand soared by 17% in 2025 and, more alarmingly, is expected to reach around **945** TWh by 2030, representing just under 3% of total global electricity consumption (International Energy Agency, 2025, 2026a).

Water Consumption
Rapid industry expansion has also strained water resources. Mostly used for cooling, a 1-megawatt (MW) data center using traditional cooling methods would use about **6.75** million gallons of water per year (Orr & Klesner, 2016).

Data Centers
There are **13,030** data centers worldwide (Programs.com, 2026).

Carbon Emissions
While nuclear and renewable energy sources produce relatively few direct or indirect emissions, coal remains the largest source of electricity, accounting for **34%** of total global generation (International Energy Agency, 2026b).

With estimated emissions of **2.31** pounds per kilowatt-hour (lb/kWh) (U.S. Energy Information Administration, 2024), the remaining **321.3** TWh of energy that would need to be generated from coal in 2030 to meet global data center energy demand would already equate to approximately **336.7** million metric tons of CO2e (MMTCO2e) annually.

Have the 13,030 data centers across the globe been built without any concern for the environment?



Reducing Environmental Impact

Amazon Web Services (AWS)

Early Solar Projects
In 2016, Amazon enabled the Eastern Shore, the first grid-scale solar project in Virginia. A year later, the company enabled the Virginia – Southampton solar project. In both cases, Amazon signed a long-term Power Purchase Agreement. The projects generate a combined total of **381,000** megawatt-hours (MWh) of electricity per year (Community Energy, 2026a, 2026b). Since then, the company has invested in over 700 carbon-free energy projects in 28 countries, with capacity to generate over **40** gigawatts (GW) of electricity.

Global Recognition
In 2025, BloombergNEF again recognized Amazon as one of the world's leading corporate purchasers of carbon-free energy, and noted that it has the largest carbon-free energy portfolio of any corporation globally (Amazon.com, 2026).

The Climate Pledge
Furthermore, Amazon co-founded and was the first signatory of The Climate Pledge, a commitment to reach net-zero carbon emissions across its operations by **2040** (Amazon Web Services, 2026b), which makes the company not just the leading cloud service provider, but also a champion of sustainability.

What can computer engineers do to build more energy-efficient systems?



Engineering More Efficient Central Processing Units

Amazon started developing the Graviton processor in 2015 and released the initial version in 2018. Amazon was the first cloud vendor to develop its own processor, a true business and engineering triumph.

The AWS Graviton processor was engineered to consume significantly less memory and deliver significantly more processing power. The AWS Graviton5, released in 2025 to power the 9th Generation of AWS instances, features 192 cores, consumes less energy per core than any predecessor, and delivers more processing power. As the company recently reported, AWS Graviton-based Amazon EC2 instances use up to **60%** less energy than comparable Elastic Compute Cloud (EC2) instances for the same performance (Amazon Web Services, 2026f).

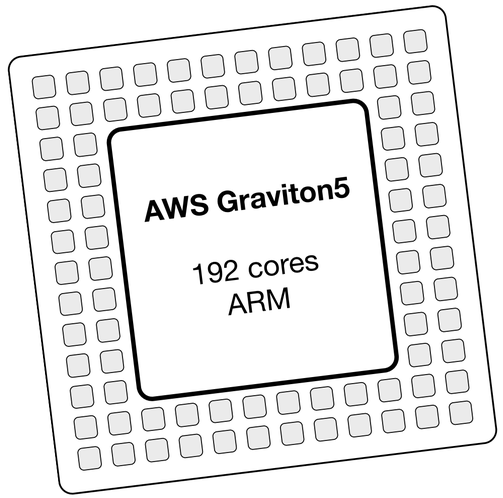
AWS Graviton Generations:

2018	16 cores	Graviton
2019	64 cores	Graviton2
2021	64 cores	Graviton3 / 3E
2023	96 cores	Graviton4
2025	192 cores	Graviton5

Energy Efficiency:
Up to 60% less energy than comparable instances

Energy Savings (2024):
243,401.76 MWh

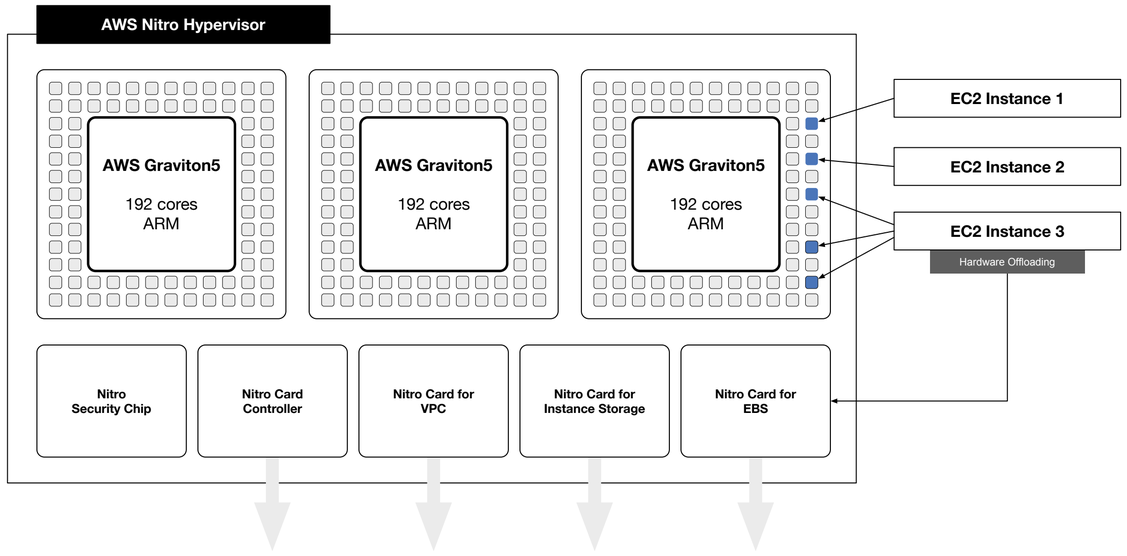
Reduced Carbon Emissions (2024):
83,000 metric tons of CO2e



Engineering More Efficient Virtualization Platforms

Although the introduction of the AWS Graviton processor was significant, the company had already made substantial changes to increase performance efficiency. Several years earlier, in 2013, Amazon began designing custom hardware to improve networking. In 2017, the company introduced the AWS Nitro System to eliminate the overhead of the software-based Xen hypervisor.

Nearly a decade later, the much more advanced AWS Nitro System encompasses multiple cards, a security chip, and a hypervisor that runs with near-zero overhead. Except for a few legacy instances still supported, all other instances today run on the Nitro System (Amazon Web Services, 2026a, 2026e).



What can software architects do to build more energy-efficient applications?

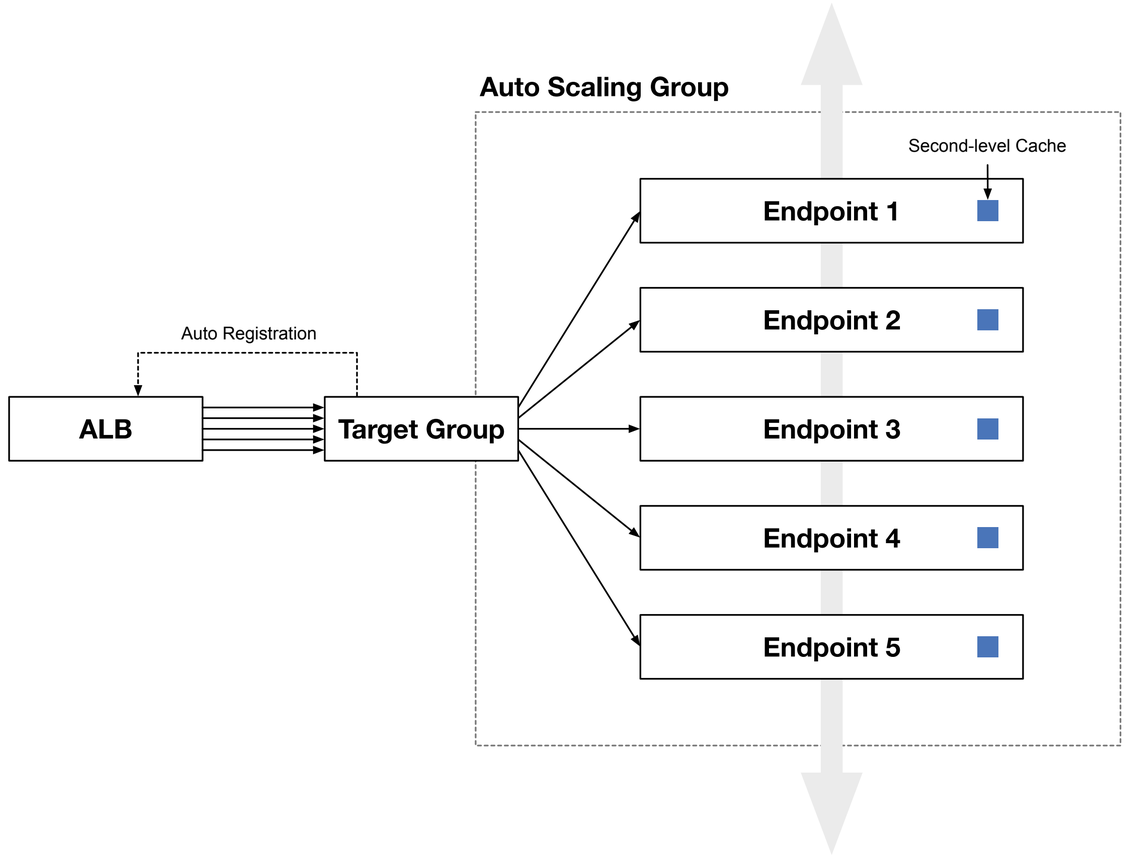


Load Balancing

A web application hosted in AWS can use an application load balancer, target group, and auto scaling group to create a highly effective load-balancing strategy. Auto scaling groups can dynamically adjust the cluster size based on incoming application traffic.

Furthermore, by combining session affinity and software patterns to implement a second-level cache within each cluster instance, software architects can achieve even greater resource utilization and lower energy consumption.

The cache eliminates the need to constantly read reference datasets over the network, drastically improving application performance and eliminating unnecessary operations across different stacks (Shrivastava et al., 2023).



Properly Sizing Instances

Properly sizing application instances is crucial to avoid overprovisioning resources. AWS offers more than **1,160** instance types across 6 major instance families (e.g., General Purpose, Compute Optimized, Memory Optimized), so that customers can choose the right instance for their specific workloads.

Solution architects, ultimately responsible for selecting instances based on customer requirements, can holistically consider instance specifications, patterns provided by software architects, and architectural design to reduce energy consumption (Sard & Wadia, 2024).

Compute Optimized
c9g.medium
c9g.4xlarge
c9g.24xlarge

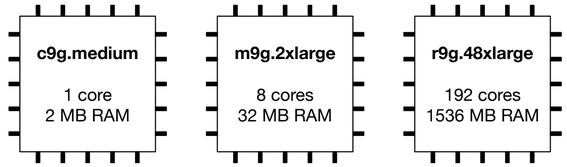
General Purpose
m9g.medium
m9g.4xlarge
m9g.24xlarge

Memory Optimized
r9g.medium
r9g.4xlarge
r9g.24xlarge

Storage Optimized
i8g.large
i8g.4xlarge
i8g.24xlarge

Accelerated Computing
g5g.xlarge
g5g.4xlarge
g5g.16xlarge

HPC Optimized
hpc7g.4xlarge
hpc7g.8xlarge
hpc7g.16xlarge

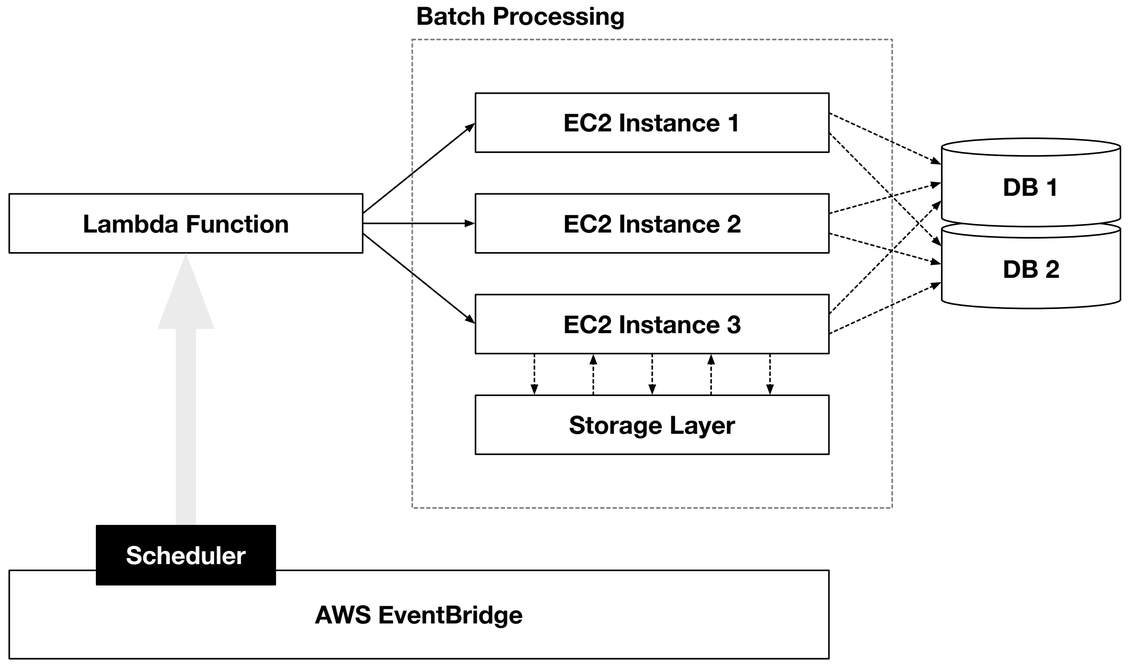


Job Scheduling and Batch Processing

Historically, scheduling jobs in on-premises data centers required an application or scheduling server (e.g., Quartz). While many offered strong functionality and scalability, these servers had to run continuously, even when no jobs were running, unnecessarily consuming energy.

AWS EventBridge is a serverless event bus with great scheduling capabilities, including support for CRON syntax. The EventBridge scheduler can trigger a Lambda function, which can then use the Elastic Compute Cloud (EC2) API to start an instance or group of instances to run a particular job.

The instances can perform the job(s) and automatically shut down after completion, optimizing resource utilization and, consequently, energy consumption (Shrivastava et al., 2023).



“Responsible cloud computing is possible. Amazon has proven that it is. However, it is not the result of superhuman abilities, but of extraordinary leadership, strategic vision, engineering excellence, and absolute customer obsession.”

— Ariel Gonzalez, 2026

Ethical Analysis

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Utilitarianism, Deontology, and Bioethics and Human Rights

Utilitarianism

Data centers have enabled sustainable transformations across a broad spectrum of industries by enabling dematerialization, powering clean energy innovation, accelerating circular supply chains, and fostering sustainable practices (Patel et al., 2025). In addition, they have enabled the development of large platform ecosystems and software-intensive systems (INCOSE, 2023; Tiwana, 2013) while using power more efficiently and producing lower carbon emissions than on-premises data centers (Amazon, 2026). Consequently, from a utilitarian perspective, data centers used by any industry result in a net ethical good.

Deontology

From a deontological perspective, when they are used to solve complex issues like global supply chain optimization, agricultural research, or extreme weather forecasting, they become a moral imperative, as we have an absolute duty to build the infrastructure needed to solve such difficulties.

Utilitarianism, Deontology, and Bioethics and Human Rights

Bioethics and Human Rights
However, from a bioethics and human rights perspective, their importance is even greater.

For example, AWS has enabled some of the largest pharmaceutical platform ecosystems in existence today, including Pfizer, Merck, Moderna, AstraZeneca, and Novo Nordisk. Medical advancements and the resulting benefits to humanity from advanced genetic treatments, accelerated drug discovery, pipelines that speed clinical trials, precision medicine patient matching, and automated pharmaceutical manufacturing are a humanitarian necessity.

"The contributions Amazon Web Services (AWS) data centers provide to humanity far surpass the limited resources they can utilize."

— Ariel Gonzalez, 2026

Global Analysis and Conclusion

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Global Analysis

Given the extensive empirical evidence identified in the literature through this research, we conclude that data centers have significantly improved computational resource utilization and, consequently, helped preserve natural resources. Running workloads on data centers can be up to **4.1** times more energy efficient and can reduce carbon footprint by up to **99** percent (Amazon, 2026). This research suggests that progressively consolidating computational resources in data centers has enabled scientific discoveries that would not have been possible with isolated on-premises data centers.

However, even if it were possible—disregarding the duplicated infrastructure waste of running small on-premises data centers worldwide—it would cost the world another **1,286.5** TWh of energy annually and require coping with a staggering additional **1,347,992,610.18** MMTCO2e.

Conclusion

Data centers, the engineering marvels powering our modern economy, are not the evil villains the media and many credulous scholars believe they are.

The extensive research supporting this paper demonstrates unequivocally that data centers are the only embodiment of the digital revolution that has contributed to the rapid development of so many other industries by democratizing advanced technologies, allowing businesses to gain a global presence in minutes, making serverless architectures ubiquitous, enabling faster experimentation, and, more importantly, considering mechanical sympathy (Amazon Web Services, 2026c, 2026d; INCOSE, 2023).

Thus, let it be known to the industry and to the world: responsible cloud computing is possible. Amazon has proven that it is.

Author

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A Passion for Building High-Impact Solutions

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Mr. Gonzalez is an undergraduate student of Information Technology at Florida International University. His independent research focuses on solution architecture, software engineering, and software complexity, with a growing emphasis on complexity visualization.

As a software engineering practitioner, he has designed and developed tailored web application frameworks currently deployed in high-traffic, critical production environments.

Disclosures
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