CHP – A Key Enabling Technology for Ensuring Data Centre Development is Efficient, Cost-Effective and Resilient

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Contents

1. Executive Summary

The data centre landscape continues to undergo rapid evolution, largely driven by AI's increasing demand in addition to energy consumption concerns and the requirement for advanced sustainability strategies. Key trends include dramatic surges in power demand, heavy investment in renewable energy, expanding use of edge computing and new approaches to cooling and energy efficiency.

Recent EU and U.S. policy reviews highlight that AI data centres are now considered energy infrastructure. According to the European Commission, AI and high-density cloud workloads are driving "unprecedented electricity demand", with global data centre capacity rising from 30 GW in 2017 to over 110 GW in 2025. The POLITICO analysis emphasises that efficiency gains cannot keep pace: while compute efficiency improves by ~5–10% annually, AI workload growth exceeds 30–40%. This establishes the need for local, firm, high efficiency generation options—including CHP and CCHP to support rapid ICT deployment.

AI data centres are projected to account for up to 70% of global capacity by 2030, with global data centre electricity usage, currently responsible for 1.5% (415TWh) of electricity consumption on course to more than double towards 945TWh by 2030

Data centres are investing heavily in renewable energy sources such as solar, wind and biomass, with PPAs and co-location of renewable generation as major trends. Furthermore, many facilities are developing microgrids or on-site storage to minimise grid dependence and transmission losses.

In terms of technology trends, advanced liquid cooling systems and AI-driven predictive management are being implemented to optimise operations whilst automation is being widely adopted for routine workflows, streamlining performance and reducing manual interventions.

Market and regulatory drivers in the form of sustainability requirements, grid limitations and policy pressures are pushing data centre developers to diversify energy portfolios, pursue heat recovery and adopt alternative power sources.

In terms of US trends, whilst early regulatory attention focused on California and East-Coast markets, the fastest growing hyperscale clusters today are located in Virginia, Utah, Idaho, Ohio and Texas, each with distinct energy characteristics.

The route to deployment of cogeneration in data centres is a multi-stage process which balances technical, regulatory, and market realities.

1. Strategic Screening – takes place at the very first stage to assess the value of CHP and looks at operational, grid access and policy parameters
2. Evaluate the counterfactual 'no CHP' to use as a comparison
3. CHP/CCHP concept options – to understand the various options in terms of technical operation, CAPEX, OPEX, efficiency etc
4. Applicability of CHP/CCHP to different data centre types – due to differences in load profiles, cooling demand and commercial priorities
5. Embed CHP into the Design Brief
6. Detailed feasibility study to included KPIs
7. Grid + CHP + BESS "microgrid" architecture
8. Heat export and third-party engagement if applicable
9. Procurement and EPC – locking in CHP
10. Operation and optimisation

EPC contractors and specifiers play central and complementary roles, each ensuring the project meets technical, cost, timeline, compliance and client requirements. Their interplay is key to timely, compliant delivery of resilient, complex and sustainable data centres.

1) Role of EPC contractors

- Provide a single point of accountability, handling all phases from design to equipment procurement, construction and commissioning
- They accelerate project delivery via integrated management, enabling early procurement, managing supply chain risks and sequencing construction alongside design
- EPCs take on significant risk, often under fixed-price contracts.
- For complex facilities, EPC expertise supports innovation such as modular builds, energy systems etc as well as compliance during all delivery stages.

2) Role of Specifiers

- Focus on detailing and documenting the specific materials, equipment and systems to be used, ensuring all equipment and systems meet project, regulatory and operational requirements
- Specifiers translate performance, safety, sustainability and compliance requirements into technical specifications which become binding in construction and procurement

Data centre requirements will need to be taken into consideration when developing the facility. A full understanding will be needed of parameters such as:

- Power capacity, reliability and redundancy
- Cooling performance and thermal roadmap
- Sustainability reporting and clean energy alignment
- Interconnection speed and flexibility
- Standards compliance and security
- Commercial certainty

The table below gives an overview of the different responsibilities.

Requirement	Supplier / EPC / Specifier fit	Notes for CHP/CCHP
Firm capacity & N+1/2N	OEMs (engines/turbines) specify block sizes, derates & H_2/biogas readiness; EPC integrates paralleling switchgear, islanding, black-start, UPS/STS interfaces; specifiers define redundancy & selectivity	Engines suit modular N+1; CCGT suits large campuses. Validate ride-through and fault selectivity to Tier targets.
Base + peak cooling	Absorption chiller OEMs (double-effect LiBr) + electric chiller vendors; EPC sizes chilled water loops, towers/dry coolers; specifiers fix ΔT, N+1, and part-load turndown	Absorption COP ~1.0–1.2 for double-effect; use as base. Electric chillers handle peaks/transients.
Sustainability metrics (PUE/ERF/WUE/REF)	Design consultants/specifiers implement EN 50600-aligned metering; controls integrators build the KPI dashboards; EPC provides metered boundaries	EU rules require annual KPI reporting to the EU database/rating scheme (2024+). Heat-reuse improves ERF/ERE.
24/7 CFE alignment	Developers/IPP/Utilities for PPAs and hourly matching; EPC integrates CHP with BESS and curtailment logic; OEMs ensure fuel flexibility	Use CHP in hours of low VRE, optimise run-hours vs. CFE score. Google's 24/7 goal sets the bar.

Fast interconnection & flexibility	EPRI DC Flex methodologies adopted by EPC/controls vendors; utilities/IDNOs collaborate on tariff/program design	Flex-by-design campuses improve planning/connection outcomes and monetise flexibility.
District heat export	DH operator (e.g., Stockholm Exergy; Helen) provides heat offtake, temperature levels, and revenue model; EPC provides heat-pump/HEX station	Creates a value stack beyond electricity—critical for CHP economics.
Compliance & permitting	EPC & environmental consultants obtain air/noise permits, gas connections, fire safety, and EN 50600 design compliance	Include H_2 readiness and biomethane options to de-risk net-zero commitments.
Commercial structure	EPC + financier/ESCO offer Energy-as-a-service with KPI Service Level Agreements; operator retains resilience control	Tie fees to availability, PUE/ERF and grid services revenue-share.

There are significant opportunities to be had by integrating cogeneration into data centres ranging from:

- Speed-to-power and firm capacity where grids are constrained – on-site CHP shortens the power critical path and de-risks large AI deployments that cannot wait for new grid expansion
- Reliability, redundancy and black start - operators get continuous, Tier-aligned power islands that can carry IT load during grid events and restart a site after an outage which is an advantage over standby-only diesel fleets that provide no efficiency benefit in normal operation
- Cooling via absorption to displace electric chillers - AI and high-density racks push cooling from 35–50% of facility loads in many sites, turning CHP heat into cold attacks one of the biggest energy line-items without sacrificing reliability
- Waste-heat reuse - heat-export revenue strengthens CHP/CCHP business cases; visible community benefit helps unlock sites in heat-led cities and supports sustainability branding
- Interconnection and grid support - instead of being seen only as large inflexible loads, DCs become flexible resources—with CHP providing controllable, dispatchable capacity that complements variable renewables
- Alignment with AI-era efficiency drives - CHP/CCHP cuts the electricity overhead for cooling and enabling hourly cleaner supply mixes as AI scales
- Using CHP as a bridging or transitional power solution to meet the rapidly increasing demand from data centres.

A number of global case studies from the US, Asia-Pacific, UK, Middle East & Africa as well as Europe give good examples of deployment of CHP/CCHP in a range of different sized data centres.

There are also significant challenges to be faced which need to be considered when integrating CHP, including:

- Physical space constraints for CCHP deployment
- Water-use perceptions
- High upfront investment
- Regulatory and permitting barriers which can slow or block CHP adoption
- Fuel supply constraints
- Complexity of the operation can add costs and the need for on-site expertise and monitoring
- Lack of awareness and expertise which can lead to hesitancy or misaligned expectations

In addition to new installations, retrofitting can be an option to add CHP and CCHP without a major rebuild of the facility. These can either be:

- Power-island retrofits where on-site prime power can be added alongside the existing setup
- Thermal-side retrofits which turn existing generation into CCHP by adding heat-recovery and absorption cooling
- Bottoming-cycle retrofits where a steam turbine or ORC can be added for extra electrical output
- Heat-export retrofits to connect to district energy schemes
- Controls and flexibility retrofits providing interconnection, and ancillary services.

In terms of power supply challenges, data centres can cause significant challenges to power supplies specifically as a result of the rapid increases (or decreases) in power loads, otherwise known as ramp rates. Two main problems arise due to their size – demanding many MWs of electricity and their load can move very fast as GPU clusters start/stop in large, synchronised chunks. AI workloads don't follow the smoother, cyclical patterns of typical enterprise or cloud IT: they're driven by batch training jobs, distributed GPU clusters, and scheduler decisions. Load can jump or fall by many MW over seconds–minutes as jobs start or end. This can provide specific challenges to the grid in the form of higher reserve and ramping requirements, stress to the local network, including voltage flicker and planning uncertainty. Furthermore, challenges for cogeneration plants serving AI data centres create different issues such as thermal/mechanical stress caused by frequent large ramps, inefficient operation due to unstable demand. In addition to electrical ramping challenges, CHP/CCHP systems must be evaluated equally on their thermal ramping behaviour.

Mitigation strategies include treating data centres as flexible loads rather than fixed demands, encouraging co-location with flexible generation and interconnection agreements, job scheduling and staggering to avoid simultaneous ramping up/down as well as data centre design using hybrid architecture.

Legislation related to data centres and their energy consumption is rapidly evolving. With the EU there are a number of policies that are relevant. These include:

- Energy Efficiency Directive which has been recast to include provision applicable to data centres such as monitoring and reporting obligations related to energy performance of data centres.

- EU Climate Delegated Act which enshrines rules for classification of data centre-related activities with a view to climate change mitigation, building on the European Code of Conduct for Data Centres (EU DC CoC), a voluntary initiative set up by the Joint Research Centre (JRC) to encourage and guide data centre operators and owners in cost-effective reductions in energy consumption

- AI Act which imposes transparency requirements for General-Purpose AI Models which includes energy consumption reporting

- Strategic Roadmap for Digitalisation and AI in Energy, due for publication in early 2026 aims to accelerate the rollout of digital solutions such as AI in key areas of the decarbonisation process

- Data Centre Energy Efficiency Package also due for publication in Q1 2026.

Similarly in the USA, the United States is rapidly developing policy and regulatory measures in response to the accelerating electricity demand of data centres, particularly those driven by AI workloads. Although the U.S. does not have a single dedicated federal law specifically regulating data-centre sustainability, a combination of federal agencies, congressional legislation, state level initiatives, and regulatory authorities (DOE, FERC, NERC) play central roles in shaping requirements related to energy consumption, grid integration, emissions, interconnection, and transparency.

The UK does not yet have a single, data centre specific energy directive equivalent to the EU's EED, but data centres are increasingly being pulled into the UK's wider net-zero, planning, heat network and grid flexibility frameworks. In 2024 the UK had around 1.6 GW of data centre capacity, mostly in Greater London, and data centres have been formally recognised as Critical National Infrastructure (CNI). Their capacity is expected to rise to 3.3–6.3 GW by 2030, with electricity use and grid connection pressure rising accordingly.

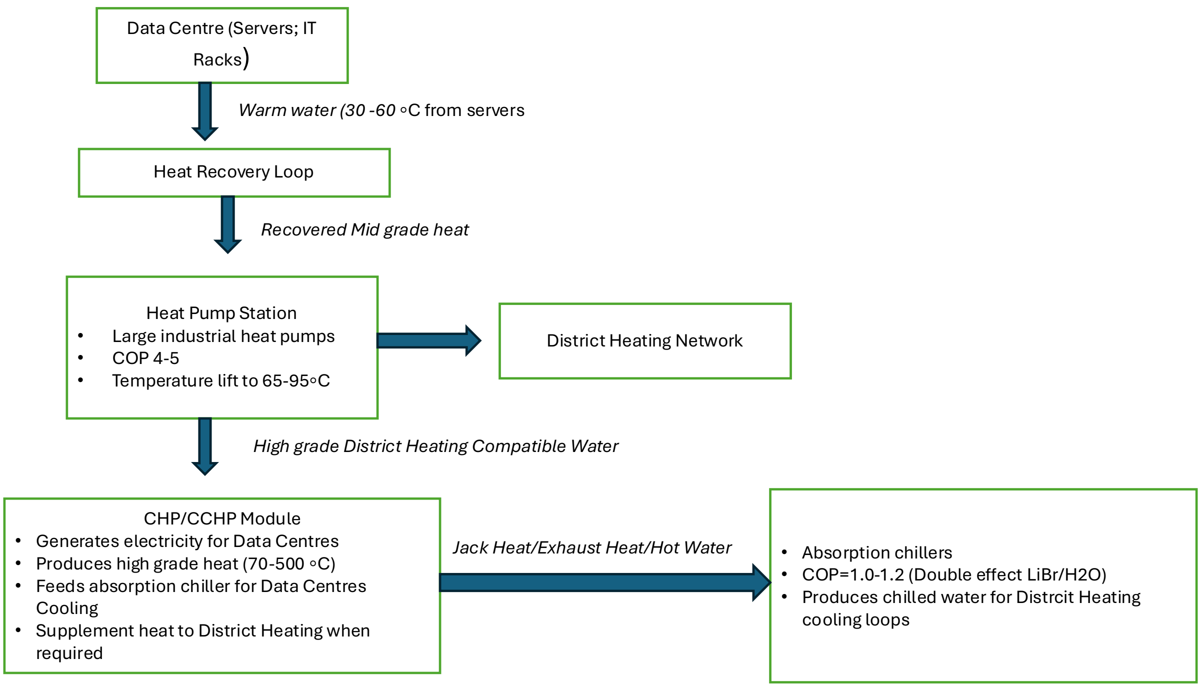
There are a number of fuel supply options that can be used to power CHP integration into data centres.

- Methane (natural gas → biomethane → e-methane) is the most straightforward transition for engine/turbine CHP because it reuses today's gas assets (pipelines, meters, burners) with minimal hardware change. Near term: pipeline natural gas; by 2030s in Europe: biomethane share rises materially; by 2040s: e-methane is technically viable, but cost and volumes are uncertain. Although biomethane is a key decarbonisation pathway, its climate valuation is inconsistent across global frameworks.
- Hydrogen (H_2) is technically proven for both engines and gas turbines (up to 100% H_2 on some models), but network rules, costs and volumes will govern pace. Anticipate H_2 blends (≤20% vol.) where policy allows in the 2030s, with dedicated H_2 supply only at select campuses or industrial clusters.
- Drop-in liquids (HVO for backup diesels) and CCS-coupled methane are credible risk-mitigations where gas/H_2 timing is uncertain; ammonia/methanol are maturing mainly in marine/industrial use and are unlikely first-choice Data Centre fuels due to toxicity/NO_x and site safety complexity.

In terms of third-party heat offtakes, data centres produce large, continuous, high quality waste heat which can be used for district heating networks; however, heat needs to be boosted to a higher temperature (65-90°C) which is where heat pumps, CHP exhaust or hybrid systems become relevant.

- Data-centre waste heat is highly feasible for recovery—especially as liquid cooling grows (AI racks).
- CHP/CCHP and DC heat are complementary: CHP provides high-grade heat; DC provides constant baseload heat.
- CHP becomes more bankable when a district heat offtake exists because utilisation rises.
- Heat pumps are the enabler: they lift server heat and CHP jacket heat to DH temperatures efficiently (COP 4–5).
- Third-party integration is straightforward when hydraulic, thermal, and control interfaces are properly engineered.
- Heat export provides revenue, ESG value, and regulatory compliance (ERF/ERE).

CHP + Heat Pump + Data Centre Server Heat Export Architecture



2. Introduction and Key Trends

The COGEN World Coalition has commissioned this study as a follow up to the study undertaken in 2024, "Meeting the energy needs of Data Centres: What Role for Cogeneration?". The aim of this study is to deepen the evaluation with a focus on how cogeneration or combined heat and power (CHP) can help supply energy to data centres, support wider communities with the heat available for energy production and reduce the overall energy footprint.

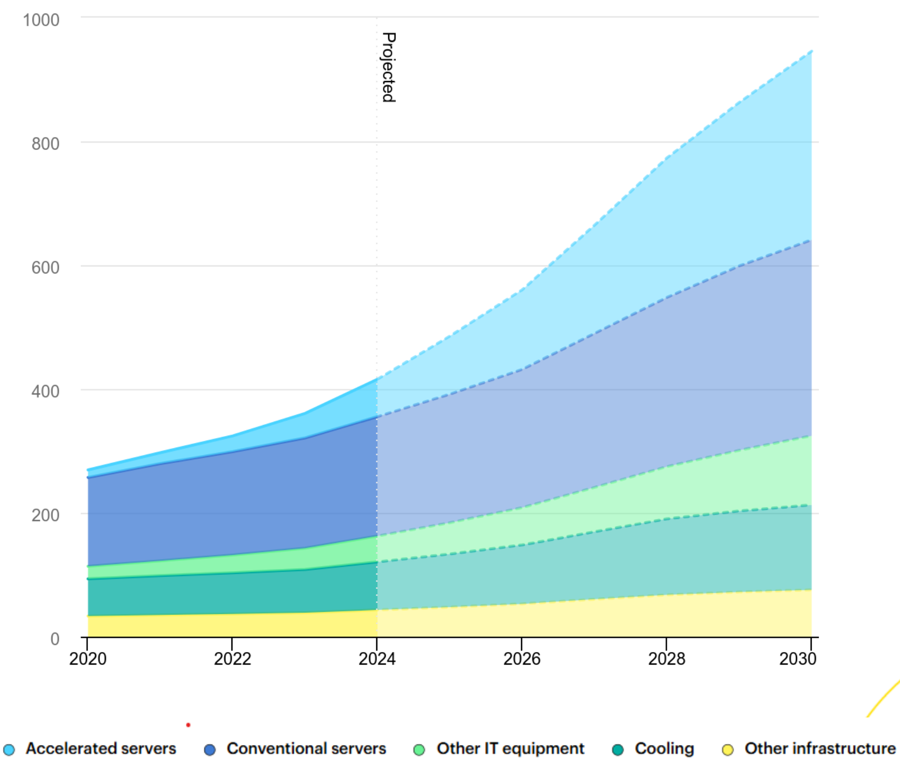
2.1 Key Trends

The data centre (DC) landscape continues to undergo rapid evolution, largely driven by AI's increasing demand in addition to energy consumption concerns and the requirement for advanced sustainability strategies. The key trends include dramatic surges in power demand, heavy investment in renewable energy, expanding use of edge computing and new approaches to cooling and energy efficiency.

2.1.1 AI and Rising Energy Demands

- Generative AI is fuelling a strong wave of new data centre developments, with AI data centres projected to account for up to 70% of global capacity by 2030. Consequently, global data centre electricity usage, currently responsible for 1.5% (415TWh) of electricity consumption is on course to more than double towards 945TWh by 2030, primarily due to the significant growth of energy-intensive accelerated computing needed for AI.

Figure 1: Global data centre electricity consumption, by equipment, Base Case, 2020-2030



Source: IEA

* Use of AI for cogeneration systems for optimising energy production and supply, performing predictive maintenance, and improving integration with smart grids and thus contributing to significant reductions in emissions.

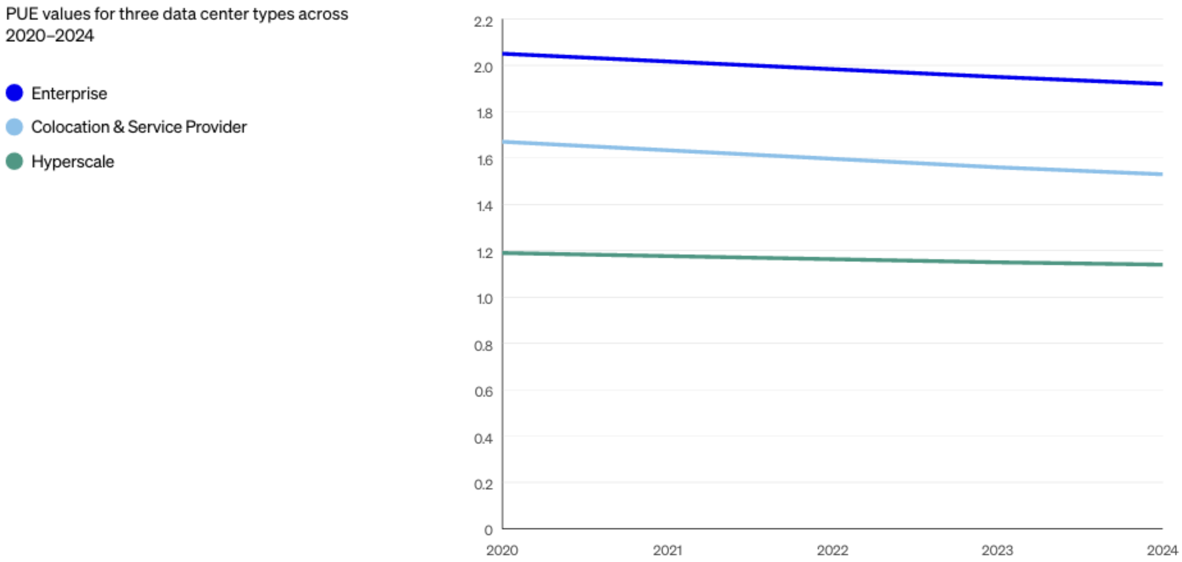
2.1.2 Sustainable Energy and Resource Strategies

* Data centres are investing heavily in renewable energy sources such as solar, wind and biomass, with PPAs and co-location of renewable generation as major trends
* Many facilities are developing microgrids or on-site storage to minimise grid dependence and transmission losses, improving reliability and reducing emissions
* Edge computing is gaining ground, with smaller distributed centres improving latency and enabling real-time applications for IoT, smart cities and autonomous vehicles.

2.1.3 Technological Innovations and Efficiency

* Advanced liquid cooling systems and AI-driven predictive management are being implemented to optimise energy and cooling resources, reduce maintenance costs, and improve operational efficiency
* Automation is being widely adopted for routine workflows, streamlining performance and reducing manual interventions.

Figure 2: Power Usage Effectiveness (PUE) improvement across enterprise, colocation and hyperscale data centres



Source: IEA

2.1.4 Market and Regulatory Drivers

* Sustainability requirements, grid limitations and policy pressure are prompting operators to diversify energy portfolios, pursue heat recovery and adopt alternative power sources (including natural gas, hydrogen, nuclear)
* Urban hubs are facing capacity constraints resulting in investment in new regional locations with better access to renewables and cooling potential.

2.1.5 U.S. Regional Growth Patterns and Implications for CHP

While early regulatory attention focused on California and East-Coast markets, the fastest-growing hyperscale clusters today are located in Virginia, Utah, Idaho, Ohio and Texas, each with distinct energy characteristics.

1. Northern Virginia (Loudoun County)

- Largest data-centre hub in the world
- Facing transmission constraints at 230–500 kV
- Strong candidate for bridging CHP to support AI load growth

Reference: Dominion Energy (2024).

2. Utah (Salt Lake Valley)

- Cheap natural gas
- Cold climate favourable for dry-cooler CCHP
- Major new AI campuses

Reference: Rocky Mountain Power IRP (2024).

3. Ohio (Columbus–New Albany)

- Rapid hyperscale expansion (AWS, Google, Meta)
- Abundant gas pipelines (Marcellus + Utica)
- Ideal for large-engine CHP

Reference: Ohio PUC (2023).

4. Idaho

- Low-carbon grid (hydro-dominant)
- CHP used mainly for peak-shaving and resilience

Reference: Idaho Power Resource Plan (2023).

5. Texas

- Deregulated ERCOT market
- Gas availability and price volatility make CHP attractive for price hedging

Reference: ERCOT Long-Term Assessment (2024).

3. Route to Deployment in Data Centres

The optimal route to deploying CHP in data centres requires a multi-stage process that balances technical, regulatory, and market realities.

3.1 Strategic screening – is CHP worth considering?

When: Very early – during site selection / concept stage.
Actions:

1. **Check four basic conditions:**
    - **Size & hours:** Is the data centre ≥10–15 MW IT and 24/7? (Ideal for CHP baseload).
    - **Grid:** Are there grid constraints or long interconnection queues? (CHP becomes more attractive for time-to-power).
    - **Thermal:** Is there a big, steady cooling load and/or a nearby heat sink (district heating, industrial user)?
    - **Policy:** Are we in EU / UK / Nordics / US states where heat reuse, efficiency or on-site generation are explicitly encouraged (EED, EN 50600 KPIs, state-level incentives)?
2. If the answer to most is "yes" → keep CHP in the design brief, not as an afterthought.
    - To be added: Evaluate on-site CHP/CCHP options (engines and/or turbines) against grid-only supply, including heat reuse and flexibility benefits.

3.2 Counterfactual "no-CHP" case – for comparison

When: Early concept / energy strategy.

We need a clear baseline to show added value of CHP, hence to:

- Assume grid-only supply with diesel backup + electric chillers.
- Estimate:
    - Annual electricity (TWh),
    - Peak MW,
    - PUE,
    - CO_2 and water use,
    - EU metrics (PUE, ERF, ERE, WUE, CER) and compliance with EED reporting.

This becomes the reference for "is CHP better or worse?".

3.3 CHP/CCHP concept options

When: Same time as main electrical / mechanical concept.

Here several CHP archetypes are defined:

1. **Engine-based CHP/CCHP (modular)**
    - 5–30 MW IT → multiple gas engines in N+1 or 2N, with heat recovery and absorption chillers for base cooling.
    - Engines can ramp fast, support flexibility and islanding, and are easy to scale in blocks.
2. **Turbine + HRSG + steam turbine (CCGT) CCHP – campus scale**
    - ≥40–50 MW IT → 1–2 gas turbines + HRSG + small steam turbine, feeding absorption chillers + District Heating.
    - High electrical efficiency (55–62%), strong match for large AI campuses.
3. **Hybrid engine + turbine** (like the Vertiv–Caterpillar/Solar model)
    - Turbine for high, steady baseload, engines for flex and redundancy; both feed CCHP.
    - Matches the "BYOP&C / grid-to-chip" architectures now being marketed for AI mega-sites.
4. **With or without heat export (DH)**
    - Option A: On-site CCHP only (heat → absorption chillers → DC cooling).
    - Option B: CCHP + district heat export, if DH network is within ~1–3 km (Stockholm, Helsinki style).

Each option gets a quick screening model: CAPEX, OPEX, Efficiency, CO_2, PUE/ERF/ERE.

3.4 Applicability of CHP/CCHP Across Data Centre Types

The suitability of CHP varies significantly by data centre class, due to differences in load profiles, cooling demand and commercial priorities.

Segmentation Table

Type	Capacity	Thermal Profile	CHP/CCHP Applicability	Example
Enterprise	0.5–5 MW	Highly variable, low density	Medium (micro-CHP or rooftop units)	Corporate HQ data centres in US Midwest
Edge	50–500 kW	High ambient exposure	High (micro-CCHP ideal)	Texas 300 kW micro-CCHP
Colocation	5–30 MW	Steady loads, multi-tenant	High	Johannesburg 3.5 MW trigeneration
Hyperscale	30–500 MW	Dense HPC + liquid cooling	Very High	Singapore Keppel trigeneration; Utah gas CHP

Key Insight

- ➢ Large hyperscale data centres benefit the most from CCHP due to dense cooling loads.
- ➢ Edge and enterprise sites benefit from micro CCHP due to energy resilience needs.

3.4.1 Small-Scale and Emerging CCHP Installations

Recent global deployments demonstrate that trigeneration is not limited to large facilities.

Australia

- 200–400 kW systems at NEXTDC Brisbane and Sydney
- Microturbines paired with absorption chillers to manage high ambient temperatures

Reference: NEXTDC (2023).

United States

- 65–260 kW Capstone microturbines used in enterprise IT centres in California and Massachusetts
- Installed on rooftops or modular platforms

Reference: Capstone Turbine (2022).

Japan

- 100 kW CHP supporting municipal data-centre cooling and dehumidification

Reference: METI Smart Energy Projects (2021).

Key Message

CCHP scales from 100 kW edge nodes to 100 MW hyperscale campuses.

3.5 Embed CHP in the design brief

This is the key to "ensure CHP is considered at design stage" and should include:

- The design team shall evaluate at least one engine-based CCHP and one turbine-based CCHP alternative, including heat recovery and, where feasible, district-heat export. Options shall be compared to a grid-only baseline using EN 50600 KPIs (PUE, ERF, ERE, WUE, CER) and EU EED requirements.

Also:

- Require evaluation of flexibility potential per EPRI DCFlex concepts (load shaping, CHP + BESS, demand response).
- Require fuel-flex spec (methane today, biomethane/e-methane later, H_2-ready if justified).

If it is written into the design brief and RFP, CHP must be evaluated by consultants and EPC bidders.

3.6 Detailed feasibility – energy, economics, KPIs

When: Pre-FEED / early design.

At this stage a full techno-economic study for the shortlisted CHP options will be undertaken including:

1. **Energy balance and performance**
    - Electrical efficiency (engine ~40–48%, CCGT ~55–62%).
    - Total utilisation (CCHP ~70–85% with cooling + heat export).
2. **Cooling integration**
    - Size absorption chillers (COP 1.0–1.2) for base cooling, retain electric chillers for peaks/N+1.
3. **Heat reuse metrics**
    - Calculate ERF/ERE with and without heat export.
    - For EU sites, show how CHP + heat export improves EED-reportable KPIs and potential future EU sustainability ratings.
4. **Economics**
    - CAPEX, OPEX, heat-export revenue (if DH).
    - IRR vs baseline; sensitivity to gas price, carbon price, and utilisation.
    - Check alignment with AI load growth and ramping (keep CHP near steady, buffer with BESS and smart scheduling).

If the business case is marginal, CHP may still be justified for time-to-power, resiliency, or regulatory/ESG reasons.

3.7 Grid + CHP + BESS "microgrid" architecture

When: FEED / single-line concepts.

CHP in Data Centres should almost always be designed as part of a hybrid microgrid:

- Grid connection sized for partial or full load depending on strategy.
- CHP plant (engines/turbines) as prime or major power source.
- UPS + BESS for ride-through and fast ramps.
- Controls that:
    - Keep CHP around 70–90% (sweet spot).
    - Use BESS and IT load shaping to handle seconds–minutes ramps.
    - Coordinate import/export to comply with interconnection and ramp-rate limits.

This is the practical way to handle AI ramping + CHP constraints together.

3.8 Heat-export and third-party engagement (if applicable)

If there is a DH or industrial offtaker:

1. **Engage early:**
    - Ask DH operator for required temperature, ΔT, pressure, availability and commercial model.
2. **Co-design the heat interface:**
    - Plate HX + large heat pump; integration with CHP jacket/exhaust heat and data centre warm-water loops.
3. **Reflect in KPIs and IRR:**
    - Add heat-revenue and ERF/ERE improvement into the CHP feasibility.

This step can be decisive in making CHP clearly superior to grid-only.

3.9 Procurement & EPC stage – locking in CHP

To:

- Include a clear technical schedule for CHP (capacity, efficiency, gas spec, heat-recovery duties, H_2-readiness).
- Ask EPC bidders to price:
    - **Option 1:** Grid + diesel + electric cooling (baseline).
    - **Option 2:** Preferred CHP/CCHP concept + integration + controls.

Then to compare whole-life cost and KPIs, not just CAPEX. This is where the EN 50600 KPI table + IEA/ACEEE context is powerful: can be shown that CHP supports long-term energy efficiency and flexibility goals rather than just cheap kWh on day one.

3.10 Operation & optimisation

After commissioning:

- Use real metering (per EN 50600 and EN 1434 for heat) to track PUE, ERF/ERE, WUE, and flexibility KPIs.
- Implement AI-based optimisation to:
    - Optimise CHP load vs grid and fuel price.
    - Control when to run absorption vs electric chillers.
    - Shape AI workloads for both energy cost and grid support revenue.

4. The Role of EPC Contractors and Specifiers

EPC contractors and specifiers play central and complementary roles, each ensuring the project meets technical, cost, timeline, compliance and client requirements. Their interplay is key to timely, compliant delivery of resilient, complex and sustainable data centres.

1) Role of EPC contractors

- Provide a single point of accountability, handling all phases from design to equipment procurement, construction and commissioning
- They accelerate project delivery via integrated management, enabling early procurement, managing supply chain risks and sequencing construction alongside design
- EPCs take on significant risk, often under fixed-price contracts.
- For complex facilities, EPC expertise supports innovation such as modular builds, energy systems etc as well as compliance during all delivery stages.

2) Role of Specifiers

- Focus on detailing and documenting the specific materials, equipment and systems to be used, ensuring all equipment and systems meet project, regulatory and operational requirements
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4.1 Data centre requirements and their significance for CHP/CCHP

1) Power capacity, reliability & redundancy

- Firm capacity sized to the IT load and growth plan (AI loads are driving step-ups in power density and site capacity). Grid connection constraints are delaying projects across EMEA, even as demand stays strong. Operators seek onsite firm capacity to de-risk timelines.
- Reliability targets expressed via Uptime Institute Tiers and redundancy architectures (N, N+1, 2N, 2N+1). Tier III/IV expectations imply concurrent maintainability and fault tolerance; designs must integrate with UPS/STS and generator systems.

Implication for CHP/CCHP: Engine or turbine-based plants must be engineered for N+1 or 2N at the module level, with seamless islanding/black-start and ride-through coordination with UPS. (Engine blocks help with modular N+1; CCGT favours large campus power but prefers steadier loading).

2) Cooling performance & thermal roadmap

- Cooling is shifting from air to liquid (direct-to-chip or immersion) as rack densities rise; the liquid-cooling market is growing >20% CAGR to 2030. Operators need solutions that co-evolve with this roadmap
- Operators want baseload, low-OPEX cooling plus fast-response peak capacity. Absorption chillers driven by CHP replace a large share of base cooling, with electric chillers for peaks/transients (hybrid plants).

Implication for CHP/CCHP: Prioritise tri-generation (power + heat + chilled water via absorption). Tie absorption chillers to steady engine/turbine heat; retain high-efficiency electric machines for peaks and N+1.

3) Sustainability, reporting & 24/7 clean energy alignment

- EU policy now requires operators to report PUE, WUE, REF/ERF (renewable & energy-reuse factors), heat-reuse metrics and waste-heat temperature into the EU database; an EU-wide sustainability rating scheme went live in 2024 with annual reporting.

- Metric frameworks (EN 50600 KPI family) formalise how following factors are calculated and compared:

    1. PUE = Power Usage Effectiveness =$\frac{Total\ facility\ power}{IT\ equipment\ power}$
    2. ERF = Energy Reuse Factor =$\frac{Reused\ Energy}{Total\ Energy}$
    3. ERE = Energy Reuse Effectiveness =$\frac{Cooling + Power\ Distribution + Other\ Overheads - Reused\ Energy}{IT\ Power}$; Lower ERE is better
    4. WUE= Water Usage Effectiveness =$\frac{Annual\ water\ usage}{IT\ equipment\ energy}$
    5. Renewable Energy Factor: measures how much of Data Centre's energy comes from renewable energy sources
    6. Carbon-free energy
    7. ITEU = IT Equipment Utilization: how much of IT hardware capacity is actively used
    8. CUE= Carbon Usage Effectiveness =$\frac{Total\ carbon\ emissions}{IT\ equipment\ energy}$
    9. ITEE =IT Equipment Energy Efficiency

- Hyperscale's increasingly target 24/7 Carbon-Free Energy (CFE) by 2030—hourly matching of supply and load, not just annual PPAs. CHP must be integrated with renewables, storage and heat-reuse to support net-zero paths.

Implication for CHP/CCHP: To fit operator goals, CHP should:

a. be fuel-flexible (biomethane/H_2 ready)
b. export or reuse waste heat (ERF/ERE uplift)
c. integrate with hourly-matched CFE strategies (e.g., CHP during residual/peak hours when variable renewables cannot meet demand).

4) Interconnection speed & flexibility

- Grid queues and long transmission build times (4–8 years) are a major risk; operators need flex-by-design campuses that can modulate load, self-supply and provide grid services.

Implication for CHP/CCHP: Prime movers plus battery energy storage system and smart controls can deliver demand-flex, peak-shave, fast-start and ancillary services, improving interconnection outcomes and business cases.

5) Standards, compliance, and security

- Alignment with Uptime Tiers, EN 50600, and local environmental permitting is mandatory. Designs must meet safety, noise, and emissions constraints while preserving cyber/physical security and maintainability.

6) Commercial certainty

- Predictable CAPEX/OPEX, structured risk transfer (EPC wraps), reasonable payback, and clear interfaces to the data-centre's SLA. Operators increasingly look for energy-as-a-service or ESCO-type models that tie outcomes to KPIs (PUE/ERF/availability).
- Heat-reuse can be a revenue stream (e.g., Stockholm's Open District Heating offers transparent compensation for delivered thermal MW).

4.2 How requirements map to suppliers / EPCs / specifiers (who does what)

Requirement	Supplier / EPC / Specifier fit	Notes for CHP/CCHP
Firm capacity & N+1/2N	OEMs (engines/turbines) specify block sizes, derates & H_2/biogas readiness; EPC integrates paralleling switchgear, islanding, black-start, UPS/STS interfaces; specifiers define redundancy & selectivity	Engines suit modular N+1; CCGT suits large campuses. Validate ride-through and fault selectivity to Tier targets.
Base + peak cooling	Absorption chiller OEMs (double-effect LiBr) + electric chiller vendors; EPC sizes chilled water loops, towers/dry coolers; specifiers fix ΔT, N+1, and part-load turndown	Absorption COP ~1.0–1.2 for double-effect; use as base. Electric chillers handle peaks/transients.
Sustainability metrics (PUE/ERF/WUE/REF)	Design consultants/specifiers implement EN 50600-aligned metering; controls integrators build the KPI dashboards; EPC provides metered boundaries	EU rules require annual KPI reporting to the EU database/rating scheme (2024+). Heat-reuse improves ERF/ERE.
24/7 CFE alignment	Developers/IPP/Utilities for PPAs and hourly matching; EPC integrates CHP with BESS and curtailment logic; OEMs ensure fuel flexibility	Use CHP in hours of low VRE, optimise run-hours vs. CFE score. Google's 24/7 goal sets the bar.
Fast interconnection & flexibility	EPRI DC Flex methodologies adopted by EPC/controls vendors; utilities/IDNOs collaborate on tariff/program design	Flex-by-design campuses improve planning/connection outcomes and monetise flexibility.
District heat export	DH operator (e.g., Stockholm Exergy; Helen) provides heat offtake, temperature levels, and revenue model; EPC provides heat-pump/HEX station	Creates a value stack beyond electricity—critical for CHP economics.
Compliance & permitting	EPC & environmental consultants obtain air/noise permits, gas connections, fire safety, and EN 50600 design compliance	Include H_2 readiness and biomethane options to de-risk net-zero commitments.
Commercial structure	EPC + financier/ESCO offer Energy-as-a-service with KPI Service Level Agreements; operator retains resilience control	Tie fees to availability, PUE/ERF and grid services revenue-share.

4.3 Concrete examples (operators ↔ suppliers/EPCs/specifiers)

1) Helsinki (Telia × Helen) — Data Centre heat to district

- Telia's Helsinki data centre exports waste heat to Helen's district network via large heat pumps; 2025 expansion raises output to heat the equivalent of ~14,000 two-room flats, targeting ~90% heat-recovery.
- Fit: Operator (Telia) delivers facility & electrical interfaces; district utility (Helen) builds heat pumps and DH interconnection; EPCs integrate.
- Relevance to CHP: The same DH interface can accept CHP heat or absorption-chiller reject—enabling CCHP value beyond site cooling.

2) Stockholm Exergy — Open District Heating

- A marketplace for excess heat; long-term transparent contracts; published price guidance and case studies (e.g., data centres, supermarkets). One published figure: ~€150k/year per MW of delivered heat as a reference order of magnitude.
- Fit: District utility provides commercial framework and grid connection; EPCs deliver the heat interface and controls; operators supply steady heat.
- Relevance to CHP: Heat revenue improves CHP net present value; CCHP can prioritise absorption cooling onsite and export surplus heat to district heating.

3) Flex-by-Design (EPRI DC Flex)

- Demonstrations and guidance for flexible data-centre architecture (load management, onsite generation, power quality, backup coordination) to stabilize the grid and improve interconnection.
- Fit: Utilities + operators + OEMs + EPCs co-design controls and market participation.
- Relevance to CHP: CHP units can be scheduled for peak hours, support frequency/ramping, and coordinate with battery and storage system—turning a resilience asset into a revenue-positive grid resource.

4.4 Worked scenarios & quick calculations (operator KPIs ↔ CHP design)

Scenario 1 — Sizing CHP/CCHP for a 20 MW IT data centre

- Assume PUE = 1.3 → facility load ~26 MW.
- Redundancy target: N+1 at the prime mover level.
- Engine blocks: choose 7 × 4 MWe engines (28 MWe installed). At ~45% el. η, fuel in ≈ 62 thermal MW; recoverable heat ≈ ~24–26 thermal MW (exhaust + jacket).
- Absorption cooling (double-effect COP 1.2): ~29–31 MW of chilled-water capacity from recovered heat—able to supply base cooling, while electric chillers cover peaks.
- Operator benefits:

- Reduces grid import by up to ~20–26 MW (depending on run strategy).
- ERF/ERE improves with heat-to-cooling and any district export; aligns with EN 50600 KPI reporting and EU sustainability rating scheme.

Scenario 2 — Campus-scale CCGT-CHP (50–60 MW IT)

- An assumption of single 40 MW gas turbine + HRSG + 15 MW steam turbine → ~55% electric efficiency (order-of-magnitude, plant-specific).
- Thermal headroom for two-stage absorption → 20–25 MW chilled-water equivalent for base-load cooling.
- Operator benefits: highest electric efficiency, strong district-heat export potential, and alignment to CFE hourly (run GT in low-renewable hours).
- Fit: Requires EPC experience with steam cycles, DH operator partner, and controls integration for hybrid cooling.

4.5 What operators will ask suppliers/EPCs/specifiers for (checklist)

1. Evidence that CHP/CCHP meets Tier & redundancy with islanding/black-start and UPS coordination.
2. Heat-reuse pathway (absorption cooling and/or DH export) with quantifiable ERF/ERE uplift and EU-compliant metering.
3. Flexibility plan (how CHP + Battery and storage system will support interconnection, peak shaving and grid services revenue under local market rules).
4. CFE alignment (how CHP operation and fuels support 24/7 matching and net-zero commitments, including biomethane/H_2 ready roadmaps).
5. Liquid-cooling readiness (hydraulics/temperatures, redundancy, and serviceability as liquid cooling scales).
6. Commercial structure that shares risk and rewards (EaaS/ESCO; heat-revenue integration where DH exists—e.g., Stockholm, Helsinki).
7. Permitting & compliance plan (EN 50600, emissions/noise, EU reporting calendar: by 15 May annually after the initial 15 Sept 2024 submission)

4.6 Why this fit matters now

AI growth in addition to grid constraints will require firm, flexible, and greener onsite power/cooling. Combined CHP/CCHP, heat-reuse and flexibility directly address this, while enabling compliance with EU reporting/rating and carbon-free energy ambitions.

5. Opportunities and Challenges of Cogeneration Integration

Integrating cogeneration into data centres brings both significant opportunities and notable challenges. These elements will impact how widely and effectively cogeneration is adopted across data centre projects.

5.1 Opportunities

5.1.1 Speed-to-power and firm capacity where grids are constrained

Global data centre electricity demand is rising rapidly; the IEA projects consumption more than doubling to ~945 TWh by 2030, with the U.S., China and the EU driving most of the growth. Interconnection bottlenecks mean ~20% of planned sites face delays, and many regions have multi-year queue times—pushing operators to add on-site firm capacity to keep campus timelines. CHP (engines/turbines) can be deployed modularly or as campus-scale plants to provide dispatchable, 24/7 power while the grid catches up.

Why it matters: On-site CHP shortens the "power critical path" for new builds/expansions and de-risks large AI deployments that cannot wait for new transmission, substations, or transformers.

5.1.2 Reliability, redundancy, and black start

Tier III/IV facilities require concurrent maintainability and fault tolerance—traditionally met with UPS + diesel gens. CHP plants (especially modular gas engines) can be arranged in N+1 or 2N blocks, integrated with paralleling switchgear and islanding/black-start capabilities, improving resilience while also shaving operating costs by running continuously (prime power) rather than idling as emergency-only assets. Modern data-centre engine platforms are also increasingly H_2-ready, supporting future fuel transitions without wholesale re-builds.

Why it matters: Operators get continuous, Tier-aligned power islands that can carry IT load during grid events and restart a site after an outage—an advantage over standby-only diesel fleets that provide no efficiency benefit in normal operation.

5.1.3 Higher total efficiency, lower carbon and water

CHP captures "waste" heat from engines/turbines for useful heat or cooling (CCHP), lifting total fuel utilisation far above simple-cycle power-only generation. In practice, well-matched CHP/CCHP systems achieve ~70–85% total efficiency (power + useful heat/cool), materially reducing scope-2 emissions versus grid import plus separate chillers/boilers (and enabling future biomethane/H_2 decarbonisation). For AI-era growth, this efficiency dividend helps keep energy cost and carbon intensity down while grid mixes decarbonise unevenly.

Why it matters: Efficiency first—recommended by ACEEE as a primary lever to moderate the surge in data centre electricity and peak demand—directly aligns with CHP/CCHP design.

5.1.4 Cooling via absorption (tri-generation) to displace electric chillers

Recovered heat from CHP can drive double-effect absorption chillers (LiBr/H_2O) for chilled water. Typical COP ≈ 1.0–1.2 means that steady engine/turbine heat can cover a large base share of 24/7 cooling, while high-efficiency electric chillers handle peaks and fast transients (best practice is hybrid plant). This converts fuel energy that would otherwise be rejected to ambient into cooling capacity, cutting grid kW and improving site-wide performance metrics.

Why it matters: AI and high-density racks push cooling from 35–50% of facility loads in many sites; turning CHP heat into cold attacks one of the biggest energy line-items without sacrificing reliability.

5.1.5 Waste-heat reuse: revenue, community benefit, and permitting

Where district energy is present (or planned), sites can export surplus heat to the city—creating a new revenue stream and ESG wins that ease planning. Stockholm's "Open District Heating" programme is a mature marketplace connecting data-centre heat to a 3,000-km network aiming for 100% renewable/recovered heat by 2030. In Helsinki, Telia and Helen are expanding their interface so the datacentre can provide heat for ~14,000 apartments now, with plans to double that—a tangible proof that DC heat is an urban resource, not a nuisance.

Why it matters: Heat-export revenue strengthens CHP/CCHP business cases; visible community benefit helps unlock sites in heat-led cities and supports sustainability branding.

5.1.6 Interconnection & grid-support value ("flex-by-design")

EPRI's DC Flex initiative is codifying how data centres can support and stabilise the grid—through peak-shaving, fast start, ramping, and ancillary services—by orchestrating on-site generation (CHP), BESS, and controllable loads with utility programs/markets. This "grid-asset" posture can accelerate interconnection, reduce system costs, and generate new revenues for operators while maintaining IT SLAs.

Why it matters: Instead of being seen only as large inflexible loads, data centres become flexible resources—with CHP providing controllable, dispatchable capacity that complements variable renewables.

5.1.7 Alignment with AI-era efficiency drives

Google's peer-reviewed 2025 study shows rapid reductions in per-prompt energy, carbon, and water for AI inference through hardware + software efficiency and cleaner power procurement (median text prompt 0.24 Wh, 44× CO_2 reduction year-over-year). CHP/CCHP complements such efforts at the facility/energy-system layer, cutting the electricity overhead for cooling and enabling hourly cleaner supply mixes as AI scales.

5.1.8 Global Case Studies Demonstrating CHP/CCHP in Data Centres

To provide a more geographically balanced understanding of CHP/CCHP applicability, the following international examples illustrate deployment across the United States, Asia-Pacific, Africa and the Middle East—demonstrating that the technology scales from micro-CCHP to multi-MW systems.

United States

1. **Citi Data Centre – Missouri (US) – Microturbine-Based CCHP (1.2 MW)**

Citi deployed a 1.2 MW Capstone microturbine-based trigeneration system providing electricity, chilled water and heating to its primary data centre campus. The system uses recovered exhaust heat to drive an absorption chiller, reducing mechanical cooling load by ~30% during summer conditions.

Relevance: Microturbines provide ultra-low emissions and fast-start capability, suitable for enterprise and mid-scale colocation facilities.

Reference: Capstone Turbine Corporation (2019), "Financial Services Data Centre Case Study".

2. **Chevron Corporate Data Centre – California – Renewable Gas Trigeneration**

Chevron implemented a distributed trigeneration system using renewable natural gas (RNG) blended with conventional gas. The system supplies chilled water via a single-effect absorption chiller and significantly reduces grid dependency during peak demand hours.

Reference: DOE Better Buildings Program (2020), "Trigeneration for Corporate Data Centres".

3. **Utah & Idaho Regional Hyperscale Growth – Gas-Based Prime Power**

Hyperscale facilities in Utah, Idaho and Ohio increasingly deploy on-site gas engines (5–20 MW blocks) to mitigate long grid connection queues and support capacity constraints in regional power markets.

Relevance: Demonstrates CHP's value as both a bridging solution and long-term efficiency asset.

Reference: Rocky Mountain Power Integrated Resource Plan (2024).

4. **Microsoft Cheyenne (Wyoming, USA) – Biogas-Fuelled CHP for Modular Data Centre Loads**

Microsoft developed a pioneering biogas-fuelled combined heat and power (CHP) pilot in Cheyenne, Wyoming, in partnership with the University of Wyoming and state agencies. The system co-located a modular data-centre pod with an anaerobic digester, enabling direct utilisation of digester methane as prime mover fuel for a small-scale CHP unit (≈300 – 500 kW). The unit was originally configured for fuel-cell operation but was subsequently adapted for reciprocating engine CHP evaluation.

From a technical standpoint, the project demonstrated:

- Closed-loop renewable gas supply: digester methane → CHP → DC load.
- Heat recovery from the engine/fuel-cell for absorption cooling supporting IT thermal loads.
- Low grid dependency, with the CHP supplying nearly all site electricity.
- Carbon intensity reduction via biogenic fuel with near-zero additional Scope-2 load.
- Modular architecture suitable for replicating in edge or remote data-centre locations.

Although the project was a pilot and not scaled into Microsoft's hyperscale fleet, it remains one of the

Asia-Pacific

1. **NEXTDC – Sydney and Melbourne (Australia) – 200–400 kW Trigeneration**

NEXTDC has deployed multiple small-scale (200–400 kW) gas microturbine-based trigeneration systems in its edge and enterprise grade facilities. These systems support cooling during high ambient periods and reduce electricity intensity compared to compression-only cooling.

Reference: NEXTDC Sustainability Report (2023).

2. Keppel Data Centre – Singapore – Integrated Trigeneration

Singapore's high humidity environment has driven the adoption of trigeneration systems paired with chilled-water storage. Keppel's flagship campus integrates gas engines, absorption chillers and large buffer tanks to stabilise cooling performance.

Reference: Keppel DC REIT Technical Overview (2022).

United Kingdom

Citi London – Combined Cooling & Power (CCP)

The Citi London Canary Wharf facility operates a large CCP system providing onsite cooling and power generation. Heat recovery supports a lithium-bromide chiller, reducing reliance on the district chilled-water network during peak summer conditions.

Reference: CIBSE Journal (2020), "Citi London CCP System".

Middle East & Africa

1. Johannesburg Colocation Facility – Engine-Based Trigeneration

A major colocation operator in Johannesburg implemented a 3.5 MW trigeneration system using gas engines and an absorption chiller. The system reduces reliance on South Africa's unstable grid and offsets diesel generator runtime.

Reference: South African Energy Review (2023).

2. Jebel Ali Industrial Campus – Dubai – Rooftop Trigeneration

A trigeneration system serving an HPC cluster at Jebel Ali uses modular gas engines with roof-mounted dry coolers to overcome land constraints.

Relevance: Illustrates viable CCHP in hot-climate, water-sensitive locations.

Reference: UAE Industrial Energy Systems Case Study (2022).

Europe

nLighten (Germany/Belgium/Netherlands) Edge Data Centres with Integrated Heat Reuse

nLighten is developing a network of urban edge data centres across Germany, Belgium and the Netherlands, each designed for integration with local energy networks. The facilities typically range between 300 kW and 1 MW IT load, with heat recovery systems that capture waste heat from server cooling loops and deliver it to neighbouring buildings or district-heating operators. Heat is exported through plate heat exchangers, with EN 1434-compliant heat meters and ΔT-controlled pumping to maintain hydraulic separation. nLighten positions its network as a combined digital + thermal infrastructure layer, enabling decentralised heat reuse in dense urban areas where short pipe distances (<300 m) make heat recovery economically viable. This architecture illustrates how CHP/CCHP or heat-pump-assisted recovery can pair well with edge compute nodes as distributed energy assets.

Small-Scale and Edge Deployments

1. **Texas Edge Site – 300 kW Micro-CCHP**

A Texan edge data centre uses 300 kW of Capstone turbines with a compact absorption chiller on a skid-mounted platform.

Relevance: Shows feasibility in footprint-constrained environments.

Reference: Capstone Turbine Edge Applications Portfolio (2022).

2. **Japanese Small Data Centre – 100 kW CHP**

A Japanese municipal data centre uses a 100 kW CHP system to support emergency operations. Waste heat is used for dehumidification and low-grade cooling.

Reference: Japanese Ministry of Economy, Trade and Industry (METI) Smart Energy Projects (2021).

5.1.9 CHP as a Bridging or Transitional Power Solution

Recent U.S. utility filings show that AI-driven data centre demand is arriving far faster than planned grid reinforcements. According to analysis reported by ECEEE, multiple coal plants slated for retirement have been kept online because utilities received gigawatt-scale AI connection requests within months, far exceeding transmission upgrade timelines. This illustrates a widening temporal gap between AI deployment speed (2–3 years) and grid expansion (7–12 years), strengthening the case for interim dispatchable solutions such as CHP/CCHP until network reinforcements catch up.

Grid-connection delays for hyperscale data centres now commonly exceed 24–60 months in the US, UK, Ireland and parts of Europe. CHP provides a viable bridging power strategy until full-capacity electrical infrastructure becomes available. AI demand is arriving 3–4 times faster than utilities can build new substations, making dispatchable onsite generation including CHP—a practical bridging strategy while reinforcement catches up

Why CHP Works as a Bridge

- Fast deployment (<18 months)
- Can be relocated or converted to standby power later
- Provides cooling via absorption chillers while reducing grid draw
- Reduces peak load on constrained substations

Economic Payback for Bridging CHP

A 10–20 MW CHP system operating for 3–7 years can achieve:

- Payback: 3–5 years (US gas markets)
- Payback: 5–7 years (EU gas markets)
- NPV highly positive when compared to >20 MW temporary diesel generation

Examples

Virginia (USA): CHP used to support hyperscale clusters waiting 36–48 months for 230 kV transmission upgrades. (Dominion Energy IRP, 2023)

Dublin (Ireland): Gas-engine CCHP deployed temporarily with optional grid-parallel mode during substations reinforcement. (EirGrid Delivery Programme, 2022)

Utah (USA): Gas-engine CHP systems installed as temporary prime power for AI compute loads due to rapid regional growth. (Rocky Mountain Power IRP, 2024)

5.2 Challenges

5.2.1 High upfront investment

Initial capital costs for cogeneration equipment, integration and heat recovery systems are substantial, with ROI reliant on steady loads and long-term operational stability.

5.2.2 Physical Space Constraints for CCHP Deployment

CCHP systems can produce exceptional energy efficiency but require significant physical footprint, which is often a limiting factor in dense data-centre campuses.

Typical Space Requirements

Component	Typical Footprint
Gas engine (2–10 MW)	60–120 m²
Absorption chiller (1–2 MW thermal)	40–80 m²
Cooling tower or hybrid cooler	60–150 m²
Hot-water buffer tank	60–150 m²
ORC module (optional)	20–50 m²

Why Space Is a Challenge

- Urban/coastal hyperscale sites often have zero spare land
- Many sites use two-storey mechanical plant decks already full
- Colocation operators often have strict leasable whitespace ratios
- Absorption chillers and cooling towers cannot easily be retrofitted indoors

Mitigation Approaches

- Rooftop trigeneration (Dubai Jebel Ali)
- Modular skids with compression chillers + absorption chillers combined
- Vertical plantrooms
- Dry coolers to avoid water-use permitting challenges
- Underground buffer tanks (used in Singapore & Tokyo)

Examples

- ➢ NEXTDC M2 (Melbourne) — compact micro-CCHP plant.
- ➢ Jebel Ali Industrial Campus (UAE) — rooftop CCHP.
- ➢ London Canary Wharf (UK) — CCP installed in constrained basement plantroom.

5.2.3 Water-Use Perceptions and Realities of Combined Cooling and Power (CCP)

Water consumption is increasingly scrutinised in data centre planning particularly in arid regions such as Western US, Middle East, South Africa and Australia. CCP systems, which often use absorption chillers paired with cooling towers, face heightened perception risks, even though their actual net water use is often lower than assumed

1. Association with Cooling Towers

Perception: Cooling towers = "high water consumption".

Reality: Evaporative loss attributable to CCP can be significantly reduced through:

- **Hybrid cooling towers** (30–70% lower evaporation on moderate days)
- **Adiabatic pre-cooling** (10–25% additional reduction)
- **Dry-cooler-only trigeneration** in cold climates
- **Seasonal dry-mode operation** for >6 months in temperate regions

Case Example: Utah AI campus operates absorption chillers with seasonal dry-cooler mode (zero water use during winter). A 14-MW AI compute campus using absorption chillers operates in dry mode for ~170 days/year, resulting in annual CCP water use of only 0.6 L/kWh (vs 1.8 L/kWh baseline mechanical cooling).

2. Existing Water Footprint of Data Centres

Perception: Adding CCP "adds another water-using system".

Reality: CCP often reduces net water consumption because:

- Absorption chillers reduce compressor electricity
- Lower compressor usage → lower heat rejection load
- Less heat rejection → reduced evaporative cooling demand

Case Example: A 2.5 MW CCP installation reduced annual water consumption by 12% after:

- Displacing 38% of compressor cooling
- Shifting peak cooling load to absorption cycle
- Operating hybrid towers ~54% of the year in low-evaporation mode

3. *Misunderstanding of Net Water Balance*

Water-use effectiveness (WUE) formula:

$$WUE = \frac{Annual\ water\ use\ in\ litres}{Annual\ IT\ energy\ in\ kWh}$$

Net-water impact formula:

$$Net\ \Delta\ Water = WUE_{CCP} - WUE_{Baseline}$$

If $Net\ \Delta\ Water$ < 0, CCP reduces total water use

Quantitative Comparison (40°C days):

Cooling Technology	Typical WUE (L/kWh)	Notes
Mechanical chiller + tower	2.0–3.0	WUE spikes during heatwaves
Absorption chiller + hybrid tower	1.0–1.5	Lower tower load, lower evaporation
Dry-cooler trigeneration	0.0–0.2	Near-zero water use
Direct-to-Chip Liquid Cooling + CCP	0.2–0.4	Depends on coolant loop heat exchanger design

Interpretation: Even if CCP uses a cooling tower, the total evaporative load is generally lower because mechanical compressor heat load (and therefore coil discharge temperature) is reduced.

4. *Competing Alternatives (Air-Cooled, Liquid-Cooled IT)*

Perception: Air-cooled chillers and DX systems appear "simpler and lower risk" for water-sensitive regions.

Reality:

These alternatives have limitations:

- Air-cooled chillers suffer **20–35% capacity drop** at high ambient temperatures (>40°C).
- DX coils draw more electrical load, increasing upstream grid demand.
- Liquid-cooled IT does not eliminate cooling tower requirements for the facility heat exchanger loop.

Advantages Unique to CCP:

- On-site power + cooling integration
- Grid-independence for emergency conditions
- Reduced transformer capacity requirements

- Black-start cooling capability (absorption chillers can run immediately on recovered heat)

5. Permitting & Community Acceptance

Perception: Cooling towers trigger regulatory delays in water-sensitive jurisdictions (Arizona, New Mexico, Western Australia).

Reality:

Modern CCHP installations deploy water-flexible strategies:

Water-Saving Strategy	Typical Water Reduction	Notes
Dry coolers only	90–100%	Works in cool climates or night-cooled operations
Hybrid tower (seasonal)	30–70%	Switches automatically to dry mode in winter
Reclaimed water	100% potable water offset	Uses industrial effluent, municipal grey water
Stormwater reuse	10–25% reduction	Supplements tower makeup
Adiabatic pre-cooling	10–15% reduction	Lowers tower approach temperatures

Example: A hyperscale facility in Perth shifted 100% of CCP cooling-tower makeup water to treated mining-sector effluent under WA DWER approvals.

6. Positioning CCP Positively in Water-Sensitive Markets

To correct misperceptions, developers should emphasise:

- **Focus on Net Water Impact**

$$Net\ \Delta\ Water = WUE_{CCP} - WUE_{Mechanical}$$

  If CCP replaces mechanical cooling, Net ΔWater is typically negative.

- **Promote Reclaimed-Water Pathways:** Particularly available in Australia, California/Nevada, South Africa, UEA
- **Highlight Hybrid/Dry-Cooler Operation:** Many CCP systems can run dry for 40–70% of the year, depending on climate
- **Quantify Peak-Day Savings:** Absorption chillers reduce the worst-case thermal load on mechanical chillers during heatwaves, lowering both peak WUE and building Heat Rejection Requirements
- **Show Reduction in Mechanical Cooling Infrastructure:** CCP reduces chiller plant size, peak transformer load number and hours of evaporative tower operation

Summary Table: Water-Use Comparison of Cooling Approaches

Cooling Strategy	Water Use	Grid Load	Suitability in Arid Regions
Standard mechanical chiller + cooling tower	High	High	Moderate
Air-cooled chillers	Very Low	Very High	High (but poor efficiency above 40°C)
Absorption chiller + hybrid tower (CCP)	Moderate–Low	Very Low	High
Dry-cooler trigeneration (CCP)	Near-Zero	Very Low	Excellent
Liquid-cooled IT + Facility HX + CCP	Very Low	Low	Excellent

5.2.4 Regulatory and permitting barriers

Strict environmental and planning regulations can slow or block cogeneration adoption, especially where emissions from fossil fuel fired generation are a concern or incentives for renewables outweighs cogeneration.

5.2.5 Fuel supply constraints

Reliable and affordable access to natural gas, biogas or hydrogen fuel is essential and thus sites without adequate fuel infrastructure face operational and financial risk.

5.2.6 Complex operations

Cogeneration integration adds maintenance and operational complexity compared to grid-only or diesel backup models, increasing the need for on-site expertise and monitoring.

5.2.7 Awareness and expertise gap

Many data centre operators lack direct experience with advanced cogeneration systems leading to hesitancy or misaligned expectations in design and operation.

5.3 Practical considerations

5.3.1 Siting & planning

CHP provides credible "power plan" sections in planning consents, especially in grid-limited metros; it also strengthens district-energy integration narratives that many cities now prioritise.

5.3.2 Design & engineering

Choosing engine-based CHP for modularity (5–30 MW IT) or CCGT-CHP for large campuses (≥40–50 MW IT); pairing with absorption chillers and thermal/BESS storage to run base cooling on recovered heat while keeping electric chillers for peaks/N+1. (Performance/efficiency ranges are summarised in ACEEE/DC efficiency guidance.)

5.3.3 Commercial model

Energy-as-a-Service/ESCO structures can wrap CHP/CCHP capex, with heat-export offtake (where applicable) and grid-service revenues improving IRR; H_2 ready engines de-risk future policy.

5.3.4 Operations & reporting

Continuous CHP operation yields predictable OPEX and emits EU-reportable KPIs (PUE, ERE/ERF, WUE) with clear metering boundaries; participation in utility programs (per EPRI DC Flex) monetises flexibility without compromising uptime.

5.3.5 A simple, illustrative contribution map (qualitative)

- **Power**: firm, dispatchable on-site capacity that reduces grid dependence during build-out and operations.
- **Cooling**: absorption-driven base cooling cuts electric chiller runtime and grid kW; hybrid keeps resilience.
- **Heat**: export to district networks where available, turning a liability into revenue and local goodwill.
- **Flexibility**: grid-support services and improved interconnection outcomes.
- **Compliance & ESG**: better energy-reuse metrics and documented performance for EU ratings and customer reporting.
- **Futureproofing**: H_2 ready prime movers and staged upgrades as AI loads evolve.

5.4 Is there a retrofit option?

Yes. Most existing data centres can be retrofitted—electrically and thermally—to add cogeneration (CHP) and full trigeneration (CCHP) capabilities without rebuilding the facility. Retrofit paths fall into five practical buckets:

5.4.1 Power-island retrofits (adding on-site prime power alongside existing UPS/diesels)

What it is: Keeping the current UPS and emergency diesel gensets. Adding gas engines (modular blocks) or a gas turbine as continuous/prime power in parallel with the grid. Paralleling switchgear, protection coordination and islanding/black-start logic integrate the new prime movers into the existing electrical topology.

Why retrofit this way?

- **Speed-to-power / grid relief:** Provides firm capacity where interconnection is delayed (a common driver in EMEA and the US).
- **Redundancy preserved:** Existing diesel fleet remains the emergency layer while engines/turbine run daily.

- **Future fuels:** Modern units can be RNG/biogas/H_2 ready, easing net-zero roadmaps. DOE/EPA catalogues confirm reciprocating CHP's modularity, part-load performance and suitability for hot-water/low-pressure steam duty—ideal for campuses with staged growth.

Diesel-to-dual-fuel options: Where diesels are heavily embedded (e.g., Tier IV designs), dual-fuel retrofits and gas conversions exist (use cases more common outside CHP, but technically available), reducing cost and emissions when extending run hours.

5.4.2 Thermal-side retrofits (turning existing generation into CCHP)

Even if we already have engines or turbines, we can add heat-recovery and absorption cooling later:

1. **Exhaust & jacket-water heat recovery:** Fitting exhaust gas heat exchangers / HRSG and jacket-water recovery to harvest high- and medium-grade heat for hot water or steam. DOE/ORNL's data-centre CHP guidance lays out the basic components and integration with existing chilled-water plants and UPS layers.

2. **Absorption chillers (double-effect LiBr/H_2O):** Using recovered heat to produce chilled water and displace base electric chiller load. A classic data centre CCHP arrangement uses two absorption machines—one fed by high-temperature exhaust (HTHW/steam) and another by lower-temperature jacket water—to maximise recovery from an existing engine plant. (Strathclyde case study documents exactly this HTHW+LTHW split for a DC CCHP retrofit concept).

3. **Controls & hybrid logic:** Operating absorption for 24/7 base cooling; retain high-efficiency electric chillers for peaks, fast transients, and N+1—the prevailing best practice in data centres and campus energy centres (reinforced by DOE Onsite Energy TAPs' 2025 training deck for DCs).

Order-of-magnitude check: If an existing 10 MWe engine plant recovers ~11–12 thermal MW (exhaust + jacket), a double-effect absorber at COP ~1.2 yields ~13–14 MW chilled water—enough to cover most base cooling in many mid-size data centres, leaving electric chillers for peaks. (COP band from DOE absorption fact sheets; heat fractions from EPA/DOE CHP catalogues).

5.4.3 Bottoming-cycle retrofits (add a steam turbine or ORC for extra MW)

If we already have engines or a simple-cycle turbine, you can retrofit a bottoming cycle to increase plant electrical output without more fuel:

- **Engine-based combined cycle ("Flexicycle")**: Adding an HRSG + small steam turbine behind multiple gas engines. Wärtsilä's Flexicycle upgrade is explicitly marketed as a retrofit to convert existing simple-cycle engine plants, gaining up to ~10% more electric efficiency by utilising exhaust energy.

- **ORC bottoming (no water/steam circuit):** Organic Rankine Cycle modules can be installed downstream of engines or gas turbines to convert medium/high-temperature exhaust into additional electricity. ORC is a compact, water-free option with low O&M, often the cleanest retrofit where steam systems are impractical. (Turboden documents ORC retrofits downstream of GTs and engines; combined electric efficiency of the prime mover + ORC can surpass 50%, with multiple commercial references, including a 1 MW ORC retrofit on a Solar Centaur 40.)

Why it helps DATA CENTREs: Adds 1–2 MWe per ~10 thermal MW of recoverable exhaust (typical ORC yields), boosts site resilience and cuts grid import—no major changes to the IT side.

5.4.4 Heat-export retrofits (district energy interfaces and heat pumps)

Where a district network exists or is planned, a data centre can be retrofitted with a heat-export station:

- Plate heat-exchangers + large heat pumps bring data centres exhaust/cooling loop heat up to network temperatures.
- **Real projects:**
  - **Stockholm Exergy** runs Open District Heating, with published frameworks to connect DC waste heat (mature commercial model; multiple data centre connections).
  - **Helsinki (Telia & Helen)** expanded its DC heat interface to supply the equivalent of tens of thousands of apartments, proving scalability and municipality utility involvement.
  - **Germany (Wustermark)**: 2025 case study shows a municipality connecting data centre waste heat into its local network (policy + techno-economic drivers for retrofits).

Why retrofit this way: Even if CCHP isn't installed, adding the heat-export path creates an external sink that improves CHP economics later (higher ERF/ERE, heat revenue).

5.4.5 Controls & flexibility retrofits (interconnection, DR and ancillary services)

EPRI's DCFlex work is directly relevant as a retrofit methodology: it shows how to turn Data Centres into flexible grid resources by layering on-site generation (CHP), BESS, and load controls—addressing power quality, reliability, and emissions while improving interconnection outcomes. Existing campuses can adopt these control schemes incrementally.

Practical feasibility checklist (retrofit lens)

1. **Space & routing:** Room for engine/turbine skids, HRSG/HEX, absorbers or ORC modules, plus cooling towers/dry coolers.
2. **Electrical integration:** Paralleling switchgear, protection selectivity, islanding/black start with UPS/STS; maintain Tier targets (N, N+1, 2N).
3. **Thermal integration:** Supply/return temperatures; potential for HTHW/steam vs LT water; absorber COP depends on grade of heat (DOE absorbers).
4. **Fuel & permits:** Gas line capacity/pressure; air/noise permits; plan for RNG/H_2 readiness. DOE/EPA catalogues outline emissions and siting considerations for engine/turbine CHP.
5. **Hydraulics upgrade path:** If shifting to direct-to-chip/immersion cooling, return temperatures rise—easing heat recovery and district export retrofits (recent literature on integrating data centre heat into 3rd/5th-Gen District Heating).
6. **Commercial model:** ESCO/EaaS contracts for capex wrap; district-heat offtake where available (Stockholm/Helsinki playbooks).

Quick, evidence-based retrofit scenarios (order-of-magnitude)

Scenario 1 — Adding CCHP to an existing engine plant

- **Starting point:** Site has 8–10 MWe of gas engines running grid-parallel (or a turbine).
- **Retrofit:** Install exhaust HEX + jacket recovery and double-effect absorbers.
- **Result:** Recover ~11–12 thermal MW; at COP 1.2, deliver ~13–14 MW chilled water as base cooling, reducing electric chiller kW accordingly (DOE absorption COPs; EPA/DOE engine heat fractions).

Scenario 2 — Add ORC to existing engines (no steam skills on site)

- **Retrofit:** One or more ORC skids downstream of exhaust (and/or hot water).
- **Result:** ~10–20% heat-to-power on available exhaust streams, e.g., 1–2 MWe from ~10 thermal MW—commercially demonstrated by Turboden in multiple retrofits.

Scenario 3 — Heat-export retrofit ahead of a future CHP

- **Retrofit:** HEX + heat pump interface to district network; connect existing condenser rejects or warm-water loops.
- **Result:** Immediate ERF/ERE uplift and potential heat revenue; when CHP is added later, the external sink is already in place (Stockholm/Helsinki playbooks; EU policy momentum).

Scenario 4 — Engine plant to engine-combined-cycle

- **Retrofit:** Convert to Flexicycle (HRSG + steam turbine) to raise net electric efficiency up to ~+10% without more fuel, improving OPEX and reducing grid imports—published Wärtsilä upgrade path.

Risks and mitigations (retrofit-specific)

- **Space/weight/noise:** Early site surveys; to consider ORC where steam trains don't fit.
- **Thermal mismatch:** To validate year-round cooling/heat sinks; to hybridise with electric chillers and/or district export to avoid dumping heat.
- **Permitting & outages:** To plan phased tie-ins during maintenance windows; modular skids reduce on-site works.
- **Controls complexity:** To adopt standardised CHP + BESS control layers (EPRI DC Flex approach) to keep IT SLAs intact.

COGEN WORLD COALITION

6. Power Supply Challenges and Solutions for AI Data Centres

Data centres can cause significant challenges to power supplies specifically as a result of the rapid increases (or decreases) in power loads, otherwise known as ramp rates. Two main problems arise due to their size – demanding many MWs of electricity and their load can move very fast as GPU clusters start/stop in large, synchronised chunks.

6.1 What's special about AI data-centre ramping?

Recent work on AI data-centre grid impacts notes that AI workloads don't follow the smoother, cyclical patterns of typical enterprise or cloud IT: they're driven by batch training jobs, distributed GPU clusters, and scheduler decisions. Load can jump or fall by many MW over seconds–minutes as jobs start or end. Key points:

- AI-optimised data centres are projected to more than quadruple their electricity demand by 2030, on top of conventional data centre growth.
- A recent technical analysis of AI data-centre impacts highlights "rapid and unpredictable ramping of AI data centre loads", which forces system operators to maintain higher spinning and non-spinning reserve margins and more fast-response capacity.
- Articles aimed at practitioners describe how synchronised GPU clusters can create "cliff-edge" drops or surges unless operators stagger workloads or reshape communication patterns.

Compared with a more constant "flat" hyperscale DC, a big AI hall can look to the grid like a very large industrial plant with poor ramp control.

6.2 Challenges for the grid (system operators & networks)

a) Higher reserve and ramping requirements
Since AI load can move quickly and is hard to forecast (non-cyclic, scheduler-driven), system operators need:

- More upward reserve -for sudden load *increases* when big training jobs kick off.
- More downward reserve -for sudden load *drops* when jobs end or are curtailed.
- Fast-ramping resources -engines, batteries, hydro, some gas turbines to follow those changes.

That raises operating costs (more plants kept part-loaded and synchronised) and can stress systems with already tight capacity margins—especially in regions where Data Centres are clustered on constrained grids.

b) Local network stress and voltage flicker
When a single campus is 100–500 MW and ramps by tens of MW, local networks may see:

- Thermal overloads on lines/transformers if ramps drive high peak flows.
- Voltage excursions if reactive power is not well managed.
- Need for more robust interconnection studies and possibly dedicated grid reinforcements (substations, lines), which can take many years.

c) Planning uncertainty
IEA and grid-planning reports emphasise that AI data centre build-out is happening quickly and often in clusters, but future utilisation and ramp patterns are hard to predict, complicating transmission planning and capacity markets.

6.3 Challenges for cogeneration plants serving AI data centres

If the data centre is partly or fully served by on-site CHP / CCHP, fast ramps create a different set of issues:

a) Prime-mover ramp capability and wear
Gas engines are actually very good at ramping:

- Typical modern engines can ramp >100% of rated load per minute when hot, with fast start times <2 minutes and minimum loads ~10% per unit (1% at plant level).

So technically, a well-sized engine plant can follow very steep AI ramps. But:

- Frequent large ramps and cycling increase thermal/mechanical stress, maintenance, and outage risk.
- Running engines far below their optimum (e.g. 20–30% load) reduces efficiency and can worsen emissions.

Gas turbines / combined cycle tends to be:

- Excellent at steady, high output,
- Less happy with frequent start–stop and deep cycling,
- And though modern aero-derivatives can ramp quite fast, the combined-cycle steam bottoming usually prefers slower changes.

Result: For a CCGT-style CHP plant supporting AI data centres, very spiky load profiles are undesirable unless there is a buffer (battery, grid export, flexible loads).

b) Part-load efficiency & heat balance
A CCHP plant is designed around a certain heat-to-power ratio and relatively stable output:

- If the data centre's electrical load dives but cooling demand remains high (e.g. GPU utilisation falls but ambient is hot), the plant may either:
    - Run engines/turbines at inefficient part load just to maintain thermal output; or
    - Hand more cooling back to electric chillers and ramp prime movers down, losing some of the CCHP efficiency benefit.
- If both IT and cooling loads ramp quickly, absorption chillers are slower to respond than electric chillers, so you need hybrid control to avoid comfort or IT temperature excursions.

c) Microgrid interactions (CHP + grid + BESS)
In a campus with both CHP and a grid connection:

- Fast load ramps can cause oscillation between importing and exporting unless control systems are carefully tuned.

- Keeping CHP at high, steady output and letting BESS + controllable IT loads absorb the swings often gives better economics and reliability than making the CHP chase every fluctuation. This aligns with practitioner advice to keep generators around 70–80% and shape load instead.

6.3.1 Thermal Flexibility and Buffering Strategies for Modern AI Data Centres

Most AI-oriented data centres experience rapid thermal swings due to GPUs shifting from idle to full load in seconds. While Section 6 focuses on electrical ramping challenges, CHP/CCHP systems must be evaluated equally on their thermal ramping behaviour. Unlike mechanical chillers, absorption chillers respond more slowly, making thermal buffering a critical design feature.

Hot-Water Thermal Buffers

Hot-water tanks (typically 20–200 m³ for enterprise sites; 500–3,000 m³ for hyperscale campuses) provide:

- 5–30 minutes of thermal "ride-through"
- Prevention of lithium-bromide (LiBr) chiller crystallisation
- Stable return-water temperature for engine heat recovery
- Reduced cycling stress on chillers and pumps

Example:

Arizona State University's HPC data centre uses a 12 MWh-thermal buffer to stabilise cooling loads during rapid GPU surges.

Reference: ASU Utilities & Energy Services (2022).

Chilled-Water Storage

Stratified chilled water tanks act as large thermal batteries, decoupling cooling production from cooling demand.

Benefits include:

- Absorption chillers can run continuously and efficiently
- Mechanical chillers avoid short cycling
- Supports high humidity markets (Asia, Middle East)

Example:

Jurong District Cooling (Singapore) operates >20,000 m³ chilled-water storage with trigeneration to manage extreme humidity and peak loads.

Reference: Keppel DCS (2023).

Phase-Change Thermal Storage (PCM)

PCMs with melting points of 10–14°C can absorb short-term thermal spikes at rack level.

Advantages:

- Smooths instantaneous IT heat load
- Reduces compressor use
- Allows CCHP systems to maintain stable low-lift operation

Reference: ASHRAE TC 9.9 (2023).

Absorption Chiller Ramp Behaviour

Absorption chillers operate best under steady loads. Typical ramp capability:

- 10–20% change per minute
- Minimum stable load ~30–40% of rated capacity
- Requires stable hot-water supply temperature

Thermal buffers and chilled water tanks eliminate the mismatch between fast IT thermal swings and slow chiller response.

So, it can be said that electrical flexibility manages power ramps; thermal buffering manages cooling ramps. For AI-class workloads, both are essential to make CCHP robust and responsive.

6.4 Mitigation strategies (from current practice & studies)

6.4.1 Grid-side & market tools

From IEA, EPRI DCFlex and grid-planning studies:

- Treat data centres as flexible loads, not just fixed demands:
  - DCFlex demos (e.g. Oracle Phoenix site) have shown 25% load reduction during peaks via demand response.
- Use time-of-use and flexibility markets so data centres are paid to ramp down during system stress, helping offset their contribution to reserve requirements.
- Encourage co-location with flexible generation (engines, hydro, BESS) and interconnection agreements that explicitly define ramp limits and response obligations.

6.4.2 Datacentre / software-level shaping

Several technical commentaries and operator case studies highlight:

- **Job scheduling & staggering**:
  - Avoid starting or stopping all large training jobs at once.
  - Stagger GPU synchronisation phases so not all accelerators ramp up/down simultaneously.
- **Smoothing the net load**:
  - Intentionally hold some background jobs as "fillers" to avoid full drop-off when big jobs end.
  - Use software-defined power caps and rate-limiters so IT load ramps at a controlled rate.

This makes the power seen by the grid or CHP plant much smoother, even if internally workloads are still very bursty.

6.4.3 On-site CHP + BESS + control

For a CHP-supplied AI data centre, recent report and studies such as from IEA, ACEEE, EPRI/DCFlex, DOE and OEMs point toward a hybrid architecture:

- Use fast-ramping gas engines as the primary on-site generation (possibly plus turbines for high baseload).
- Keep engines operating near optimal load (70–90%) to maximise efficiency and lifetime.
- Use battery storage for seconds–minutes ramps; use CHP load-following for slower ramps.
- Coordinate with grid import/export so that net injection respects agreed ramp limits and interconnection conditions.

This is very close to the "grid-to-chip" / BYOP&C architectures Vertiv + Caterpillar/Solar Turbines are now marketing: on-site engines and turbines, UPS/BESS, and advanced cooling managed as one integrated control system to handle both ramping and resilience.

7. Legislative Frameworks

EU legislation related to data centres and their energy consumption is rapidly evolving. The following highlights the current key regulations and expected legislation for 2026.

7.1 EU Legislation

7.1.1 Energy Efficiency Directive (EED)

There is no EU directive that applies exclusively to data centres, but the Energy Efficiency Directive contains important provisions applicable to data centres. The first iteration of the directive was adopted in November 2012 (Directive (EU) 2012/27/EU), while the new recast Energy Efficiency Directive (Directive (EU) 2023/1791) entered into force in October 2023.

The EED aims to ensure that the EU meets its greenhouse gas reduction and energy efficiency targets. The revised EED raises the EU energy efficiency target to a reduction in energy consumption of 11.7% by 2030 compared to projections of the expected 2030 energy use. Member States must set indicative national contributions to identify how they will contribute to reaching this target.

Under Article 12 of the Energy Efficiency Directive, data centre operators are obliged to monitor and report on the energy performance of data centres. Regardless of the transposition status of the EED, the reporting obligation is directly applicable in all Member States.

The European Commission adopted a new delegated regulation, (EU) 2024/1364 in March 2024, on the first phase for establishing and EU-wide scheme to rate the sustainability of EU data centres. This secondary legislation requires data centre operators to report key performance indicators (KPIs) to the European database on a yearly basis. The first reporting date was 15 September 2024, with the second reporting date set as 15 May 2025, and then by 15 May thereafter.

The new regulation is intended to increase transparency and potentially to promote new designs and efficiency developments in data centres that reduce energy and water consumption as well as promote use of renewable energy, increased grid efficiency, or the reuse of waste heat in nearby facilities and heat networks.

The delegated act outlines what information and KPIs should be reported as well as defines the first sustainability indicators that will be used for the rating of data centres. They will also be required to publish information on their energy performance and sustainability.

A European database overseen by the Commission collects and publishes data related to the energy performance and water consumption of data centres with a significant energy consumption. The Delegated Regulation (EU/2024/1364) sets out the information and key performance indicators to be reported.

The EED illustrates the transition the data centre industry is undergoing in terms of policy as this year, for the first time, data centre operators across the EU are required to report data related to their operations. Although this framework is European, the national transpositions will vary. As an example, Germany is imposing additional measures including minimum performance requirements and mandating waste heat recovery within data centres.

7.1.2 EU Climate Delegated Act

The EU Climate Delegated Act enshrines rules for classification of data centre-related activities with a view to climate change mitigation. It builds on the European Code of Conduct for Data Centres (EU DC CoC), a voluntary initiative set up by the Joint Research Centre (JRC) to encourage and guide data centre operators and owners in cost-effective reductions in energy consumption. Ambitious voluntary standards are set out which identify and focus on key issues and agreed solutions as outlined in the Best Practices document. This document includes the latest technology developments and is updated yearly.

The Best Practices document is accompanied by the Assessment Framework which is more requirement- driven and provides auditors with tools to assess if data centres apply the Practices correctly and enables market players to complete disclosures for Taxonomy alignment as part of their non-financial reporting.

More than 500 data centres have joined so far and those that can demonstrate a significant reduction in energy consumption are eligible for the annual EU Data Centres Code of Conduct Awards.

7.1.3 AI Act

The AI Act lays down harmonised rules on the development and use of AI in the EU. It imposes transparency requirements for General-Purpose AI Models which includes energy consumption reporting. The aim is to create standards focused on AI aimed, for example, at improving energy efficiency. It does not specifically include rules on data centres; however, it requires the EC and Member States to create voluntary codes of conduct on energy efficiency of data centres.

7.1.4 Strategic Roadmap for Digitalisation and AI in Energy

The Strategic roadmap for digitalisation and AI in energy is due for publication in early 2026 and was highlighted under Action 5 of the Affordable Energy Action Plan published in February 2025. The roadmap ails to accelerate the rollout of digital solutions such as AI in key areas of the decarbonisation process. These include electricity grid optimisation, energy efficiency in buildings as well as industry and demand-side flexibility.

Furthermore, it will consider the increasingly high energy consumption of data centres and look at how they can be more sustainably integrated into the energy system as well as the need to implement safeguards to mitigate potential challenges linked to large-scale deployment of AI solutions in the energy sector.

7.1.5 Data Centre Energy Efficiency Package

This package will be published together with the Strategic Roadmap in Q1 2026, though as yet further details have not been made available.

7.2 US Legislation

As in the European Union, the United States is rapidly developing policy and regulatory measures in response to the accelerating electricity demand of data centres, particularly those driven by AI workloads. Although the U.S. does not have a single dedicated federal law specifically regulating data-centre sustainability, a combination of federal agencies, congressional legislation, state level initiatives, and regulatory authorities (DOE, FERC, NERC) play central roles in shaping requirements related to energy consumption, grid integration, emissions, interconnection, and transparency.

The following sections outline the key U.S. regulatory frameworks relevant to energy, grid connections, heat recovery, and power system planning for data centres.

7.2.1 Federal Policy Landscape (DOE, CRS, White House)

There is growing federal attention on the electricity demand surge associated with AI and cloud data centres. In 2024–2025, the U.S. Department of Energy (DOE) issued multiple analyses warning that data centre demand could rise from approximately 4.4% of U.S. electricity in 2023 to between 6.7% and 12% by 2028. DOE emphasised the need for accelerated permitting, generation planning, transmission upgrades, and flexible load integration for data centres.

A 2024 Congressional Research Service (CRS) report similarly highlighted that U.S. data centre electricity demand is approximately 176 TWh in 2023 which is expected to double or triple by 2028, driven largely by AI GPUs and cloud growth. The report underscored policy gaps in energy-efficiency requirements, transparency, and long-term planning.

Federal-level actions in 2024–2025 have therefore focused on:

- Interconnection reform for large, fast-growing loads
- Grid reliability risks posed by AI clusters
- Preparatory studies for future energy-efficiency standards
- National monitoring of data-centre power trends

Although no exclusive national reporting scheme exists yet (unlike the EU's), several states and agencies have begun implementing elements of one.

7.2.2 FERC and NERC: Interconnection, Grid Reliability & Large Load Integration

In 2024–2025, the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC) started developing new rules and best practices tailored to large datacentre loads due to grid stress and reliability concerns.

Key measures under review include:

- Accelerated interconnection processes for large loads like those used for large generators
- Assessment of ramp-rate impacts from AI workloads on local reliability
- Requirements for load-modelling, including fast-ramping and demand-flexibility capabilities
- Consideration of on-site generation (including CHP/CCHP) as part of interconnection studies
- Guidance for co-located generation + data centre microgrids

These discussions highlight the shift toward treating large data centres not as ordinary commercial loads but as critical large-scale power entities requiring bespoke regulatory treatment.

7.2.3 State-Level Legislation: Emerging Mandatory Reporting

Because there is no single nationwide directive like the EU's EED, several U.S. states have introduced their own reporting and efficiency laws. Such as:

- New York – "New York State Sustainable Data Centres Act": They would limit new AI data centre builds unless they meet renewable-energy and reporting requirements

- Connecticut – "Senate Bill 1292": They propose energy and water-efficiency performance standards for AI data centres, including reporting of energy and water use.
- California – proposed "SB 57 and AB 222" bills to set special tariffs/zero-carbon targets for large consumers and to require reporting on energy used by AI systems.

7.2.4 DOE's Future of Resource Adequacy & National Grid Planning

DOE's 2024 "Future of Resource Adequacy" report explicitly identifies AI driven data centres as a new class of large, fast-growing, difficult to forecast loads. The report calls for:

- Flexible load integration, including load shifting, ramp-rate smoothing, and behind the meter resources such as CHP/CCHP
- High fidelity forecasting models for AI workloads
- Microgrid options for resilience and local grid relief
- Recognition of data centres as potential contributors to grid instability without proper planning

This establishes the first federal acknowledgement that data centres require special treatment in national electricity planning.

7.2.5 Federal and Industry Codes of Conduct (Voluntary Standards)

While not legally binding, U.S. operators often follow:

- ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) thermal guidelines for data centres
- Uptime Institute Tier Standards (Tier III & IV resiliency obligations)
- ENERGY STAR for Data Centres

These voluntary standards influence design and operations but do not impose sustainability KPIs like the EU's PUE/ERF reporting. Nonetheless, DOE and state agencies are considering the incorporation of such metrics into future mandatory frameworks.

7.3 UK Legislation

The UK does not yet have a single, data centre specific energy directive equivalent to the EU's EED, but data centres are increasingly being pulled into the UK's wider net-zero, planning, heat network and grid flexibility frameworks. In 2024 the UK had around 1.6 GW of data centre capacity, mostly in Greater London, and data centres have been formally recognised as Critical National Infrastructure (CNI). Their capacity is expected to rise to 3.3–6.3 GW by 2030, with electricity use and grid connection pressure rising accordingly.

7.3.1 Climate and Net-Zero Framework

Data centres sit under the UK's economy wide climate legislation:

- The Climate Change Act 2008, amended in 2019, makes net-zero greenhouse gas emissions by 2050 a legally binding target, implemented through five-year carbon budgets.
- The Net Zero Strategy and subsequent updates set out sectoral decarbonisation plans, electricity decarbonisation and electrification of heat are central pillars.

Recent analysis for the Department for Energy Security and Net Zero (DESNZ) on the "Impact of growth of data centres on energy consumption" stresses that data centres add new electricity demand but can also enable system-wide efficiency (e.g. dematerialisation, digital services). It highlights the need to integrate data centre growth with net-zero power system planning rather than treating them as isolated loads.

7.3.2 Planning System and NSIP Regime

Planning policy is being reshaped to treat major data centres as nationally significant infrastructure:

- Data centres have been designated Critical National Infrastructure, and the National Planning Policy Framework (NPPF) was updated in 2024 so that local planning authorities must "consider the need for data centres" and recognise their specific locational requirements in making plan and decisions.
- In October 2025 the government laid the Infrastructure Planning (Business or Commercial Projects) (Amendment) Regulations 2025, so that data centres become "prescribed projects" capable of being directed into the Nationally Significant Infrastructure Projects (NSIP) consenting regime under section 35 of the Planning Act 2008.

Under this regime, large, nationally important data centre projects in England can, on request, be decided by the Secretary of State rather than local planning authorities, with a single Development Consent Order (DCO) and statutory timescales. A dedicated National Policy Statement (NPS) for Data Centres is being prepared to set out the policy tests for NSIP-scale facilities, including sustainability, energy use and grid impacts.

For CHP/CCHP developers this means that very large campus style data centre and energy projects may be consented through the same national infrastructure regime as power stations, potentially allowing more integrated treatment of on-site generation, heat export and grid connection.

7.3.3 Heat Networks, Waste Heat Reuse and Zoning

The UK is moving toward a regulated heat network sector in which data centre waste heat is explicitly recognised as a strategic low-carbon source:

- The Energy Act 2023 creates a regulatory framework for heat networks and powers to designate Heat Network Zones (HNZs) in England (and equivalent powers for technical standards GB-wide). Within these zones, new buildings and some existing buildings will be required to connect to a heat network, and low-carbon heat sources (including data centres) can be mandated or strongly incentivised to supply heat.
- Government and industry guidance on heat networks explicitly lists waste heat from data centres as a target source for zoning and network design.

Policy is already being backed by funding:

- The Green Heat Network Fund (GHNF) has awarded £36 million to the Old Oak and Park Royal Development Corporation (OPDC) in West London to build a low-carbon heat network that captures waste heat from several local data centres, supplying heat to over 10,000 homes and 250,000 m² of commercial space (including Central Middlesex Hospital).

In recent Lords debates on infrastructure planning, ministers acknowledged that data centres produce significant recoverable heat and stated that current policy is to encourage heat capture and use in district heating networks, while leaving open the possibility of stronger future interventions as heat network zoning and technical standards mature.

Taken together, the Energy Act 2023 and GHNF and zoning pilots create a regulatory pathway by which data centre developers in designated zones may in future be expected or required to connect to heat networks and supply waste heat which is directly relevant for CHP/CCHP and heat pump-based schemes.

7.3.4 Grid Connections, Flexibility and AI Growth Zones

Rapid AI-driven growth has brought grid connection and ramp rate issues to the forefront in Britain:

- The government's "Data Centres: Planning Policy, Sustainability and Resilience" paper notes that UK data centres already use around 2.5 % of UK electricity, with demand potentially quadrupling by 2030, and highlights grid connection delays as a major constraint.
- Ofgem and the National Energy System Operator (NESO) are reforming the demand connection queue, with updated guidance and calls for input aimed at tackling long lead times for large loads such as data centres and aligning them with wider grid reinforcement plans.
- The joint Clean Flexibility Roadmap from government, Ofgem and NESO sets out a programme to scale demand side flexibility, explicitly identifying large flexible loads (including data centres) as key participants in future flexibility markets.

Alongside these system wide measures, the UK has launched AI Growth Zones to cluster AI-intensive data centre projects in areas where power can be delivered more quickly. Government guidance suggests these interventions could reduce time to power by up to five years for a 500 MW data centre and significantly cut electricity costs.

For CHP/CCHP developers, this evolving framework means:

- More scope to propose on site or nearby generation and cogeneration as part of AI Growth Zone or NSIP-scale developments
- Increasing regulatory emphasis on flexibility and demand response, where CHP plants with thermal storage and backup capability can provide ramp rate support, reserve and black start type services to the electricity system
- Growing expectation, particularly in heat network zones, that waste heat is utilised rather than rejected.

8. Fuel Supply Options

Executive view (what's prudent to plan for)

- Methane pathway (natural gas → biomethane → e-methane) is the most straightforward transition for engine/turbine CHP because it reuses today's gas assets (pipelines, meters, burners) with minimal hardware change. Near term: pipeline natural gas; by 2030s in Europe: biomethane share rises materially; by 2040s: e-methane is technically viable, but cost and volumes are uncertain.
- Hydrogen (H_2) is technically proven for both engines and gas turbines (up to 100% H_2 on some models), but network rules, costs and volumes will govern pace. Anticipate H_2 blends (≤20% vol.) where policy allows in the 2030s, with dedicated H_2 supply only at select campuses or industrial clusters.
- Drop-in liquids (HVO for backup diesels) and CCS-coupled methane are credible risk-mitigations where gas/H_2 timing is uncertain; ammonia/methanol are maturing mainly in marine/industrial use and are unlikely first-choice Data Centre fuels due to toxicity/NO_x and site safety complexity.

8.1 Methane family: natural gas → biomethane (RNG) → e-methane (synthetic methane)

Supply scale & policy trajectory

- **Biomethane (EU):** The EU has set a target of 35 bcm/yr by 2030 (≈ one-tenth of today's EU gas demand). Studies show technical potential up to ~41 bcm by 2030 and >100 bcm by 2050 with AD + gasification build-out. This underwrites increasing green-gas shares on existing networks.
- **RNG (US):** Rapid scale-up—>400 facilities operating in 2024, ~130 under construction, ~233 planned; policy drivers include LCFS/RFS. This matters for multi-region operators and certificate markets.
- **e-methane:** Japan and the EU are building early supply chains (imports to Japan from 2030; 35 operating EU plants and 20 in planning as of 2024), but current costs are high (order-of-magnitude $50–200/MMBtu), implying selective early adoption before 2040.

Equipment readiness (engines/turbines)

- **Engines/turbines** need little/no hardware change moving from fossil methane to biomethane—the molecule is the same (CH_4). For e-methane, likewise. (Combustion tuning may change slightly for Wobbe index/trace components).
- OEMs position H_2 ready engines while affirming RNG/e-methane drop-in compatibility for current fleets. (Jenbacher data centre pages, Wärtsilä literature).

Carbon & reporting

- Biomethane's lifecycle CO_2 e depends on feedstock and avoided methane emissions; many pathways qualify as low/negative carbon intensity, which helps ERF/ERE and customer ESG. EU policy recognises biomethane and is advancing certificate frameworks.

Commercial notes

- **Contracts:** Standard gas supply with book and claim biomethane certificates (EU Guarantees/registries; US RINs/LCFS) lets you green the gas ahead of physical offtake.
- **Risk:** Biomethane price premia vs fossil gas; volume risk early on (hedge with a graduated offtake). For e-methane, treat 2030s as pilot/optionality, not base fuel, given costs.

Implication for Data Centre-CHP:

- Near term, methane fuels de-risk deployments (fastest path to power).
- 2030s: blend biomethane to lower scope-1; consider heat export to raise ERF/ERE.
- 2040s: e-methane can "backstop" net-zero strategies if costs fall and certificate rules mature.

8.2 Hydrogen (H_2): blends → dedicated supply

Technical readiness (prime movers)

- **Gas turbines:** GE Vernova documents operating experience on hydrogen blends up to 100% across 120+ units with 10M+ hrs; new H-class turbines are 50% H_2 capable today with a pathway to 100%. The HyFlexPower project demonstrated 100% renewable H_2 in a 12-MW industrial gas turbine in 2023.
- **Engines:** INNIO Jenbacher offers upgrades to accept up to 25% vol. H_2 in pipeline gas and 100% H_2 Type-4 engines for new builds, with dedicated packages aimed at data-centre power.

Networks & regulation (Europe/UK snapshot)

- **EU:** The Hydrogen & Decarbonised Gas Market Package (2024) creates EU-wide market rules and allows repurposing gas assets for H_2, but cross-border hydrogen quality/acceptance still needs harmonisation. Expect dedicated H_2 networks to grow where industrial clusters justify it.
- **UK:** Current GS(M)R limit is ~0.1% H_2 on the transmission system; government supports up to 20% by volume blending on distribution networks and is consulting on transmission-level options and value for money (2025). Translation: system-wide H_2 blends are not yet available for most large sites, but policy is evolving.

Costs & volumes

- **IEA 2024–2025:** Electrolyser capacity is expanding but utilisation and FIDs lag; the IEA cut its 2030 low-emissions H_2 outlook by ~25% after cancellations. Expect uneven regional supply and premium pricing through the 2030s, improving with auctions and local RES build.

Integration considerations

- **Derating & NO_x:** Moving to high-% H_2 typically requires dry-low-NO_x combustors and/or SCR, with derating on some machines; dedicate time for burner change-outs and safety (leak detection, hazardous area zoning). OEM data and pilots (GE/HyFlex) confirm feasibility.
- **On-site logistics:** Tube trailers/liquid H_2 are possible but have space/safety implications. Where available, cluster pipelines are the efficient route.

Implication for DC-CHP

- **Blended H_2**: treat as incremental decarbonisation where allowed (engines/turbines validated).
- **100% H_2**: viable at select campuses (e.g., collocated with H_2 production/cluster pipelines), not universal in the 2030s. To plan a fuel-flex specification (methane today; H_2 ready kit; space for skid upgrades).

8.3 CCS-coupled methane (blue pathway)

- Japan's gas sector now allows natural gas with CCS to count within its 2050 net-zero plan (flexible mix alongside e-methane/biogas), reflecting practical constraints on e-fuels scale/cost. Where geology and hubs exist, CCS + CHP can materially cut scope-1/2 emissions.
- **What it means for data centres:** Feasible at campus-plus-district-energy hubs tied to CCS clusters; otherwise consider book-and-claim for captured CO_2 credits attached to purchased gas or power.

8.4 "Other" fuels (role for data centres)

- **Ammonia/methanol:** Active pilots in marine; ammonia engines entering service mid-2020s. For data centres: safety (toxicity), NO_x, and storage make these unlikely near-term choices versus methane/H_2.
- **HVO for backup:** As a drop-in for diesel gensets, HVO reduces lifecycle CO_2 and improves local air quality; useful where we retain emergency diesels in Tier IV designs.

8.5 How this fits Data Centre buildouts and OPEX

Scenario 1 — Methane-first with green ramp

- **2025–2030:** Commissioning CHP on pipeline natural gas; contracting biomethane certificates; implementing heat-to-cool (absorption) + DH export where possible to lift ERF/ERE.
- **2030–2040:** Blending physical biomethane as volumes materialise (EU 35 bcm target); keeping certificate ladder; considering pilot e-methane contracts for a fraction of load.
- **2040–2050:** Increasing e-methane share if costs fall; maintaining drop-in compatibility—engines/turbines unchanged.

Scenario 2 — H_2 ready campus

- Spec engines/turbines with H_2 ready packages; to operate on methane now.
- When policy/grid allow, to accept H_2 blends (≤20% vol.) via networks; for select campuses near H_2 clusters, we should plan dedicated H_2 (skids, safety, burners) in the 2030s.
- **Controls:** To anticipate NO_x compliance (DLN/SCR) and derating curves; to budget for change-outs. (GE/Jenbacher documentation and HyFlexPower results).

8.6 Biomethane Valuation and Certification Challenges

Biomethane is a key decarbonisation pathway for CHP, yet its climate valuation is inconsistent across global frameworks.

1. Divergent Carbon-Intensity Methodologies

- UNFCCC / IPCC count only direct combustion emissions unless lifecycle data is provided.
- EU RED II / Guarantees of Origin (GOs) treat biomethane as low carbon based on verified feedstock.
- SBTi restricts market-based instruments and often does not allow biomethane credits unless physical pipeline delivery is proven.
- US RFS2 (EPA) allocates RIN credits based on lifecycle emissions, meaning biomethane from landfill gas can score significantly better economically.

This produces carbon intensity values ranging from 0–40 gCO_2e/MJ (EU) to >50 gCO_2e/MJ (SBTi) for the same fuel.

2. Impact on Data-Centre Investment

Conflicting valuation frameworks affect:

- Corporate carbon accounting
- Feasibility of RNG-powered CHP
- Payback periods
- Energy-as-a-service contracts
- Long-term net-zero commitments

3. Examples

- **Denmark & Germany**: Biomethane widely used in large CCHP installations due to RED II compliance.
- **California**: RNG projects supported by LCFS credits significantly reduce operating cost of CHP.
- **Ireland**: SBTi corporate members (tech sector) cannot rely on GOs for Scope-1 reductions, complicating RNG adoption.

4. Implications for CHP

Biomethane is attractive for CCHP, but its value depends entirely on the accounting regime a data-centre operator must report under.

9. Third Party Heat Offtakes

9.1 Can data centre servers provide usable heat?

Yes — data centre servers produce large, continuous, high-quality waste heat, typically:

- 30–60°C supply temperature for air-cooled data centres
- 40–70°C for liquid-cooled racks (direct-to-chip, rear-door cooling)
- Up to 60–80°C for immersion-cooled or high-density AI racks

This heat is valuable because it is:

- 24/7, flat profile (unlike industrial process cycles)
- Predictable
- High exergy relative to typical low-grade waste heat in buildings

However: To be fed into most district heating networks, heat must be boosted to 65–90°C. This is where large heat pumps, CHP exhaust, or hybrid systems become relevant.

Evidence (from sources):

- **HEATNET DATA CENTRE Workshop (06 October 2025):**
  - Data centre waste heat is viable and increasingly sought by utilities.
  - Liquid cooling sharply improves heat capture efficiency and temperature lift (COP 4–5).
  - Multiple case studies (Helsinki, Stockholm, Lund) prove data centre heat can operate as baseload for district heat.
- **EU Directive (2023/1791) & 2024 Delegated Regulation:**
  - Data centres must report waste-heat temperature & availability; encourages energy-reuse factors (ERF/ERE).
- **Stockholm Exergy – Open District Heating:**
  - DATA CENTREs are major contributors; DH network scale > 3,000 km.
- **Helen–Telia (Helsinki):**
  - Heat from one data centre now supports 14,000 flats, showing large-scale feasibility.

9.2 How heat-offtake interacts with CHP/CCHP supply pathways

A) Heat-offtake improves the business case for CHP

CHP/CCHP generates:

- Electricity for the data centres
- High-grade heat (exhaust/steam/hot water)
- Cooling (through absorption chillers)

Data centres produce:

- Long-duration, moderate-temperature heat (~30–60°C)
- This is ideal for pre-heating district return lines, reducing lifting work for the DH heat pump.

Combined benefit: CHP + data centre heat export = Hybrid Thermal Hub

Thermal source	Temperature	Uses	Benefit
CHP exhaust heat	120–500°C	Absorption cooling OR DH via heat pump	Highest-grade heat for cooling or DH
CHP jacket heat	70–95°C	DH preheat, absorption	Useful without major lift
DC server waste heat	30–60°C	DH via heat pump	Large baseload volume increases utilisation

Why CHP improves data centre heat-offtake economics?

- A district heating operator prefers continuous baseload → data centre heat is flat 24/7.
- But district networks need higher temperatures (70–95°C).
- If a CHP is onsite, its waste heat + district heat pump can combine to meet DH temperature levels efficiently.

So even if data centre heat alone is modest grade, CHP heat (especially turbine exhaust) can be blended to supply higher-temperature DH demand.

This hybridisation:

- Provides guaranteed minimum temperature
- Allows the DH operator to take more volume
- Increases CHP heat utilisation, improving ERF/ERE
- Reduces CHP curtailment risk

CHP and data centre heat act as complements

Server heat is:

- Lower grade, high volume

CHP heat is:

- High grade, flexible

Together they make a stable, attractive supply profile for a DH network.

9.3 Feasibility of exporting heat (technical and economic)

A) Technical feasibility — high

Real-world projects demonstrate:

- **Helsinki (Telia × Helen):** DC → heat pump → DH → 14,000 flats
- **Equinix PA10 (Paris) Heat Export to Olympic Facilities and Eco-District:** Equinix's PA10 data centre in Paris delivers up to 12 thermal MW of recovered waste heat to local buildings and

public infrastructure. Through a dedicated heat interface, the warm-water loop from IT equipment is connected to Paris' district heating system. The system supplies heat to nearby residential buildings and was also used to warm two Olympic swimming pools for the Paris 2024 Games.

Technically significant features include:

a. Stable 30–35°C server-outlet temperatures providing an excellent baseload for district-return preheat.
b. Heat pumps raising temperatures to ~65°C for DH network injection.
c. Integration of heat meters (EN 1434), ΔT-controlled pumps, and SCADA link with the DH operator.
d. High operating hours (>8000 h/year) providing strong heat-revenue potential.
e. Demonstrates regulatory alignment with EU EED 2023/1791 and future sustainability rating frameworks.

Figure 3: Olympic swimming pool warmed by data centre waste heat in Paris, 2024

- **Stockholm Exergi:** Multiple data centres exporting heat; scalable commercial model
- **Lund, Sweden:** data centre heat + 5th-generation DH network
- **London (Eonecto):** Sub-80°C networks integrate data centre heat efficiently

Temperatures & lifting:

- Air-cooled data centres: 25–35°C exhaust air → best for low-temp (5G) DH
- Liquid-cooled data centres: 40–60°C → compatible with district preheat loops
- CHP exhaust: 120–500°C → absorption chillers, steam, or DH injection
- Heat pumps: COP 4–5 when boosting from 30–40°C to 70–85°C (HEATNET evidence)

Therefore, combined CHP + DC heat → district heat pump is highly feasible and energy efficient.

B) Economic feasibility — medium to high

Heat-reuse success depends on:

- Scale of DH network
- Proximity (≤1–3 km preferred)
- Contract structure (volume guarantee, availability, €/MWh price)

Stockholm examples show heat-export revenues in the range of €20–40/MWh (market dependent).
For a 10 MW data centre exporting 7–8 thermal MW average:

- Annual heat exported ≈ 60–70 GWh
- Heat revenue ≈ €1.5–3 million/year
- Heat pump OPEX included, still positive margin

9.4 Does data centre heat-offtake help CHP supply

- Ensures year-round heat sink, allowing CHP to run more hours
- Enables higher total efficiency (70–85%+)
- Improves CHP project IRR by monetising heat
- Enhances PUE/ERF/ERE metrics required by EU KPIs
- Supports planning consent (local councils favour heat reuse)
- Makes data centre campuses anchor heat sources for urban DH expansion
- CHP does not *need* data centre heat, but data centre heat makes CHP more flexible
- District heating systems prefer higher-grade heat → data centre heat alone is often too cool → CHP heat complements it
- Without a DH network, data centre heat reuse is limited to internal uses (e.g., office heating, hot water), which is small compared to data centre cooling load

Heat offtakes DO NOT help CHP when:

- No DH network exists
- No space for heat pumps/piping
- Local regulation restricts heat monetisation
- Data centre temperature too low without viable lift (rare for liquid-cooled AI racks)

9.5 Third-party heat-offtake technical considerations

When exporting to district heating or industrial off takers, several technical aspects matter:
1) Temperature and thermal quality

- DH operators require:
    - 65–95°C supply

- 30–50°C return

- Data Centre + CHP supply must meet this envelope
- Large heat pumps raise server heat and/or CHP jacket heat to DH temperature

2) Flow rates and hydraulic balancing

District Heating networks expect stable flows:

- DATA centres generate constant heat → excellent baseload
- Integration requires:
    - Primary/secondary loop separation
    - Variable speed pumps
    - Plate heat exchangers
    - ΔT control (strict return temperatures)

3) Reliability & availability

District heating companies demand:

- High availability (95–98%)
- Flexible turn-down ratios
- Redundancy (N+1 heat pumps)
  This fits DC cooling operations well.

4) Controls & interoperability

- SCADA integration
- Heat meters certified to EN 1434
- Temperature control loops
- Real-time data exchange

5) Water quality and corrosion

- DH networks require specific water chemistry
- DC/CHP loops must be isolated through plate heat exchangers

6) Space & routing

- Space for:
    - Heat pump skid
    - Buffer tank
    - HX station
    - DH substation
- Routing for:
    - DH supply/return mains
    - Underground pipe corridor

7) Pressure levels

- DH networks operate at 6–16 bar
- DC cooling loops operate at much lower pressures → again require isolation

8) Noise, vibration, and permitting

- Heat pumps and CHP engines require noise controls
- Planning approval often accelerated if the DC provides community heat benefit

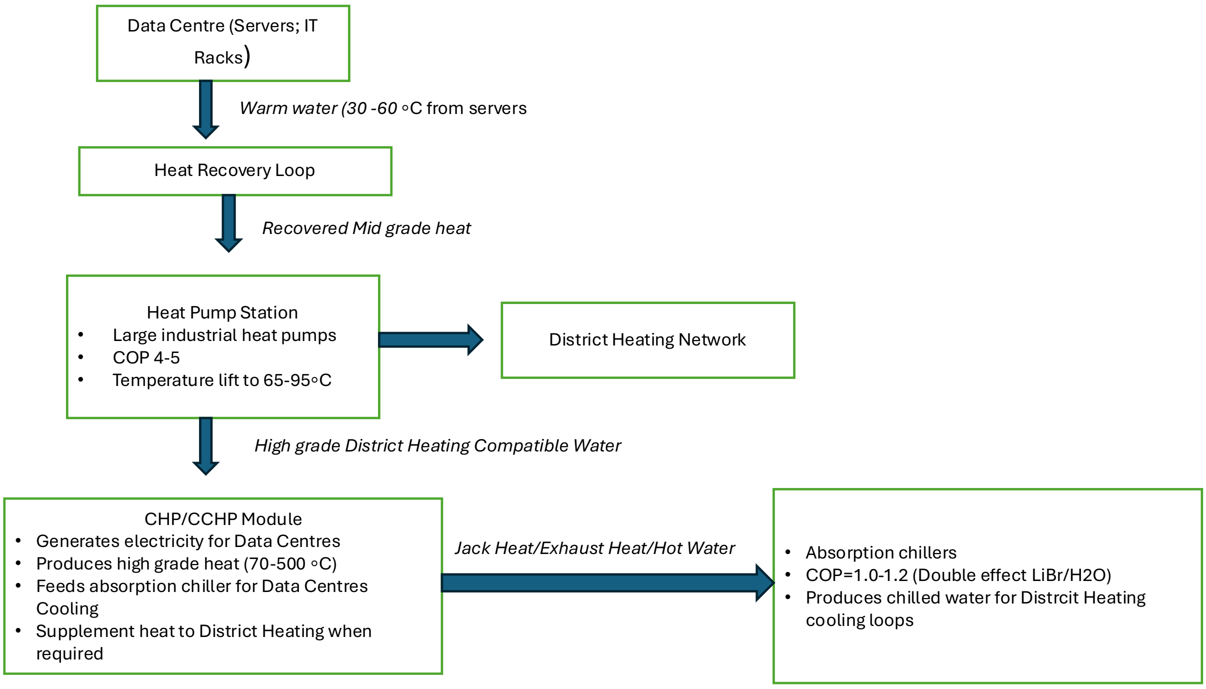
9) Business model

- Fixed + variable heat purchase contracts
- Take-or-pay clauses
- Availability payments for stability
- Clear SLA on delivery temperature

9.6 Overall feasibility statement

- Data centre waste heat is highly feasible for recovery—especially as liquid cooling grows (AI racks).
- CHP/CCHP and DC heat are complementary: CHP provides high-grade heat; DC provides constant baseload heat.
- CHP becomes more bankable when a district heat offtake exists because utilisation rises.
- Heat pumps are the enabler: they lift server heat and CHP jacket heat to DH temperatures efficiently (COP 4–5).
- Third-party integration is straightforward when hydraulic, thermal, and control interfaces are properly engineered.
- Heat export provides revenue, ESG value, and regulatory compliance (ERF/ERE).

Figure 4: CHP + Heat Pump + Data Centre Server Heat Export Architecture



10. Glossary

Term / Short Form	Full Form	Meaning / Simple Explanation
CHP	Combined Heat and Power	Plant that makes electricity and useful heat from one fuel.
CCHP / Trigeneration	Combined Cooling, Heat and Power	CHP where recovered heat also drives chillers to provide cooling.
GT	Gas Turbine	Turbine driven by hot combustion gases; used for larger power blocks.
ST	Steam Turbine	Turbine driven by steam, often from recovered exhaust heat.
ICE	Internal Combustion Engine	Reciprocating gas engine used as modular CHP prime mover.
HRSG	Heat Recovery Steam Generator	Boiler that turns GT exhaust into steam for a steam turbine or heating.
ORC	Organic Rankine Cycle	Uses an organic fluid to generate power from low/medium-temperature heat.
CCGT	Combined-Cycle Gas Turbine	Gas turbine + HRSG + steam turbine for very high electrical efficiency.
PUE	Power Usage Effectiveness	Total facility power ÷ IT equipment power (lower = more efficient).
ERF	Energy Reuse Factor	Fraction of total energy that is reused (e.g. exported heat).
ERE	Energy Reuse Effectiveness	PUE adjusted for energy reuse; rewards heat export.
WUE	Water Usage Effectiveness	Water consumption per unit of IT energy delivered.
CER / CUE	Carbon Emission Ratio / Carbon Usage Effectiveness	Carbon emissions per unit of IT energy delivered.
REF	Renewable Energy Factor	Share of energy coming from renewable sources.
CFE (24/7 CFE)	Carbon-Free Energy	Share of hours where load is matched with zero-carbon power.
UPS	Uninterruptible Power Supply	Battery/flywheel system that protects IT load during power disturbances.
STS	Static Transfer Switch	Electronic switch that transfers load between sources in milliseconds.
BESS	Battery Energy Storage System	Large battery system for backup, peak-shaving or grid services.
EPC	Engineering, Procurement & Construction	Turnkey contractor delivering design, equipment and construction.
OEM	Original Equipment Manufacturer	Company that manufactures engines, turbines, chillers, etc.
ESCO / EaaS	Energy Service Company / Energy-as-a-Service	Third party finances, owns and operates energy plant and sells energy as a service.
DH / 3G–5G DH	District Heating (3rd–5th Generation)	Piped hot-water networks; 5G uses lower temperatures suitable for DC waste heat.
DH Substation	–	Local interface (heat exchangers, pumps, meters) between a site and the DH network.
HX / HEX	Heat Exchanger	Device transferring heat between fluids without mixing them.
Tier III	–	Uptime classification: concurrently maintainable facility (N+1).

Tier IV	–	Uptime classification: fault-tolerant facility (typically 2N or 2N+1).
N / N+1 / 2N	Capacity / Redundancy Notation	N = required capacity; N+1 = one spare; 2N = two full independent systems.
Thermal Lift	–	Temperature increase that a heat pump must provide (e.g. 35°C → 75°C).
ΔT / Del T	Delta-T	Difference between supply and return temperature in a loop.
ITEU	IT Equipment Utilisation	How much of the IT hardware capacity is actually used.
ITEE	IT Equipment Energy Efficiency	Efficiency of IT hardware in turning electricity into useful computation.
H_2-ready	Hydrogen-Ready	Engine/turbine designed to run on hydrogen blends (and sometimes 100% H_2) in future.
RNG	Renewable Natural Gas	Biomethane upgraded to pipeline quality; drop-in replacement for natural gas.
e-methane	Synthetic Methane	Methane produced from green hydrogen + captured CO_2; behaves like normal gas.
HVO	Hydrotreated Vegetable Oil	Low-carbon diesel substitute used as drop-in fuel for backup gensets.
CCS	Carbon Capture and Storage	Capturing CO_2 from flue gas and storing it (e.g. in geological formations).
CCS-coupled methane	–	Natural gas use where associated CO_2 is captured and stored via CCS.
SCR	Selective Catalytic Reduction	Catalyst + reagent system to cut NO_x emissions from engines/turbines.
DOE/EPA catalogues	US Dept. of Energy / Environmental Protection Agency Technology Catalogues	Official US reference docs giving typical performance, emissions and costs for CHP technologies.
bcm	Billion Cubic Metres	Volume unit used for gas (e.g. biomethane potential in Europe).
AD + gasification	Anaerobic Digestion + Gasification	Two processes for making biogas/syngas which can then be upgraded to biomethane/RNG.
US RINs / LCFS	Renewable Identification Numbers / Low Carbon Fuel Standard	US policy instruments that give credits for low-carbon fuels like RNG.
GS(M)R limit	Gas Safety (Management) Regulations Limit	Legal limit (in GB) on hydrogen content in the gas network (very low today, proposals up to ~20% vol on distribution).
FID	Final Investment Decision	Point where a project is formally committed and capex is authorised.
IRR	Internal Rate of Return	Discount rate at which a project's net present value becomes zero (key finance metric).
GWh / MW / MWth / TWh	Gigawatt-hour / Megawatt / Megawatt-thermal / Terawatt-hour	Standard units for electrical energy, electrical power, heat power and large-scale energy.
Heat-offtake	–	Agreement and infrastructure to export waste heat from a site (e.g. DC) to a third party such as a DH network.
Base load	–	The minimum continuous load that runs 24/7; DCs typically have high baseload.

Flexibility (Grid Flex)	–	Ability to ramp up/down or shift load/generation to support the grid.
EN 50600	–	European data-centre standard defining KPIs like PUE, ERF, WUE, etc.
EED	Energy Efficiency Directive	EU directive requiring DCs above a threshold to report KPIs and heat-reuse info.
DCFlex	Data Centre Flexibility Initiative	EPRI program showing how DCs can provide grid services and flexibility.
EPRI	Electric Power Research Institute	Non-profit research organisation; runs DC-related grid and flexibility studies.
CIBSE	Chartered Institution of Building Services Engineers	UK professional body that publishes design guides (e.g. for absorption cooling).
Heat Pump COP	–	COP of heat pumps; in DC heat-reuse cases often around 4–5 when boosting to DH temps.
EN 1434	–	European standard for heat meters used in district heating/cooling billing.
DX	Direct Expansion (cooling)	Cooling where refrigerant directly expands in coils (no separate chilled-water loop).
SLA	Service Level Agreement	Contractual performance/availability commitment between operator and customer.
Black-start	–	Ability of a power plant to start up without external grid supply.
ACEEE	American Council for an Energy-Efficient Economy	US NGO producing analysis on energy efficiency, including data-centre impacts.

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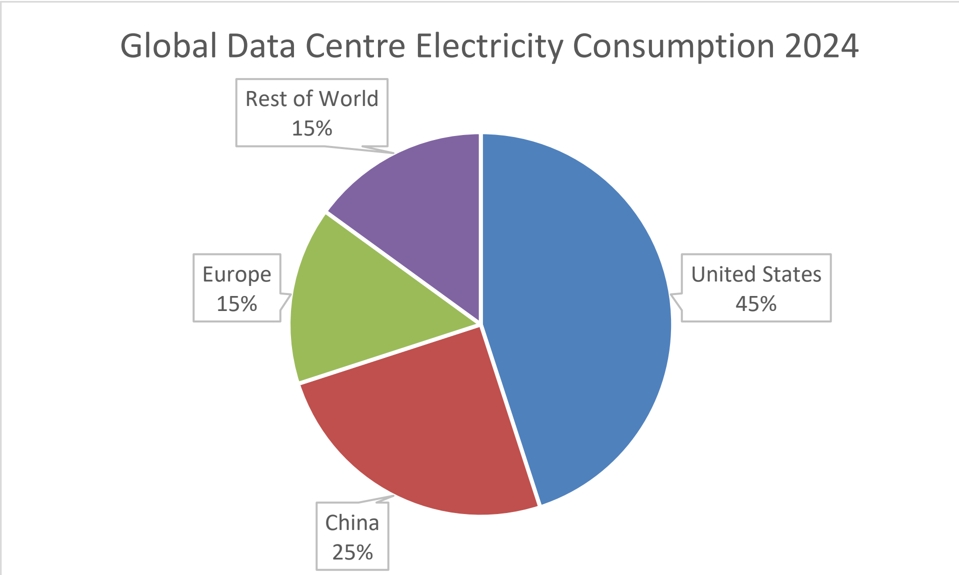
ANNEX 1: Summary of IEA Report Findings

How big is AI data-centre electricity use today?

- Data centres used ~415 TWh in 2024 – about 1.5% of global electricity demand, growing ~12% per year since 2017 (4× faster than total electricity demand).
- The load is highly concentrated:



  - In some systems, data centres already dominate: Ireland ~20% of metered electricity; six US states >10%, Virginia ~25%.
- A "typical" hyperscale AI data centre is ~100 MW, using as much electricity as ~100,000 households; the largest under construction could equal 2 million households.

Outlook to 2030–2035: scenarios and uncertainty

The IEA builds a new global data-centre model with four cases.

- **Base Case:** data-centre electricity more than doubles to ~945 TWh in 2030.
- **Lift-Off Case (strong AI uptake):** >1,260 TWh in 2030.
- **High-Efficiency Case:** ~800 TWh in 2030 (aggressive hardware + software efficiency).
- **Headwinds Case:** ~670 TWh in 2030 (constraints on build-out, grid and supply-chain bottlenecks).
- By 2035, the range across cases widens to ~700–1,720 TWh, showing very high uncertainty.

Fuel mix implications:

- In the Base Case, natural-gas generation for data centres rises by ~175 TWh to 2035, and by ~290 TWh in the Lift-Off Case, mostly in the US.
- Renewables provide the largest incremental supply, rising by ~450 TWh to 2035 because of their cost, speed of deployment and corporate PPAs; nuclear also contributes.

The report stresses that all historical global DC numbers are modelled estimates, not direct measurements, and that published 2030 projections vary by a factor of seven because of inconsistent definitions and assumptions (e.g. IT vs design capacity, PUE, server utilisation).

Energy use of AI models: training vs inference

- A modern frontier model (example: GPT-4) was trained on ~25,000 GPUs with ~10 MW GPU power, ~22 MW total including other IT and cooling, operating for ~14 weeks.
- IEA estimates cumulative training electricity for 283 large AI models since 2020 at ~1.7 TWh, with the largest single model ~154 MW training power and ~310 GWh for one training run. This is ~0.1% of all data-centre electricity in that period – i.e. training is visible but much smaller than ongoing inference and other workloads.
- In controlled tests, one LLM query for text uses ~2 Wh, large "reasoning" models use at least twice that, and generating a short video is roughly 25× more energy-intensive than a text response.
- A heuristic "100 TWh of AI inference" example: that energy could produce ~4,250 trillion words of text, ~55 trillion images, or ~950 million hours of video, illustrating how large service volumes can correspond to hundreds of terawatt-hours.

Local system impacts and heat-recovery potential

- Because data centres cluster around cities and fibre routes, local grid impacts are much larger than the 1.5% global share suggests, driving congestion and connection-queue issues. Around 20% of projected additions to 2030 in the Base Case risk delay without faster permitting and grid upgrades.
- On waste heat, IEA's geospatial assessment finds that even in a "strong coupling" scenario, global DC waste heat is far smaller than total building heat demand. In Europe, space-heating demand is >9× global data-centre waste heat. Still, around 10% of European building heat demand lies within 5 km of a DC on a district-heating network, and connecting suitable sites could avoid ~5 $MtCO_2$/year – a niche but meaningful decarbonisation option.

"AI for energy": optimisation, savings and emissions

The report introduces a **"Widespread Adoption Case"** that scales up only already-proven AI applications (no speculative breakthroughs) across the energy system to 2035.

Key quantified impacts:

- **Industry:** AI-optimised process control in heavy and light industry could save ~8 EJ (Exajoule) of energy by 2035 (≈ total current energy use of Mexico), including ~3 EJ in energy-intensive sectors like steel and cement, and ~5.2 EJ in lighter industries, cutting industrial electricity demand by ~700 TWh. Case studies show 2–6% energy savings per plant (e.g. ArcelorMittal steel plants, Heidelberg Materials cement plant in Czechia).
- **Buildings:** With current digitalisation trends, AI controls for HVAC and demand response could save >300 TWh of electricity in 2035 (~5% of global electricity for heating and cooling) and provide ~400 GW of flexible load, or ~10% of peak demand; the technical potential rises to nearly 500 TWh savings and 700 GW flexibility with full digitalisation.
- **Transport:** AI-enabled eco-driving, routing, logistics and autonomy could reduce road passenger-transport energy by ~1.5 EJ (over 3% of demand) and road freight by >1.5 EJ (≈4%) in 2035; the report notes real-world cases of 5–20% fuel savings for fleets and up to 20% for autonomous or optimised vehicles.
- **Power systems:** AI for power-plant optimisation and predictive maintenance could yield up to USD 110 billion/year fuel and O&M savings by 2035, and AI-enhanced grid operation could unlock up to 175 GW of extra transmission capacity without new lines, mainly by better thermal rating and congestion management.

Aggregated across sectors, widespread adoption of existing AI applications could reduce end-use CO_2 emissions by ~1.4 Gt in 2035—about three times the data-centre emissions in the Lift-Off Case—though the report cautions that rebound effects and current slow uptake mean this potential will not be realised automatically.

Overall message

- AI is both a rapidly growing source of electricity demand (especially via data centres) and a powerful tool to improve energy efficiency, flexibility and system planning.
- The IEA stresses massive uncertainty in future data-centre loads and AI service growth, plus the need for better data, harmonised methods and close coordination between tech firms, utilities and policymakers to ensure that power systems, generation (including CHP/CCHP) and networks are ready.

ANNEX 2: Example of Hybrid ON-Site Power and CCHP for AI Data Centres

Vertiv and Caterpillar (including Solar Turbines) have announced a strategic collaboration to deliver pre-engineered, on-site energy architectures for AI-scale data centres.

The solution is marketed as:

- Bring Your Own Power & Cooling (BYOP&C)
- A fully integrated, "grid-to-chip" architecture that combines:
  - Natural gas reciprocating engines
  - Natural gas turbines (Solar Turbines)
  - CCHP (Combined Cooling, Heat and Power) – i.e. power + heat + cooling
  - Vertiv UPS, switchgear, power distribution, BESS and thermal management

Key technical and commercial points:

- **Combining engines and turbines**
  - The reference architectures explicitly combine gas engines + gas turbines in the *same* solution to provide dependable, scalable on-site power plus thermal energy for CCHP.
- **CCHP and efficiency**
  - Waste heat from engines/turbines is used for combined cooling, heat and power, targeting lower PUE and better overall efficiency.
  - The focus is specifically on AI data centres, where cooling and power density are very high.
- **Pre-designed, modular reference architectures**
  - Vertiv + Caterpillar/Solar emphasise pre-engineered, interoperability-tested building blocks rather than bespoke one-off designs.
  - Aim: shorter time to power, reduced integration risk, and repeatable multi-MW / GW-scale deployments.
- **Resilience and grid constraint angle**
  - The collaboration is targeted at sites that want to reduce or even eliminate dependence on the grid, especially under interconnection constraints.
  - On-site generation is integrated with Vertiv's UPS and power trains, plus optional BESS, to maintain Tier III/IV-style resilience.
- **Scale & positioning**

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- Vertiv's AI Hub frames this as suitable for "gigawatt-scale AI centres" and advanced energy optimisation, not just small pilots.
- It's clearly positioned as a mainstream, commercial path for AI data-centre power and cooling, not just a concept.

Relevance to the report

- *It is live, OEM-level evidence that:*
    - *Engines and turbines are being combined in a single data-centre-specific CCHP package.*
    - *On-site CCHP is being treated as a strategic solution to grid constraints and AI energy demand.*
- It backs up your arguments about:
    - *Hybrid engine + turbine CHP plants.*
    - *Combined-cycle / multi-prime-mover configurations for campuses.*
- *It also illustrates the themes on:*
    - *Operator requirements (time-to-power, resilience, PUE, grid constraints).*
    - *How cogeneration contributes to DC development and AI growth.*

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