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Fourth Industrial Revolution

Artificial Intelligence and the next Critical Mineral Supercycle

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The world is on the precipice of a transformative era driven by artificial intelligence (AI). This powerful technology is rapidly reshaping industries, from healthcare and finance to transportation and manufacturing. As AI continues its exponential growth, it will trigger a surge in demand for commodities.

The algorithms may be the brain, but energy and critical minerals are the brawn of artificial intelligence.

- operating AI models requires substantial computing power, which translates to higher energy demands
- building extensive data centers and manufacturing semiconductor chips is not possible without critical minerals

Exponential growth of AI applications, from autonomous vehicles and smart grids to precision agriculture and advanced robotics, mean AI-driven technologies are already starting to impact every aspect of modern society.

This new growth for commodities is driven by a potent combination of tech companies, consumer and business demand, facilitated by government support.

The large tech companies are betting hundreds of billions on new data centers — Amazon plans to spend almost US$150 billion over the next 15 years on data centers — as they face the challenges to their ambitions of AI growth.

Critical mineral supply chains, already facing mounting pressure with net-zero and energy transition demands, are expected to tighten further.

"The [data center] market is moving a lot faster than supply chains that have historically supported a very physical business have been set up to do… It's a sprint. Its a sprint that requires all the capital in the world."

— Brian Venturo, co-founder of the cloud-computing unicorn CoreWeave

"I've never seen any technology advance faster than this… I think we really are on the edge of probably the biggest technology revolution that has ever existed"

— Elon Musk, CEO Tesla

"The surge in electricity demand that's coming… not only the energy transition but data centers, AI. Is the capacity going to be there? That used to be a developing world question. Now it's also a developed world question"

— Dan Yergin, vice chairman S&P Global

What's in this report

The AI revolution

The AI (Artificial Intelligence) revolution refers to the transformative impact of AI technologies across industry and human society, including the rapid advancement of machine learning, automation, data analysis and natural language processing.

As a sign of the times, in 2024, NVIDA, one of the world's leading chipmakers, became a proxy for AI demand and soared to become the third largest company in the world behind Apple and Microsoft, with a market cap of $2.2 trillion.[1]

The challenge is that NVIDIA's chips (used across AI, crypto, data centers) need an enormous amount of energy. So, just as cardboard box companies are an investment play on Amazon, we explore which critical minerals are needed to build and power AI — and gain exposure to the next tech revolution.

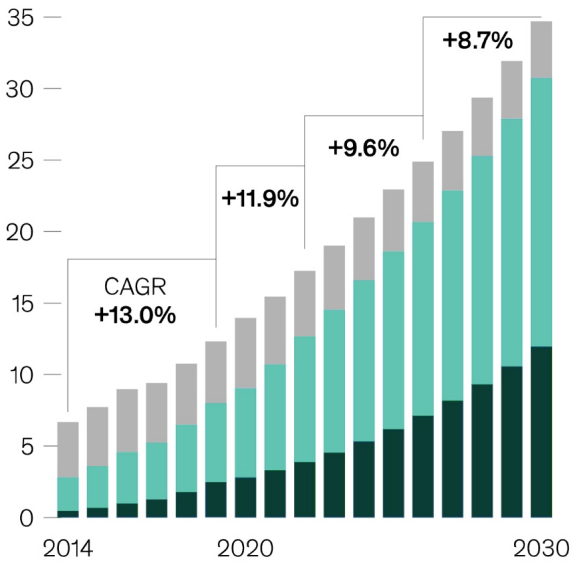
AI Energy Demand

McKinsey estimates[2] the energy demand from data centers will explode from 17GW in 2022 to 35GW by 2030, growth of 10% a year. To put this in context, US grid planners have been forecasting a mere 0.5% annual growth rate over the last decade.[3]

And this growth is already well underway with annual peak demand growth in the US up to at least 0.9% in 2023.

- 2,700 data centers in the US account for more than 4% of the country's total electricity in 2022, expected to reach 6% by 2026[4]
- 1,240 data centers in the EU account for more than 4% of the continent's total electricity in 2022[4]
- China expects electricity demand in the country's data centre sector to double to 400 TWh by 2030, compared to 2020[5]

Data center power consumption, by providers/enterprises,[1] gigawatts



Note: 'Demand is measured by power consumption to reflect the number of servers a data center can house. Demand includes megawatts for storage, servers, and networks
Source: McKinsey & Company

Chart 1 US data center demand is forecast to grow by some 10% a year until 2030

Estimates by researcher Alex de Vries[6] suggest the energy consumption of a single Nvidia DGX A100 server is between 3kW-6.5kW, as much as several US households combined, while the H100 version of the chip can consume more than 10kW across an entire server with multiple chips. NVIDIA shipped 100,000 of these chips in 2023, and that could increase to 1.5 million chips a year by 2027.[7] The US CHIPS Act of 2022 is super charging this trend with US$39 billion in manufacturing incentives and 25% investment tax credit for capital expenses.

The challenge is that electricity grids across the world are already under significant strain after decades of under investment. The not-for-profit international regulatory authority, NERC, in charge of US and Canada grid reliability, warns most regions across the US risk blackouts over the next 10 years.[8]

Nammo, one of Europe's largest manufacturers of military ammunition, is reportedly struggling to expand its largest factory in Norway to produce ammunition for the Ukraine war due to the energy requirements of a nearby data centre that lists TikTok as its main customer.[9]

> "We are facing an absolute step change in the risk environment surrounding reliability and energy assurance. In recent years, we've witnessed a decline in reliability, and the future projection does not offer a clear path to securing the reliable electricity supply that is essential for the health, safety and prosperity of our communities"
>
> — John Moura, [North American Electric Reliability Corporation (NERC) director of Reliability Assessment and Performance Analysis

The net-zero energy challenge

As energy demand is expected to surge, so too governments and companies, especially in the West, still aim to meet their net-zero targets.

For example, the EU wants data centers to be carbon neutral by 2030, and Apple, Google, Meta all pledge to be carbon neutral by 2030.

Without traditional base-load fossil fuels, such as coal-fired power stations, critical minerals take a more important role in meeting energy demand.

So, how will energy supply be increased to meet this new demand?

Nuclear Energy and Uranium

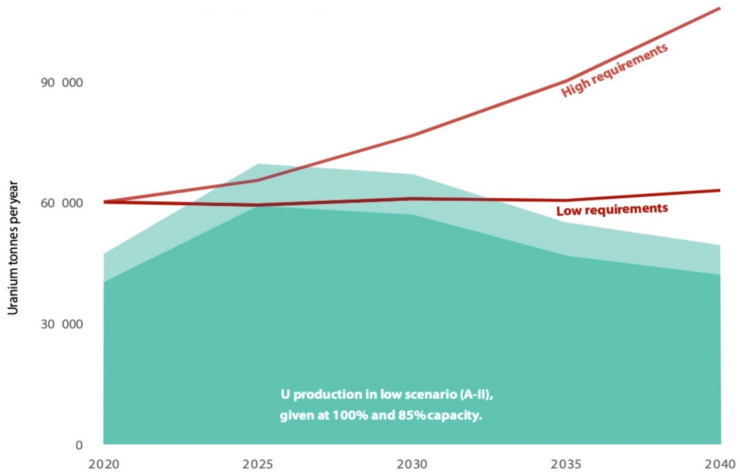
Tech company demand

The US tech giants are increasingly turning to nuclear power as a solution, for example:

- Amazon Web Services (AWS) has bought a 960MW data centre powered by a a nuclear power plant in Pennsylvania for US$650 million
- Microsoft has agreed to buy nuclear power to cover up to 35% of the energy needs for its Virginia data centers
- US Energy Secretary Jennifer Granholm announced a US$1.52 billion loan to restart the Palisades nuclear plant in Michigan with an interview where she said conversations with big tech companies need "to accelerate, because this [AI] demand for power is only going up"
- OpenAI CEO Sam Altman has in a nuclear startup called Oklo, which is working on SMRs
- Green Energy Partners, a US data center and energy developer, has proposed 30 new data centers powered by a new 1.6GW Surry Nuclear Power Plant in southeastern Virginia

And any new nuclear power will need uranium to power it. As our recent report, The Uranium Bull Market and Coming of the Second Atomic Age, warns: uranium is at the start of a 10-year bull market as supply struggles to meet demand, expected to expand 28% by 2030 and nearly 200% by 2040.

Chart 2 **Projected world uranium production capability to 2040 (supported by identified resources at a cost of <USD 130/kgU compared with reactor**



Note: Figure a) illustrates the A-II case (production capability of existing, idled and committed centres supported by RAR and inferred resources recoverable at <USD 130/kgU). Figure b) illustrates the B-II case (production capability of existing, idled, committed, planned and prospective centres supported by RAR and inferred resources recoverable at <USD 130/kgU). Both figures illustrate two production capacities per case: the light shaded area represents 100% of production capacity, the darker shade represents 85% of the production capacity. Note that figures do not include the secondary supply forecast, which has in the past filled the gap between primary production and demand
Source: IAEA, NEA, Uranium 2022: Resources, Production, Demand

It is important to note, many of the current projections for nuclear power and uranium demand are *not* factoring in new AI demand.

For clarity, the US Department of Energy does not list uranium as a critical mineral due to a technicality, but with fast-tracked US plans to reduce purchases of enriched uranium from Russia, we are treating this listing as exactly that - a technicality.

Uranium supply vs demand

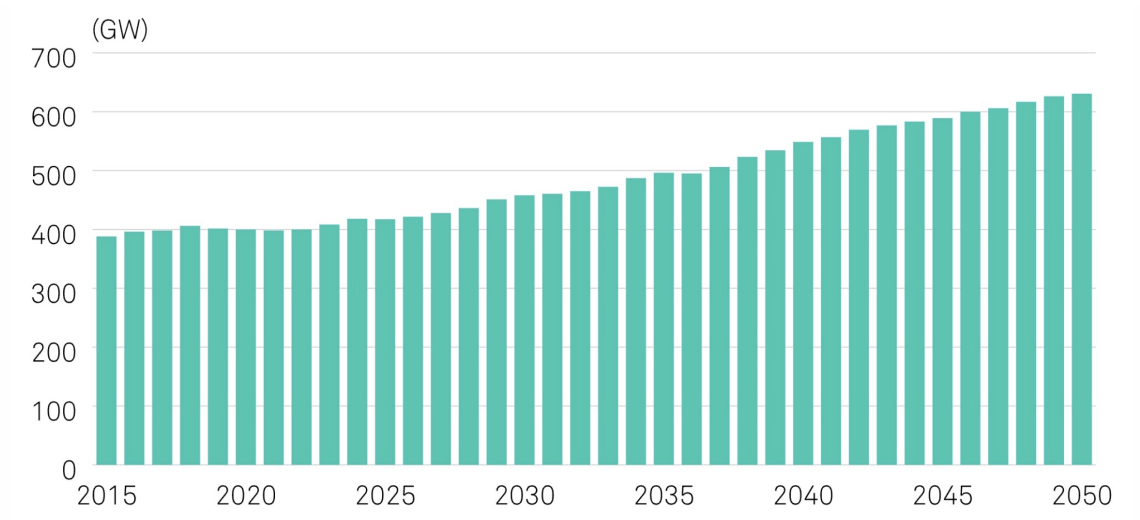
Global concerns over uranium supply include:

- investment in uranium exploration and mine development has fallen steadily over the last 10 years, especially after the Fukushima accident in 2011
- Western sanctions on Russia have complicated the import of Russian uranium, with threats of banning imports into the US completely
- Kazatomprom, the world's largest uranium producer (accounting for 23% of global supply in 2022), has now warned production will be 20% below levels allowed by permits in 2024, with production impacted possibly into 2025[10]

In the meantime, announcements for new nuclear power projects are at a historic high, for example:

- more than 20 countries, across 4 continents, have pledged to triple global nuclear capacity by 2050
- China plans at least 150 new reactors in the next 15 years, at a cost of more than US$440 billion more than the rest of the world has built in the past 35 years
- India announced this year, plans to increase nuclear capacity from 6780 MWe to 22,480 MWe by 2031, with nuclear accounting for nearly 9% of India's electricity by 2047
- according to the International Atomic Energy Agency (IAEA), nuclear energy capacity is set to expand anywhere from 24% to 100% by 2050, depending on use case scenario. And once these reactors are switched on, they will be using uranium all day, every day for 60–80 years

Chart 3 Global nuclear capacity forecast

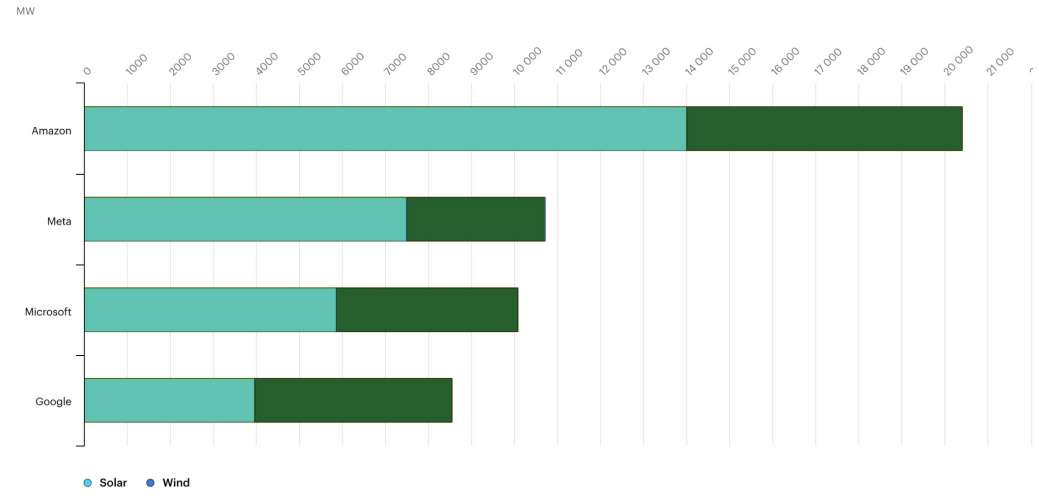


Source: S&P Global Commodity Insights

Renewable Energy and Critical Minerals

Amazon, Google, Microsoft and Meta are the four largest purchasers of corporate renewable energy agreements, contracting more than 50GW by 2023, primarily for data centers — the same power generation as Sweden[11].

Chart 4 Top corporate off-takers of renewable energy power purchase agreements, 2010-2022

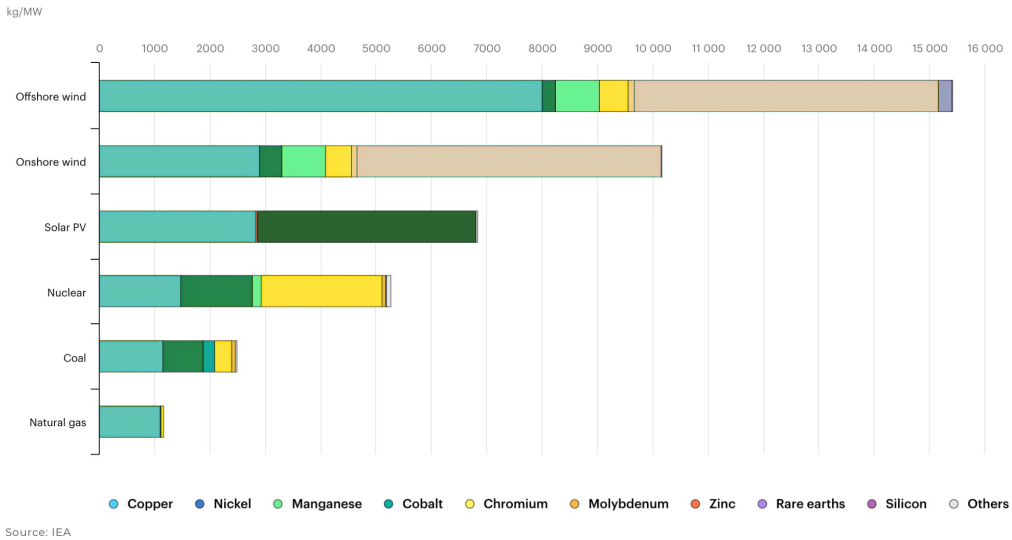


Source: IEA

- Amazon is the world's largest corporate purchaser of renewable energy for the fourth year in a row
- Google claims to have achieved 100% annual renewable energy matching every year since 2017
- Apple's data centre in Viborg, a 45,000-square-meter facility, is run entirely on renewable energy

Data center owners are not just signing power purchase agreements, but building their own renewable energy plants. And, compared to fossil fuels, renewable energy is extremely critical mineral intensive.

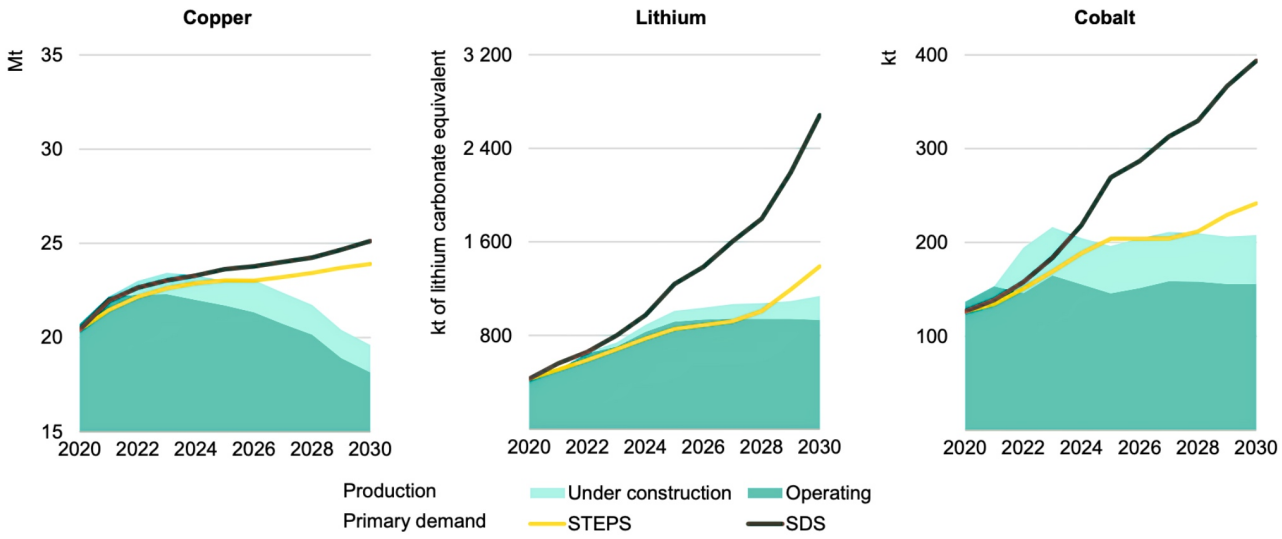
Chart 5 Minerals used in clean energy technologies compared to other power generation sources



Source: IEA

However, many of these critical minerals are already facing significant supply and demand concerns in the race to net-zero over the next few decades.

Chart 6 Committed mine production and primary demand for selected minerals



Notes: Primary demand is total demand net of recycled volume (also called primary supply requirements). Projected production profiles are sourced from the S&P Global Market Intelligence database with adjustments to unspecified volumes. Operating projects include the expansion of existing mines. Under-construction projects include those for which the development stage is indicated as commissioning, construction planned, construction started or preproduction. Mt = million tonnes
Source: IEA analysis based on S&P Global (2021)

The challenge is that renewables to not offer base-load electricity capacity, essential for data centers that need to run 24/7. For example, solar doesn't work when the sun doesn't shine, or wind doesn't work when the wind doesn't blow.

Electric Batteries: Lithium, Rare Earths, Nickel, Graphite, Cobalt, Manganese

Many data centers already use electric batteries for emergency backup power, or UPS (uninterruptible power supply), with a move away from traditional lead-acid batteries to lithium-ion[12]. With the rapid expansion of data centers, the global data center UPS market is estimated to increase from US$6.1 billion in 2022 to US$9.1billion in 2028[13].

This will impact demand across a variety of critical minerals, in particular:

- cobalt
- graphite
- lithium
- nickel
- manganese
- rare earths
- fluorspar

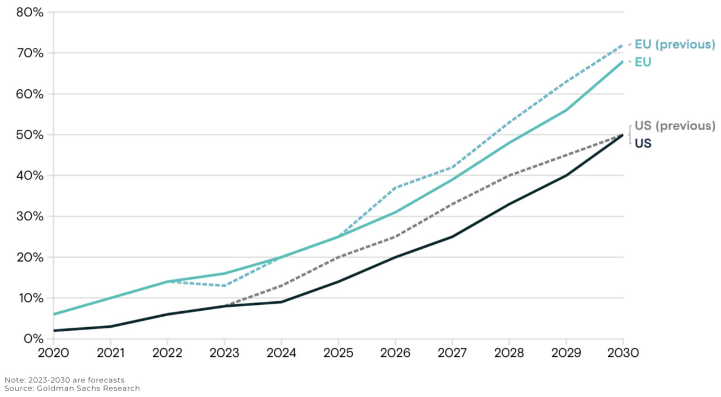
> "Batteries are a big part of the game. The market is moving more and more towards Li-ion batteries. Around five or ten years ago, it was questionable. But now, the market is pretty convinced"
>
> — Mustafa Demirkol, Vice President of Data Centre Systems at Schneider Electric Performance Analysis

And rare earth elements also have a variety of direct uses in data centers, for example:

- **Indium**: used in the production of transparent conductive coatings for touchscreens and displays, which may be present in data center equipment
- **Tantalum**: tantalum capacitors are used in electronic devices within data centers due to their high capacitance and stability
- **Gallium**: used in semiconductor materials and devices, including those used in data processing and superconducting technologies
- **Germanium**: used in fibre optics, including in data centers, and in semiconductors
- **Neodymium**: used in permanent magnets and data center drive boards
- **Yttrium**: used in conjunction with barium and copper to create the most common type of high-temperature superconductor (YBCO)

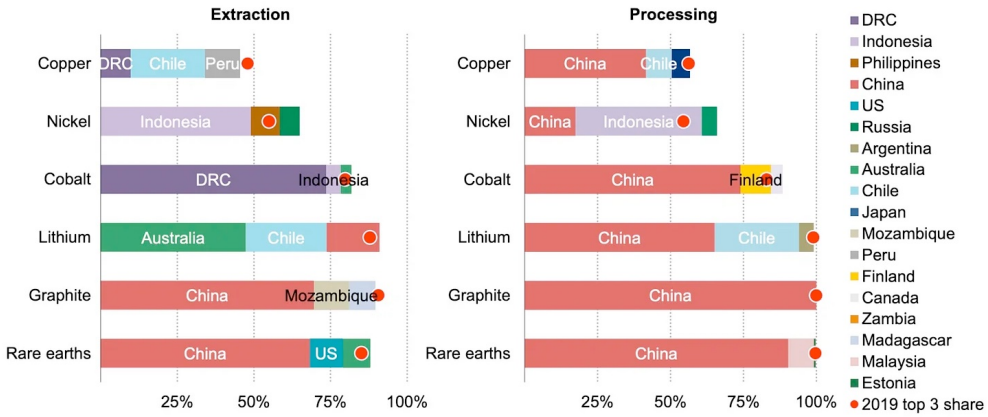
This demand is in addition to the expected soaring demand for critical minerals in the electric batteries needed to power electric vehicles, even with anticipated disruption due to higher interest rates and inflation[14].

Chart 7 Battery electric vehicle penetration rates, share of passenger car sales



The challenge for many of these critical minerals is securing supply, with mining and processing largely concentrated in a handful of countries after decades of lack of investment elsewhere.

Chart 8 Share of top three producing countries in total production for selected resources and minerals, 2022



Notes: DRC = Democratic Republic of the Congo. Graphite extraction is for natural flake graphite. Graphite processing is for spherical graphite for battery grade.
Source: IEA analysis based on S&P Global, USGS (2023), Mineral Commodity Summaries and Wood Mackenzie

Copper and the Electric Grid

Copper has the highest electrical conductivity rating of all non-precious metals, making it essential for both:

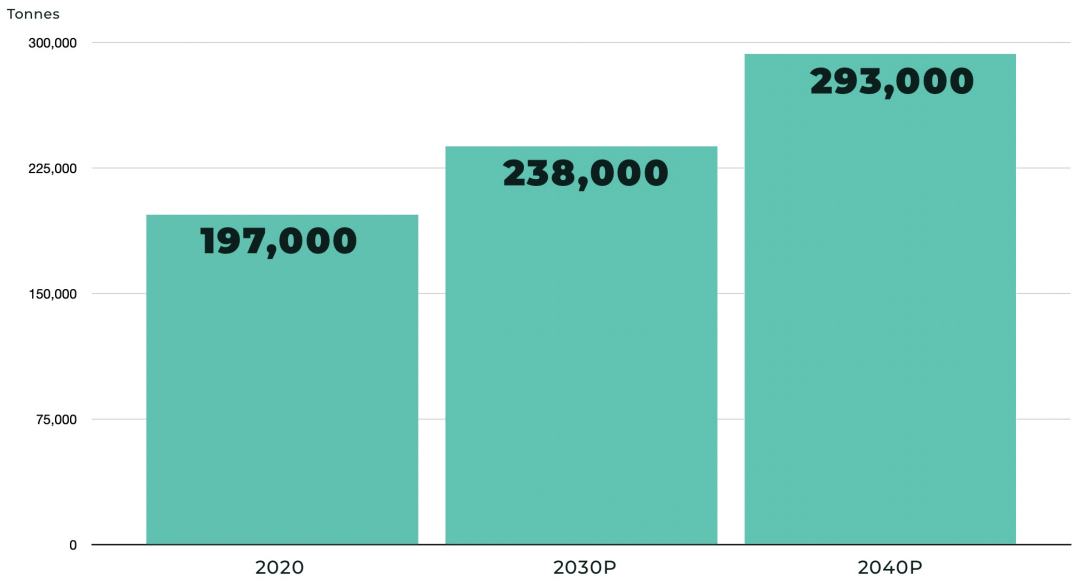
- expansion of data centers, for example, as electric connectors, busbars, heat exchangers, etc
- expansion of electric grids to meet new demand

Morgan Stanley forecasts demand from data centers will grow rapidly, accounting for up to 3.3% of copper demand by 2027[15]. Goldman Sachs estimates copper demand for data centers in the US will increase from 200,000kt in 2023 to as much as 400-500,000kt by 2024[16].

By 2030, demand for copper from data centers could rise to 2.5mt a year[17]. Microsoft's US$500m data centre in Chicago required 2,177 tonnes of copper for construction.

And these numbers are just for the US.

Chart 9 Copper consumption in North American Data Centers[18]



Source: Copper Development Association, BlueWeave Consulting

To meet net-zero demands, estimates suggest the global electricity grid will need to double in size, costing US$21 trillion[19].

The IEA forecasts annual copper demand for electricity grids will need to double from 5MT in 2020 to 10MT by 2040. BloombergNEF estimates approximately 427MT of copper will be needed by 2050, accounting for more than a third of global copper demand by mid-century — more than x8 as much as wind turbines, solar panels and energy storage combined.

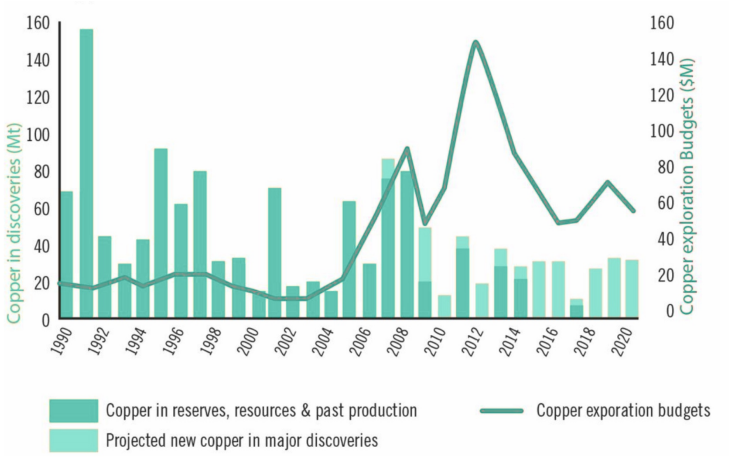
And, just as with uranium demand projections, many of these estimates are not yet factoring in AI demand.

Copper supply shortfall

Global supply of copper, essential for a host of industries and crucial to green technology and the global energy transition, is expected to face a supply gap of nearly 10 million mt within the next ten years, according to our recent report “Copper, at the centre of the metal supercycle”

Years of underinvestment by producers means primary copper supply is ill-equipped to meet the approaching tidal wave of new demand. There aren’t enough mines, there aren’t enough near-term producers, there aren’t enough high-grade ore bodies. For example, Chile’s copper exports were at their lowest in 6 years in 2023, with warnings that output may fall further.

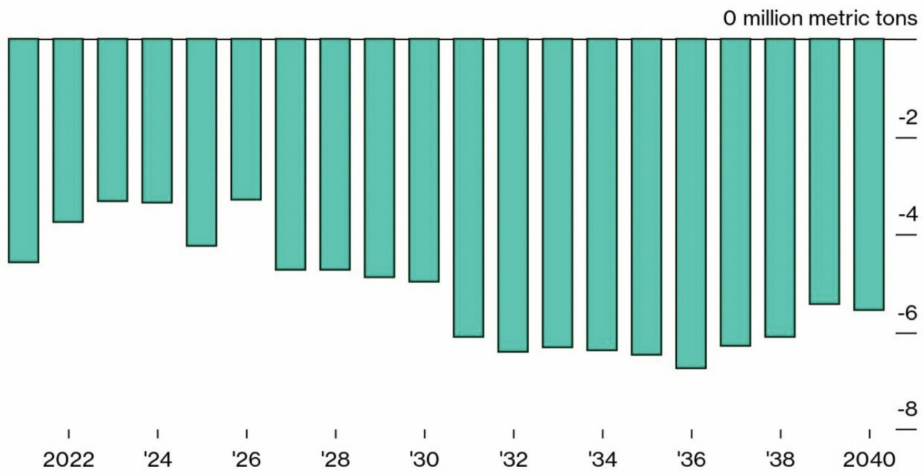
Chart 10 Copper discoveries



> "If you look at the demand that is coming from data centers and related to that from AI, that growth has suddenly exploded. [An extra one million tonnes per annum deficit is] on top of what we have as 4-5 million tonne deficit gap by 2030”
>
> — Saad Rahim, chief economist at Trafigura

By 2035, the copper supply shortfall could be as much as 9.9MMt, 20% less than what is needed to meet global 2050 net-zero goals. To put this figure in context, the biggest shortfall between 1994-2020 was 2.5%.[20]

Chart 11 Forecast Refined Copper Supply Deficit

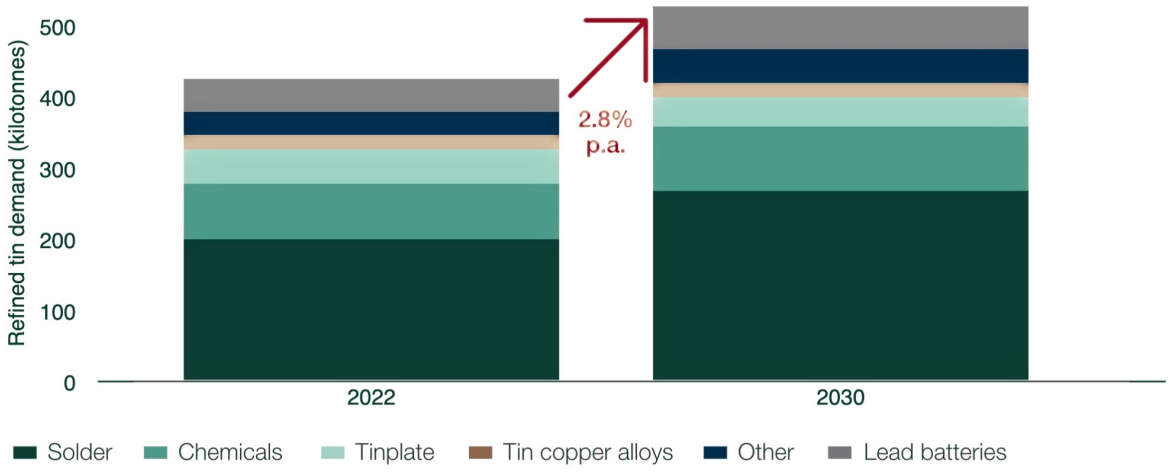


Note: excludes recylcing supply. Best-case supply growth scenario
Source: BloombergNEF

Tin, the solder that binds

Often overlooked, tin is listed as a critical mineral in the US for good reason. Almost 50% of tin is used as solder in circuit boards, essential for semiconductors, as well as mobile phones and data centers. It is also essential to build solar panels and electric batteries.

Chart 12 Refined tin demand, kilotonnes

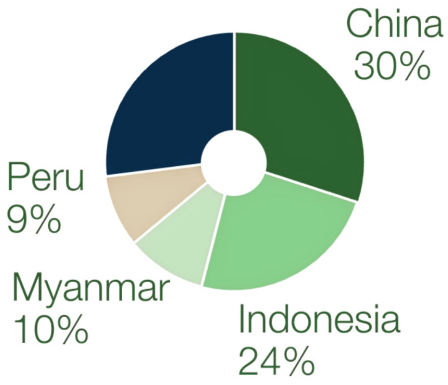


Sources: "Roskill Tin: Outlook to 2030 (12th edition)" and "Tin - the forgotten foot soldier of the energy transition." WoodMackenzie, accessed November 2023.
For illustrative purposes only

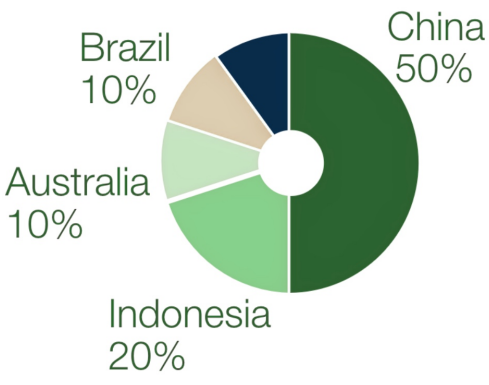
The International Tin Association estimates $1.4 billion is needed to deliver 50,000 tpa more tin by 2030, yet supply, instead expanding, is tightening with global refined tin production in 2023 declining 2.1% from 2022 to 370,100t.

The challenge is that 90% of reserves are located in regions where geopolitical risk is ranked as high, in particular, Indonesia and Myanmar.

Top tin mining countries



Top tin refining countries

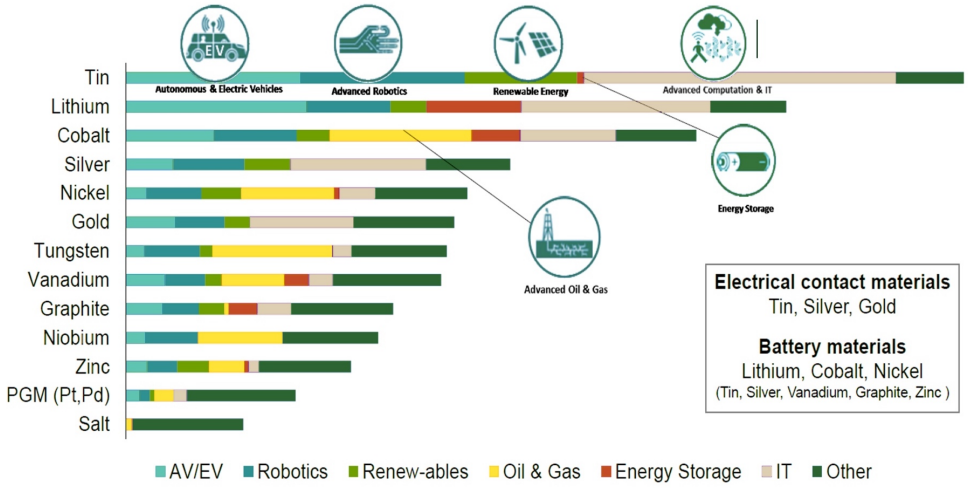


Sources: U.S. Geological Survey, Mineral Commodity Summaries, January 2023; A Roskill, "Tin: Outlook to 2029", July 2021; Bloomberg, December 2022; WoodMackenzie, "Tin - the forgotten foot soldier of the energy transition", April 2021

The size of the industry, relative to other major metals such as copper or nickel, is small, but it's importance for current and future technologies, such as AI, as well as the "electrification of everything" in the energy transition, cannot be underestimated.

A 2018 study by MIT and Rio Tinto found that tin is the metal most impacted by new metals[21].

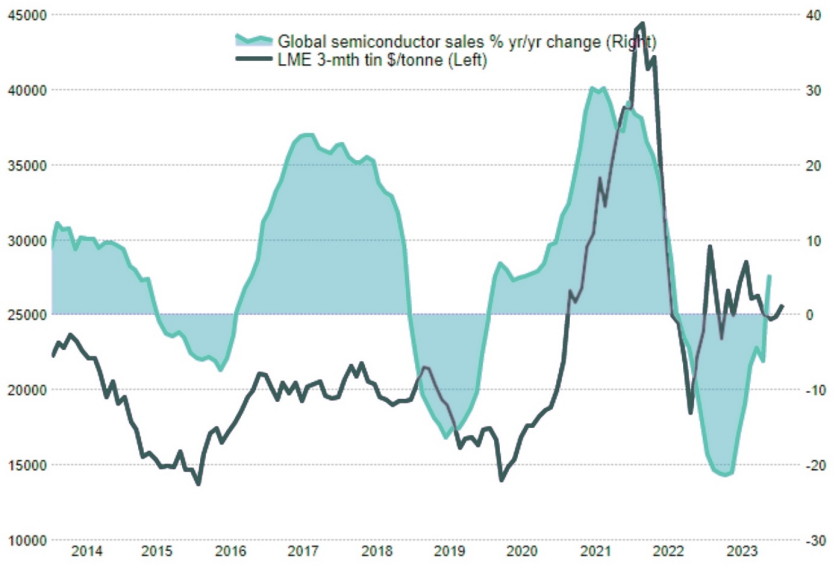
Chart 13 Metals most impacted by new technology



Sources: MIT Energy Initiative, Rio Tinto; 2018

Governments are starting to take note of the possible opportunities and challenges, for example, both Australia and Indonesia recently added tin to their national list of critical minerals.

Tin's importance for semiconductors and electronics was highlighted during the Covid pandemic, when tin producers across Asia and South America were hit with lockdowns — output from the world's top 10 tin producers fell by 13% between 2020-21 — but sales of consumer electronics soared as populations were forced to stay and work from home. Global semiconductor sales are a good proxy for tin demand as solder.



Source: LSEG Datastream

And it's not just semiconductors:

- an electric vehicle (EV) uses an estimated x3 more tin than an internal combustion engine due to the significant increase in electronic components that need solder[22]
- tin is essential for solar panels, as a "solar ribbon", that is a copper wire coated in tin solder connecting each solar cell
- and it's the same across the energy transition, with the "electrification of everything", from wind turbines to expansion of electric grids, EV chargers to hydro energy

> "The energy transition is the biggest long-term demand driver of tin. As this is in effect a switch from energy delivered via a pipe to energy delivered via a cable it will require increasing volumes of tin to join it all up"
>
> — Wood MacKenzie, Tin – the forgotten foot soldier of the energy transition

Tight tin supply

In theory there are plenty of reserves of tin, but there are two major concerns over future growth:

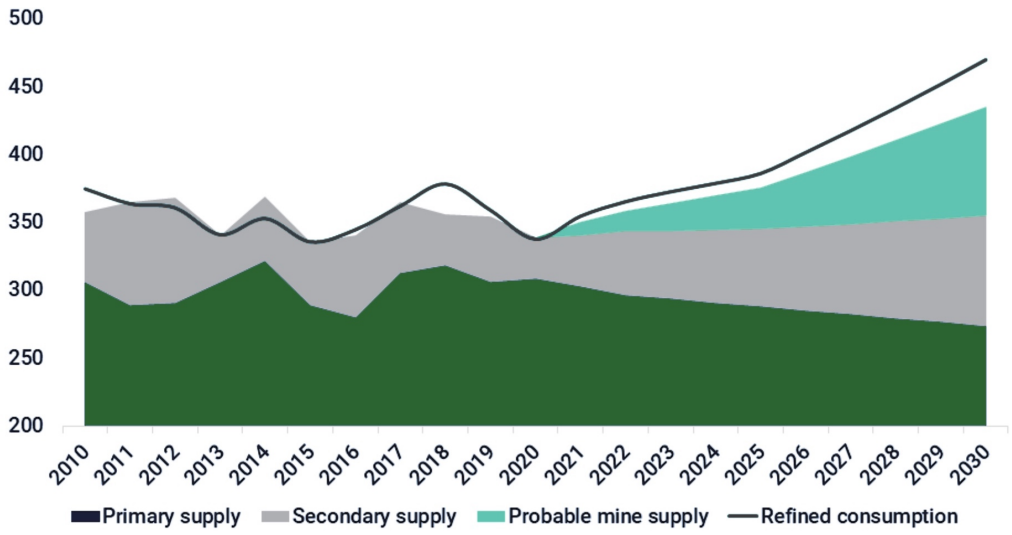
- tightening supply and lack of investment in new projects
- geopolitical risk over current concentrated supply

In particular, the concentration of tin's supply chains and reserves in volatile regions has meant investors are cautious about deploying significant capital in new projects.

- Myanmar is the world's third largest producer of tin ore, but due to China's dependence on its exports, it has significant leverage over the market. In 2023, Myanmar's United Wa State Army, which controls Wa State (approx 10% of global supply) ordered a ban on all mining and processing operations for an extensive audit. The ban was lifted in January 2024 (with an increased export tax of 30%) — except for the Man Maw mine, the largest in the region. There is also an ongoing insurgency against the military government, with the acting president warning the country is in danger of falling apart after recent military losses
- Indonesia is the second largest miner in the world and exported 78,000mt of refined tin in 2023, approximately 20% of global demand. But a temporary government ban on exports of refined tin, due to a change in permitting, caused exports to collapse. It is a similar strategy used by the Indonesian government to push resource nationalism over their nickel production. It is expected that exports will resume but the risk — or threat — from Indonesia to global supply is under the spotlight
- Peru, Bolivia, and Brazil make up an estimated 16% of world tin mine production. The US imported 27% from Peru and 21% from Bolivia in 2022. However, South American supply is concentrated into a handful of major mines which are vulnerable to local protests
- Less than 4% of global tin mine production comes from the Democratic Republic of Congo (approx 9% of China imports), Uganda, Burundi, Rwanda and Nigeria. Mostly artisanal, small-scale mines, the supply is also vulnerable to local conflicts, from Kivu's ongoing conflict to sectarian conflict and lawlessness in Nigeria's Middle Belt

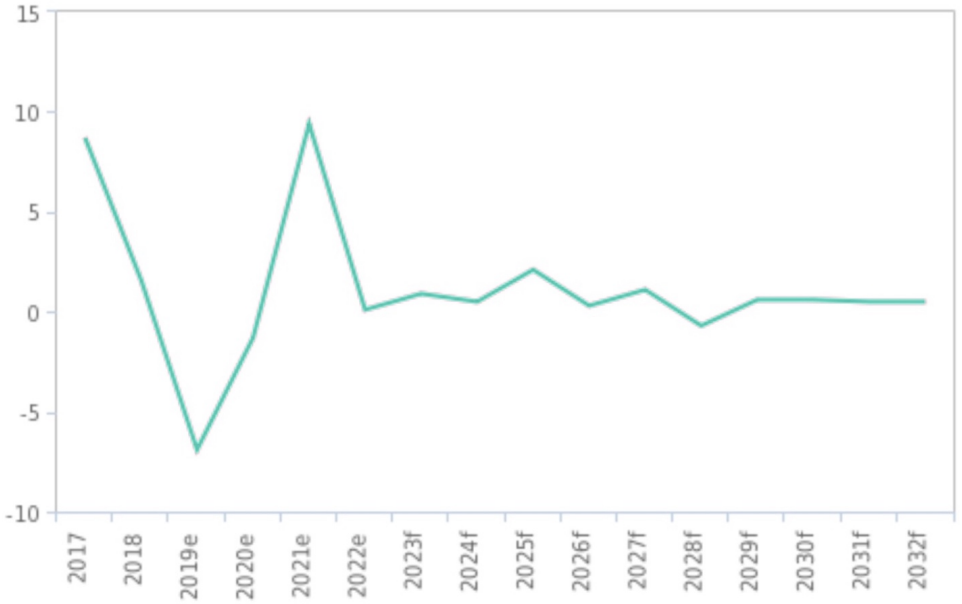
In the meantime, the International Tin Association (ITA) estimates just 11 new projects (and one expansion) are likely to be commissioned by 2030, providing an additional 35,000mt.[23]

Chart 14 Supply-demand balance for tin in kilotonnes, 2010-30



Source: Wood Mackenzie, ITA, USGS, Metallum Commodity Consulting

Chart 15 Global tin mine production growth % year-on-year, 2017-2032



NotE: e/f = estimate/forecast.
Source: BMI

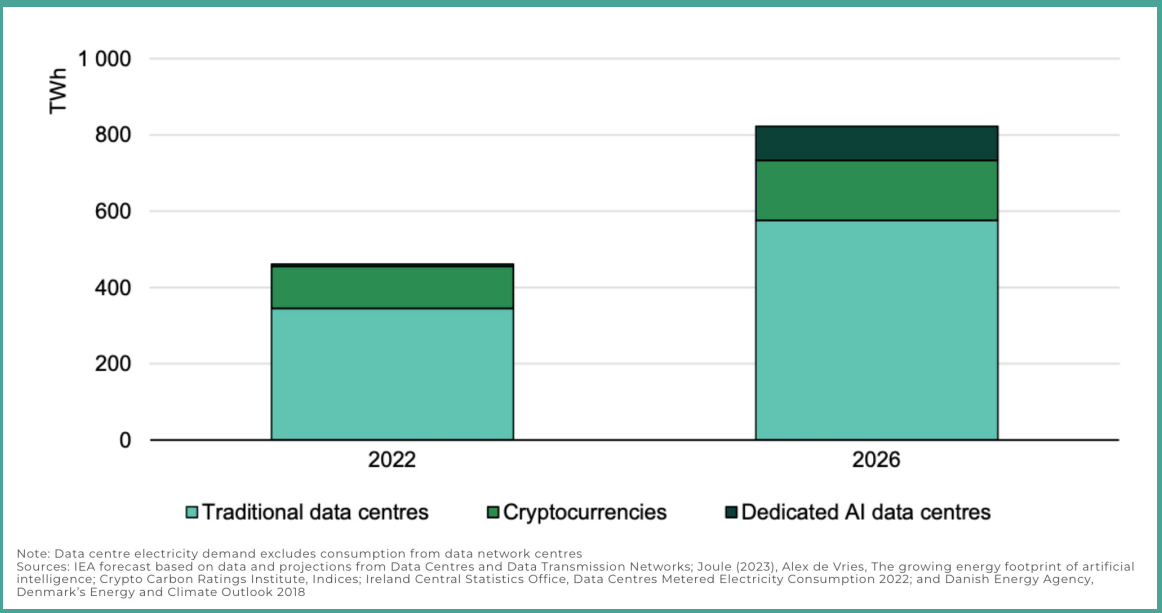
Crypto, net-zero and a fragile electricity grid

It's not just AI that is expected to put unprecedented demands on data centers and global electricity grids. Global energy use in mining bitcoin doubled in 2023, with the US one of the largest bitcoin miners in the world.

Electricity demand associated with US cryptocurrency mining operations in the US represents from 0.6%-2.3% of US electricity consumption. This is expected to increase further if bitcoin prices continue to rise.

Data source: U.S. Energy Information Administration
Note: The representative size shown for a facility is based upon estimates contained in our bottom-up approach. Number in brackets represents the number of facilities.

Chart 16 Estimated electricity demand from traditional data centre, dedicated AI data centers and cryptocurrencies, 2022 and 2026, base case



Note: Data centre electricity demand excludes consumption from data network centres
Sources: IEA forecast based on data and projections from Data Centres and Data Transmission Networks; Joule (2023), Alex de Vries, The growing energy footprint of artificial intelligence; Crypto Carbon Ratings Institute, Indices; Ireland Central Statistics Office, Data Centres Metered Electricity Consumption 2022; and Danish Energy Agency, Denmark's Energy and Climate Outlook 2018

THE OREGON GROUP PROJECTIONS

McKinsey forecasts generative AI has the potential to generate value equivalent to $2.6 trillion to $4.4 trillion in global corporate profits annually.

Any restrictions on data center expansion, as NVIDIA's stock price highlights, are unsustainable in the face of the scale of the market growth predicted.

And this growth is driven by consumer and business demand on the tech corporations, facilitated by governments, all who want to maintain their global cutting edge.

And, as we have highlighted throughout this report, these growth figures are largely only for the US, not China, Japan, Europe, India, and the rest of the world. For example, China has announced it plans to plans to force foreign-made chips out of its telecom systems and develop its own.[24]

Such financial incentives, we believe, will be the new driving force behind renewable energy, electric batteries — and especially nuclear power. The reason we believe nuclear power will be so important is the challenge of intermittency in renewable energy, that will struggle to meet the demands of new energy-intensive AI chips.

There are, of course, other options to meet AI energy demands especially in the immediate term, and we expect fossil fuels to remain important, in particular natural gas, with governments and companies across the West already investing heavily in gas power plants.

However, the combined incentives of significant corporate profits, technological breakthroughs, environmental restrictions, and consumer pressure, will mean many obstacles to investment across the sector, that ironically stand in the way of net-zero, will be pushed aside.

And the supercycle has already started as tech companies rush to keep up with demand. There will be corrections but, for the next 10 years, the bottom of the AI supercycle is now.

The Bottom Line

Critical Minerals are an AI (and crypto) play.

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