Goldman Sachs Research

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AI/DATA CENTERS' GLOBAL POWER SURGE

The push for the 'Green' data center and investment implications

As global data center power demand grows 165% by 2030 vs. 2023 per our estimates, we continue to see Big Tech taking an all-in approach to sourcing power and pursuing low-carbon solutions. Our analysis of levelized cost of energy suggests while there is not a Green Premium for intermittent solar/wind power in the US, there is a significant Green Reliability Premium for low-carbon round-the-clock power solutions (nuclear, solar, wind, battery storage). Nevertheless, we view the Green Reliability premium as relatively modest in the context of hyperscalers' EBITDA and strong corporate returns. While we continue to assume renewables meets only 40% of data center power demand growth through 2030 (natural gas meeting the bulk of the remainder), we see potential for a significant rise in nuclear share in the 2030s.

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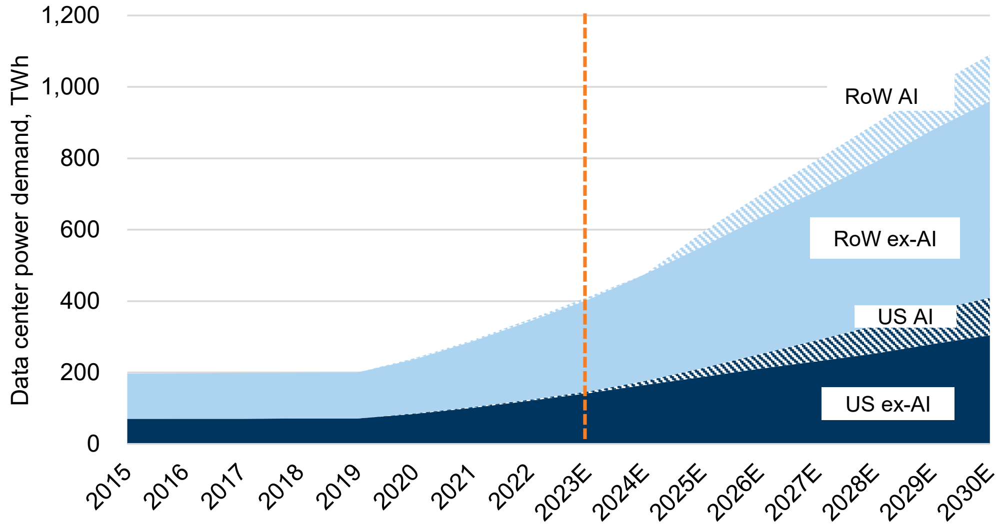
Six key takeaways

1. **We continue to see data center power demand growing 165% through 2030 vs. 2023 levels**, with risk over the medium term from AI skewed to the upside in our view.
2. **While we do not see a Green Premium for intermittent power in the US, our analysis suggests a Green Reliability Premium for low-carbon round-the-clock power solutions vs natural gas combined cycle in the US.** We expect the Green Reliability Premium to be greater in the US vs. other developed markets in part due to lower-cost natural gas in the US, even before taking into account country-level carbon prices in some other markets.
3. **We expect hyperscalers will remain committed to pursuing low-carbon power solutions based on our analysis of Green Reliability Premiums, industry discussions and recent contracts.** Our analysis suggests that the capital requirements for Green Reliability Premiums to source data center power demand to be modest relative to the EBITDA (<5%) and corporate returns of key hyperscalers (1 percentage point impact vs. 32% average baseline estimates; median across all sectors is about 12%-13%).
4. **We are in the early stages of nuclear renaissance in US and globally.** Recent contracts for small modular reactors (SMRs) and larger-scale nuclear to source data center power demand growth, combined with increased country-level embrace of nuclear power appears poised to drive a significant rampup of investment in the next 5 years and power in the 2030s. Lowering the capital costs of SMRs and accommodating nuclear expansion while minimizing impact to reliability/pricing elsewhere in the grid will be key for long-term competitiveness, in our view.
5. **We expect Big Tech's all-in approach to low-carbon technology deployment will continue, supportive of upside for Green Capex.** Our analysis suggests less variability in levelized cost of energy among low-carbon power solutions such as large-scale nuclear and solar/wind/energy storage. We also expect continued hyperscaler support for carbon capture and carbon removal.
6. **We expect natural gas-fired power use by data centers to rise** with 60% of data center power demand from thermal sources (largely gas). Policy and technology will likely help guide the split between combined cycle and peaker unit deployment.

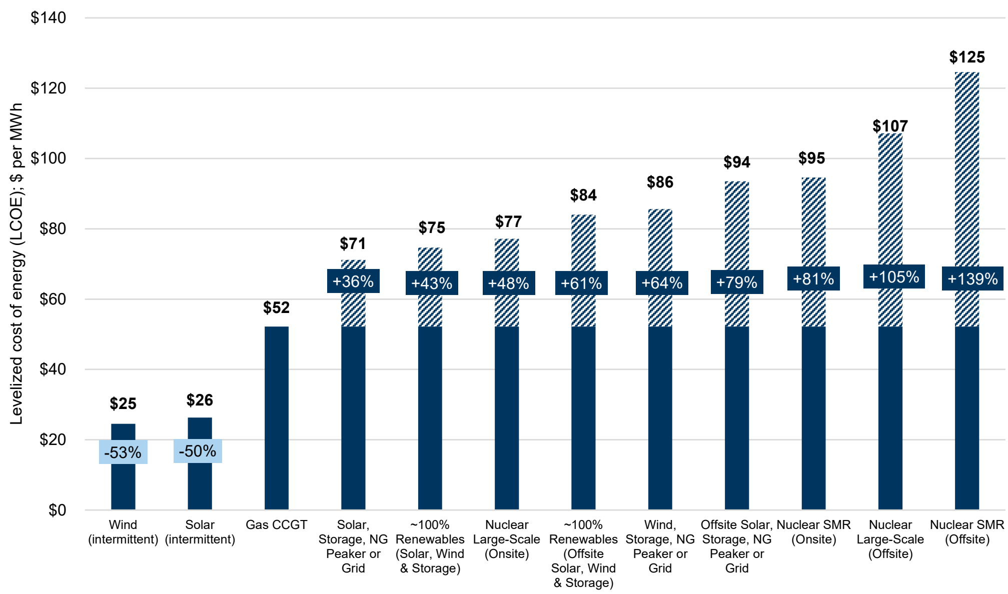
Exhibit 1: After being flat for 2015-19, we have seen data center power demand accelerate in 2021-23 and expect a 165% increase through the rest of the decade
Global data center electricity consumption, TWh; includes AI and excludes cryptocurrency



Source: Masanet et al. (2020), Cisco, IEA, Goldman Sachs Global Investment Research

Exhibit 2: We see a Green Reliability Premium to source round-the-clock low-carbon solutions, even as intermittent solar/wind have lower levelized energy cost vs. combined cycle natural gas in the US

Levelized cost of energy of various fuel & technology combinations to power new data centers, inclusive of assumed transmission and distribution (except intermittent solar/wind); call out boxes show LCOE discount/premium vs. natural gas combined cycle (CCGT) benchmark



Wind is assumed to be offsite, solar/gas/nuclear is assumed onsite unless noted; ~100% renewables assumes ~5% power sourced from natural gas peakers or grid due to day-to-day intermittency variability

Source: Goldman Sachs Global Investment Research

Exhibit 3: Relative tradeoffs of various technologies which can all provide capacity for new data center-driven power demand

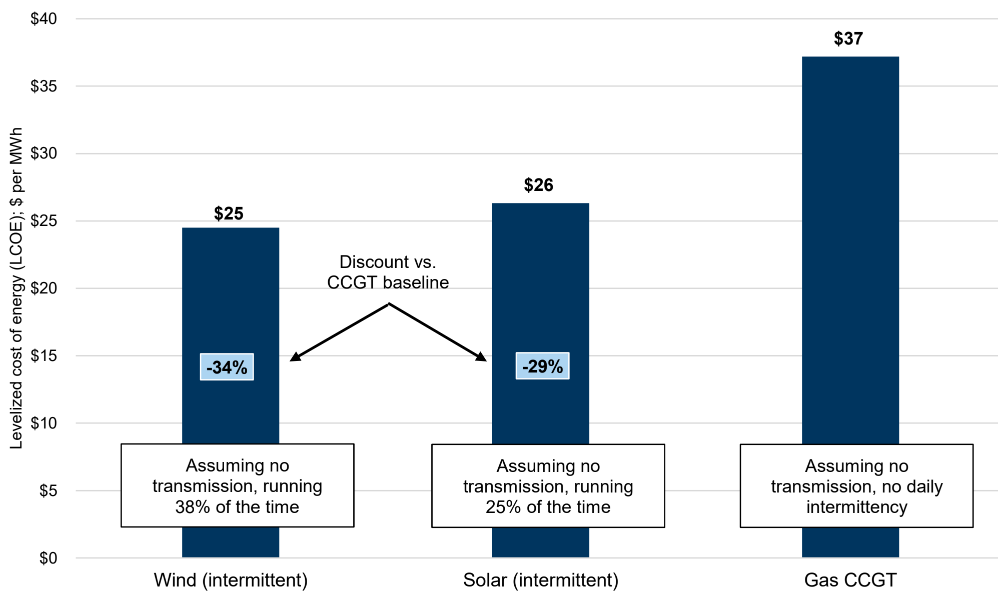
	Capacity Factor	Emissions Intensity	Land Footprint Intensity	Advantages / Challenges
Solar				**Advantages:** carbon footprint **Challenges:** land requirements, intermittent power
Onshore Wind				**Advantages:** carbon footprint **Challenges:** land requirements, intermittent power
Nuclear Large Scale				**Advantages:** small land footprint, reliable, carbon footprint **Challenges:** waste, labor, enriched uranium supply, lead time
Nuclear SMR				**Advantages:** small land footprint, reliable, carbon footprint **Challenges:** waste, labor, enriched uranium supply, lead time
Battery Storage				**Advantages:** enables greater clean energy reliability **Challenges:** capacity limits
Natural Gas CCGT				**Advantages:** reliable, small land footprint **Challenges:** carbon footprint
Natural Gas Peaker				**Advantages:** reliable, small land footprint **Challenges:** carbon footprint; less carbon efficient than CCGT
Grid (natural gas)				**Advantages:** reliable, land footprint **Challenges:** carbon footprint, interconnection wait times

Source: Goldman Sachs Global Investment Research

Powering a 'Green' data center: Balancing Reliability, Cost and Low-Carbon objectives

Before taking intermittency and land footprint/flexibility into account, building and operating onshore solar/wind power does not require a Green premium in the US. Our US Utilities team's analysis shows the levelized cost of energy for onsite onshore wind is $25/MWh vs. $26/MWh for utility-scale solar and $37/MWh for combined cycle natural gas without carbon capture. This takes into account incentives offered by the IRA and does not take into account the need to invest in carbon capture for natural gas combined cycle plants that will require capture solutions starting in 2032 as per current EPA regulations.

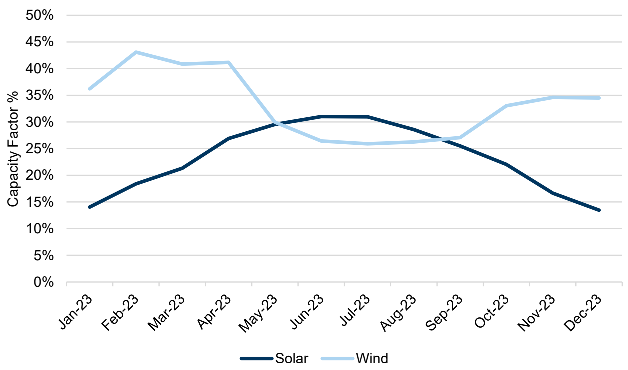
Exhibit 4: At face value before considering intermittency and transmission, renewables enjoy a lower levelized cost of energy than natural gas
LCOE of various power generation technologies, assuming no transmission costs or need to solve for intermittency



Source: Goldman Sachs Global Investment Research

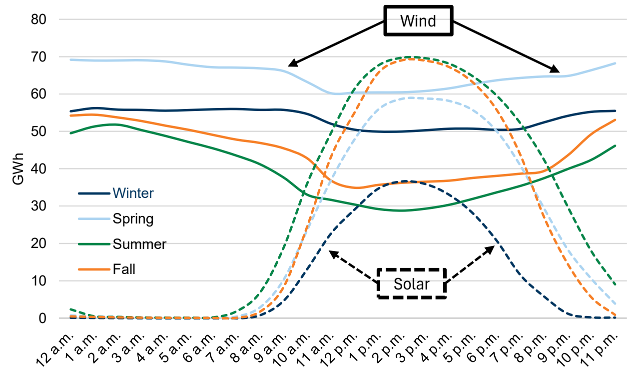
But solar plants and wind plants will run for a much lower percent of the day than a natural gas combined cycle plant or a nuclear plant. We expect typical utility-scale solar plants have a 25% capacity factor, i.e., run for 6 hours a day on average based in part on historical run rates. We expect typical wind plants to have a 35%-40% capacity factor, i.e., run for 9 hours a day on average. Importantly, there is day-to-day volatility in these capacity factors depending on the variability of the radiance of the sun and the level of wind. Among thermal power sources, we assume capacity factors for nuclear plants of 90%, natural gas combined cycle plants of 75% and natural gas peaker plants of 25%. Natural gas is most flexible to turn on/off, and neither natural gas nor nuclear faces hourly intermittency challenges.

Exhibit 5: Wind and solar capacity factors are 15%-45% and vary widely throughout the year
2023 monthly US nationwide capacity factor averages for wind and solar



Source: EIA, Goldman Sachs Global Investment Research

Exhibit 6: This variability comes on top of intraday variability for both wind/solar
TTM US nationwide averages of hourly solar and wind generation output by season (GWh)



Seasonal averages are based on 30 days of hourly data for each period

Source: EIA, Goldman Sachs Global Investment Research

Solar/wind power requires much greater land footprint than natural gas and nuclear. Natural gas and nuclear require a much more modest acreage footprint of less than 1 acre per MWh vs. utility-scale solar of around 6 acres per MWh and onshore wind of 1-2 acres per MWh (from permanent direct area impacted; a much greater total footprint is needed when taking into account land that could be utilized for separate purposes), according to the US Department of Energy, the Nuclear Energy Institute and the Solar Energy Industries Association. This provides a constraint (not necessarily a gating constraint) to deployment in urban areas and/or means transmission/distribution will be needed. We use our US Utilities team's $30/MWh estimate for T&D. Our Utilities team has continued to highlight the need/opportunity for transmission investment as well as the potential bottlenecks due to permitting and product lead times.

Data centers focused on AI training have greater geographical flexibility relative to data centers focused on AI/non-AI inference. Data centers that are training AI models and do not face latency requirements by customers have much greater geographic flexibility relative to inference focused data centers that largely need to be closer to data consumption (i.e., metropolitan areas). Conversations with corporates on our Green Capex and data center field trips suggest that ideally data centers used for training AI models will be sited in areas with easy access to land and fiber, low power prices, less physical risk and cooler temperatures. We expect wide diversity of geographies globally to see data center growth both for training and inference.

When taking intermittency and geographic flexibility into account, we highlight 6 different options data centers are pursuing

1. **Onsite combined cycle natural gas.** Our US Utilities team's levelized cost of energy analysis suggests as mentioned earlier a $37/MWh cost for natural gas combined cycle plant before transmission/distribution. This assumes a 6.5 heat rate (ratio of natural gas consumption to power), 75% capacity factor and a $3.50/MMBtu gas price. Given that on-site natural gas combined cycle solutions will

likely require a grid connection even if for redundancy, we assume a $15/MWh transmission cost which pushes the adjusted levelized cost to $52/MWh. We note that the levelized cost is likely to vary regionally depending on the price of natural gas (within the US and in the US vs. other countries). Importantly, current US EPA rules call for thermal power plants running at a greater than 40% capacity factor to deploy carbon capture technology by 2032. This has the potential to both increase the levelized cost and potentially limit the optionality among some Utilities for deployment of combined cycle given high CO2 transportation costs and that sequestration availability is not ubiquitous. Our recent discussions in Washington DC suggest that in the event of a Republican presidential election victory, we could see a greater focus on easing emissions restrictions, while in the event of a Democratic presidential election victory, we expect continued focus on policies that would advance decarbonization goals.

2. **Virtual power purchase agreements for renewable energy that do not necessarily match the data center demand every hour of the day.** The lowest-cost way to source clean power is contracting for new onshore wind and solar plants to be deployed, based on our estimates. This would be at a $25 and $26 per MWh levelized cost for wind and solar, respectively, if transmission/distribution is not required and a $55 and $56 per MWh levelized cost if it is, based on our estimates. For non-onsite solutions like virtual agreements as well as wind generation broadly, we assume the T&D cost. Battery storage support and additional associated cost would be needed if round-the-clock hourly matching is desired.
3. **Solar, battery storage and either grid power or onsite natural gas peaking power.** Data centers and other industrial users are looking to augment solar with battery storage to increase the hours of the day covered by power and reduce intermittency. Given the day-to-day volatility in solar radiance, we believe not all data center customers will pursue onsite round-the-clock power. As such we have a scenario where solar and battery storage provides on average 18 hours of power per day, augmented by natural gas peaking units onsite or grid connection for the remaining 6. Our Clean Technology team estimates the levelized cost of 6-hour battery storage to be about $64 per MWh after accounting for US IRA credits. Assuming grid power or onsite natural gas peaker units that meet not only the 6 hours but also additional redundant capacity for day-to-day intermittency volatility yields a total levelized cost of $71 per MWh for onsite solar and $94 per MWh for offsite solar (i.e., requiring transmission and distribution). We estimate this solution would lower emissions by 67% vs. baseline combined cycle natural gas. A key constraint is land footprint required which is why virtual options may be considered, particularly for data centers largely geared towards inference vs. AI training.
4. **Solar, within-grid wind and battery storage for round-the-clock renewable power.** Utilities and companies providing data center capacity to technology companies are increasingly looking to offer round-the-clock renewable energy solutions. We assume a combination of both solar and wind, with solar plus 6-hour battery storage providing 12 hours of coverage and offsite wind with battery storage meeting the remaining 12 hours. We assume there will also be need for backup grid or natural gas peaking capacity to offset day-to-day intermittency volatility. Together

this yields an estimated levelized cost of $69-$75 per MWh if the solar is onsite and $84 if the solar is offsite and requires transmission. We estimate this solution would lower emissions by 87%-100% vs. baseline combined cycle natural gas. A key constraint is land footprint required which is why virtual options may be considered, particularly for data centers largely geared towards inference vs. AI training.

5. **Large-scale nuclear.** Greater confidence in electricity demand growth along with Big Tech pursuit of contractual arrangements for low-carbon reliable energy is leading to both de-mothballing of recently retired nuclear generators along with consideration for new larger-scale reactors. Beyond the Three Mile Island unit which Constellation Energy recently announced it plans to bring back online (driven by take-or-pay power contract with Microsoft), we see potential for ~2 additional plants that could be potentially brought online in the US. We believe the economics will be variable based on plant-by-plant requirements. For new large-scale reactors, our US Utilities team assumes a $77 per MWh levelized cost of energy in the scenario where transmission/distribution is not required and $107 per MWh in the scenario in which transmission/distribution is required. This assumes a $7K per kW capital cost. We estimate this solution would lower carbon dioxide emissions by 100% vs. baseline combined cycle natural gas. Key challenges are skilled labor, permitting, and sufficient production/conversion/enrichment of uranium from acceptable geographic sources.
6. **Small Modular Reactor nuclear.** The prospects of more localized onsite low-carbon reliable power has led to a surge in contracting by hyperscalers (among others) to support development of small modular nuclear reactors (SMRs). We expect the size of these units to vary from 50 MW to 350 MW based on commentary in recent company announcements, and we assume capacity factors of 90%+. While there appears to be less industry concern regarding technological efficacy, the key debates center around cost and execution. We assume a $95 per MWh levelized cost of energy if transmission/distribution is not required and $125 per MWh if it is. This assumes a $9K per kW capital cost average based on our industry discussions (initial SMR reactors will likely see higher capital costs based on our industry dialogues) — we note a wide range of unit capital costs implied by companies pursuing SMRs above and below our average. We estimate this solution would lower carbon dioxide emissions by 100% vs. baseline combined cycle natural gas. Key challenges beyond execution/cost are skilled labor, permitting, and sufficient production/conversion/enrichment of uranium from acceptable geographic sources.

So while we do not see a Green Premium for power …

When we compare these solutions before taking into account carbon and land footprint, Utility-scale solar and onshore wind are the lowest levelized cost if transmission is not needed for the portion of the day in which the sun is shining and the wind is blowing. As such, we believe we will continue to see growth in contracting from technology companies via virtual power purchase agreements at a minimum. We also continue to see broad deployment of renewables by Utilities given cost competitiveness.

… We see a Reliability Premium for constant power…

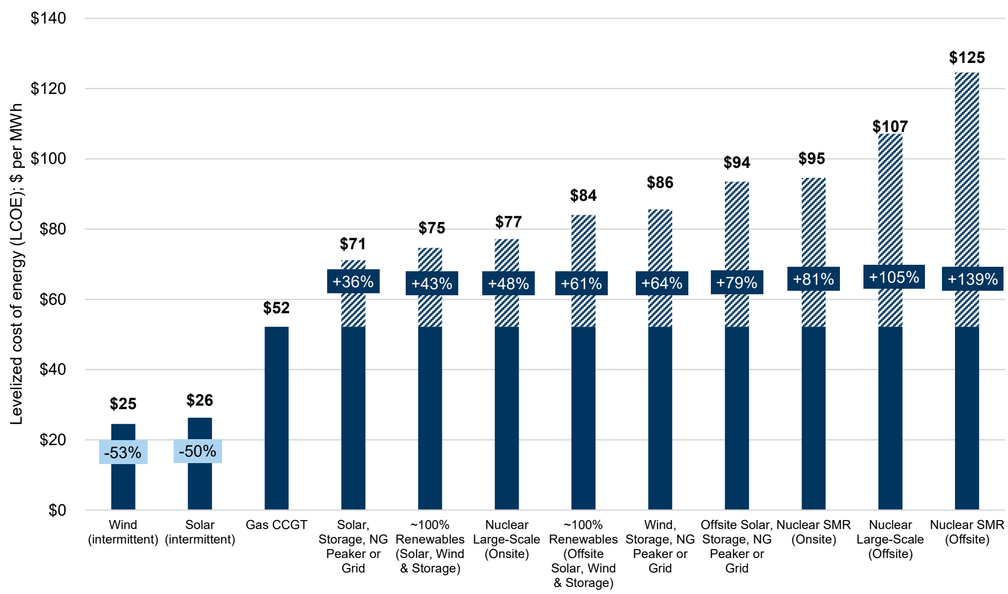
We see combined cycle natural gas as the lowest cost power solution in the US while providing reliability assuming carbon capture is not required. Ultimate deployment and market share among data centers will be a function of both the commitment of Big Tech to decarbonization alongside regulations regarding deployment with vs. without carbon capture.

… And a Green Reliability Premium for Green Reliable Power

Low-carbon solutions that meaningfully reduce emissions and provide more constant coverage than when the sun is shining/wind is blowing require willingness to pay Green Reliability Premiums. Our analysis suggests that in the US the Green Reliability Premium is $19-$72 per MWh (based on the difference between the above-mentioned low-carbon options relative to the baseline natural gas combined cycle) depending on the solutions being considered. As we have highlighted, potential cost reductions in nuclear and battery storage could lead to lower Green Reliability Premiums over time.

Exhibit 7: We see a Green Reliability Premium for clean energy solutions that meet baseload power demands of data centers

Levelized cost of energy of various fuel & technology combinations to power new data centers inclusive of assumed transmission/distribution (except intermittent solar/wind); call out boxes show LCOE premium vs. natural gas combined cycle (gas CCGT) benchmark

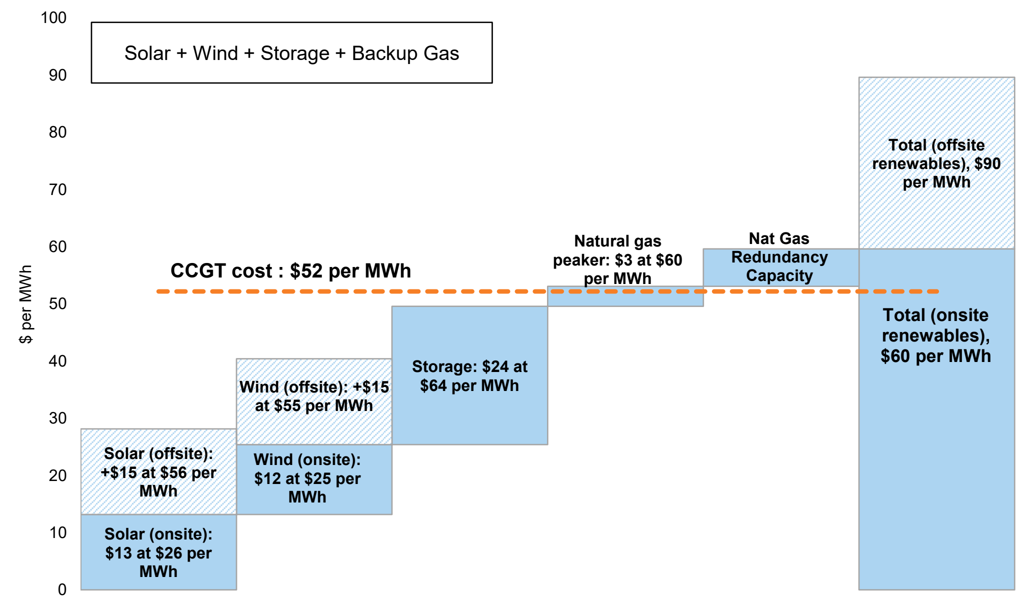


Wind is assumed to be offsite, solar/gas/nuclear is assumed onsite unless noted; ~100% renewables assumes about 5% of power sourced from natural gas peakers or grid due to day-to-day intermittency variability

Source: Goldman Sachs Global Investment Research

Exhibit 8: The addition of storage and redundancy to fill intermittency gaps drives the Green Reliability Premium

Total cost ($/MWh) for a solar + wind near 24-hour power system relative to cost of baseline new natural gas combined cycle; includes potential impact of transmission/distribution if generated offsite and assumes grid connection for combined cycle natural gas



Onsite solar and wind boxes do not factor in transmission costs

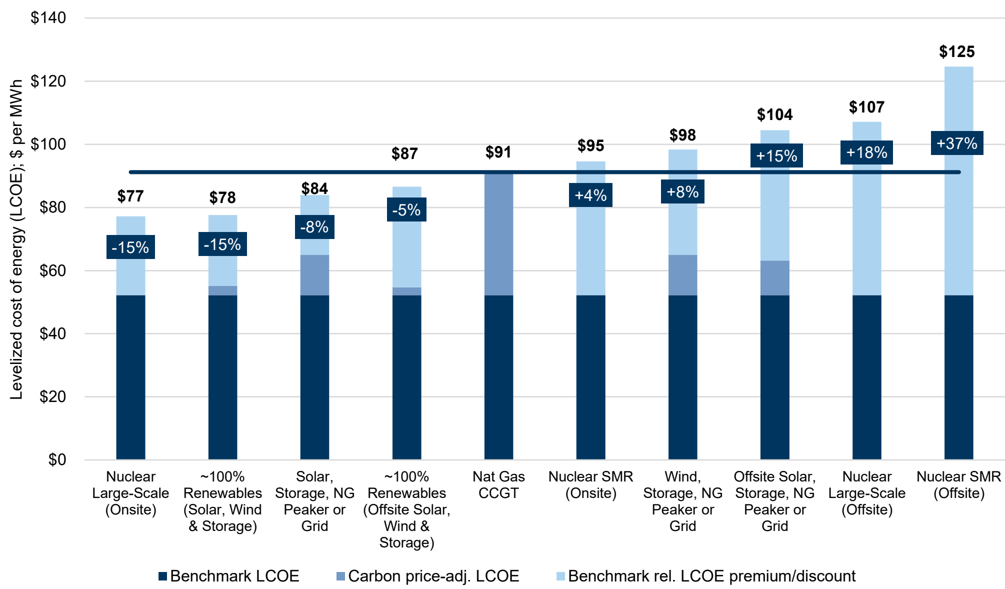
Source: Goldman Sachs Global Investment Research

At a triple digit price for carbon, much or all of the Green Reliability Premium goes away depending on the technology

While the US does not have a federal carbon pricing mechanism like the EU, and we do not expect we will see one in the near to medium term at a minimum (based on discussions from our recent Washington DC trip and the 2022 incentives-driven Inflation Reduction Act), some companies are voluntarily choosing to use internal carbon prices. A report published in December 2023 led by the World Economic Forum cited industry press that Microsoft in mid-2022 raised its internal business travel fee to $100 per ton (from $15/ton previously). While not all the major hyperscalers have indicated whether they are using an internal carbon price (and, if so, what the price is), adding $100/ton price for carbon dioxide meaningfully offsets the Green Reliability Premium. This would move natural gas combined cycle to $91 per ton based on historical reported gas-fired power emissions intensity, much more competitive with many of the low-carbon solutions.

Exhibit 9: A $100 per ton price on carbon makes multiple low-carbon solutions attractive or near cost parity with natural gas combined cycle

Levelized cost of energy of various fuel & technology combinations to power new data centers inclusive of transmission/distribution and assuming $100/ton carbon price; call out boxes show LCOE premium/discount vs. CCGT benchmark; line shows CCGT benchmark LCOE with $100/ton carbon price



Source: Goldman Sachs Global Investment Research

Putting the Data Center Green Reliability Premium into context

The average Green Reliability Premium of the various low carbon solutions highlighted earlier (without assuming a price on carbon) is about $39/MWh. If all the AI power we forecast in 2030 were delivered at a $39/MWh Green Reliability premium, this would represent about 4% of 2026 forecasted EBITDA for key hyperscalers. In the context of corporate returns, this would be equivalent to a 1 percentage point impact to projected average 2026 cash return on cash invested for these companies (base case CROCI of 32% for key hyperscalers). Because we do not expect these companies to be the sole drivers of data center power demand, the ultimate impact to these companies' returns if Green Reliability Premiums of this magnitude are supported is likely to be meaningfully less. Additionally, as we discuss below, we note the Green Reliability Premium may be larger in the US vs. other key markets due to low natural gas prices and no federal carbon pricing mechanism.

We continue to expect hyperscalers to take an all-of-the-above approach to power contracting and low-carbon solutions

In recent months we have seen hyperscalers/cloud computing companies sign multiple contracts for larger-scale nuclear (Amazon and Microsoft as examples), small modular reactor nuclear (Google and Amazon as examples), renewables power purchase agreements (Microsoft as an example) and carbon removal (Microsoft as an example). Data center providers more focused on inference have also told us on our recent field trips of their ability to provide — and interest from customers — in renewable power solutions, usually via virtual solutions (including round-the-clock solutions). Given strong data center demand, we continue to expect Big Tech to support all of these solutions.

Our base case continues to assume that this decade, 40% of the data center power increase will be met with renewables, and we assume modest nuclear capacity increase by the end of the decade targeted for data centers. This leads to expected global emissions increase of 215-220 million tons, equivalent to 0.6% of global energy emissions. As nuclear comes online at end of decade and into the 2030s while the focus within AI shifts more towards inference (less energy intensive) vs. training (more energy intensive), we see potential for a significant reduction of data center emissions intensity and potentially in absolute emissions.

Exhibit 10: Recent announcements around data centers sourcing clean energy and related technologies

Corporate	Technology Provider	Technology	Date	Scale (MW/ tonnes CO2)	Timing
Carbon Capture					
Google	Holocene	Carbon Capture - Direct Air Capture	Sep-24	100,000 ton target	Targeting delivery in the early 2030s
Microsoft	1.5/OXY	Carbon Capture - Direct Air Capture	Jul-24	500,000 ton target	Stratos plant expected to start up in mid-2025; 10 year contract
Amazon	1.5/OXY	Carbon Capture - Direct Air Capture	Sep-23	250,000 tons	Stratos plant expected to start up in mid-2025; 10 year contract
Microsoft	Heirloom Carbon Technologies	Carbon Capture - Direct Air Capture	Sep-23	up to 315,000 ton offtake	Multi-year agreement, unspecified start date
Microsoft	Climeworks	Carbon Capture - Direct Air Capture	Jun-22	10,000 tons	10 year capture period, unclear start date
Microsoft	Applied Carbon	Carbon Capture - Biochar	Jun-24	77,526 tons	-
Microsoft	The Next 150	Carbon Capture - Biochar	Mar-24	95,000 tons	6 year contract with credits starting to be delivered in mid-2024
Microsoft	Orsted	Carbon Capture - bioenergy + CCS	May-24	3,671,500 tons	Starting in 2026
Microsoft	Stockholm Exergi	Carbon Capture - bioenergy + CCS	May-24	3,330,000 tons; 800,000 tons per year	10 year deal, starts in 2028
Nuclear					
Microsoft	Constellation	Nuclear - Large Scale	Sep-24	835 MW	Restarted unit is expected to be online in 2028, 20 year PPA
Amazon	Talen Energy	Nuclear - Large Scale*	Mar-24	960 MW campus; AWS has a one-time option to cap commitments at 480MW.	Minimum commitments that ramp up in 120MW increments and two 10-year extension options, tied to license renewals.
Amazon	X Energy	Nuclear - SMR	Oct-24	5+GW target by 2039, AMZN committed to supporting initial 320 MW project in WA.	Targeting full capacity by 2039
Amazon	Dominion	Nuclear - SMR	Oct-24	300 MW	Targeting full capacity by 2039
Google	Kairos	Nuclear - SMR	Oct-24	500MW	Aim to bring first SMR online by 2030, followed by additional reactor deployments through 2035.
Equinix	Oklo	Nuclear - SMR	Apr-24	500 MW	20 year PPA with right for a further 20 year renewal
Standard Power	NuScale	Nuclear - SMR	Oct-23	NuScale will provide 24 units of 77 MW modules, collectively producing 1.85 GW	Plans to be operational by 2029
Microsoft	Helion Energy	Nuclear - Fusion	May-23	50 MW target	Plant is expected to be online by 2028
Renewables - Aggregate commitments in 2024					
Alphabet	Mutliple	Renewables	2024 YTD	3+ GW	Agreements range from sourcing power effecitve immediately to through the end of the next decade.
Microsoft	Mutliple	Renewables	2024 YTD	10.5+ GW	Agreements range from sourcing power effecitve immediately to through the end of the next decade.
Meta	Mutliple	Renewables	2024 YTD	1+ GW	Agreements range from sourcing power effecitve immediately to through the end of the next decade.
Amazon	Mutliple	Renewables	2024 YTD	3+ GW	Agreements range from sourcing power effecitve immediately to through the end of the next decade.

*existing nuclear plant, not new plant; above table represents select announcements and is not an exhaustive list

Source: Company data, Goldman Sachs Global Investment Research

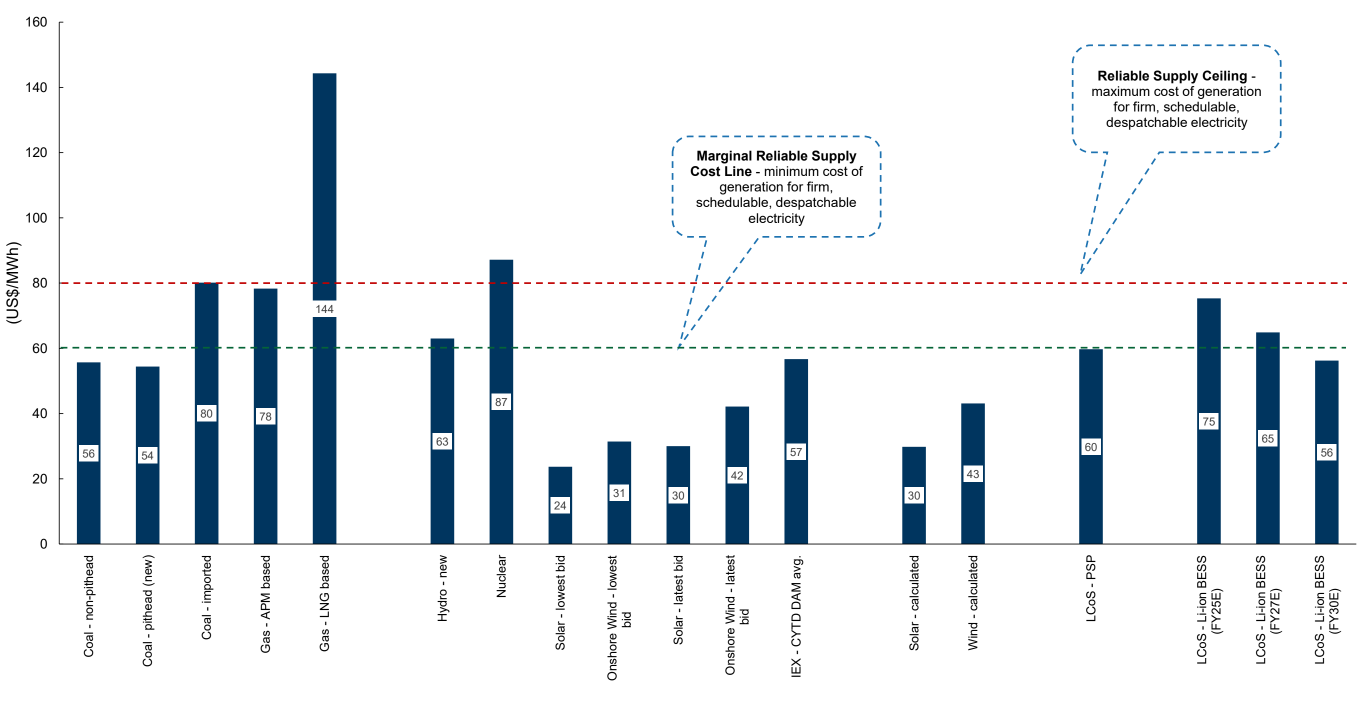
Power costs and Green Reliability Premium vary by region/country

The cost of various power solutions and the attractiveness of low-carbon options vary by country (and even region within a country). The availability/cost of baseload power (natural gas or coal) combined with policy incentives lead to regional variability in the levelized cost of power and the Green Reliability Premium. In general, we expect the premium to be wider in the US relative to other markets due to the low cost of natural gas. If imported LNG becomes the baseload source of reliable power, the Green

Reliability Premium narrows significantly. As an example, at a $10/MMBtu natural gas price instead of the $3.50/MMBtu base case in our US analysis, the Green Reliability Premium (before taking any carbon price into account) to large-scale nuclear goes away. We also note that regionally within the US there will likely be differences in the Green Reliability Premium based on regional natural gas prices as well as variability in capacity factors for solar and wind. **Because we expect the US Green Reliability Premium to be greater than other developed markets, we believe our application of the US Green Reliability Premium to global data center power consumption growth is conservative in considering the potential financial implications to hyperscalers — i.e., the actual impact will likely be less.**

A look at India and the cost of Round-the-Clock power solutions. Our Asia energy team led by Nikhil Bhandari has done similar work to consider the supply cost of various solutions in India including round-the-clock renewables. Coal-fired power is the baseline with a higher levelized cost of energy than natural gas combined cycle in the US. This results in a more modest Green Reliability premium. The team notes that India's country-wide grid connectivity allows for new renewables to be located in disparate locations which can reduce some of the intermittency risk.

Exhibit 11: Relative to the US, our Asia Energy team's analysis of India power supply cost suggests narrower Green Reliability Premium LCOE of various fuel types/technologies in India



Source: Goldman Sachs Global Investment Research

What to watch for going forward

1. **Big Tech commitment to decarbonization.** Continued willingness to pay Green Reliability Premiums by Big Tech companies as data center demand accelerates is a key driver of decarbonization efforts and broader Green Capex. We see a continued focus by Big Tech, broader consumers and regulators/policymakers on Reliability

which we believe will be bullish for stocks across the reliability supply chain (power, water, energy).

2. **US policy around carbon capture at natural gas combined capture plants.** As referenced earlier, EPA policy calls for natural gas power plants running more than 40% of the time to capture 90% of carbon dioxide beginning in 2032. However, this has been challenged in courts, and it remains to be seen if the next US Administration is supportive to this policy or looks to make alterations. Greater visibility will help to determine if the baseline for Reliable Power should be combined cycle gas without carbon capture vs. alternatives.
3. **Confidence in execution and costs at SMRs and large-scale nuclear plants.** As mentioned earlier, there is significant optimism for nuclear generation renaissance even as multiple challenges remain. Challenges include capital cost intensity, skilled labor availability, permitting and sufficient nuclear-power enriched uranium supply. There is a wide array of cost assumptions for various SMR technologies being deployed that could lead to both lower and higher levelized cost of energy vs. our assumed average, making execution key. Additionally, regulators and corporates will need to solve the challenge of accommodating increased data center demand for baseload power via behind-the-meter contracts without impacting reliability and pricing elsewhere on the grid.
4. **Gas-fired power carbon capture technology/cost.** We continue to expect carbon capture and sequestration initiatives to receive greater investment by industrial emitters as well as other companies looking to participate in decarbonization initiatives. We expect CCUS would be more likely to be deployed for power generation in areas that minimize carbon dioxide transportation costs and have sequestration-friendly geology. Technological innovation will also be important — as an example, NET Power's gas capture plants expected to startup in 2027-28.
5. **Broader innovation.** Our Clean Technology team expects battery storage costs will continue to fall with continued innovation. More broadly, as there is a greater focus on energy efficiency and bringing emerging low-carbon technologies to scale, supply cost efficiencies could change the Green Reliability Premium of power supply. On the demand side, how data center customers respond to continued innovations that lower AI server energy intensity will be key, which we address further later in the report.

The nuclear option continues to gain steam; potential inflection in 2030s

We are currently in the contracting and planning stage of a nuclear renaissance. Over the past year, we have seen corporate and government interest in increasing nuclear generation via:

- New contracts by hyperscalers — more than 10+ GW of potential new capacity agreements in the US for new SMRs and de-mothballed nuclear capacity (in addition to contract to take power from existing plant).
- Greater support by governments — Switzerland reconsidering nuclear, bipartisan support in the US, opposition party proposal in Australia, and global agreement at the COP28 conference for a tripling of global nuclear capacity by 2050.
- Recognition of accelerated power demand growth from Utilities — increases in expectations for load growth leading to willingness to consider new large-scale reactors.

Industry confidence high for SMRs. Conversations with investors and corporates suggest increased confidence in more widespread deployment of small modular reactors (~50-350 MW units) either as on-site or near-site sources for growing data center demand. While our meetings have suggested less debate about the efficacy of the technologies (though some hope that industry will coalesce around 1-2 of them), there is greater concern on project lead time and cost/execution. We assume a higher levelized cost for SMRs than for large-scale nuclear on account of higher assumed unit capital costs, though there is a wide range — greater clarity upon execution will be key. Project lead times for nuclear tend to be 5+ years, but the potential for modularization will also be key to a potential narrowing.

Accommodating increased data center demand for baseload power via behind-the-meter contracts without impacting reliability and pricing elsewhere on the grid will be key. Both corporates and regulators have expressed concern that behind-the-meter power contracts that either take from existing generation capacity or require grid transmission/distribution resources could lead to higher power/capacity prices and/or reliability issues elsewhere on the grid. On November 1, the US FERC rejected an amendment to an interconnection service agreement that would have supported increased data center load for the in-operation Susquehanna nuclear power plant in PA owned by Talen Energy. While we do not believe the rejection is likely to derail US nuclear expansion, it highlights that further work is needed — particularly with regards to existing capacity — for greater confidence that consumer reliability/pricing risk will be minimized as data center power growth accelerates.

Timeline: Potential pickup in 2030s. We see nuclear capacity expansions most impactful in the 2030s. We expect the initial SMRs to come online around the end of the decade. We see potential for 2-3 demothballed plants in the US to potentially come online before the end of the decade based on our industry discussions. Regardless, we expect the impact to emissions will be seen more in the 2030s. Notably, we see nuclear has the potentially to meaningfully shift what we expect to be an upward trajectory for data center emissions through 2030 to a flat or declining trajectory in the 2030s. We note that 85-90 GW of new nuclear capacity would be needed to source 100% of the data center power demand growth we expect by 2030 vs. 2023, based on a 90% capacity factor. But even with 5 GW of new nuclear capacity we expect by 2030 globally, we begin to see a second derivative inflection in emissions, driven also by data center power intensity efficiency gains and a shift towards inference vs. training.

Exhibit 12: Recent corporate nuclear power capacity agreements

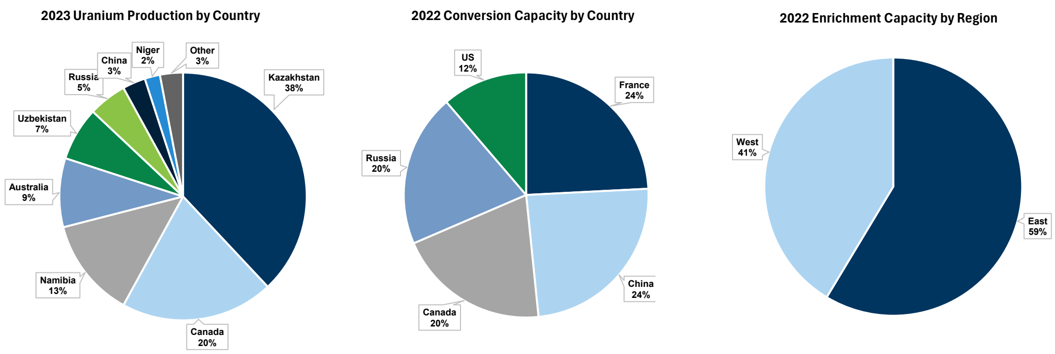
Corporate	Technology Provider	Technology	Date	Scale (MW/ tonnes CO2)	Timing
				Nuclear - Large Scale	
Microsoft	**Constellation**	Nuclear - Large Scale	Sep-24	835 MW	Restarted unit is expected to be online in 2028, 20 year PPA
Amazon	**Talen Energy**	Nuclear - Large Scale*	Mar-24	960 MW campus; AWS has a one-time option to cap commitments at 480MW.	Minimum commitments that ramp up in 120MW increments and two 10-year extension options, tied to license renewals
				Nuclear - SMR	
Amazon	**X Energy**	Nuclear - SMR	Oct-24	5+GW target by 2039, AMZN committed to supporting initial 320 MW project in WA.	Targeting full capacity by 2039
Amazon	**Dominion**	Nuclear - SMR	Oct-24	300 MW minimum target	Targeting development by 2039
Amazon	**Energy Northwest**	Nuclear - SMR	Oct-24	360 MW with option to increase to 960 MW	Projects beginning in the early 2030s
Google	**Kairos**	Nuclear - SMR	Oct-24	500MW target	Aim to bring first SMR online by 2030, followed by additional reactor deployments through 2035
Amazon, Google & Microsoft	**Nucor, Duke Energy**	Nuclear - SMR	May-24	MOUs signed to explore new carbon-free generation	-
Equinix	**Oklo**	Nuclear - SMR	Apr-24	max target of 500 MW	20 year PPA with right for a further 20 year renewal, plant timing unclear
Standard Power	**NuScale**	Nuclear - SMR	Oct-23	NuScale will provide 24 units of 77 MW modules, collectively producing 1.85 GW	Plans to be operational by 2029
				Nuclear - Fusion	
Nucor	**Helion Energy**	Nuclear - Fusion	Sep-23	500 MW	Targeting operations by 2030
Microsoft	**Helion Energy**	Nuclear - Fusion	May-23	50 MW target	Plant is expected to be online by 2028

*(a) existing nuclear plant, not new plant; above table represents select announcements and is not an exhaustive list

Source: Company filings, Goldman Sachs Global Investment Research

Key challenge: Confidence in enriched uranium supply. Our Energy equity research team highlighted the three processes needed to supply nuclear plant feedstock: Uranium production, Uranium Conversion and Uranium Enrichment. Each is not done in the same place so could also require transportation. As shown in the below exhibit, Europe and the Americas source about 30% of uranium production, hold 56% of uranium conversion capacity, and hold 41% of uranium enrichment capacity. The key participants outside these countries are China/Russia/Kazakhstan, together representing about 46% of uranium supply, 44% of uranium conversion capacity and 59% of uranium enrichment capacity. We note that the enrichment requirements for SMRs are expected by IAEA to be 5%-20% vs. 3%-5% for large-scale reactors. We expect greater clarity on rules and confidence surrounding uranium sourcing will be key towards moving forward with a meaningful rampup in nuclear generation capacity in the US and Europe. Other challenges include permitting, nuclear waste siting/storage, plant security and skilled labor.

Exhibit 13: As momentum builds for nuclear capacity expansion, we expect greater focus on geographical exposure to Uranium — not just production but conversion and enrichment as well



Source: World Nuclear Association, UxC, Goldman Sachs Global Investment Research

We remain bullish on the AI/non-AI data center global power surge

We believe data demand — driven in part by AI and in part from deceleration in non-AI efficiency gains — will catalyze generational growth in global power demand. Our analysis suggests a 165% increase in data center power demand by 2030 vs. 2023 levels. In the US, this implies that data centers will contribute a 0.9% CAGR to overall US power demand, bringing the total expected CAGR to 2.4% through 2030. We see data centers adding a 0.3% CAGR to overall global power demand. Our base case implies data center power demand moves from 1%-2% of overall global power demand to 3%-4% by 2030. The increase in the US is even greater — from 3% to 8%. If global data center growth in 2030 vs. 2023 levels were its own country, it would be a top 10 global power consumer.

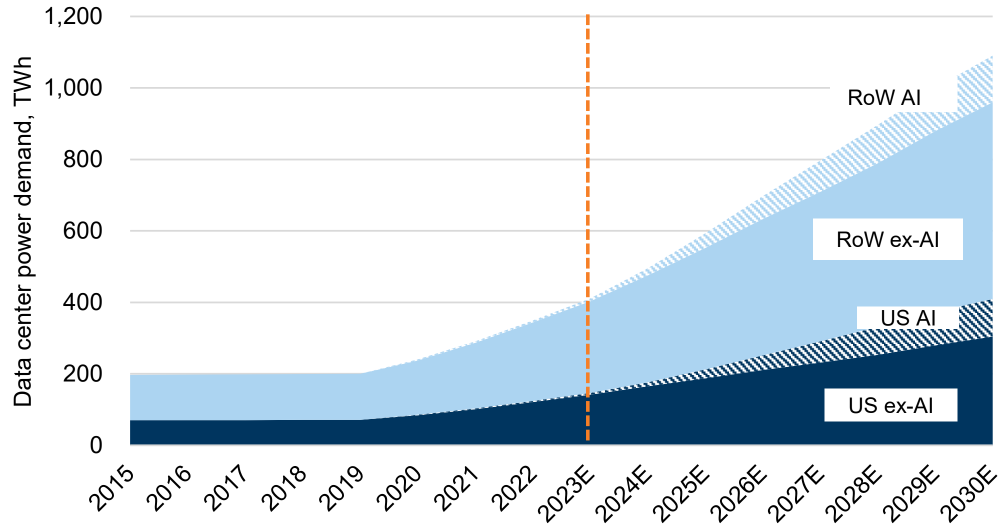
Three key assumptions should help drive data center power demand forecast

(1) Data consumption outlook — both AI and non-AI. Post our recent meetings, we remain bullish on appetite for data center growth. The ultimate success of AI in driving profitable solutions for customers will be key to whether power demand will be unconstrained or constrained by technology company budgets or AI compute speed demand.

- In the shorter term, we believe there is potential for greater upside risk to AI power demand as commentary suggests fewer constraints while managements are using AI training to determine whether there are sufficient returns-enhancing benefits. **While some Utilities in prior meetings have reflected a lack of clarity on whether requested electricity demand for data centers will actually materialize, Utilities commentary from our September 2024 Dallas trip was more supportive of the data center power surge.** Managements highlighted that while data center customers often build facilities nearby competitors in metropolitan areas — which are now at greater risk of power constraints — there is increasingly rising data center power interest in West Texas because of fewer constraints and easier/shorter cycle times to deliver power. We believe this could represent a clearer sign of pent-up demand. Minimizing water use will remain a key challenge in West Texas.
- Longer term, the success of AI in transforming business opportunities and costs will help to govern whether we are in a demand constrained, budget constrained or unconstrained environment.
- There is a healthy debate on non-AI demand and whether CPU demand will be cannibalized by GPU demand. Our base case assumes a deceleration in broader CPU workload demand over the rest of the decade but with growth still above 10%. **Co-location/retail-focused data center providers expect demand growth will remain favorable even without clear visibility on AI's impact.**

Exhibit 14: After being flat for 2015-19, we have seen data center power demand accelerate in 2021-23 and expect a 165% increase through the rest of the decade

Global data center electricity consumption, TWh; includes AI and excludes cryptocurrency

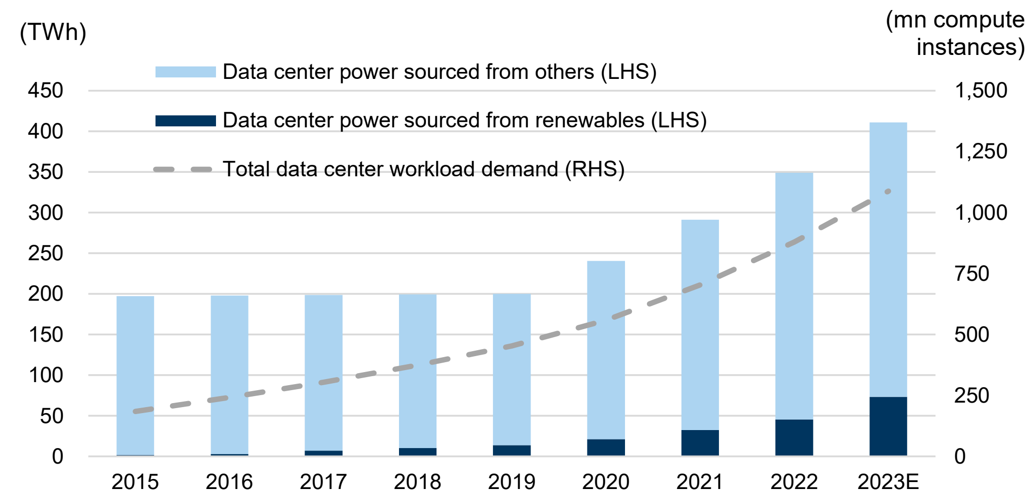


Source: Cisco, IEA, Goldman Sachs Global Investment Research, Masanet et al. (2020)

(2) Power efficiency gains. Data center power demand was flat in 2015-19 even as workload demand nearly tripled. This largely results from efficiency gains as: (a) data center workload has shifted from higher energy-intensity traditional data centers to more efficient cloud and hyperscale data centers; and (b) cloud/hyperscale data centers have separately become more energy efficient, which we attribute in part to innovation and hyperscale/cloud consolidation. But starting in 2020, efficiency gains have significantly decelerated, which we attribute to more limited than prior period opportunities for mix shift away from traditional centers and cloud/hyperscale consolidation. We continue to expect innovations that can drive efficiency gains that lower power intensity. It does not appear from our recent corporate dialogues that efficiency gains are leading to a reduced need for data center infrastructure and rack space.

Exhibit 15: Data center workload demand nearly tripled between 2015-2019 but electricity consumption from data centers was flat

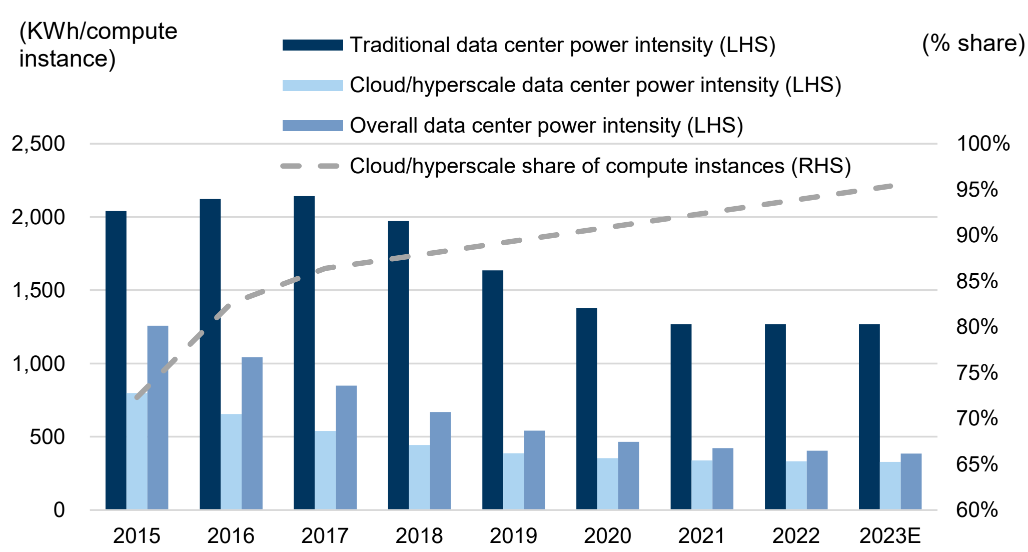
Data center workload demand (RHS) in million compute instances; data center power demand (LHS) in TWh



Source: Masanet et al. (2020), Cisco, IEA, Goldman Sachs Global Investment Research

Exhibit 16: Data center efficiency gains and the shift to cloud/hyperscale have been critical drivers of the moderate increase in data center power demand, but decelerating efficiency gains have helped to drive a pickup in power demand from data centers in recent years

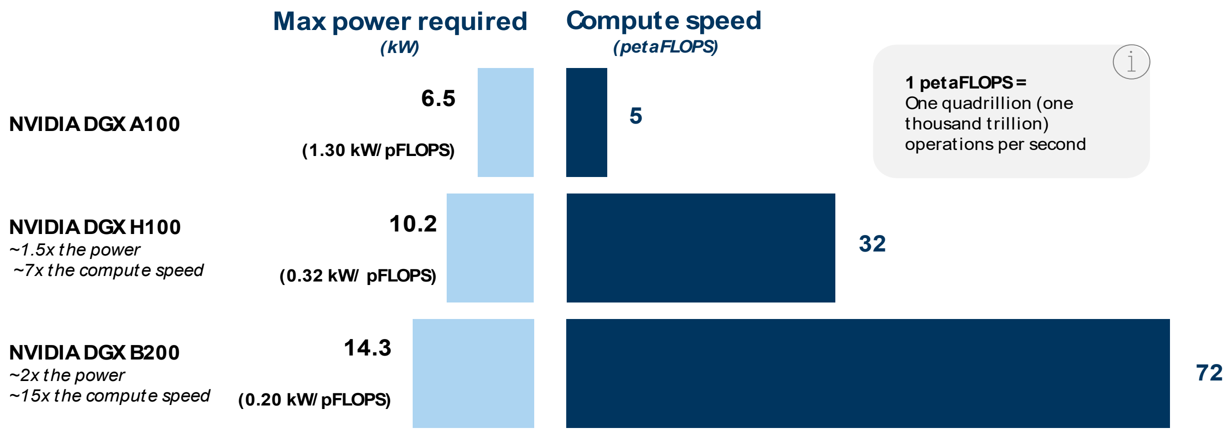
Data center power intensity (LHS) in KWh per compute instance; share of cloud/hyperscale data centers (RHS) as % of workload



Source: Masanet et al. (2020), Cisco, IEA, Goldman Sachs Global Investment Research

Exhibit 17: We have seen new AI innovations increase max power consumption per server but increase computing speed per server by an even greater level, representing a meaningful reduction in power intensity

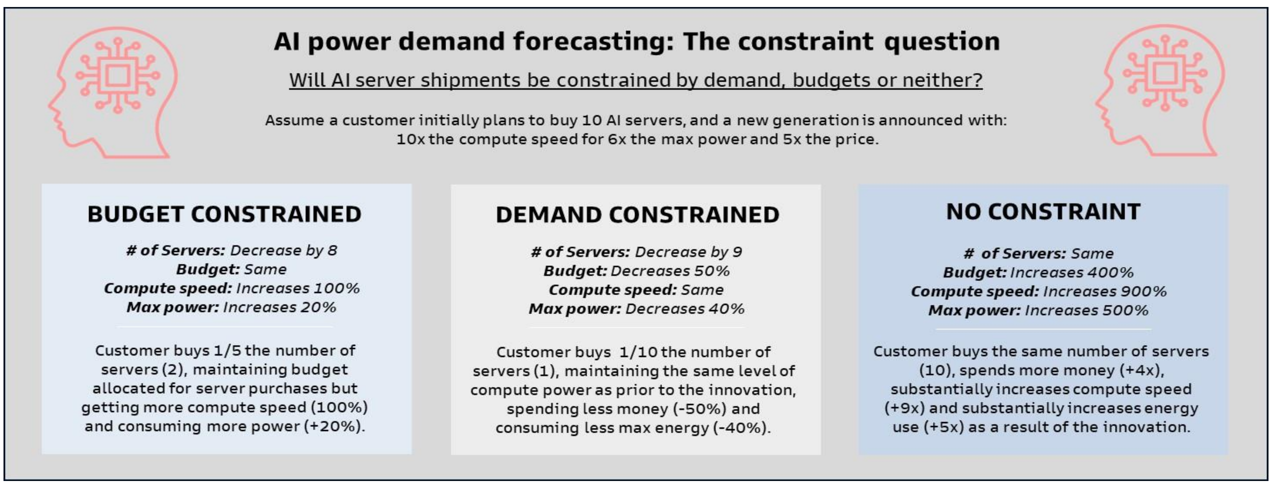
Recent evolution of NVIDIA server system specifications is indicative of increasing max power per server but with lower power intensity relative to computing speed (for training)



Source: NVIDIA, Goldman Sachs Global Investment Research

Exhibit 18: Extent of pent-up demand for AI server supply and voraciousness of technology capex budgets will be critical for pace of AI power consumption

Indicative scenario analysis of how demand vs. budget constraints could impact AI compute speed and power use

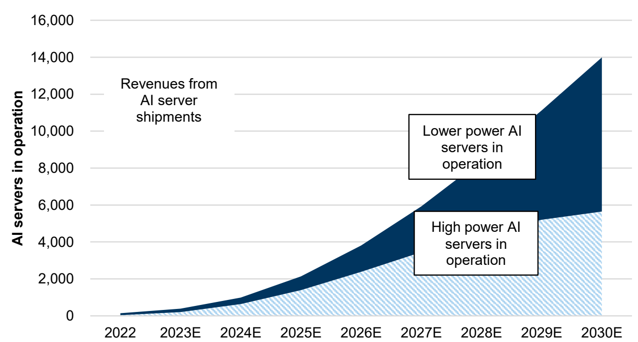


Assumes power generation, transmission and interconnection are not a constraint for indicative purposes

Source: Goldman Sachs Global Investment Research

Exhibit 19: We expect AI servers in operation will grow sharply through 2030 even as revenues from AI server shipments decelerate in 2027-30

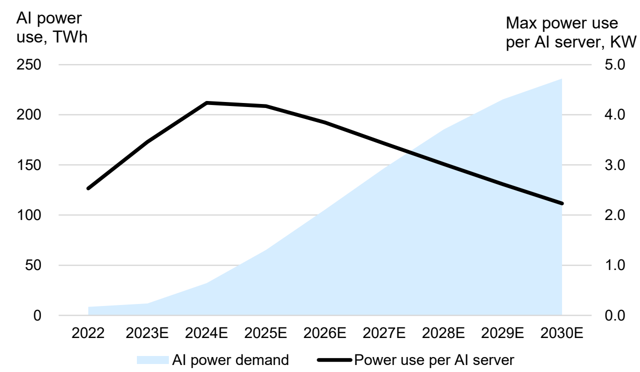
AI servers in operation and implied revenues from our global TMT team forecasts



Source: Goldman Sachs Global Investment Research

Exhibit 20: We see AI power demand growing rapidly even as power use per AI server falls later in the decade due to mix shift and expected efficiencies

AI power use, TWh (LHS); max power use per AI server, KW (RHS)



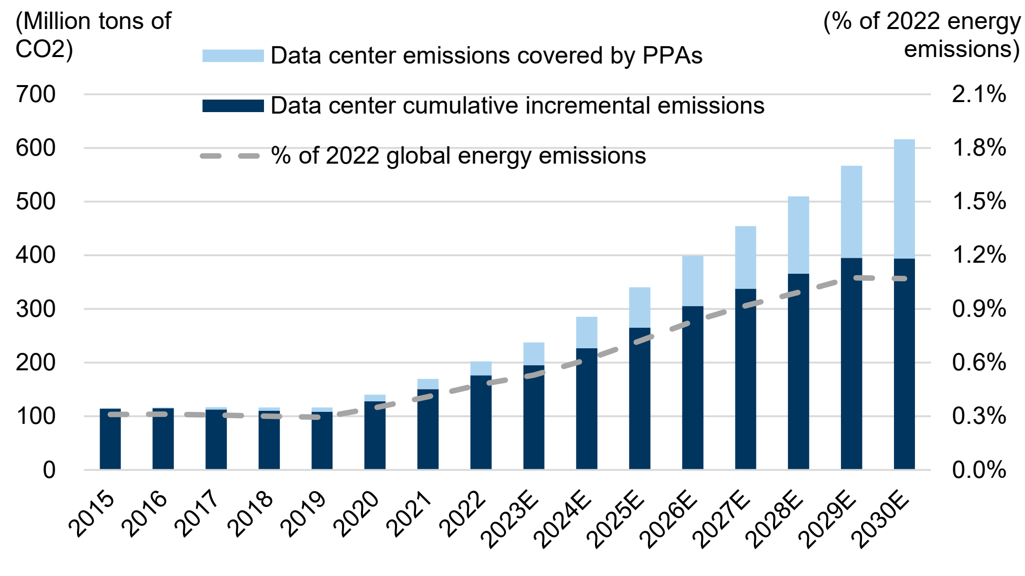
Source: Goldman Sachs Global Investment Research

(3) Potential infrastructure constraints. Managements in recent discussions highlighted various constraints without clear consensus on weighting — transmission, transformer lead time, generation capacity execution, permitting, regulatory, community support. We believe Utilities will continue to seek clarity multiple years ahead of data center startups to be able to include in stated plans to the grid/regulators as well as execute on transmission and generation.

Sustainability considerations

How power generation is sourced will be key for overall data center carbon dioxide emissions. Data center power demand growth is on track to drive a more than 100% increase (about 215-220 mn tons) in data center carbon dioxide emissions by 2030 vs. 2022 per our updated analysis, the increase representing about 0.6% of global energy emissions. This assumes data centers fund renewable PPAs for around 30% of total needs in the coming years and that natural gas fills the bulk of power generation on the margin.

Exhibit 21: We see data center emissions doubling in 2030 vs. 2023 levels, net of impact of power purchase agreements (PPAs) from technology companies
Carbon dioxide emissions in millions of tons (LHS); percent of 2022 energy emissions (RHS)



Source: IEA, Goldman Sachs Global Investment Research

Confidence in hyperscalers' long-term commitment to decarbonization, but certainty of time to market may be shorter-term priority. From our recent trips, Global Sustainability Forum and industry discussions, corporates were confident in hyperscalers and cloud leaders' commitment to minimizing carbon dioxide emissions and signing power purchase agreements to add renewables capacity — solar, onshore wind and battery storage.

- Mitigating intermittency risk remains key — with day-to-day volatility as well as geographical differences in solar radiance and wind speed/reliability.
- We expect technology companies will continue to support development of emerging nuclear technologies such as small modular reactors, though we continue to expect potential impact to be in the 2030s. Our base case expectation is for renewables PPAs to represent about 30% of data center power demand in the 2028-30 period on average with grid renewables contributing to an additional 10%.
- On our September 2024 data center trip to Texas, managements reiterated their own optimism and the optimism of Big Tech customers that nuclear could be a meaningful source of clean reliable energy in the 2030s. In the shorter term, however, managements see data center customers prioritizing execution on meeting demand with reliable energy even if it creates hurdles to meeting shorter term carbon reduction goals.
- **We believe the result will likely be investment across the board in renewables, battery storage, natural gas peakers (and potentially combined cycle, depending on regulations), and grid infrastructure.** We also believe this will continue to lead large AI data center customers to consider carbon removal and broader carbon capture as part of their all-in approach towards decarbonization

solutions.

We continue to see potential AI benefits via speeding up drug/vaccine/therapeutic discoveries, improving crop yields, and increasing energy efficiency among other potential innovations, though with uncertainty on the magnitude and timing. The AI power surge and emissions increase is likely to prompt greater interest among Sustainable investors to quantify AI value added (similar to avoided emissions frameworks) vs. the rising emissions from AI power consumption. We estimate a **present value of about $125-$140 bn social cost from the data center carbon dioxide emissions growth we forecast** (AI + non-AI) in 2024-30, which could act as a benchmark for measuring offsetting benefits.

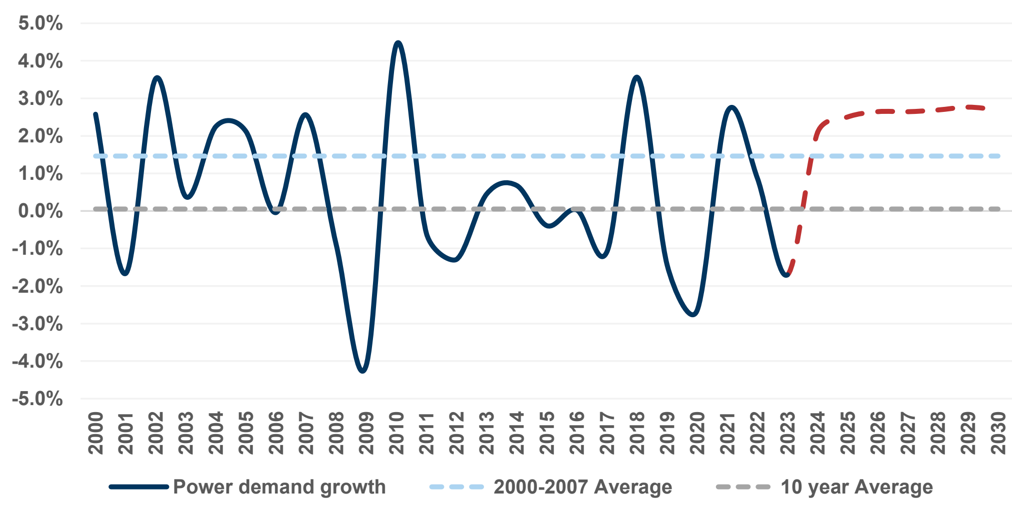
We believe that data center power demand growth will be a tailwind for many companies that are already set to benefit from broader Green Capex themes — decarbonization, Infrastructure and Clean Water. We also believe rising energy use by data centers will result in greater investment towards renewable generation and related supply chain as well as efficiency solutions for resources and land. We see opportunity for Sustainable Investors among companies that have exposure to the data center power surge which either: (a) could directly benefit from increased renewables development; or (b) also overlap with at least two themes among decarbonization, Adaptation, Circular Economy, Biodiversity and Affordability/Accessibility where we see tailwinds.

For more details, please see our April 2024 report, Generational Growth: AI/data centers' global power surge and the Sustainability impact.

US Power Demand Expectations

Over the past decade, power demand in the US has remained flat despite economic and population growth in that same time period as technological efficiencies have offset demand growth. However, now, in large part due to AI and non-AI related data demand and a slowdown in efficiency gains related to data centers, power demand is at an inflection point. We expect power demand to increase to 5,036 TWh by 2030, which represents a 2.4% CAGR from 2022-2030. By 2030, we expect data centers to drive roughly 8% of power demand compared to ~3% at present. This means data center electricity demand is poised to grow at 16% CAGR through 2030 and will contribute 90 bps to overall power demand CAGR of 2.4%.

Exhibit 22: We expect US power demand to grow at a 2.4% CAGR through 2030
US power demand growth, %



Source: EIA, Goldman Sachs Global Investment Research

Implications for Sustainable Investing and the Additionality debate

We see substantial opportunities for investment by Sustainable funds in companies receiving tailwinds from the AI/data center global power surge. We continue to see substantial overlap with companies exposed to decarbonization and Adaptation as well as efficiency. We continue to see the overlap of Adaptation and Decarbonization as providing opportunities amid uncertainty over interest rates, inflation, investment levels vs. needs for Sustainable goals and post-election policy shifts.

Our Green Reliability Premium analysis gives us more confidence Big Tech will continue to pursue decarbonization solutions, one of the key legs of the stool of the Green Capex theme. We believe the all-in approach from Big Tech combined with preference by regulators/policymakers as well as consumers for Reliability, Efficiency, Affordability and (for consumers) minimal behavioral changes support investment in solar, battery storage, carbon capture, energy infrastructure, water infrastructure and efficiency (energy, resource and land). This is another reason why we remain positive on Green Capex amid uncertainty and also as we have seen from our September 2024 Global Sustainability Forum and May 2024 Green Capex field trip that managements remain confident in the investment environment for their companies as well as for customers.

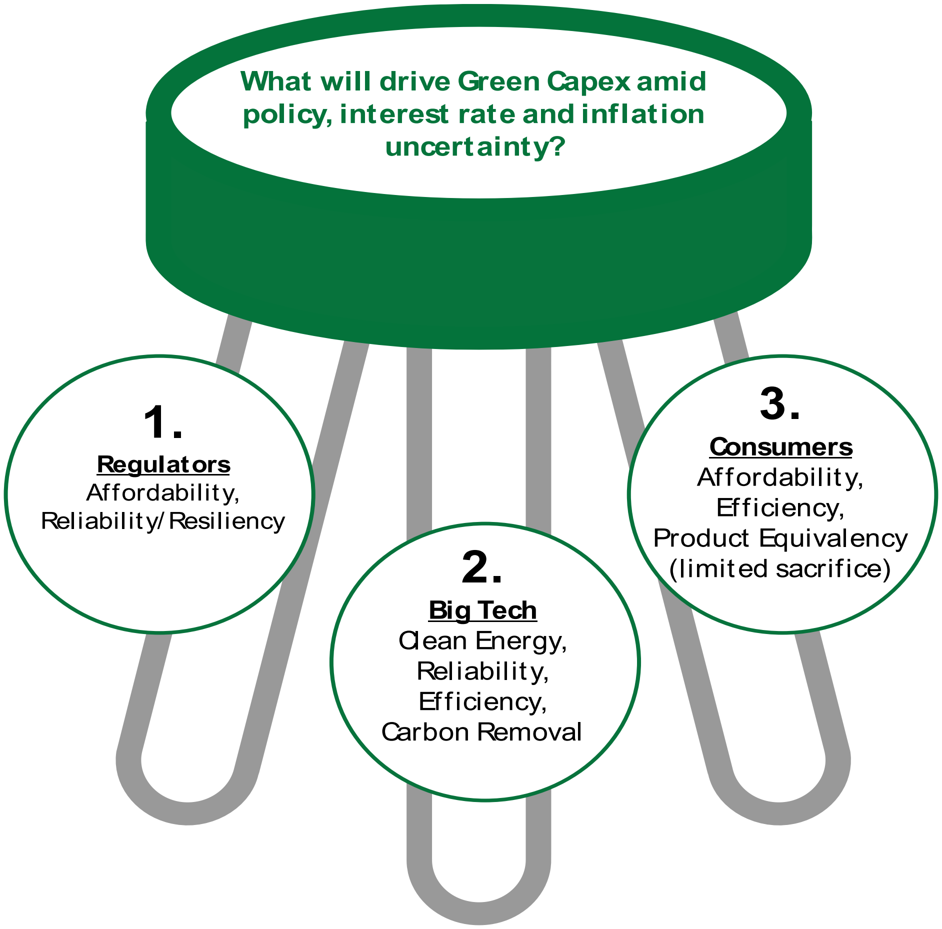
How will Sustainable Investors view increased power use for hyperscalers? We believe Sustainable Investors will look at AI/data centers and the hyperscalers that are operating/investing in them with three key questions:

1. What benefits to Sustainable Development Goals are advanced by AI solutions, and how can the value of these benefits be quantified?
2. What was the power use and carbon footprint of the power use required?
3. Of the low-carbon solutions deployed, what was additional vs. pre-existing or already on track to occur?

We believe currently Sustainable Investors are highly focused on (2) but will become more focused on (3) in the shorter term and (1) over the medium term. We believe additionality is critical for companies to receive credit for their low-carbon solutions. The accounting for carbon footprint may look similar for a company that contracts for nuclear power offsets/power solutions from an existing plant (Amazon-Talen as an example) vs. a company that contracts for nuclear power that would otherwise have not been brought online (Microsoft-Constellation as an example). But from a real-economy impact perspective, there is a difference, and we believe the shift we see to greater pragmatism and nuance among Sustainable Investing will begin to differentiate this.

Exhibit 23: We believe substantial Green Capex will be supported by regulators, Big Tech and Consumers with a focus on Reliability, Efficiency and Product Equivalency (limited pricing premiums, behavioral sacrifice)

Our expectation for three legs of Green Capex stool supported in an environment of uncertainty over policy, inflation and interest rates

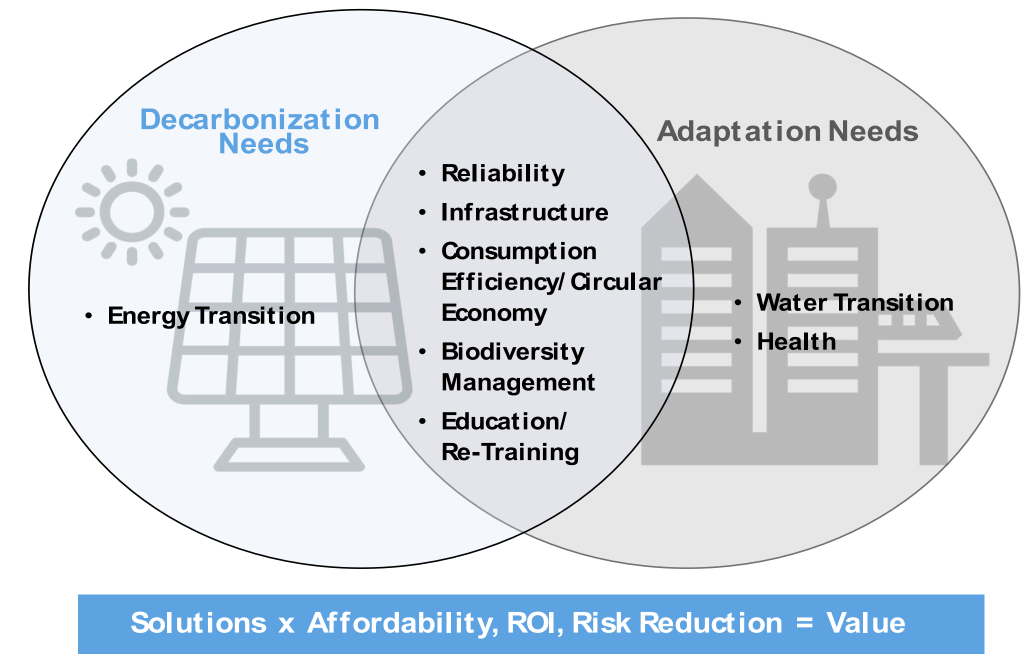


Technologies that will likely be supported

- Solar
- Battery Storage
- Carbon capture
- Efficiency Solutions – Energy, Resource, Land
- Energy Infrastructure
- Water Infrastructure

Source: Goldman Sachs Global Investment Research

Exhibit 24: We continue to see opportunity amid uncertainty in the overlap between Decarbonization and Adaptation



Source: Goldman Sachs Global Investment Research

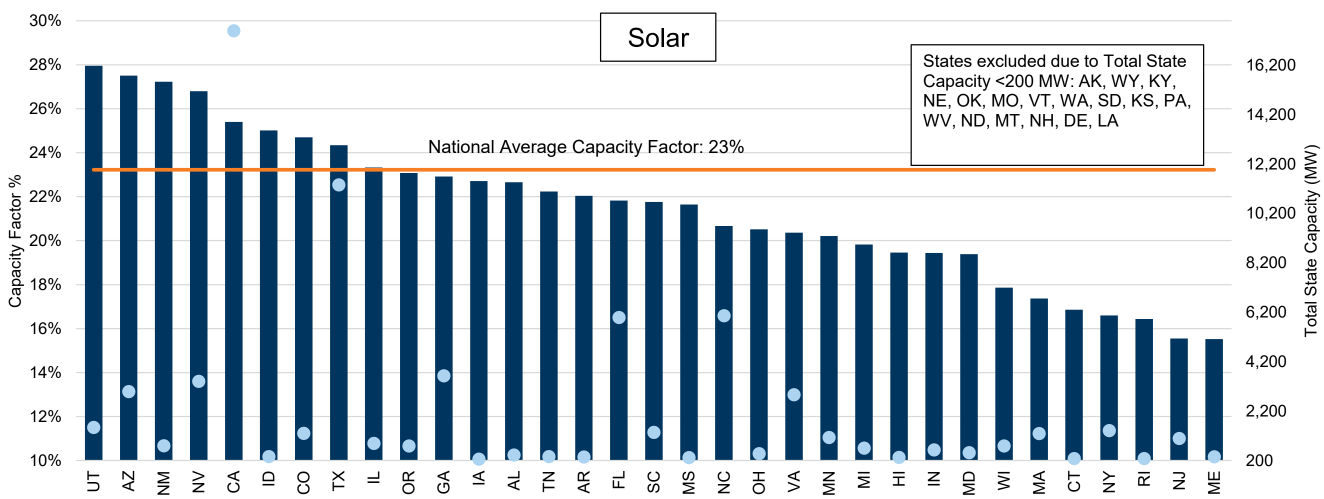
Exhibit 25: We see AI accelerating progress across a range of Sustainable Development Goals (SDGs)

Source: Goldman Sachs Global Investment Research

Appendix: Solar/Wind power intermittency in pictures

Exhibit 28: The southwest US has considerably higher solar capacity factors than the northeast

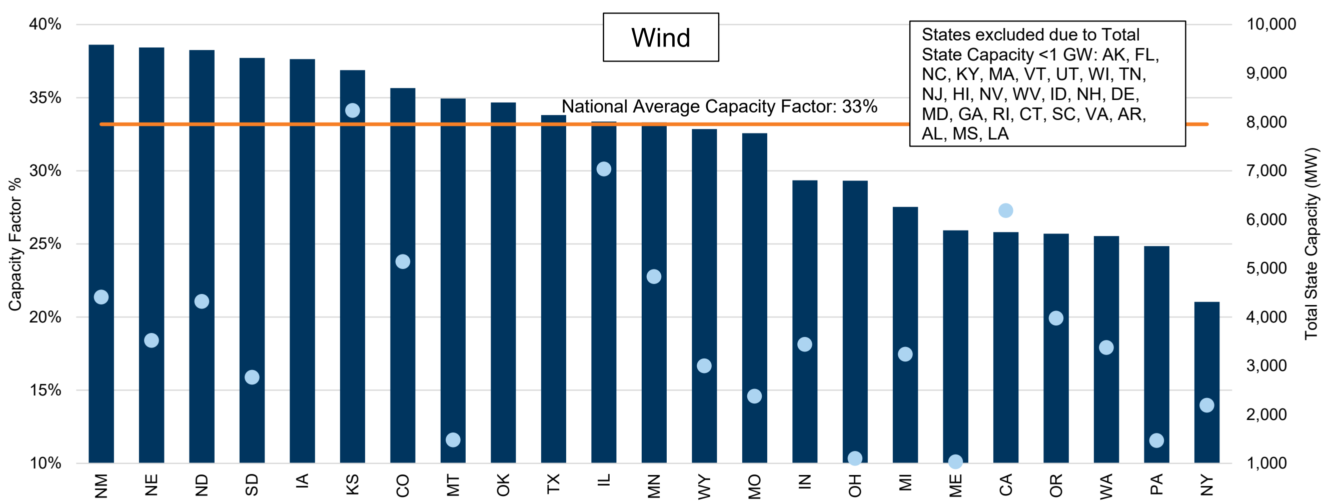
Average statewide capacity factors for utility-scale solar projects for US states with >200MW of total capacity (bars - LHS); Total utility-scale solar capacity (dots - RHS)



Source: EIA, Goldman Sachs Global Investment Research

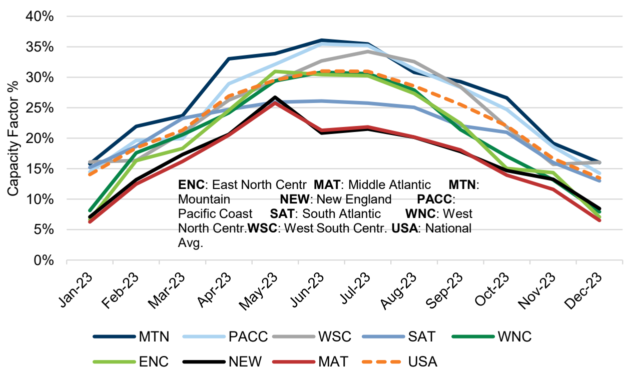
Exhibit 29: The Midwest and Mountain West have some of the best wind resources in the US

Average statewide capacity factors for utility-scale wind projects for US states with >1GW of total capacity (bars - LHS); Total utility-scale wind capacity (dots - RHS)



Source: EIA, Goldman Sachs Global Investment Research

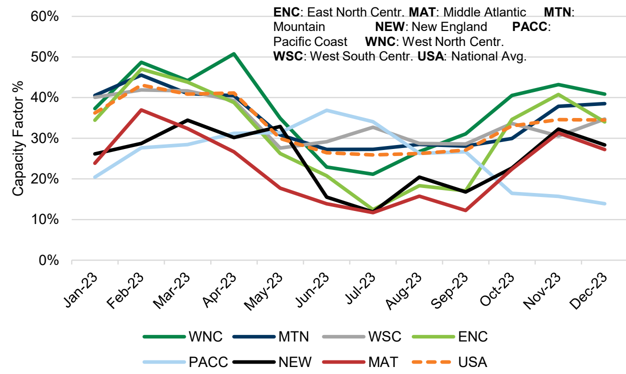
Exhibit 30: Solar intermittency varies by region and by season...



States included in each region: ENC: IL, IN, MI, OH, WI; MAT: NJ, NY, PA ; MTN: AZ, CO, ID, MT, NV, NM, UT, WY ; NEW: CT, ME, MA, NH, RI, VT; PACC: CA, OR, WA; SAT: DE, DC, FL, GA, MD, NC, SC, VA, WV ; WNC: IA, KS, MN, MO, NE, ND, SD; WSC: AR, LA, OK, TX

Source: EIA, Goldman Sachs Global Investment Research

Exhibit 31: ... As does wind



States included in each region: ENC: IL, IN, MI, OH, WI; MAT: NJ, NY, PA ; MTN: AZ, CO, ID, MT, NV, NM, UT, WY ; NEW: CT, ME, MA, NH, RI, VT; PACC: CA, OR, WA; SAT: DE, DC, FL, GA, MD, NC, SC, VA, WV ; WNC: IA, KS, MN, MO, NE, ND, SD; WSC: AR, LA, OK, TX

Source: EIA, Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Brian Singer, CFA, Brendan Corbett, Carly Davenport, Brian Lee, CFA, John Mackay, Neil Mehta, Eric Sheridan, Kash Rangan, James Schneider, Ph.D., Alberto Gandolfi, Tyler Bisset, CFA, Adam Wijaya, John Miller, Derek R. Bingham, Evan Tylenda, CFA, Emma Jones, Madeline Meyer, Varsha Venugopal, Grace Chen, Xavier Zhang, Ati Modak, Joshua M. Frantz, CFA, Michael Smith and Olivia Halferty, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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GS Factor Profile

The Goldman Sachs Factor Profile provides investment context for a stock by comparing key attributes to the market (i.e. our coverage universe) and its sector peers. The four key attributes depicted are: Growth, Financial Returns, Multiple (e.g. valuation) and Integrated (a composite of Growth, Financial Returns and Multiple). Growth, Financial Returns and Multiple are calculated by using normalized ranks for specific metrics for each stock. The normalized ranks for the metrics are then averaged and converted into percentiles for the relevant attribute. The precise calculation of each metric may vary depending on the fiscal year, industry and region, but the standard approach is as follows:

Growth is based on a stock's forward-looking sales growth, EBITDA growth and EPS growth (for financial stocks, only EPS and sales growth), with a higher percentile indicating a higher growth company. **Financial Returns** is based on a stock's forward-looking ROE, ROCE and CROCI (for financial stocks, only ROE), with a higher percentile indicating a company with higher financial returns. **Multiple** is based on a stock's forward-looking P/E, P/B, price/dividend (P/D), EV/EBITDA, EV/FCF and EV/Debt Adjusted Cash Flow (DACF) (for financial stocks, only P/E, P/B and P/D), with a higher percentile indicating a stock trading at a higher multiple. The **Integrated** percentile is calculated as the average of the Growth percentile, Financial Returns percentile and (100% - Multiple percentile).

Financial Returns and Multiple use the Goldman Sachs analyst forecasts at the fiscal year-end at least three quarters in the future. Growth uses inputs for the fiscal year at least seven quarters in the future compared with the year at least three quarters in the future (on a per-share basis for all metrics).

For a more detailed description of how we calculate the GS Factor Profile, please contact your GS representative.

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Goldman Sachs Investment Research global Equity coverage universe

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