HEARING ON CHINA'S DOMESTIC ENERGY CHALLENGES AND ITS GROWING INFLUENCE OVER INTERNATIONAL ENERGY MARKETS

HEARING

BEFORE THE

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

ONE HUNDRED NINETEENTH CONGRESS
FIRST SESSION

THURSDAY, APRIL 24, 2025

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WASHINGTON: 2025

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THURSDAY, APRIL 24, 2025

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

Washington, DC

The Commission met in Dirksen Senate Office Building, Room 419, and via videoconference at 9:30 a.m., Commissioner Carte Goodwin and Commissioner Hal Brands (Hearing Co-Chairs) presiding.

OPENING STATEMENT OF COMMISSIONER CARTE GOODWIN HEARING CO-CHAIR

COMMISSIONER GOODWIN: Good morning, and welcome to the fifth hearing of the U.S.-China Economic and Security Review Commission's 2025 report cycle. I want to begin by welcoming our newest Commissioner, Livia Shmavonian, who has been appointed to the Commission just last week by Senator Schumer. So welcome aboard.

I also want to extent my appreciation to everyone joining us today and the witnesses for all the hard work they put into their testimony. Thank you to the Senate Foreign Relations Committee for use of this hearing room today, as well as the Senate Recording Studio for their assistance in livestreaming this event.

For those attending in person or watching online, witness testimonies and a transcript of today's proceedings will be available on the Commission's website.

Today's hearing will examine China's domestic energy challenges, both market-based challenges and those rooted in policy choices. We will also look at supply chain and cybersecurity risks posed by China's growing influence over clean energy and transmission infrastructure.

Since 2020, China's demand for electricity has outpaced its economic growth, a trend that seems set to continue.

The electrification of China's energy-intensive manufacturing sector, movement of households from coal-based heating to electric climate control, and the rapid rise of electric vehicles have all put pressure on China's energy infrastructure.

Even as this pressure on China's electric grid builds, oil and natural gas still account for over 25 percent of China's primary energy use. And while China may have diversified its suppliers, it is still heavily reliant on imports through the Malacca Strait. While these imports have declined for the first time in 20 years, oil remains central both to Chinese domestic industry and China's military, making it China's most significant resource vulnerability in the event of a crisis scenario.

China's concerns about addressing energy security are driving a wedge between what it is doing and what it has been saying. China positions itself as a climate champion, but in reality it has been the world's largest annual emitter of carbon dioxide for almost 20 years. As of two years ago, China had emitted more carbon historically than the entire European Union. Despite building two-thirds of solar and wind capacity under construction globally and bringing nuclear power online faster than any other country, China's coal consumption also continues to grow. China has made misleading promises to stop financing coal-fired power plants internationally, yet it does not appear to be on track to meet any of its own domestic emissions targets in 2025.

This gulf between China's stated objectives and its domestic actions raises questions about whether the Party is putting its finger on the scale to enforce its purported policies, or whether it is letting energy security, political pressure from coal producers, and tensions between electricity-producing provinces and electricity-consuming provinces get in the way of what it has promised. More importantly, it casts doubt on whether China's international commitments to peak emissions by 2030 and become carbon neutral by 2060 are indeed credible.

I want to again thank my fellow Commissioners for their participation, and our witnesses again for their thoughtful testimony, as well as our hard-working staff for all their support in organizing today's hearing.

Before introducing our first panel I want to turn the floor over to my colleague and co-chair for this hearing, Commissioner Hal Brands.

PREPARED STATEMENT OF COMMISSIONER CARTE GOODWIN HEARING CO-CHAIR

Hearing on "China's Domestic Energy Challenges and Its Growing Influence over International Energy Markets"

April 24, 2025

Opening Statement of Commissioner Carte Goodwin

Good morning, and welcome to the fifth hearing of the U.S.-China Economic and Security Review Commission's 2025 annual report cycle. Thank you all for joining us today. Thank you to our witnesses for all their hard work and for sharing their expertise in the preparation of their testimonies this morning. I also want to extend our appreciation to the Senate Foreign Relations Committee for use of this hearing room today, as well as the Senate Recording Studio for their assistance in livestreaming this event. For those attending in person or watching online, witness testimonies and a transcript of this hearing will be available on the Commission's website. Finally, I want to welcome Commissioner Livia Shmavonian, who has been appointed to the Commission by Senator Schumer.

Today's hearing will examine China's domestic energy challenges, both market-based pressures and those rooted in policy choices. We will also look at the supply chain and cybersecurity risks posed by China's growing influence over clean energy products and transmission infrastructure.

Since 2020, China's demand for electricity has outpaced its GDP growth, a trend that seems set to continue. The electrification of China's energy-intensive manufacturing sector, households' movement from coal-based heating to electric climate control, and the rapid rise of electric vehicles all put pressure on China's energy infrastructure. Even as this pressure on China's electric grid builds, oil and natural gas still account for over 25 percent of China's primary energy use. China may have diversified its suppliers, but it is still heavily reliant on imports through the Malacca Strait. While China's oil imports declined for the first time in 20 years, oil remains central to both domestic industry and China's military, making it China's most significant resource vulnerability in a crisis scenario.

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The gulf between China's stated goals and its domestic actions raises questions around whether the Communist Party is putting its finger on the scale to enforce its purported policies, or whether it is letting energy security concerns, political ties to coal producers, and tensions between electricity-producing and electricity-consuming provinces get in the way of doing what it has promised. More importantly, it casts doubt on whether China's international commitments to peak emissions by 2030 and become carbon neutral by 2060 are credible.

I would like to thank my fellow Commissioners for their participation, our witnesses for their thoughtful testimony, and the staff for their support in organizing today's hearing. I will now turn the floor over to my colleague and co-chair for this hearing, Commissioner Hal Brands.

OPENING STATEMENT OF COMMISSIONER HAL BRANDS
HEARING CO-CHAIR

COMMISSIONER BRANDS: Thank you, Commissioner Goodwin, and thank you to our witnesses for participating in the hearing today.

China has emerged as a pivotal force in international energy infrastructure and clean energy technologies. Its dominance in renewable energy technology, energy transmission and storage, and related supply chains threatens to create strategic leverage for Beijing and security risks for America and other countries.

Today, among other issues, we'll consider China's emergence as a top financier of foreign energy infrastructure. Chinese policy banks and state-owned enterprises are funding and building power generation and transmission projects across emerging and developed economies. As with telecommunications nearly a decade earlier, officials in capitals around the world are now investigating the risks of Chinese investment and control over critical electrical infrastructure. Indeed, as the 2021 National Intelligence Assessment warns, Chinese-manufactured hardware could introduce hidden vulnerabilities such as remote kill switches and data collection capabilities.

Recent intrusions into U.S. infrastructure by state-sponsored actors like Volt Typhoon serve as a stark indicator of both Chinese capabilities and intent. When the United States raised concerns about these cyber operations last December, Chinese officials reportedly linked these activities to geopolitical tensions over Taiwan, a sobering reminder that energy infrastructure has become a potential battlefield in great power competition.

Yet critical minerals are perhaps the most vivid illustration of how Beijing leverages its central position in energy supply chains to support state interests. China secured a dominant market position through decades of state intervention. Now, recent restrictions on rare earth exports and mineral processing technology reveal a willingness to weaponize supply chain dependencies for strategic objectives. Moreover, China's application of export restrictions on refined critical minerals shows an evolution in both the sophistication and the assertiveness of its economic coercion toolkit.

Security of energy systems is vital to U.S. and global prosperity, as well as for the ability of U.S. and allied militaries to operate around the world. China's growing influence as a supplier, builder, and in some cases owner or operator of energy infrastructure raises difficult questions about resilience, diversity of supply, and international cooperation. I look forward to hearing from our witnesses on these issues, and I welcome their suggestions of steps Congress can take to mitigate these challenges.

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PANEL I INTRODUCTION BY COMMISSIONER CARTE GOODWIN

COMMISSIONER GOODWIN: Thank you, Commissioner Brands.

Our first panel will focus on China's energy ecosystem and growing needs, and we are pleased to welcome Michal Meidan, who is the Head of China Energy Research at the Oxford Institute for Energy Studies. Prior to joining OIES, Dr. Meidan headed cross-commodity China research at Energy Aspects, and previous to that she headed China Matters, an independent research consultancy, providing analysis on the politics of energy in China. Welcome.

We are also pleased to welcome Mr. David Fishman, a principal at the Asia-Pacific focused energy consulting firm, the Lantau Group, where his areas of expertise cover regulatory and economic intelligence for the Chinese power sector, including solar, wind, coal, nuclear, hydro, as well as transmission grid and power market issues. Prior to joining TLG, Mr. Fishman was a managing co-director of the nuclear energy-focused consulting firm, Nicobar Group in Shanghai. Welcome, Mr. Fishman.

And finally we are pleased to welcome back Dr. Erica Downs, a Senior Research Scholar at the Center on Global Energy Policy at Columbia University's School of International and Public Affairs, focusing on Chinese energy markets and geopolitics. Dr. Downs previously worked as a senior research scientist in the China Studies program at CNA Corporation, an analyst at the Eurasia Group, a fellow at the John L. Thornton China Center at the Brookings Institution, an analyst at the CIA, and a lecturer at the Foreign Affairs College in Beijing. Welcome back, Dr. Downs.

Dr. Meidan, we will begin with you, and I remind the witnesses to try to keep their remarks to seven minutes. Thank you.

OPENING STATEMENT OF MICHAL MEIDAN, HEAD OF CHINA ENERGY RESEARCH, OXFORD INSTITUTE FOR ENERGY STUDIES

DR. MEIDAN: Commissioner Goodwin, Commissioner Brands, distinguished members of the Commission, I would like to thank you for this opportunity to testify here today.

In my talk I'll focus on China's changing energy ecosystem and highlight a number of emerging trends that I think could be quite transformative and therefore merit some consideration.

First, as Commissioner Goodwin just mentioned, China's electricity demand is growing at a rapid pace and for a variety of reasons, right? Like in many other parts of the world this includes AI, data centers, cooling demand, industrial activity, a growing part of which is associated with clean tech manufacturing, but significantly, because China is electrifying its economy. So it's replacing fossil fuels in transport and in some heating processes, and there is scope for more of this.

Already electrification in transport is displacing oil, and the pace could be faster than markets anticipate. Fuel switching is also happening in the passenger vehicle segment, where gasoline demand is declining, but in trucking, as well. So we are seeing a shift to LNG, but increasingly also to electric trucks. These trends will continue, and they could accelerate because EVs and batteries are strategic industry for the Chinese government but also because the market is big and fiercely competitive. In many vehicle categories, EVs today are cheaper than traditional ICE vehicles, and they are also pretty cool to drive in, and there is a lot of innovation that happens through consumer preferences.

So China is electrifying rapidly, but it is also decarbonizing. I''s adding record amounts of wind and solar, to the extent that installed wind and solar capacity today exceeds coal and gas-installed capacity.

Now, of course, installation and utilization are not the same thing. Renewable integration into the grid still faces numerous challenges, the most significant of which is the institutional bias in favor of coal. There is still a perception in many corners in China of the need to rely on coal to deal with the intermittency of renewables. Coal plants are being retrofitted in order to provide this source of flexibility, a role that gas typically plays in a number of economies, including in the U.S.

Power markets in China are designed in a way to prioritize coal. Now, there are efforts to change this. They are slow, they are gradual, and it will take time to phase out coal. But renewable manufacturing and deployment will continue. This is a dynamic that could also impact gas demand in China. Gas today is consumed in industry more than in the power sector in China, but demand is growing in both these sectors. However, going forward, it could grow more slowly than expected, especially if prices are high and domestically source fuels, both coal and renewables, are available to mitigate some of the external vulnerabilities associated with gas imports.

So renewables will also continue to be manufactured and deployed because these are strategic industries. Beijing has, for many years, encouraged the development of the industries of the future, sort of clean tech, AI, and today what is known as the "new three industries" in China -- electric vehicles, batteries, and solar panels -- have become important drivers of economic activity and of energy security. These are home-developed, if not homegrown industries, where Chinese companies have a strong footprint throughout the supply chain, in some upstream activities overseas, but they do remain reliant on imports of minerals, metals, and ores. So dominance does not mean independence.

But if we take all these factors together, we are seeing the emergence of an energy sector that is shifting increasingly to renewables and coal. This energy system has redundancies. It has inefficiencies and high costs associated with it. There are weakness and vulnerabilities, distortions related to the strong role of the government in administratively set prices as they push back against market dynamics. There are different stakeholders that are pushing diverse agendas.

But on the whole, this is a system that increasingly will be able to support optionality in fuel switching. It can also support a low-cost and increasingly a low-carbon footprint industrial machine or industrial activities. It ticks, therefore, a number of policy priorities -- economic growth, industrial competitiveness, geopolitical leverage, energy security, and, over time, emission reductions.

So what does this mean for the U.S.? What could the U.S. do? I think first of all we need to keep monitoring and understanding the dynamics in China, through research, through hearings like these, but more, through exchanges with a variety of counterparts but also partners in China. I''s important to maintain a deep understanding of these trends, the motivations, the actors. Access to reliable data is always a bugbear and becomes even more significant now as we need to understand the speed and the scope of change.

For instance, if oil demand in China is falling faster than expected, that will have implications for supply-demand balances, for global oil prices. As oil product demand is peaking and Chinese refiners are shifting to petrochemicals, this also impacts prices, margins, and then investment decisions.

Prices, understanding pricing mechanisms in China are key. We need to understand how prices are set in the different sectors, where they are administratively set, and how market prices interact with that. What are the fuel-switching thresholds between gas and coal or renewables and other sources? What are the input costs that inform the Chinese industrial activity? All of these are important for us to then make policy decisions, but also for corporate investment decisions.

There are also areas where there is room for collaboration on technical areas. CCUS -- carbon capture, utilization, and storage -- is one area of common interest, as coal is going to remain a part of the energy mix, even though ''s declining. Storage technologies, flexibility in power markets are other areas that China is grappling with, and many other countries are grappling with as the system evolves.

Fundamentally, though, I think the U.S. needs to decide if and how it competes with China on these new technologies. We say industries of the future, but they are industries of today, and China is leading in many of them. And I think we have to bear in mind that China's lead is the result of years of supportive government policies but not just subsidies, and that has created strong competition domestically that has enabled the creation of vertically integrated supply chains, industrial clusters, manufacturing hubs. These are complex ecosystems that support innovation and talent, of which there is plenty in China today.

So there is also plenty of clean tech capacity that will continue to find its way to other markets. If it doesn't go to OECD markets it will go to emerging economies.

So the energy landscape in third countries is also changing as China invests in mining and refining but also in selling clean tech. It shapes the way countries are thinking about energy security and industrial competitiveness. I think the U.S. needs to think through if and how it engages in that thinking but also in that competition, how much of it is done in collaboration with China and maybe learning from some of the technology, gaining potential technology transfers from China, but of course with other partners in third countries, as well.

I would like to thank you for your attention, and I look forward to hearing my co-panelists and to the Q&A.

COMMISSIONER GOODWIN: Thank you, Doctor. Mr. Fishman.

PREPARED STATEMENT OF MICHAL MEIDAN, HEAD OF CHINA ENERGY RESEARCH, OXFORD INSTITUTE FOR ENERGY STUDIES

THE OXFORD INSTITUTE FOR ENERGY STUDIES

Testimony before the U.S.-China Economic and Security Review Commission

China's Domestic Energy Challenges and Its Growing Influence over International Energy Markets

Dr Michal Meidan, head of China energy research, Oxford Institute for Energy Studies

April 24, 2025

China's Energy Ecosystem and Growing Needs

China's energy demand increased four-fold between 2000 and 2024. Demand was met primarily by fossil fuels and most notably coal. Throughout the period, China's energy demand grew more rapidly than global averages, reflecting the country's industrialisation and economic development, with CO2 emissions rising strongly. Between 2000 and 2015, a combination of policy interventions and structural economic changes led to reductions in energy intensity (the amount of energy consumed per unit of GDP) but efficiency gains slowed after 2015, decelerating further in recent years[1].

Since 2019, however, China's energy system seems to be undergoing significant shifts. To be sure, energy consumption trends in China during and following the COVID-19 lockdowns, as in many other parts of the world, have been volatile. The initial lockdowns in 2020 were followed by a spike in economic activity and energy demand, which outpaced supplies and contributed to the power outages of 2021. Another bout of stringent lockdowns in 2022 depressed economic growth and energy use, followed by a boost in activity when they restrictions were eased. Travel resumption boosted gasoline and jet fuel demand while renewed industrial activity bolstered diesel use. At the same time, rapid electrification in the transport sector and a surge in new energy vehicle (NEV) sales has slowed gasoline demand growth, to the extent that gasoline consumption in China may have now peaked.

Meanwhile, electricity demand growth also outpaced GDP growth for five consecutive years between 2019 and 2024 due to a combination of strong industrial activity, electrification and bouts of extreme weather events. At the same time, China's renewable energy expansion accounts for almost half of global wind and solar capacity additions. Installed wind and solar capacity in early 2025 reached 1,456 GW, exceeding thermal coal and gas capacity.

These green-shoots are worth noting because they point to a number of potential structural changes: First, China's economy is electrifying rapidly. As a result, energy, and mainly electricity demand, is likely to continue growing. Second, in the transport sector, accelerated electrification and fuel switching could lead to steeper than expected declines in gasoline use. Diesel consumption could also plateau soon if it hasn't already. While China's oil demand may not fall until the early

[1] For more background, see Michal Meidan, written testimony for U.S.-China Economic and Security Review Commission, Hearing on China's Energy Plans and Practices, March 17, 2022, 11 and David Sandalow et. al., Guide to Chinese Climate Policy 2022, https://chineseclimatepolicy.oxfordenergy.org/

2030s due to growing chemicals consumption, the rapid electrification is changing dynamics, impacting the country's appetite for oil imports and its relations with its suppliers.

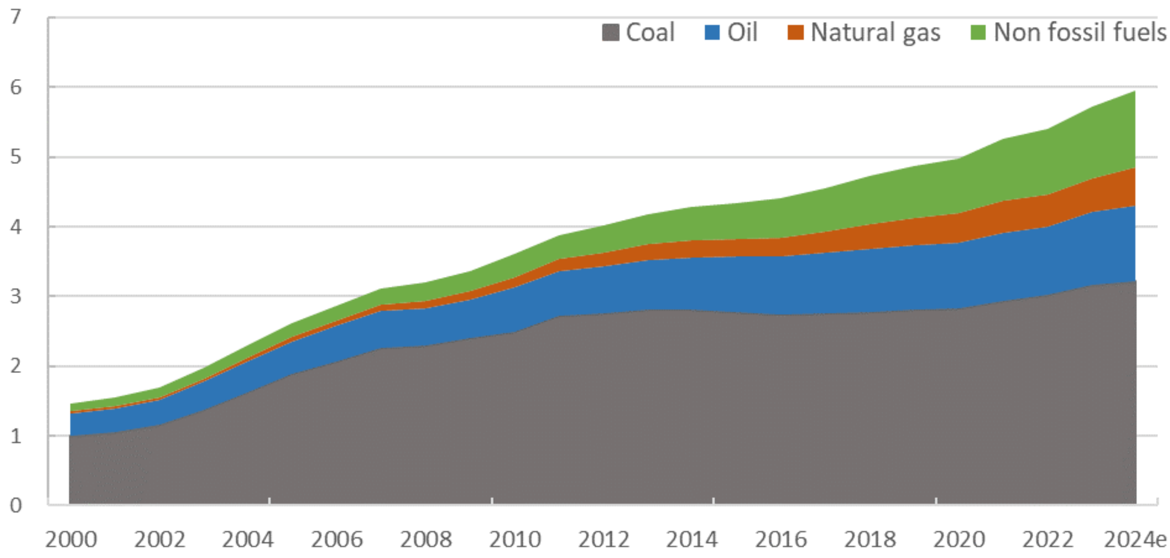
Third, rapid renewable deployment is set to continue even as connections to the grid face technical and institutional constraints. Renewable additions have already moderated China's CO2 emissions, and could lead to their stabilisation even though they have not yet led to a decline. Curtailment is an ongoing policy challenge and coal remains a pillar of China's energy system. This is complicating China's ability to meet its "dual carbon" goals, namely to peak emissions by 2030 and achieve carbon neutrality. But Beijing's support for renewables will continue even as climate policies take a back seat because the "new three industries" (solar photovoltaic, batteries and electric vehicles) are now significant drivers of China's economic growth, a key pillar of the country's industrial strategy and a source of exports and geo-economic leverage. Excess capacity in this industries is leading to lower prices which, in turn, could support accelerated deployment. In the context of a fraught trade and geopolitical environment, Beijing is prioritising resilience and flexibility in its energy system over economic efficiency and emission reductions. But the rapid build out of clean technologies could still lead to faster emissions reductions over time.

Going forward then, even as China's fossil fuel demand growth slows, it will remain a large importer of oil and gas, and will still be a critical market for producers. At the same time, its importance as a supplier of new energy supplies will also grow. This position will come with new strengths, but also new vulnerabilities.

1. China's new sources of energy demand

China's energy demand increased four-fold between 2000 and 2024 with coal and oil consumption growing three-fold. Non-fossil fuel and gas consumption surged, albeit from a much lower base than coal and oil (Figure 1).

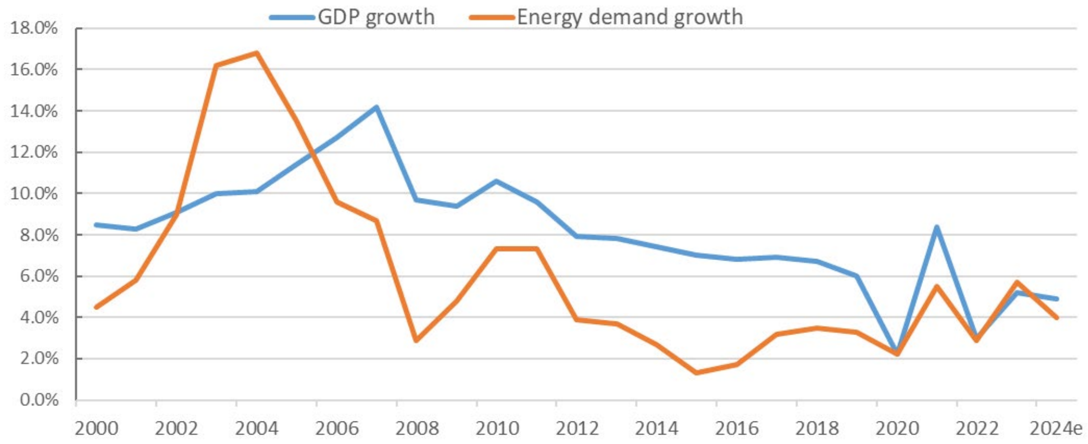
Figure 1: China primary energy consumption (btce)



Source: CNPC ETRI, OIES

A combination of policy interventions and structural economic changes in the early 2000s led to substantial reductions in energy intensity (the amount of energy consumed per unit of GDP). Efficiency gains slowed after 2015 but continued nonetheless (Figure 2).

Figure 2: China's GDP growth and energy demand growth, y/y change (%)



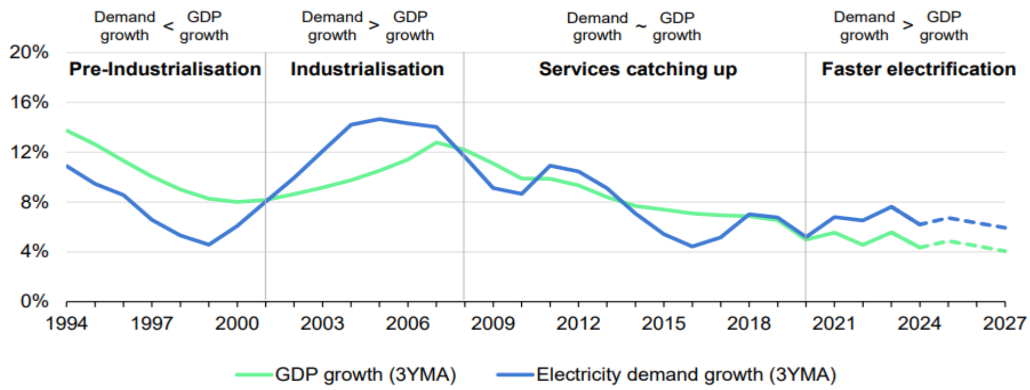
Source: CNPC ETRI, OIES

Since 2019, however, as mentioned above, China's energy use and supply structure has been undergoing significant changes. Given the economic shock of the pandemic and government efforts to boost growth, demand has been volatile, making underlying trends harder to discern but a number of potential trends are noteworthy.

1.1 Rapid electrification…

First, energy demand, and in particular electricity consumption is growing faster than GDP, reversing a decade-long trend of alignment between power consumption and GDP growth (Figure 3), highlighting the rapid electrification of China's economy.

Figure 3: Growth rates of electricity demand and GDP in China, 1994-2027



Note: 3YMA stands for 3-year moving average. GDP growth is based on the October 2024 edition of the IMF World Economic Outlook.

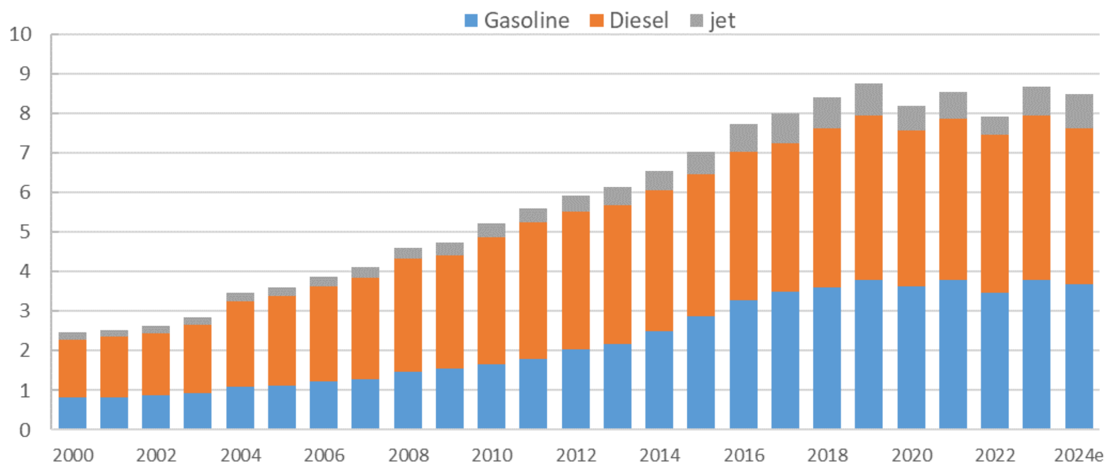
According to the IEA, the share of electricity in China's final consumption reached 28% in 2024, compared to 22% in the United State and 21% in the European Union[2]. Electric heating is replacing a number of fossil-fuel based heating in processes in the chemical industry and refining, while industrial heat pump uptake is on the rise. Electric vehicle (EV) charging demand[3] is also growing.

The country's industrial sector remains a key driver of electricity demand, consuming an estimated 60% of the country's power use, well above the 32% commonly seen in OECD countries. This is unlikely to change going forward given the country's focus on the production of new energy products such as solar PV modules, batteries and EVs which are electricity-intensive. The IEA further estimates that between 2022-2024, these new energy products made up nearly 35% of the increase in industrial electricity demand and 16% of the growth in total electricity use across China. When accounting for the electricity-intensive upstream processes associated with these products, such as the refining and processing of the related materials, power demand is likely higher[4]. In addition to strong industrial activity in new sectors, heatwaves and the resulting need for cooling have driven up electricity consumption in recent years, alongside the expansion of data centres and 5G. Finally, improved automation in manufacturing is also leading to higher electricity demand.

1.2 …means accelerated fuel switching in transport

Second, and related to this, oil product demand is set to peak sooner than previously anticipated, in large part due to the electrification of transport. China's oil majors estimate that gasoline and diesel demand have both peaked already (Figure 4).

Figure 4: China's gasoline, diesel and jet fuel demand (mb/d)



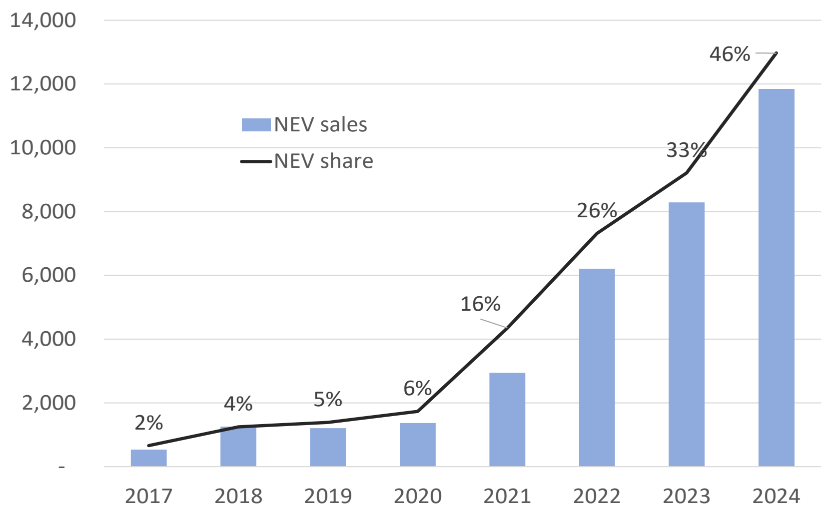
Source: CNPC ETRI, OIES

There are a number of uncertainties surrounding the timing of peak gasoline demand and perhaps more significantly the pace at which gasoline use could decline after the peak, especially in light of the rising share of plug-in hybrids in the NEV fleet (which consume both electricity and gasoline).

[2] IEA, "Electricity 2025: Analysis and forecast to 2027" February 2025, https://iea.blob.core.windows.net/assets/77522eb7-49c8-4611-851e-59bd5b93454c/Electricity2025.pdf
[3] IEA, "Electricity 2025: Analysis and forecast to 2027" February 2025, https://iea.blob.core.windows.net/assets/77522eb7-49c8-4611-851e-59bd5b93454c/Electricity2025.pdf
[4] IEA, "Electricity 2025: Analysis and forecast to 2027" February 2025, https://iea.blob.core.windows.net/assets/77522eb7-49c8-4611-851e-59bd5b93454c/Electricity2025.pdf

Nonetheless, rising NEV penetration rates suggest a structural shift is already underway. NEV sales which stagnated at around 5% from 2018 to 2020, rose rapidly from 2020 to 2024 (See Figure 5). Given the government's support for the sector alongside the cut-throat competition within China, NEVs are cheaper than many ICE vehicle models sold in China[5] suggesting that the boom is far from over.

Figure 5: China NEV annual sales and share of total vehicle sales, 2017-2024 (thousands)



Source: Anders Hove, data from China Association of Automobile Manufacturers, OIES

Diesel demand is also set to slow. Diesel is consumed in a variety of sectors in China, including transport, agriculture and industries making the outlook more complex. To date, the weakness in diesel demand has been linked to the real estate slowdown, limited infrastructure projects due to rising local government debt and broader macro-economic shifts away from construction toward less diesel-intensive activities such as semi-conductors, AI and others. Even the "new three" as discussed above are more electricity-intensive than diesel-intensive. But government policies to support economic growth could reverse some of these weaknesses.

At the same time, diesel use in transport is falling due to government policies such as generous trade-in subsidies to replace diesel trucks with lower-emission fuel trucks, and stricter fuel consumption standards for heavy-duty vehicles. In this sector, the pace of the shift away from diesel toward LNG and electric trucks will depend on the availability and cost of the alternatives. In 2024, for instance, diesel trucks accounted for 57% of China's heavy truck sales[6], down from 70% in 2023, and trucks powered by natural gas made up 29% of total sales. Battery electric trucks reached a 13% sales share and were the third most popular powertrain technology. For medium trucks[7], diesel remained the dominant powertrain accounting for 81% of total sales, but battery electric trucks reached a 14% market share, making it the second most popular powertrain[8]. As the cost of

[5] David Fickling, "In China, It's Already Cheaper to Buy EVs Than Gasoline Cars", 8 August 2023, Bloomberg, https://www.bloomberg.com/opinion/articles/2023-08-08/chinese-evs-are-now-cheaper-than-gasoline-cars
[6] Defined as trucks with a gross vehicle weight above 12 tonnes.
[7] Trucks or vans with a gross vehicle weight between 3.5 and 12 tonnes.
[8] Shiyue Mao and Felipe Rodríguez, "Zero-emission medium- and heavy-duty vehicle market in China, 2024", 25 March 2025, ICCT, https://theicct.org/publication/ze-mhdv-market-china-2024-mar25/

batteries continues to decline and battery swapping technologies evolve, electrification in the heavy duty segment is also likely to accelerate, although it remains unclear how rapidly.

Even though demand for jet fuel continues to rise, the combustion uses of petroleum fuel in China have already likely plateaued and that the potential for future growth may be very limited. Chinese oil demand continues to increase, with growth dominated by petrochemical feedstocks: Oil demand for petrochemicals in China rose by almost 5% in 2024 as new plants came online, a trend that is expected to continue in the next few years. Combined, these trends suggest that China's oil demand and imports will slow[9] but China is still likely to remain a key importer of crude and an important customer for global oil suppliers[10]. The country's large refining system will need to adapt to this change faster than expected, likely accelerating a shift toward petrochemicals. Nonetheless, Beijing remains concerned about the price implications of volatility in the Middle East (that it attributes to US policy actions) and the impact of sanctions on Iranian, Russian and Venezuelan oil[11].

2. **Changes to China's fuel mix: keeping both the old and the new**

A third notable development over the past five years has been the acceleration of renewable energy deployment. In 2024, China added 356 GW of new capacity including 276 GW solar and 80 GW of wind. In 2025, the National Energy Administration (NEA) set a conservative target of over 200 GW of new renewable capacity additions[12] for the year. The aim is for total installed renewable capacity to exceed 1,610 GW, meaning that non-fossil energy sources will account for around 20% of total energy consumption, a target set out in the 14th Five Year Plan. Meanwhile, the China Electricity Council forecast is more ambitious, estimating that China will add around 119 GW of wind and 213–255 GW of solar capacity in 2025, an estimate shared by the China Photovoltaic Industry Association (CPIA). The Chinese Wind Energy Association (CWEA) also expects wind power to maintain a growth rate of about 100-120 GW/year from 2025 to 2026. From 2027 to 2030, the construction of wind power and solar PV is expected to accelerate, with newly added wind power reaching as much as 150 GW/year and newly added solar PV of 260-280 GW/year. In an aggressive scenario, solar PV could reach 300-340 GW/year.

Figure 6: Total installed wind capacity (GW) and share of total (%)

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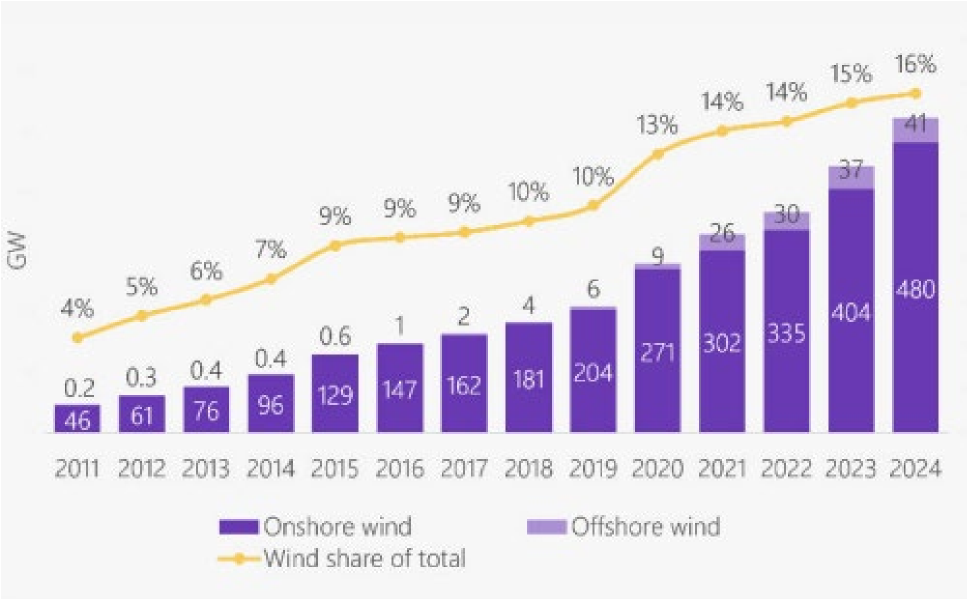
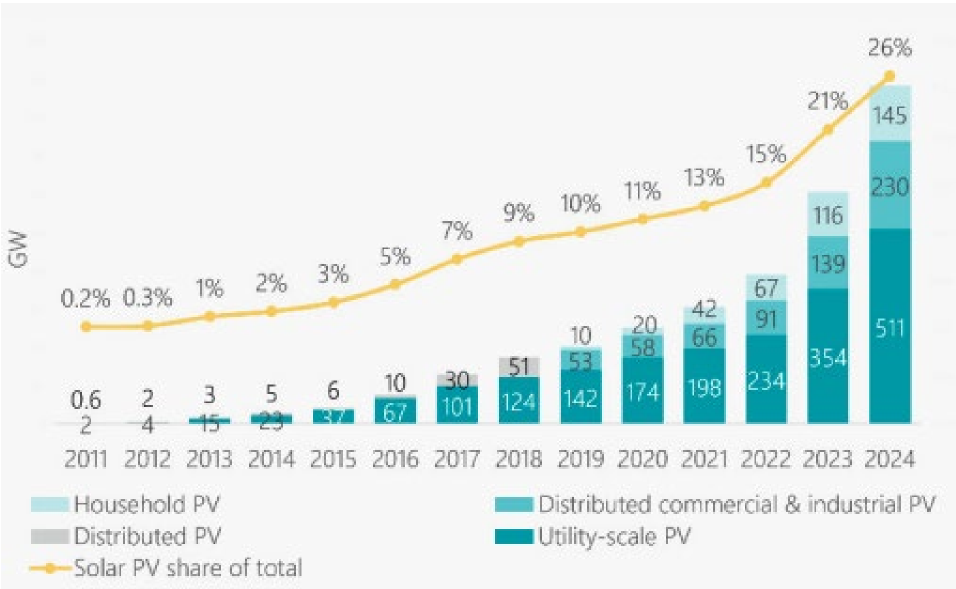
[9] Ciarán Healy, Rebecca McKimm, Ivo Walinga, "Oil demand for fuels in China has reached a plateau", IEA, 11 March 2025, https://www.iea.org/commentaries/oil-demand-for-fuels-in-china-has-reached-a-plateau
[10] Michal Meidan, "The outlook for China's fossil fuel consumption under the energy transition and its geopolitical implications", OIES Paper C8, June 2023, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/06/CE8-The-outlook-for-Chinas-fossil-fuel-consumption.pdf
[11] Zhong Feiteng, "Geopolitical risk and China's energy security", World Energy Development Report, 2019;
[12] NEA, Policy interpretation of the "Guiding Opinions on Energy Work in 2025", 27 February 2025, https://www.nea.gov.cn/20250227/105a07a9be2c4727b7fe12c11c7b84cf/c.html



Source: NEA

Figure 7: Total installed solar capacity (GW) and share of total (%)



Source: NEA

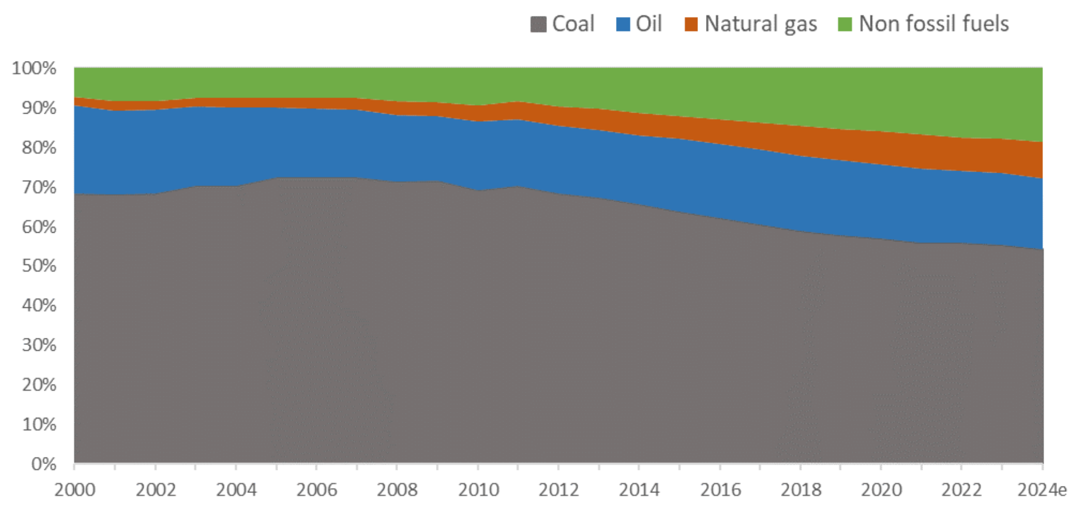
2.1 Renewables rising

By the end of 2024, China's installed wind and solar capacity had exceeded installed coal power generation and at 1406 GW was well in advance of China's nationally determined contribution (NDC) which consisted of reaching 1200 GW of installed wind and solar capacity by 2030[13]. As such, non-fossil fuels at the end of 2024 accounted for 18.5% of the energy mix, exceeding the share of oil for the first time (Figure 8). What is more, renewables accounted for 86% of incremental electricity consumption.

[13] Summary of China's energy and power sector statistics in 2024, China Energy Policy newsletter, https://www.cet.energy/category/data/

Despite this, the strong increase in energy demand combined with the government's concerns about energy security and reliability, as well as limited progress in power market reforms have all meant that coal continues to play an outsized role in China's energy system. In 2024, it accounted for 54% of primary energy consumption and roughly 60% of power generation.

Figure 8: China primary energy consumption by fuel (%)



Source: CNPC ETRI, OIES

The rapid additions of renewable generation, at times exceeding the grid's ability to absorb new capacity, has led to curtailment, i.e. a deliberate reduction or shutdown of capacity. In April 2024, the Chinese government raises the allowed curtailment limit from 5% to 10%, indicating that policymakers want to add renewable capacity, even if transmission capacity and technology can't keep pace. In 2024, official wind curtailment rates reached 4.1% and solar PV curtailment was reported at 3.2%, rising from 2023 levels, but the national pictures masks a strong variation in regional trends. In 2024, for instance, curtailment rates hovered around 10% in a a number of provinces and regions in northern and north-western China including Inner Mongolia, Xinjiang, Hebei and Shanxi, where most of the country's utility-scale solar and wind power bases are located[14].

2.2 Barriers to renewable integration

Renewable integration, like in many other parts of the world, face a number of challenges. Given the large renewable bases in in northern and north-western China, ultra-high voltage (UHV) transmission lines are needed to deliver the power to the demand centres in central, southern and east China. China's 14th Five-Year Plan includes plans to add UHV transmission lines, but they are likely insufficient[15] and take a longer time to build than renewable capacity additions. In the East China region, where distributed solar is widespread, the regional grid and power distribution network are

[14] "China's new energy grid connection and consumption", 2024年全国新能源并网消纳情况 , https://finance.sina.com.cn/roll/2025-02-08/doc-ineiufta9005634.shtml

[15] Aiqun Yu et. al, "China continues to lead the world in wind and solar, with twice as much capacity under construction as the rest of the world combined", Global Energy Monitor, July 2024, https://globalenergymonitor.org/report/china-continues-to-lead-the-world-in-wind-and-solar-with-twice-as-much-capacity-under-construction-as-the-rest-of-the-world-combined/

ill-equipped to deal with the distributed solar boom, leading to temporary suspensions of distributed solar applications[16] .

China also has limited storage: at the end of 2024, China had an estimated 74 GW of "new type energy storage" which refers to flexible storage solutions critical for integrating high shares of renewable energy into the power grid (excluding traditional pumped hydro storage), a twenty-fold increase compared to 2021. Despite the large increase, this represented an average 2.3 hours of storage time with over half of the projects located in Northern and North-western China, far from the key consumer centres[17]. But the technical and physical constraints are overshadowed by institutional barriers.

China's policy makers view coal power as an important source of flexibility to mitigate the intermittency of renewables. Since 2022, the National Energy Agency (NEA) has mandated that new coal power plants should focus on supporting peak load and regulating renewable energy. In practice, and especially after the power outages of 2021, few coal power projects were actually aimed at facilitating solar and wind integration. Instead, they are aimed at ensuring local energy supply, driving economic development, meeting heating demands, or supporting industrial parks. Still, China approved 66.7 gigawatts (GW) of new coal-fired power capacity in 2024[18]. That same year, 94.5 GW of new coal power projects started construction and 3.3 GW of suspended projects resumed construction, the highest level since 2015.

China's power market design prioritises coal through long term power purchase agreements (PPAs). Since 2020, long-term PPAs have required coal power plants to secure contracts covering at least 80% of their projected annual output, effectively guaranteeing baseline utilisation rates. Electricity buyers must then fulfil their coal power obligations, even when cleaner and cheaper energy options like solar and wind are available. Most of the new coal-fired plants also secure these purchase agreements before coming online.

The simultaneous expansion of coal and clean energy has created regional oversupplies of coal power, leading to lower prices[19]. While lower prices could discourage new renewable investments, they also provide low input costs for industry. With greater concern for economic growth as well as energy and industrial resilience than economic efficiency or emission reductions, the government is intent on keeping coal plants in the mix to secure supplies. In 2023, in light of the financial losses in the coal sector and in a bid to enable coal to remain in the mix to back up renewables, the government also introduced a capacity payment mechanism which offers a guaranteed annual payment for coal plants per megawatt of available capacity, regardless of how many hours a generation unit operates. The aim of the plan is to ensure coal plants are available when needed to back up intermittent renewables. In reality, however, the criteria for inclusion under the plan for

[16] https://www.china5e.com/news/news-1161773-1.html
[17] Summary of China's energy and power sector statistics in 2024, China Energy Policy newsletter, https://www.cet.energy/category/data/
[18] Qin Qi, Christine Shearer, "When coal won't step aside: The challenge of scaling clean energy in China", CREA, 13 February 2025, https://energyandcleanair.org/wp/wp-content/uploads/2025/02/CREA_GEM_China_Coal-power_H2-2024_FINAL.pdf
[19] Qin Qi, Christine Shearer, "When coal won't step aside: The challenge of scaling clean energy in China", CREA, 13 February 2025, https://energyandcleanair.org/wp/wp-content/uploads/2025/02/CREA_GEM_China_Coal-power_H2-2024_FINAL.pdf

coal plants is loose while alternatives like batteries and flexible demand do not qualify, further risking the build out of excess coal power.[20]

But even as Beijing keeps allowing more coal to be added to the mix, it is also looking to move to a less emissions-intensive power generation system with solar and wind power at its core, eventually displacing coal as the main power source. In 2024, the NDRC issued a decarbonisation plan for coal power, focusing on co-firing with biomass or green ammonia and deploying carbon capture, utilisation and storage (CCUS)[21]. Provincial governments and central state-owned enterprises were tasked with proposing retrofits to lower coal power emission intensity to gas power levels. There are still open questions, however, about the scale of retrofits and implementation[22]. Meanwhile, in early 2025, the government introduced a new pricing regime for renewables[23], which will take effect in early June. The new regime is akin to a market-oriented contract-for-difference pricing system for domestic wind and solar power and will include a strike price, set by provincial governments based on their local targets for renewable additions and production. The price will have to be set below the coal benchmark tariff, but the initial price range is likely to be narrow, striking a balance between a desire to drive down prices but keeping them high enough to ensure the viability of wind and solar. For renewable generators, the change is a mixed bag: they will no longer have the guarantee of offtake and revenue, but will benefit from minimum prices, albeit subject to local policy maker decisions.

Finally, in April 2025, the National Development and Reform Commission (NDRC) and National Energy Administration (NEA) reportedly jointly issued guidelines mandating continued coal plant construction through 2027 in regions with renewable penetration exceeding 35% in order to provide peaking capacity during periods of low wind and solar output; maintain frequency stability in grids with high variable renewable shares and serve as emergency reserves during extreme weather events[24].

China's plans to reduce carbon emissions from coal power and the insistence on coal as a baseload power source indicate that coal power will continue to play a significant role in the near-term energy landscape, complicating Beijing's dual carbon targets in 2030 and 2060. Even though storage combined with renewables could provide a more cost effective and flexible alternative to coal power for balancing the grid, coal power remains shielded from competition. To be sure, the Chinese government is looking to establish a low emissions power generation system, but there still seems to be limited appetite for dramatic reforms that would greatly increase the role of market mechanisms in resource allocation or shift the incentives of local officials decisively away from coal[25].

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[20] Qin Qi, Christine Shearer, "When coal won't step aside: The challenge of scaling clean energy in China", CREA, 13 February 2025, https://energyandcleanair.org/wp/wp-content/uploads/2025/02/CREA_GEM_China_Coal-power_H2-2024_FINAL.pdf

[21] https://www.ndrc.gov.cn/xwdt/tzgg/202407/P020240715559357737744.pdf

[22] Qin Qi, Christine Shearer, "When coal won't step aside: The challenge of scaling clean energy in China", CREA, 13 February 2025, https://energyandcleanair.org/wp/wp-content/uploads/2025/02/CREA_GEM_China_Coal-power_H2-2024_FINAL.pdf

[23] NDRC, "Notice on deepening market-oriented reforms of new energy grid-connected electricity prices and promote the high-quality development of new energy", 9 February 2025, https://www.ndrc.gov.cn/xwdt/tzgg/202502/t20250209_1396067_ext.html

[24] "China to keep building coal plants through 2027, state planner says", Reuters, 14 April 2025

[25] Anders Hove, "New moves in China's power market reform chess game", OIES Energy Insight no 139, November 2023, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/11/Insight-139-New-moves-in-Chinas-power-market-reform-chess-game-1.pdf

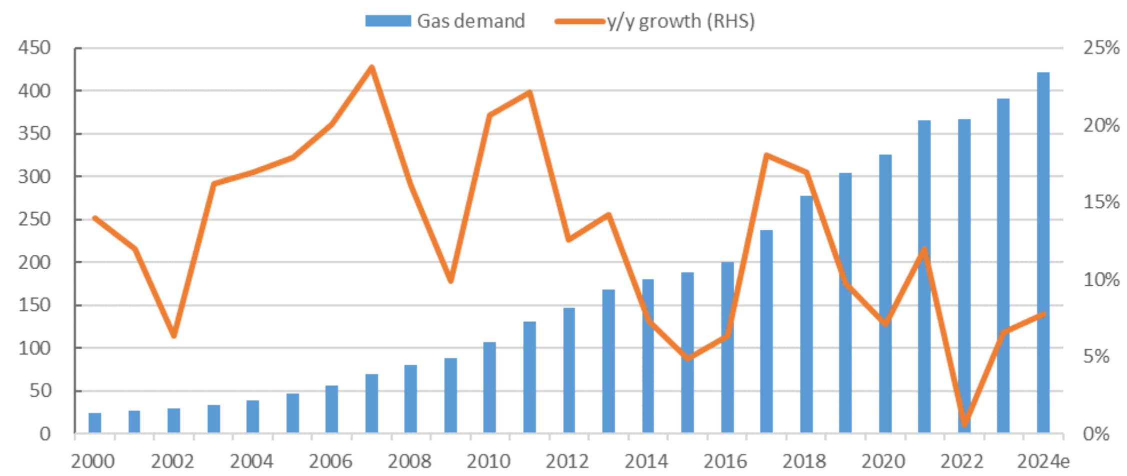
And in the current global environment, the government remains focused on ensuring ample supplies (and even oversupplies), perhaps also in order to keep industrial power prices low. Even prior to the COVID-19 pandemic, as the first US-China trade war began, the Chinese leadership began to focus on industrial and technological leadership as well as energy security. The two trends may now already be converging in Beijing's focus on coal, and its lead in clean-tech industries.

2.3 Natural gas can support the transition, but it is not a priority

These changes in China's energy structure raise questions about the outlook for natural gas. China's gas demand has increased by an annual average of 9% between 2014 and 2024, with consumption more than doubling from 180 bcm in 2014 to 422 bcm in 2024 (Figure 9). This strong growth was driven by a combination of favourable policies and competitively priced resources (both domestic and imported). But just as the availability of supplies, favourable policy and competitive prices have enabled gas consumption, they have also, at times hindered it: When overly ambitious fuel switching policies led to supply shortages and price spikes in 2017-2018, appetite for gas waned. Weak economic activity in 2022 combined with global market volatility and concerns about import dependence, led to a slowdown in gas consumption.

Even though China's gas use has grown substantially over the past two decades, it still accounts for under 10% of the country's primary energy mix, and annual growth rates have varied considerably (Figure 9), depending on both prices and policies.

Figure 9: China's gas demand (bcm) and y/y change (%)

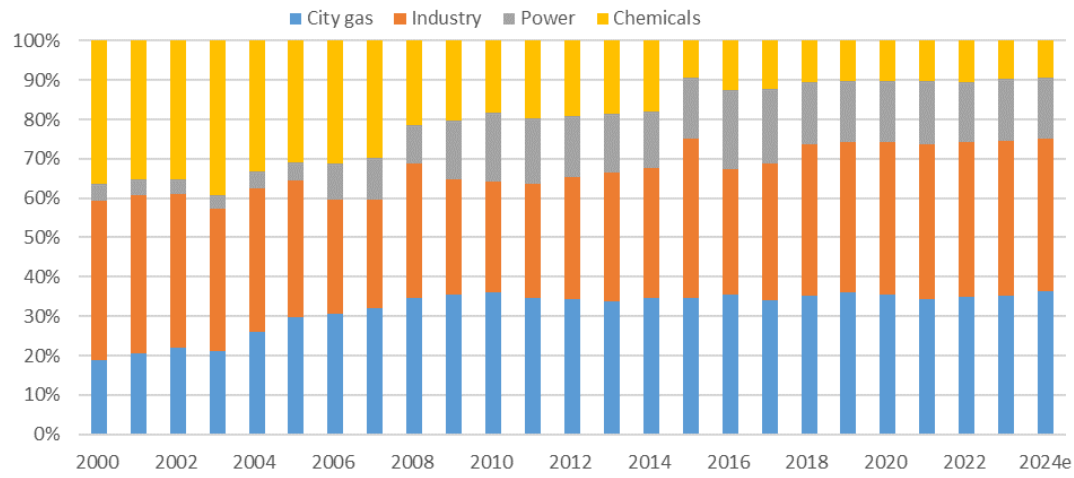


Source: CNPC ETRI, OIES

Estimates of the country's future demand vary widely with divergences as to whether industry or power will be the main drivers of demand growth. Sinopec, China's second largest oil and gas company, estimated that between 2020 and 2040, industrial demand will account for 180-200 bcm of new gas demand while the share of power in this growth will be more muted. CNPC, China's largest oil and gas company, reckons that gas demand will reach around 520 bcm in 2030 and peak at 606 bcm in 2040 but that power will soak up almost 170 bcm of that increment through 2040[26].

[26] Michal Meidan, "Gas in China: It's the policy, stupid!", Oxford Energy Forum, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/09/OEF-141.pdf

Figure 10: China gas demand by sector

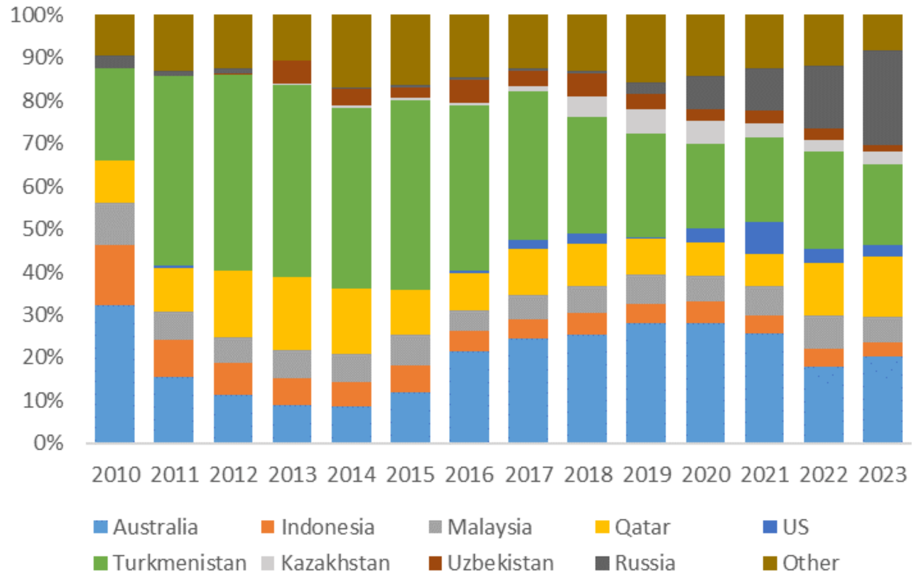


Source: CNPC ETRI, OIES

Gas is viewed as a partner fuel in the country's energy transition and is central in a number of industries as well as in the power systems of a number of provinces[27], as such, gas consumption will continue to grow but its growth trajectory could be volatile given that it is constrained by the availability of both coal and renewables and by price volatility.

To date, China's domestic supplies account for just under 60% of demand, with LNG and pipeline flows filling the gap. While demand is expected to rise, production growth is unlikely to keep up, increasing China's dependence on imports. Over the last decade, China has diversified its import sources but remains reliant on a handful of countries for its imports.

Figure 11: Gas imports (pipeline and LNG) by country



[27] Yan Qin, "Natural gas in China's power sector: Challenges and the road ahead", OIES Energy Insight 80, December 2020, https://www.oxfordenergy.org/publications/natural-gas-in-chinas-power-sector-challenges-and-the-road-ahead/

The fraught geopolitical environment combined with high tariffs on imports of US LNG could lead Beijing to prioritise other supply sources given that future supplies are expected to come overwhelmingly from the US, Qatar and potentially Russia. This means that without a clear mandate to switch from coal to gas, the cost competitiveness of coal and renewables—both of which in Beijing's eyes offer greater supply security—could limit the growth potential for gas.

3. New energy paradigms?

China's energy system, as discussed above, is in flux. Discerning structural shifts from cyclical change is complicated by the extreme market volatility since the COVID-19 pandemic and the aftermath of the Russian invasion of Ukraine. But a number of trends need to be monitored carefully as they may herald deeper changes to China's energy system. Moreover, these changes need to considered in the context of intensifying US-China competition: Already back in 2018-2019, Beijing began reinforcing coal as part of its energy security, prioritising domestic production of all energy sources (and critical minerals), building out storage of oil and gas, while also doubling down on its ability to produce and deploy the energy industries of the future.

3.1 New energy (in)securities

China's sense of energy insecurity has not disappeared, but policies now focus on balancing fossil fuel stability with renewable expansion, emphasizing domestic production capacity, diversifying import channels, including a focus on the Belt and Road countries, and diversifying domestic energy sources[28]. Given the growing importance of the power sector, energy security policies now also include efforts to enhance the physical aspects of grid modernisation (infrastructure build out, technology innovation, digitisation) as well regulatory and market tools to improve efficiency. Infrastructure flexibility and resilience are all parts of the energy security equation.

Critically, though, as electrification is accelerating, deploying renewable energy is an additional source of energy security given China's centrality in new energy supply chains. Not only are clean tech costs falling, but these industries are now significant drivers of China's economic growth[29], a key pillar of the country's industrial strategy and a source of exports and geo-economic leverage.

China produces enough lithium-ion batteries, solar panels and electric vehicles to meet most or more than the world's demand. Chinese lithium-ion battery production in 2023 was roughly equivalent to global demand, at around 950 GWh[30] while China's solar PV manufacturing capacity is estimated at about 1,200 GW as of early 2025, or double global market demand.

But China's lead extends beyond manufacturing. Chinese companies have a deep footprint in the extraction and mining of ores both in China and abroad, they have developed expertise and leadership in the processing of many minerals and materials and are leading producers of components and end goods such as batteries, electric vehicles, solar panels and wind turbines. While estimates of China's market concentration vary depending on data and methodologies, all point to

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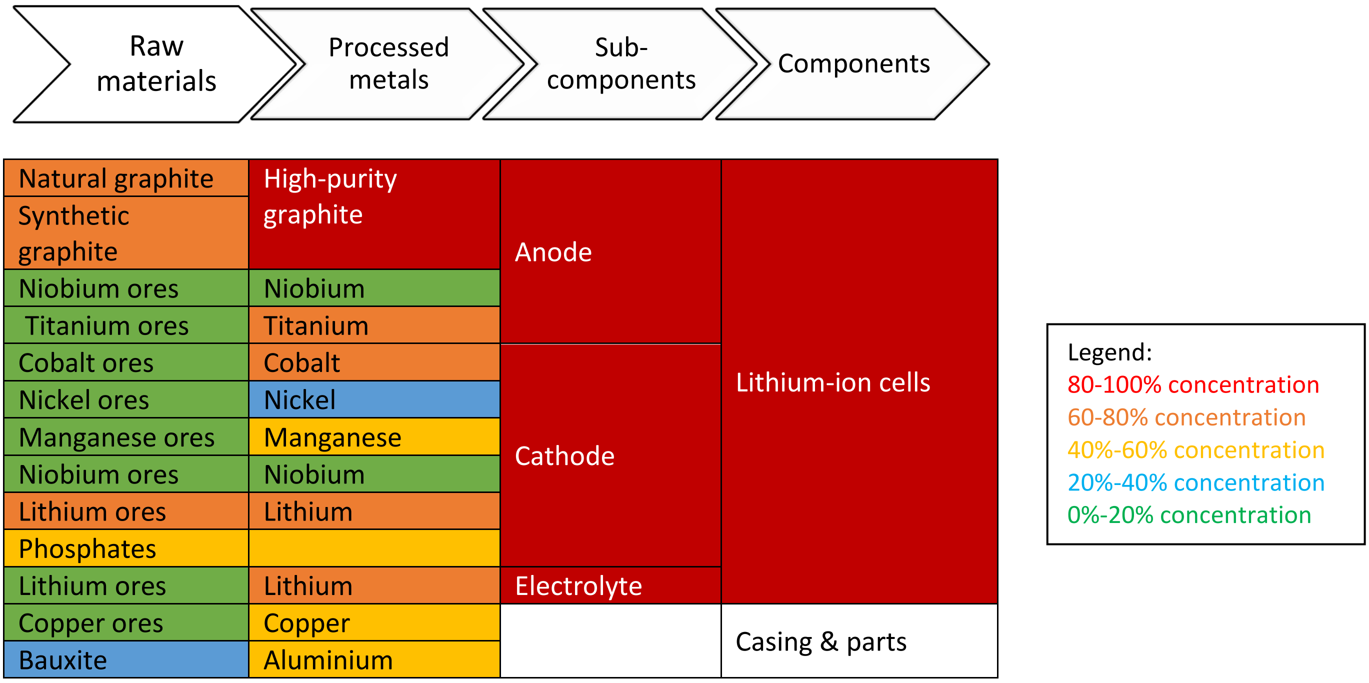
[28] Lin Boqiang "China can deal with local energy security issues from these aspects", Yicai, 28 February 2023, https://www.yicai.com/news/101688159.html; Wang Yongzhong, "Trump's energy plans, impact and response", World Energy Studies, July 2, 2018, http://www.iwep.org.cn/xscg/xscg_sp/201807/W020180703586326878428.pdf

[29] Lauri Myllyvirta, Qi Qin, and Chengcheng Qiu, "Analysis: Clean energy contributed a record 10% of China's GDP in 2024", CREA, 19 February 2025, https://energyandcleanair.org/analysis-clean-energy-contributed-a-record-10-of-chinas-gdp-in-2024/

[30] Colin McKerracher, "China Already Makes as Many Batteries as the Entire World Wants", BloombergNEF, 19 April 2024, https://about.bnef.com/blog/china-already-makes-as-many-batteries-as-the-entire-world-wants/

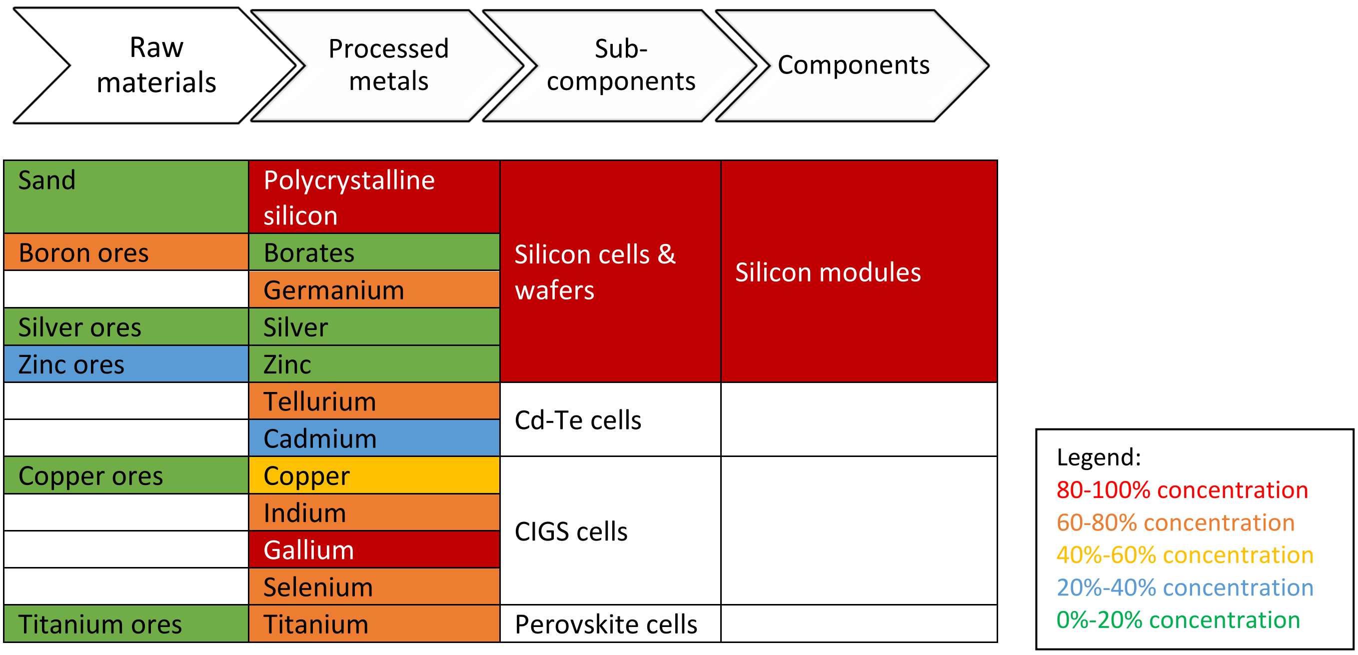
extremely high levels of dominance especially in the processing of minerals and materials, but to reliance on imports for raw materials and ores. Flows of cobalt, nickel, lithium and manganese, among others, come from a host of countries in Africa, Latin America and South East Asia.

Figure 12: China's involvement in the supply chain for Li-ion batteries in 2022



Note: The table is a schematic, simplified, representation of supply chains depicting China's share of production
Source: Philip Andrews-Speed, OIES[31]

Figure 13: China's involvement in the supply chain for solar PV in 2022



[31] Based on USGS 2025, Mineral Commodity Summary; GWEC 2024. Global Wind Report 2024; IEA 2024. Clean Energy Technology Manufacturing; IEA Global critical mineral outlook; US DOE 2022 Rare earth permanent magnets. Supply chain deep dive assessment; Sivaram et al 2024. Winning the battery race. Sivaram Gordon - Battery Race-2024.pdf; China to hold over 80% of global solar manufacturing capacity from 2023-26 | Wood Mackenzie

Zinc ores	Zinc		
Bauxite	Aluminium		
Zirconium ores	Zirconium		
Tin ores	Tin		
Bauxite	Aluminium		Frame
Nickel ores	Steel		
Molybdenum ores			
Iron ores			
Lead ores	Lead		Installation
Copper ores	Copper		

Note: The table is a schematic, simplified, representation of supply chains depicting China's share of production
Source: Philip Andrews-Speed, OIES[32]

China's industrial prowess, which has been supported by government policies and subsidies, has enabled a significant scale up in clean tech manufacturing. This has led to cost reductions and a leading role for Chinese companies globally. In 2023, the average price of a Chinese battery electric vehicle into the EU was 16 percent lower than other imported battery electric vehicles.[33] Similarly, manufacturing solar panels in the EU is estimated to be 70–105 per cent more expensive than in China.[34]

While the cost reductions offered by Chinese clean-tech are significant, so are the policy challenges posed by Chinese competition. Central and local government backing has been an important part of Chinese corporate success, but there is also considerable innovation in China in a cut-throat competitive corporate environment. What is more, the creation of industrial parks and manufacturing hubs has allowed Chinese firms to scale up and innovate rapidly,[35] and this suggests that in certain areas, they will remain leaders. The raft of supportive policies that both central and local governments have issued and fine-tuned over the years has spanned innovation and production of clean tech (often with strong localization policies and forced technology transfers), support for deployment, and demand, as well as infrastructure development.

Trade defence measures alone will not offset these factors. Excluding Chinese companies and know-how from Western markets may reduce some of the above-mentioned risks, but it does not

[32] Based on USGS 2025, Mineral Commodity Summary; GWEC 2024. Global Wind Report 2024; IEA 2024. Clean Energy Technology Manufacturing; IEA Global critical mineral outlook; US DOE 2022 Rare earth permanent magnets. Supply chain deep dive assessment; Sivaram et al 2024. Winning the battery race. Sivaram Gordon - Battery Race-2024.pdf; China to hold over 80% of global solar manufacturing capacity from 2023-26 | Wood Mackenzie

[33] 'The EU's drive on China: What EV tariffs mean for Europe', https://www.cer.eu/insights/eus-drive-china-what-ev-tariffs-mean-europe#:~:text=In%202023%2C%20the%20average%20Chinese,30%2C200)%20(Chart%202).

[34] 'China dominates EU solar photovoltaic (PV) market: 98% of solar panels come from China', 21 October 2024, https://www.evwind.es/2024/10/21/china-dominates-eu-solar-photovoltaic-pv-market-98-of-solar-panels-come-from-china/101922#:~:text=According%20to%20Eurostat%20data%2C%20a,panels%20from%20China%20in%202023.

[35] Hove, Anders (2024, July), 'Clean energy innovation in China: fact and fiction, and implications for the future', OIES Paper CE14, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/07/CE14-Clean-energy-innovation-in-China-Final.pdf.

guarantee that Western countries will be able to develop their own supply chains[36] and insulate themselves from China's perceived predatory industrial policies or economic statecraft. Consistent and comprehensive industrial policies that support the creation of the relevant ecosystems alongside certainty around the demand for these technologies, will be required in order to foster growth and innovation.

What is more, tariffs and duties will lead to constant supply chain readjustments that will, in part, support geographic diversification, but will also incur additional costs for companies operating in this space. New supply chain reconfigurations could also end up cutting off Western companies from Chinese suppliers. Even though, over time, fragmentation could spur new innovation and new market responses, it will be a lengthy and costly process.

Over the coming years and decades, Chinese companies will remain active globally. And Western policymakers should not underestimate the dynamic corporate space in China which spans the extractive industries, processing, and manufacturing. Chinese companies operating in this space have different ESG strategies and standards. Some, because of international pressure or Chinese government mandates, are looking to set better common ESG reporting frameworks.[37]

More importantly perhaps, it is important to ascertain when and where dependence on China is a vulnerability, where it is a threat, and where the risks outweigh the benefits. Even though at the outset Beijing did not have a strategy to dominate these supply chains, the end result is still that China today has a powerful economic and geostrategic tool that it can wield. Moreover, Beijing increasingly resorts to it as part of its toolbox. But using export controls is not without cost to the Chinese economy and to Chinese companies. At the same time, China still relies on imports of minerals, materials, and ores that it then processes; it views this reliance as a vulnerability.[38] Finally, the Chinese economy is growing increasingly reliant on exports of clean tech. Dominance, therefore does not mean independence.

Conclusions

Even though China's energy system remains heavily dependent on fossil fuels, the combination of geopolitical competition with the US—which is leading Beijing to focus on industrial development

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[36] The EU Parliament 'calls on the Commission and the Member States, in coordination with industry stakeholders to implement the decision to gradually reduce the dependence on China by diversifying the sources of critical raw minerals and rare earth elements, establishing strategic partnerships with reliable third countries with a view to ensuring a secure and reliable supply of critical raw materials; urges the EU to assist Member States in developing projects that will aim for greater independence from Chinese production'—https://www.europarl.europa.eu/doceo/document/TA-9-2024-0028_EN.html.

[37] Deberdt, Raphael, DiCarlo, Jessica, and Park, Hyeyoon (2024), 'Standardizing "green" extractivism: Chinese & Western environmental, social, and governance instruments in the critical mineral sector', *The Extractive Industries and Society*, 19, https://doi.org/10.1016/j.exis.2024.101516; DiCarlo, Jessica (2024), 'Can the race for decarbonization be "green"?: critical minerals, China's responsible mining initiatives, and the role of non-state actors', 2023-2024 Wilson China Fellowship, https://www.wilsoncenter.org/sites/default/files/media/uploads/documents/2024-WCF_DiCarlo.pdf

[38] Yu, Shiwei et. al. (2021), 'An evaluation of the supply risk for China's strategic metallic mineral resources', *Resources Policy,* 70, https://www.sciencedirect.com/science/article/abs/pii/S0301420720309223?via%3Dihub; Chen, Weiqiang (2022, November), 'Challenges and security strategies of China's critical metals supply for carbon neutrality pledge', *Bulletin of Chinese Academy of Sciences*, 37(11).

and energy security—and dramatic cost declines in clean technologies are altering the country's energy dynamics.

Electrification is accelerating rapidly and is set to continue rising, suggesting a faster than expected decline in oil use. Renewable deployment is surging and while coal power remains the dominant strategy for grid flexibility and dealing with the intermittency of renewable, progress in storage technologies cannot be ruled out. The role of gas is an open question: if supplies are available and cost-competitive, its market share will grow but its role in China's energy mix could remain constrained by the availability of coal and renewables.

China's policy makers are more preoccupied with building a flexible and resilient energy system that can provide low-cost electricity to fuel industrial development than they are with economic efficiencies or emission reductions. Perceptions of a weakening global commitment to emissions reductions are reducing the pressure on Beijing to build out a low-carbon economy. But China's policy makers are still working toward a low-carbon economy because of the advantages it will offer over time. Beijing is looking to build a robust and flexible, low-carbon system that will be competitive globally on both cost, and over time, on a lower emissions footprint.

Rapid electrification of transport and declining oil demand could lead to redundancies in the petrochemical sector while excess supplies of clean-tech are weighing on Chinese companies' margins, prompting them to look overseas for export markets. New trade frictions are emerging. Meanwhile, old dependencies on oil and gas suppliers are being supplemented with reliance on providers of minerals, metals and ores as well as export markets for intermediate goods and finished products. Even though China's energy structure is changing, leading to reduced reliance on imported oil and gas, new sources of external and domestic insecurity are emerging.

OPENING STATEMENT OF DAVID FISHMAN, SENIOR MANAGER, LANTAU GROUP

MR. FISHMAN: Can you hear me okay? Great, well, thank you, Commissioners Goodwin, Brands, and all members of the Commission. Today I would like to take the conversation a little bit farther forward, so, of course, we start by taking a look at what has happened now or what is happening in the next few years, going out to 2030. That's, of course, China's deadline for its carbon peaking. But then really what happens after 2030 is what I think is worth focusing on for the longer perspective, and that's where I get to talk about the topic I was asked to discuss, which is really focusing in on heavy industry and industrial decarbonization, the insertion of electricity, of green hydrogen, or failing those two options, of carbon capture, into the heavy industry decarbonization process.

My core message here is that independent of short-term investments [audio distortion] certainly the energy-intensive industry is still expanding like coal chemicals, for instance. China is currently laying the groundwork to be able to achieve dominance not just in those current three industries -- the solar panels, the batteries that were just mentioned -- but the next wave of clean tech, the clean tech meaning the green hydrogen, the electrolysis of green hydrogen, meaning the insertion of electricity into certain fossil fuel industrial processes and the carbon capture, and this will have profound global climate and economic consequences.

These technologies will come into especially clear focus after 2030, as they are in the demonstration phase right now, and they will both rely on and build upon the already considerable advantage sometimes that China has built in the foundational clean tech areas, like wind turbines, solar panels, and hydrogen electrolyzers.

Taking a look at where we are for electricity, even as we get closer to what would potentially be an energy peak, perhaps by the end of the decade or in the early years of the 2030s, there is really no expectation for an electricity peak, and that's really an important distinction to make, that as energy peaks, as petroleum consumption comes to a peak, as coal consumption starts to come to a peak, that electricity will continue to play a larger and larger role as it is inserted into every single aspect of the industrial economy and of the power generation sector, naturally, so that Chinese electricity demand continues to grow all the way out to 2030, '40, '50, maybe even out to 2060.

To be able to do that, to be able to continue increasing electricity demand and continue increasing the contribution, or at least holding stable the contribution that heavy industries are able to play in the overall Chinese industrial economy but still be able to commit to slowly decarbonizing, as is stated and as intended to be happening between 2030 and 2060, there must be some trick, right. There must be some way to balance that out. And the way that it looks like it will have to be balanced is to be able to look at some of those most fossil fuel-dependent, heavy industry fossil fuel-centric processes and be able to swap them, substitute them for something else.

Looking at some of the ways that that will be achieved or that the groundwork is being set for those right now, we can take a look at some of the broader climate and electrification policies that are directly affecting heavy industry right now. We talk about policies like the carbon Dual Controls policy, which has been in place for a few years and is now slowly ramping up to become more of an aggressive force for the industry, to be able to be held to certain energy intensity and then later carbon intensity benchmarks, set on the national level and then distributed out to provincial levels.

We take a look at the renewable portfolio standard, a requirement for first provincial power entities to consume a certain minimal renewable power level, and that also getting spread out to heavy industries like steel, cement, petrochemicals, that they will be held to a minimum renewable energy consumption level just to be able to operate.

We look at the emissions trading scheme, and we look at the rollout of this national emissions trading scheme that is also now pulling in some of those heavy industries like steel and cement and aluminum, with the expectation that they be able to cap their emissions at a certain level, and if they exceed those that they have to pay for carbon.

And then finally we look at some of the things going on in the power generation sector, specifically when it comes to coal-fired power plants. Yes indeed, they will continue playing a pivotal role. Even as the renewable sector expands, even as renewables become the major server of power consumption growth in the coming decade, the coal will still be there. And if the coal still has to be there, how can it be as clean -- and maybe there is no such thing truly as clean coal, but how can it be as clean as possible, with efficiency updates, with high efficiency boiler retrofits, with incredibly, incredibly low usage of coal per kilowatt hour of power generated. All of these very niche, leading-edge industrial applications currently taking place in China, and then China really leading the world in some of these niche applications.

And then we look at the actual industrial applications for the industry. We take steel, for instance. Are we going to be able to introduce more electrification of steel? Are we going to be able to insert green hydrogen into the steel production process? The answer probably is yes, and the demonstrations are happening in China.

When we take a look at carbon capture, are we going to be able to apply carbon capture to the production of cement, because cement has certain unavoidable emissions associated with limestone calcination. Can we do those? The answer is yes, and i's demonstrating right now in China.

When we take a look at aluminum and the production of aluminum being very energy intensive, an awful lot of electricity. Can it be done with green electricity? Yes. That's demonstrating a demo project right now in China. Can we swap out the carbon anodes in aluminum for inert anodes instead and remove those emissions? That demonstration project is also happening in China.

Right now, all of the 2030 to 2040, 2050, 2060 industrial technology applications to be mastered in order to decarbonize heavy industry, they are demonstrating them right now. Are they all going to be successful? No, of course not. They're expensive. They're incredibly expensive when we are talking about electricity, when we are talking about hydrogen, carbon capture. Some of them will fail. But these are part of the overall broad industrial strategy. They have the full backing of the state when they are named demonstration projects. They have backing to ensure the risk is taken out of them. And increasingly, the successful ones will find their way to the top. They will float their way to the top.

The way I see it right now, and what I am tracking in the world, is that really China and some European companies have pulled out to a pole position in applying these technologies, and unfortunately, from what I see, the United States is at critical risk of falling behind. I do hope some of the recommendations in my testimony can be considered to that effect about how the United States can engage with China and some of its other partners around the world and try to make sure it stays part of that critical technology transition. Thank you.

COMMISSIONER GOODWIN: Thank you, Mr. Fishman. Dr. Downs.

PREPARED STATEMENT OF DAVID FISHMAN, SENIOR MANAGER, LANTAU GROUP

Testimony Before the U.S.-China Economic and Security Review Commission

Hearing: "China's Domestic Energy Challenges and Its Growing Influence over International Energy Markets"

David Fishman
Principal, The Lantau Group

25 February 2025

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FOREWORD

Members of the Commission and Commission staff, thank you for inviting me to testify on China's groundwork for the clean energy economy.

I was invited to present an overview of the Chinese energy and electricity landscapes, a review of energy consumption and energy efficiency policies, and an in-depth of decarbonization potential through industrial electrification in heavy industries. Recognizing the complexity of this topic, I have slightly expanded the scope beyond the initial parameters to provide more comprehensive coverage of China's energy ecosystem. While this broader approach risks appearing unfocused, it enables me to present a cohesive framework that may serve both current and future policy discussions. The urgency of China's dual carbon goals (peaking emissions by 2030 and achieving carbon neutrality by 2060) as well as the enormity of the topic itself, demands such thorough examination.

For the last decade, the Chinese tech sector has repeatedly embodied the narrative of: "*slowly, then suddenly all at once"*. From solar panels, to EVs, to next-gen nuclear power, to artificial intelligence, Chinese tech stakeholders have repeatedly demonstrated the capacity to effectively funnel resources towards a strategic technology objective, rapidly make up for lost ground versus their global peers and then leap from relative obscurity into a world-leading position, often within the matter of just a few short years.

Much has been said already about topics like solar panels and EVs, and I don't intend to retrace such well-trodden earth here. Instead, the discussion will focus on China's current efforts to develop and master carbon-reducing technologies for heavy industry and process emissions, which still garner insufficient publicity, though they will be no less impactful over the long run. These include technology solutions like coal plant high-efficiency retrofits, electrification of petrochemical production, injection of green hydrogen into steelmaking, or deployment of carbon capture for decarbonized cement production, to name just a few.

While much discourse on the China energy sector has focused on short-term negative developments on the carbon emissions front, like China's thermal power expansion and coal-dependent chemical production processes, these framings critically overlook the pivotal question: are China's current approaches structurally aligned to fulfil its climate commitments to peak and eventually neutralize carbon emissions? Independent of short-term developments appearing this year or next, is the necessary groundwork being laid to actually achieve those long-term goals? I believe the answer to those questions is yes.

To put it bluntly, there's no way for China to continue to see heavy industry to continue to play such a dominant role in its overall economy, *and* simultaneously realize whole-of-economy emissions reduction, without developing, demonstrating, and deploying *en masse* practical substitutions for fossil-fuels use in industrial processes. As I will introduce in this piece, industrial decarbonization technology is now entering the take-off phase, crossing the tipping point from academic research to rapid commercial scaling. In many of these segments, Chinese companies are already quietly leapfrogging to the front of the development race. By assertively laying the foundation for their post-2030 industrial decarbonization blueprint, China is positioning itself to dominate the critical technologies bridging its carbon peaking and carbon neutrality milestones, reshaping global climate technology markets in the process. This blueprint will transform all energy-consuming sectors, with especially profound implications for the power generation and heavy industry segments, which must pioneer a number of emergent and often still unvalidated technologies to hit their goals. These technologies are seeing demonstration implementation now, and while they won't necessarily all be successful, the ones that *are* successful will come to define global best-practices.

That being said, immense challenges still remain, particularly regarding the cost of electrification, the cost of green hydrogen, and the immaturity of the carbon-capture technology that will be needed for the hardest-to-abate sectors with the most unavoidable emissions. These challenges should not be understated or underestimated. China indeed has quite a mountain to climb, but at least it has already begun ascending. As China and Europe pull out to a dual pole position in industrial cleantech research and commercial deployment, the United States is at critical risk of being left behind.

US policymakers are also suffering, in my estimation, from a severe and persistent gap in up-to-date market intelligence on Chinese technology progress and achievements, even for segments where the relevant information is readily published via public channels and platforms. It is impossible to engage effectively with a peer nation, regardless of whether you view them as collaborator, adversary, or any combination of the two, when decision-making is predicated on incomplete or outdated views of your counterparty's activities, efforts, intentions, and capabilities. This must be rectified.

In the interest of full transparency, my hope is, and always will be, for greater cooperation between the United States and China on all cleantech sectors, industrial decarbonization included. I believe such collaboration is an unadulterated net positive for all citizens of planet Earth, regardless of nationality. An adversarial relationship can only make this monumental task at hand – the task of decarbonizing the global economy – slower and more difficult, and the outcomes for the environment (not to mention global economies) that much more damaging.

1. CHINA ENERGY OVERVIEW

1.1. ENERGY:

China's total primary energy production reached a new high in 2024, hitting 4.9 billion tons (5.4 billion short tons) of standard coal equivalent (SCE), up 3.1% from 2023. Raw coal continued to dominate the energy mix, although its share of primary energy use has declined from 72% in 2015 to approximately 67% in 2024.

Despite the slow re-orientation of the primary energy mix away from coal and in favor of primary electricity[1], fossil fuels still comprise most of China's energy use. However, primary energy demand is expected to peak in the coming years and enter a gradual decline thereafter, with coal's role declining as well.

Figure 1: China Primary Energy Composition 2015-2024

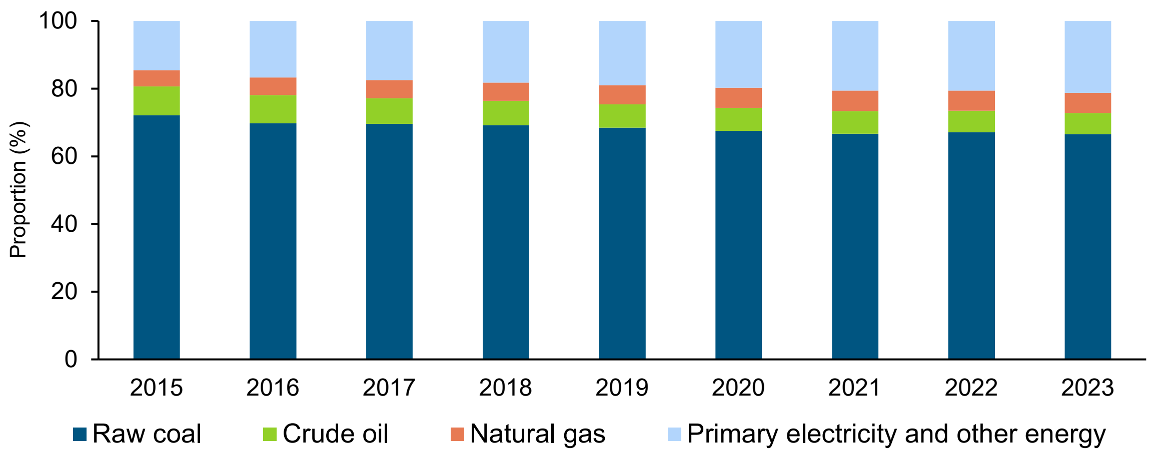
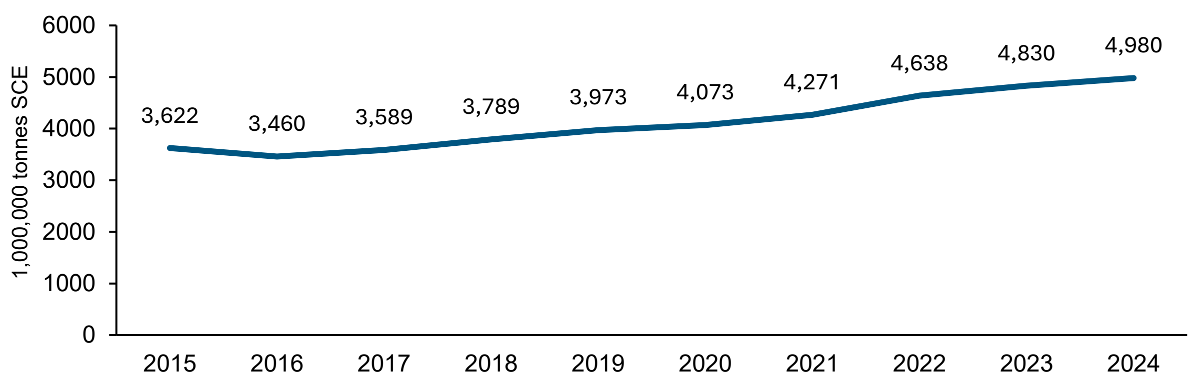


Figure 2: China Primary Energy Consumption Growth 2015-2024



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[1] Chinese statistics on primary energy employ report a metric not often used in the United States called "primary electricity." Electricity itself is *usually* defined as a secondary energy source. However, the category of 'primary electricity", when it is used, refers to electricity not produced from another primary energy source like coal or natural gas. Thus, "primary electricity" covers sources like hydropower, nuclear, solar PV, geothermal, and wind.

1.1.1. Petroleum

Chinese petroleum consumption hit 750 million tonnes (roughly 5.5 billion barrels) in 2024, declining 1.2% year-on-year. Whether this becomes a long-term petroleum consumption peak is still unclear, although the peak should certainly arrive before the end of the decade. Researchers at the state-owned China National Petroleum Corporation (CNPC) project Chinese total oil demand will peak at 770 million tonnes (5.6 billion barrels) in 2025 and decline thereafter,[2] while their state-owned competitor Sinopec projects Chinese oil consumption will peak in 2027 instead, at 800 million tonnes (5.8 billion barrels).[3] Meanwhile, financial services provider UBS Securities expects the petroleum peak will arrive as late as 2029 and start declining from 2030.[4] Notably, all these forecasts were performed *prior* to the current U.S. – China trade tensions of April 2025.

Among petroleum-consuming segments, demand in the transportation sector is widely agreed to have *already* peaked, driven by growth in alternative transportation sources, including high-speed rail, LNG trucking, and electric passenger vehicles (which accounted for 50% of new Chinese car sales in 2024). The International Energy Agency expects Chinese oil demand for transportation fuels will continue declining at an accelerating pace going forward.[5] Currently, the main segment driving petroleum demand growth in China is the petrochemicals sector, which added more than 250,000 barrels/day of demand in 2024 and is expected to continue growing at a modest pace, balancing the decline in transportation demand.

Chinese domestic petroleum reserves are limited, and expansion opportunities are limited. China imported about 73% of its petroleum in 2024, a number widely expected to fall as petroleum demand falls.

1.1.2. Natural Gas

Chinese natural gas consumption in 2024 reached 428 bcm (15.11 tcf), rising 8.4% over the previous year.[6] Industrial fuel gas was the largest consumption subsector, accounting for over 40% of total gas consumption. However, city gas has been the fastest-growing subsector, driven by the rapid expansion of the LNG-powered heavy duty trucking fleet. Power-to-gas remains a relatively small segment in China, accounting for just 67 bcm (2.37 tcf) of demand in 2023.[7]

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[2] "中石油经研院：中国石油需求将于 2025 年左右达峰," December 11, 2024. https://companies.caixin.com/2024-12-11/102267051.html.

[3] Cao, Ella. "China's Oil Consumption to Peak by 2027, Says Top Refiner Sinopec | Reuters." Reuters, December 19, 2024. https://www.reuters.com/world/china/sinopec-forecasts-chinas-petroleum-consumption-peak-by-2027-2024-12-19/.

[4] Liu Yukun. "Petroleum Demand Forecast to Peak by 2029." Chinadaily.com.cn. November 21, 2024. https://www.chinadaily.com.cn/a/202411/21/WS673e8e56a310f1265a1cec40.html.

[5] IEA. "Oil Demand for Fuels in China Has Reached a Plateau – Analysis - IEA," March 11, 2025. https://www.iea.org/commentaries/oil-demand-for-fuels-in-china-has-reached-a-plateau.

[6] "2024 年 12 月份全国天然气运行快报." 国家发展和改革委员会 January 23, 2025. https://www.ndrc.gov.cn/fggz/jjyxtj/202501/t20250123_1395858.html.

[7] Center on Global Energy Policy at Columbia University SIPA, CGEP. "Rising Production, Consumption Show China Is Gaining Ground in Its Natural Gas Goals - Center on Global Energy Policy at Columbia University SIPA | CGEP %," April 7, 2025. https://www.energypolicy.columbia.edu/rising-production-consumption-show-china-is-gaining-ground-in-its-natural-gas-goals/.

Chinese gas demand will continue to grow beyond 2030 and potentially not peak until the end of the next decade, according to the state-owned China National Offshore Oil Corporation (CNOOC).[8] CNOOC predicts Chinese annual gas consumption will reach 700 bcm (24.72 tcf) when it peaks in 2040, while the International Gas Union expects Chinese gas consumption will reach 650 bcm (22.95 tcf) by that time.

China produced about 250 bcm (8.83 tcf) of gas domestically in 2024, meeting about 60% of its gas needs.

1.1.3. Coal

Coal meets the majority of China's primary energy demand, with raw coal consumption rising 2.3% YoY in 2024 to 4.59 billion tonnes (5.06 billion short tons). Major coal consumption segments include power generation (estimated to comprise about 60% of Chinese coal consumption), production of steel (15%), production of coal chemicals (8-10%) and production of building materials like cement and glass (about 6-10%). The last few percentage points go to smaller industrial applications, production of non-ferrous metals, and heating buildings (particularly in northern China, where small-scale coal boilers may still be found, despite official policy discouraging their use).

While coal consumption for power generation has seen slow growth and is close to peaking as renewable deployments ramp, the outlook for consumption of coal in other industry sectors is less clear as it depends on those sectors' performance. Demand for building materials has been sluggish following the contraction of the Chinese real estate market, and this sector is not expected to contribute much growth to coal demand going forward, but demand in the steel and chemicals segments could still rise. After coal consumption for power generation peaks, consumption in industrial segments could continue to prop up coal demand, even beyond the overall emissions peaking deadline of 2030. The likelihood of this happening is likely highest in the coal chemicals segment. However, the China National Coal Association currently forecasts overall Chinese raw coal use will peak by 2028.[9]

China is particularly notable for its heavy reliance on its abundant domestic coal to produce chemicals like ammonia, methanol, and even olefins, which in other countries are often produced using petroleum or natural gas as feedstock instead. Producing these chemicals with coal in China is rational, considering the distribution of China's fossil fuel resources; However, the coal-based pathway to production of these chemicals is usually much more carbon-intensive than using natural gas; for instance, ammonia produced from coal instead of gas releases 4x more carbon emissions.

More than 90% of Chinese coal consumption is met by domestic production. While Chinese domestic coal production capacity is sufficient to meet 100% of domestic needs, domestic mines are mostly located in the north of the country, which opens the door for competitively priced imports in the south.

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[8] Argus Media. "China's Natural Gas Consumption to Peak in 2040: CNOOC." *Latest Market News*, May 23, 2024. https://www.argusmedia.com/en/news-and-insights/latest-market-news/2571046-china-s-natural-gas-consumption-to-peak-in-2040-cnooc.

[9] Liu Yukun. "Association: Coal use forecast to peak by 2028." Chinadaily.com.cn. April 10, 2025. http://chinadailyglobal.com/a/202504/10/WS67f71da0a3104d9fd381e7f9.html

1.2. Electricity

1.2.1. Power Generation

The Chinese power sector is the largest in the world, with total power generation from all sources in 2024 reaching 10,087 terawatt-hours (or over 10 petawatt-hours).[10] After accounting for line losses, this allowed for 9,846 terawatt-hours of electricity consumption across all segments.

Table 1: China Electricity Generation Mix 2024

Power Source	Generation Volume	Percentage of Total *(with rounding)*	Comments
Coal	5528 TWh	54.8%	
Wind and Solar	1836 TWh	18.2%	
Hydropower	1426 TWh	13.4%	*Recovered partially, but not fully, from drought conditions in 2022/23*
Nuclear	451 TWh	4.5%	
Gas	241 TWh	2.4%	
Other	606 TWh	6.0%	*Includes biomass, waste-to-power, geothermal, wave energy, etc.*

In 2024, Chinese power generation rose 6.8% year-on-year, adding 631 TWh of new generation. For context, this is roughly equal to the entire power consumption of South Korea in 2023 (618 TWh). Of this growth, 522 TWh was provided by low-carbon sources (wind, hydro, solar PV, and nuclear). Again, to place this in context, this is slightly more than the entire power consumption of Germany in 2023 (506 TWh). Low-carbon power generation met roughly 83% of China's 2024 growth in power generation, with the remaining 17% met by rises in coal, gas, and other thermal generation.

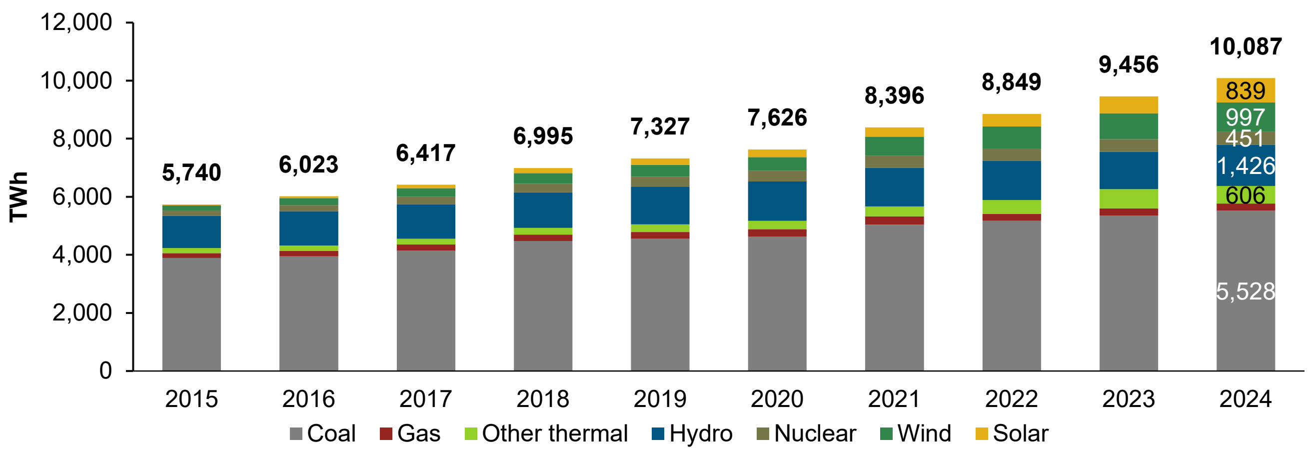
Coal-fired power generation grew 1.7% year-on-year to 5528 TWh, however its overall role in the generation mix continued to decline, as other generation sources grew at a faster pace, causing it to end the year at roughly 55% of the total mix. Looking ahead, coal's share of the overall power generation mix will continue to decline, driven by tightening climate targets, slowing power consumption growth rates, and continued high levels of investment in clean energy. The portion of power provided by burning coal should drop to ~50% by 2030.

Once clean energy generation growth is able to consistently meet or exceed 100% of power consumption growth, coal-fired power generation will peak and begin to decline. This is likely to happen sometime in the next 2-3 years, depending on renewable capacity additions, hydropower performance, and economic conditions in the industrial sector. Long-term, power consumption will continue to grow well past China's carbon emissions peaking deadline, as industrial sectors, transportation, and buildings continue to substitute fossil fuels for electricity. Thus, while Chinese *energy* consumption is expected to peak in the

10 "国家数据." National Bureau of Statistics. https://data.stats.gov.cn/search.htm?s=%E5%8F%91%E7%94%B5%E9%87%8F;

early 2030s, *electricity* consumption could continue growing for many decades thereafter. Consistent high rates of renewables additions plus industrial transformation to be needed to decrease reliance on coal as consumption continues to rise.

Figure 3: China Power Generation 2015-2024



1.2.2. Power Consumption

China divides its power consumption segments thusly:

- Primary industry (agriculture, aquaculture, and animal husbandry)
- Secondary industry (manufacturing and mining[11])
- Tertiary industry (commerce and services)
- Residential (commonly also called households or domestic consumption in international reporting)

Traditionally, secondary industry has been the largest power-consuming segment, driven mostly by manufacturing (which accounts for 95% of power consumed in the segment). The tertiary industry and residential sector have only started to play a larger role in the consumption mix in the last decade, following the growth of the consumption economy and continuing expansion of household wealth. However, power consumption in tertiary industry and households together still only account for about half as much as secondary industry.

Table 2: 2024 China Power Consumption by Segment[12]

Segment	2024 Total Consumption	% of Total
Primary Industry	136 TWh	1.4%

[11] Mining is classically considered to be part of primary industry in economics theory; however, within China's national accounting system is it counted within secondary industry.

[12] "2024 年全社会用电量同比增长 6.8%." 国家能源局. January 20, 2025. https://www.nea.gov.cn/20250120/4f7f249bac714e7693adecac996d742f/c.html.

Secondary Industry	6390 TWh	64.8%
Tertiary Industry	1830 TWh	18.6%
Residential	1490 TWh	15.2%
Total	9846 TWh	100%

1.2.3. Drivers of Power Consumption Growth

- **Secondary industry power consumption** trends are strongly correlated with economic activity in the manufacturing segment. In other words, when industrial value-added portion of GDP rises, industrial power consumption also rises.
- On the other hand, **tertiary industry power consumption** is driven by two things: economic activity (i.e., services consumption) AND the weather (severe hot or cool weather drives cooling and heating demand in, e.g. shopping malls and hotels). Regression analysis can help isolate out the effects.
- Finally, **residential power consumption** growth in developing countries is typically driven by the household electrification rate. However, since China's household electrification rate is already 100%, Chinese residential power consumption growth is now mostly driven by the rising penetration rate of electrical appliances (especially air conditioners) and the weather (hot or cold weather drives cooling or heating demand, just like in the services segment).

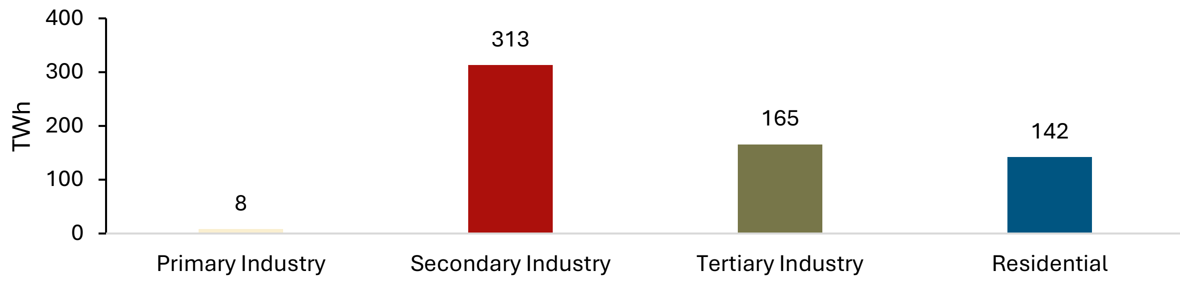
Table 3: 2024 China Power Consumption Growth Drivers

Segment	2024 YoY Consumption Growth Rate	% of 2024 Consumption Growth
Primary Industry	6.3%	1.3%
Secondary Industry	5.1%	49.7%
Tertiary Industry	9.9%	26.3%
Residential	10.6%	22.7%

While secondary industry remains the largest consumption segment in China by far, its growth rate in 2024 was considerably lower than that of the tertiary industry and residential segments, reflecting both a much higher base and persistent economic headwinds for the industrial sector.

In 2024, the tertiary industry and residential segments together added nearly as much new power consumption as the secondary industry segment, reflecting their higher rates of growth from a lower base. This trend will likely continue and even accelerate into the coming years, as manufacturing portion of GDP continues to shrink, services portion of GDP continues to grow, and household incomes continue to rise.

Figure 4: Comparison of China 2024 Power Consumption Growth Drivers by Segment



Despite its high total power consumption levels, China's annual power consumption *per capita* is still relatively modest, reaching roughly 7,000 kWh in 2024. This is now roughly on par with developed economies like Germany and Japan, and about 70% of the power consumption level per capita in countries like the United States, Canada, or Australia.

Furthermore, Chinese households still consume much less power per capita than their counterparts in developed countries. In 2024, Chinese residential power consumption per capita was approximately 1,000 kWh, around one-fourth of the average residential consumption level per capita in the USA.[13]

1.3. GDP Growth vs. Power Consumption Growth

Chinese GDP growth and power consumption growth have historically been well correlated, exhibiting a strong and predictable elastic ratio. In recent years, this relationship has changed slightly, with the correlation remaining, but elasticity ratio changing, with power consumption growth rate now consistently surpassing the GDP growth rate. This can be attributed to a combination of several factors:

- The ongoing electrification of industrial processes that traditionally use fossil fuels, such as steel, cement, and machinery production. This drives up electricity consumption while leaving GDP unchanged. This driver will continue to be relevant while there are still industrial processes to electrify.
- Extreme weather patterns, particularly hotter summers, have increased the use of air conditioning in residential, commercial, and industrial settings. This drives up electricity consumption but contributes little to GDP growth. This driver will continue to be relevant as extreme weather and hotter summers become more common.
- Stronger post-pandemic growth in energy-intensive industrial sectors like coal chemicals and aluminum manufacturing. Heavy industries tend to use more electricity to generate GDP activities than light industry or services like finance or healthcare.
- Intensive competition among industrial producers, causing them to focus on cutting costs and expanding output, rather than improving profit margins. This leads to increased power consumption sans a proportional rise in GDP, as lower-margin goods contribute less value in an accounting sense.

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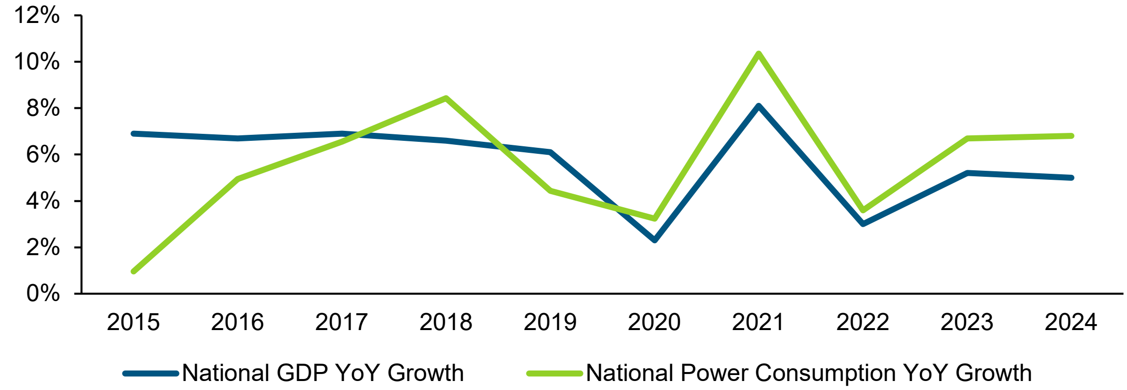
[13] Francis, Mickey. "Per Capita U.S. Residential Electricity Use Was Flat in 2020, but Varied by State ." U.S. Energy Information Administration, August 6, 2021. https://www.eia.gov/todayinenergy/detail.php?id=49036#:~:text=Per%20capita%20U.S.%20residential%20electricity%20use%20varied%20widely%20across%20the,Missouri%20(%2D3%25%20each.

Figure 5: China 2015-2024 Power Consumption Growth versus GDP Growth



However, this gap between GDP growth and power consumption growth is unlikely to persist in the mid/long term. As China accelerates its transition toward a more service-oriented and high-value economy, electricity consumption growth rates will slow again, re-aligning with GDP growth, and shrinking the gap between the two, which could happen by around 2030. In the long run, especially under a new economic model centered around services and innovation, electricity consumption could even grow more slowly than GDP.

1.4. The Role of AI and Data Centers in Driving Power Consumption Growth

Chinese power industry association the China Electricity Council (CEC) predicts total power consumption for computing infrastructure will hit 360 TWh in 2025, comprising 3-3.5% of total power consumption.[14] Of this, some smaller fraction represents the capacity needed to support artificial intelligence (AI) computing, representing a small but rapidly growing portion of services power consumption growth.

According to CEC estimates, as recently as 2019, data centers in China consumed just 60-70 TWh of electricity, accounting for only 0.8% to 1% of the country's total electricity consumption. According to calculations by China's computing power platform, in 2023, data center consumption had grown to approximately 150 TWh, or about 1.6% of total electricity consumption nationwide, with an average annual growth rate of around 21%. [15] According to 2024 comments from the Vice GM of the China Energy Engineering Corporation (CEEC) power consumption for computing infrastructure will expand very rapidly in the next five years reaching as much as 1,100 TWh by 2030.[16]

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[14]"电力消费新增长点 今年用电量将达 3600 亿千瓦时." 北极星电力新闻网, April 2025. https://m.bjx.com.cn/mnews/20250401/1434821.shtml#:~:text=%E4%B8%AD%E7%94%B5%E8%81%94%E9%A2%84%E8%AE%A1%EF%BC%8C2025,%E9%87%8F%E5%8D%A0%E6%AF%94%E6%8E%A5%E8%BF%916%25%E3%80%82.

[15]Chen, Yu. "算力的尽头是支撑性电源." 中国电力企业管理, February 27, 2025.

[16] As reported in Southern Energy Observer by reporter He Nuoshu on 11 July, 2024. Article retrieved at https://mp.weixin.qq.com/s/COfGh1l_254hNaYMIRPn4Q

2. ENERGY POLICY AND DECARBONIZATION

2.1. THE 2030/2060 "DUAL CARBON" TARGETS

China has set an official target of 2030 to peak its carbon emissions, followed by a 2060 target for carbon neutrality. The 2030 peak is likely to be reached early, and perhaps already arrived last year, according to analysis from the Helsinki-based Centre for Research on Energy and Clean Air[17], suggesting an "early peak". However, this early peak is likely to be more of a plateau from 2025-2030, before declining from 2030 onward, based on the continued high rate of electricity consumption growth. The Chinese government has made no official acknowledgement of the flat emissions growth in 2024 and maintains the official peaking target to be 2030.

2.2. ENERGY CONSUMPTION CONTROL AND DECARBONIZATION POLICIES

2.2.1. China's High Energy-Consuming Industries

Chinese energy policymakers have promoted many targeted policies in recent years to control/reduce energy and carbon emissions, across the economy and in heavy industry especially. These policies usually specify actions for China's 8 High Energy-Consuming Industries (HECI). The 8 HECIs are:

- Power generation
- Petrochemicals (ethylene, propylene, benzene, xylene, etc.)
- Other basic and fine chemicals (methanol, ammonia,[18] caustic soda, soda ash, sulfuric acid, etc.)
- Building materials (mostly cement and glass)
- Steelmaking
- Non-ferrous metals (production of aluminum, copper, zinc, nickel etc.)
- Papermaking
- Aviation (particularly fuel)

Decarbonization policies enacted at the highest level to control energy consumption and carbon emissions across the 8 HECIs include:

- The "Dual Controls" mandates, which impose performance benchmarks for energy consumption and energy intensity for high energy-consuming industries. Dual-controls policies have been amended to focus on carbon consumption and carbon intensity, rather than energy consumption and intensity.
- Minimum renewable power consumption mandates, called a renewable portfolio standard (RPS) which have already been rolled out for the power sector and some HECIs, with all HECIs to be folded into the RPS system by 2030.

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[17] Myllyvirta, Lauri. "Analysis: Record Surge of Clean Energy in 2024 Halts China's CO2 Rise ." Centre for Research on Energy and Clean Air, January 27, 2025. https://energyandcleanair.org/analysis-record-surge-of-clean-energy-in-2024-halts-chinas-co2-rise/.

[18] Methanol and ammonia are typically classified as petrochemicals, however they are primarily produced via coal gasification in China, thus they are considered coal chemicals here, not petrochemicals.

- A carbon emissions cap and trade system, which has only been rolled out for the power industry, but will soon include cement, steel, and aluminum, along with the rest of the HECIs by 2030.

Other policies, for example enforcement of energy efficiency benchmarks for certain sectors, are generally driven by these national objectives. Energy efficiency initiatives specifically support the Dual Controls mandates by reducing both energy consumption and intensity.

2.2.2. Energy Dual Controls and Carbon Dual Controls

The Energy Consumption Dual Controls: Introduced in 2015 during the 13th Five-Year Plan, the first iteration of this scheme aimed to **cap total energy consumption** at 5 billion tons of SCE and **reduce energy intensity** (defined as energy use per unit of GDP) by 15% by 2020 (energy consumption and energy intensity are the dual indicators to be controlled). This initial intensity goal was met by 2020.[19]

In 2021, the Chinese government proposed the "energy dual controls" evolve into "carbon dual controls" instead, targeting total carbon emissions and carbon intensity. Key goals for 2025 included another 18% reduction in carbon intensity and another 13.5% reduction in energy intensity. Provinces are evaluated individually and scored on their progress like a "report card". Provincial governments, in turn, promote implementing policies to the heavy industries operating within their jurisdiction.

To meet the dual controls objectives, provinces have pushed heavy industries to align themselves with industry best practice equipment and production standards, with manufacturers who are unable to meet the industry benchmarks forced to retrofit or shut down. However, some HECIs are just naturally high in carbon intensity or energy intensity, even when they are meeting industry best practice benchmarks. The post-pandemic economic development strategic in China has seen considerable growth in energy intensive industries, making adherence to the Dual Control targets a challenge.

By 2024, China had made some progress towards these goals but was **behind pace** to meet its 2025 targets. According to analysis published in Carbon Brief in early 2024, China would need to reduce carbon intensity by 7% in each of 2024 and 2025 to hit its 2025 carbon intensity goal, which it did *not* accomplish. Carbon intensity ended up falling just 3.4% in 2024, which missed the official target of 3.9%.[20] and the energy intensity goals for 2025 are likely to be missed as well.[21] This doesn't necessarily endanger the 2030 carbon peaking target, which is still five years away, but is a concerning sign worth monitoring.

2.2.3. Renewable Portfolio Standard (RPS)

China enforces a Renewable Portfolio Standard (RPS) policy, mandating certain sector entities to meet minimum renewable power consumption levels. Obligated entities may comply with RPS by buying green power or green energy certificates. The RPS level is differentiated by province, according to their renewable energy resources, and rises each year (usually +1% per year). Thus, a province like Sichuan with its

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[19] To be precise, Chinese official sources state *carbon intensity* decreased by 18.8% from 2015-2020, which is an imperfect proxy for energy intensity, which unfortunately was not reported following the re-focus from energy controls to carbon controls.

[20] Hale, Erin. "China's Missed Emissions Target Poses Challenge to Global Climate Efforts." Al Jazeera, March 25, 2025. https://www.aljazeera.com/news/2025/3/25/chinas-missed-emissions-target-poses-challenge-to-global-climate-efforts.

[21] Myllyvirta, Lauri. "Analysis: Record Drop in China's CO2 Emissions Needed to Meet 2025 Target." Carbon Brief, May 10, 2024. https://www.carbonbrief.org/analysis-record-drop-in-chinas-co2-emissions-needed-to-meet-2025-target/.

abundant hydropower has a relatively high RPS level (70%) while a coastal province with no hydropower resources and limited available land to build local renewables will have a lower RPS level (e.g., 20%).

The NEA and NDRC have called for the nationwide total share of renewables generation currently at 32%, to reach 40% by 2030.[22]

Until recently, only power sector entities, including grid companies, retailers, and wholesale power buyers, were mandated to meet the RPS at the national level. However, HECIs are now starting to be added into the RPS scheme as well, including aluminum since 2024. All HECIs will be included in the RPS scheme before 2030. Additionally, power consumption for data center operations is now subject to national mandates for renewable power consumption too, although data centers were not traditionally included in the list of HECIs.

Policies in some provinces have already moved faster than the national mandates. Inner Mongolia, for instance, has already announced *all* HECIs will be folded into its RPS by the end of 2025.

2.2.4. Emissions Trading Scheme

China launched a national carbon trading scheme in 2021, which initially covered just power generators. However, in March 2025, the carbon trading market was expanded to cover steel, cement, and aluminum, covering 60% of China's total emissions, according to the Ministry of Ecology and Environment.

Under the national carbon trading scheme, firms are allocated a quota of free emission allowances according to national benchmarks. If their emissions exceed the quota, they must purchase additional carbon emission allowances via the carbon market. So far, the quotas have been quite generous, leading to low demand for allowances and depressed carbon prices. Carbon trading will become a more effective tool for decarbonization when more firms are pulled into the scheme, free quotas drop, and higher carbon prices become an effective motivator to promote changes in behavior. This should all happen before 2030, but for now the national carbon market is currently still more of a pilot/demonstration effort, teaching obligated entities the mechanics of carbon trading while limiting the real burden imposed.

2.2.5. Coal Plant Efficiency Standards and Retrofits

While Chinese power generation is still highly reliant on coal-fired power, policy stakeholders have also set very aggressive policies for coal plant efficiency and performance standards, ensuring Chinese coal plants are among the most efficient and "cleanest" in the world (as least, as clean as coal can get). This has been reported previously by other international research institutions for nearly a decade, for instance, the DC-based Center for American Progress, in their provocatively-titled 2017 report: "*Everything You Know about Coal in China is Wrong*":[23] Their findings included:

- China's new coal-fired power plants are more efficient than anything operating in the United States.
- China's emissions standards for pollutants from coal-fired power plants are stricter than comparable standards in the United States.

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[22]北极星储能网. "能源局可再生能源消纳目标征意见！2030 年全国统一消纳责任权重 40%." February 10, 2021. https://news.bjx.com.cn/html/20210210/1135946.shtml.

[23] Center for American Progress. "Everything You Think You Know About Coal in China Is Wrong," May 15, 2017. https://www.americanprogress.org/article/everything-think-know-coal-china-wrong/.

- Despite rapid growth in generation capacity, Chinese coal-fired power plants continue to see lower annual operating hours as they are displaced by low-carbon alternatives.

These trends have only deepened since 2017, as power sector reform and aggressive policy mandates for coal-power have ensured Chinese coal plants continuously operate at the frontier of what is technologically possible for the technology. Using coal efficiently, in new ultra-supercritical coal plants, with high-efficiency boilers that maximize the energy extracted from the coal, makes just as much of a contribution to trimming emissions as replacing coal with renewable power, especially considering the long-term backup/peak smoothing role China's coal plants are expected to play in the grid mix.

In 2022, the NDRC mandated the coal-fired fleet reduce its coal consumption rate from 305.5 grams (10.78 oz) of standard coal per kWh to 300 grams (10.58 oz) by 2025. Back in 2005, this number stood as high as 370 grams (13.05 oz), making the 2025 target a 23% reduction. Meanwhile, no new plants can be approved that consume more than 285 grams/kWh (10.05 oz). Retrofits applied to already-existing plants ensure they can operate as efficiently or even more efficiently than newbuilds. A 2023 POWER magazine article described a newly retrofit Chinese coal plant as "The World's Most Efficient Coal Plant"[24] with the Phase 2 unit consuming as few as 251 grams/kWh (8.85 oz).[25]

Beyond this, newly-built coal plants are mandated to be able to ramp from 80% power output to as low as 30% output, and back up to 80%, in a matter of just hours, an uncommon and technically challenging operating regime for any coal plant in the world, but increasingly typical for Chinese coal plants forced to operate as load followers, like gas plants in the USA. Meanwhile, power market reforms have forced coal plants into the merchant market, competing against other generation types, where they now see annual fleet-wide capacity factors lower than 50%, necessitating capacity payment to maintain their solvency.

Such actions are necessary for China's long-term energy transition planning; China simply does not have the natural gas reserves countries like the United States are able to leverage to support the integration of variable renewable generation like wind and solar. Instead, coal will fill this role. Coal will remain integral to China's power generation mix for a long time, and while they are, it's in both China's and the world's interest that those coal plants operate as efficiently as possible. While early and more proactive steps to reform power markets could have resulted in fewer coal plants being added over the long-term, the new coal plants built in China these days are as superlatively efficient and "clean" as they possibly can be.

2.3. National Low-Carbon Demonstration Projects

Far from being just an empty title, National Demonstration Project is a powerful designation with many practical benefits to project owners, including direct financial and fiscal support, policy and approval advantages, increased access to technology and talent resources, prioritization in government procurement events, and long-term institutional backing from local authorities (for example, being written into the province's five-year plan). China uses the official designation of National Demonstration Project to identify projects with high strategic or symbolic value for technological breakthrough application.

[24] Patel, Sonal. "China's Pingshan Phase II Sets New Bar as World's Most Efficient Coal Power Plant." POWER Magazine, October 4, 2023. https://www.powermag.com/chinas-pingshan-phase-ii-sets-new-bar-as-worlds-most-efficient-coal-power-plant/.

[25] NS Energy. "Pingshan Thermal Power Plant Phase Two, Anhui Province, China," November 5, 2020. https://www.nsenergybusiness.com/projects/pingshan-thermal-power-plant-phase-two/.

In 2025, China added 101 projects[26] to its national low carbon demonstration project list, building on the 47 projects named in 2024. These projects are a direct proxy for what Chinese energy stakeholders think are the most important cutting-edge items in furthering the national low-carbon energy agenda. Some notable energy efficiency items are mentioned below (heavy industry is excluded, as it will be covered in the next section).

2.3.1. High-Efficiency Motors

China has focused heavily on improving the efficiency of electric motors. As of 2020, the efficiency level of domestic industrial motors remained below international standards, with unit efficiencies averaging approximately 75%—about 10 percentage points lower than their overseas counterparts—and system operational efficiency ranging from 30- 40% lower than the international benchmark by 20 to 30 percentage points. High-efficiency motors accounted for only 32% of total production that year. [27]

In response, Chinese authorities have adopted increasingly stringent energy efficiency standards and introduced industrial upgrading policies. The 2022 "Action Plan for Industrial Energy Efficiency Improvement," issued by the Ministry of Industry and Information Technology, aims to transform motor manufacturing through performance optimization, high-efficiency core design, and lightweight motor casings. The plan also promotes high-efficiency motor remanufacturing, targeting a 70% share of high-efficiency motors in new installations by 2025.

2.3.2. Building Retrofits

Public building retrofits are a core pillar of China's commercial sector decarbonization strategy. One notable demonstration project is the Beijing Future Building Innovation Center, designed as a near-zero energy and near-zero carbon structure. The building integrates multiple novel technologies, including high-efficiency motor systems, building-integrated photovoltaics (BIPV), hybrid photovoltaic-storage-direct current systems, and a comprehensive smart energy-carbon management platform. Upon completion, the Center achieved a 38% reduction in building-level energy use and an overall 70% improvement in energy efficiency, lowering energy intensity to below 26 kWh/sqm/year.

A second example, the Xi'an Taikoo Li Complex, similarly advances sustainable commercial architecture using shallow and mid-depth geothermal heat pump systems, multi-energy coupling heating technologies, and prefabricated construction with low-carbon materials. The facility incorporates solar panels with adjustable angles and an integrated energy storage system. Upon completion, it achieved a 70% overall reduction in energy use and a renewable energy utilization rate of 25%, serving as a model for zero-carbon commercial infrastructure. [28]

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[26] List of Advanced Green and Low-Carbon Technology Demonstration Projects (Second Batch). NDRC. https://yyglxxbs.ndrc.gov.cn/file-submission/20250402115327890451.pdf

[27] "电机能效标准严苛及降低能耗背景下 我国节能电机行业发展潜力充足." 观研报告网. May 3, 2024. https://www.chinabaogao.com/detail/706141.html.

[28] Ibid.

2.3.3. High-Efficiency Data Centers

China has also prioritized improving the energy efficiency of data centers, which are a rapidly growing source of new electricity demand.

In Zhejiang, the Jiaxing Advanced Intelligent Computing Center was developed as a near-zero carbon data center. It employs energy-efficient servers, variable-frequency centrifugal chillers, and cold-plate liquid cooling, resulting in a PUE below 1.2 and 100 percent reliance on green electricity.

In Shanghai, an underwater data center project integrates offshore wind power with ocean-based cooling systems. The 2.3 MW computing module, completely submerged underwater and powered by offshore turbines, achieved a PUE below 1.15 and 95 percent wind energy utilization, while avoiding freshwater consumption and reducing land use by 90 percent.

In Inner Mongolia, the Flexible Cooling Green Computing Center combines air and liquid cooling technologies, indirect evaporative cooling, and fluorine-pump HVAC systems. This facility maintains an average PUE of 1.14 and consumes approximately 90% green electricity. A parallel initiative in Ulanqab City further scaled this approach: the Smart Power-Computing Coordinated Data Center incorporating a 200 MW wind farm, 100 MW of solar capacity, and 180 MWh of storage, enabling direct green electricity supply. The facility's PUE remains below 1.2, with annual green electricity use exceeding 600 GWh, equivalent to an annual reduction of approximately 320,000 tons of CO2.

2.3.4. Residential Sector Applications

Energy-Efficient Appliance Innovation

One notable example is the High-Efficiency Refrigerator Green and Low-Carbon Technology Demonstration Project in Qingdao, led by Haier. This initiative integrates industrial internet systems with green manufacturing technologies, including inner-liner adsorption materials and low-cost, energy-saving insulation. The demonstration factory includes a high-efficiency refrigerator assembly line and three modular production lines, enabling the manufacture of one million energy-saving units per year and establishing a potential model for intelligent, low-carbon appliance production.

Clean Heating

Clean residential heating has also been prioritized as part of China's broader air pollution control and rural revitalization strategies. As outlined in the 2023 central government budget report, 33 billion yuan (approximately USD 4.8 billion) was allocated to promote clean winter heating in northern regions. By the end of that year, over 39 million rural households were reported to have transitioned to cleaner heating systems. These efforts have collectively reduced annual coal consumption by more than 70 million tonnes and carbon dioxide emissions by over 100 million tonnes, representing one of the world's largest energy-use transitions in rural housing. This transformation was described by Chinese authorities as both an environmental and a public welfare project, "revolutionizing" rural energy use.

Among the most prominent examples is the Phase II Geothermal Heating Demonstration Project in Xixian New Area, Shaanxi. The project employs mid-depth geothermal wells without centralized heating stations, instead utilizing distributed underground pipe arrays. With a seasonal coefficient of performance (COP) exceeding 4.5, the system serves 1.13 million sqm (12.2 million sqf) of building area and displaces nearly 20,000 tonnes of standard coal annually, corresponding to a 50,000-tonne reduction in carbon emissions.

In Jilin, the China-Korea International Cooperation Demonstration Zone established a hybrid geothermal heating and cooling system that combines shallow and mid-depth geothermal wells with multi-energy smart control systems. The project includes 11,345 shallow wells and six mid-depth wells, along with a centralized energy station and a smart supply network. Upon completion, the system will serve 1.33 million sqm (14.3 million sqf) meters of residential and commercial space.

3. HEAVY INDUSTRIAL DECARBONIZATION

3.1. High Energy Consuming Industry (HECI) Decarbonization Logic and Pathways

Before examining Chinese efforts in this space, it's important to first broadly describe the underlying chemical and physical principles of fossil fuel use and CO_2 emissions in these industrial processes. At a high level, consumption of fossil fuels in HECIs can be split into two broad buckets:

Usage of fossil fuels as an **energy carrier**, usually combusting them to produce the high temperatures necessary for some step of the industrial process.

Usage of fossil fuels as a **chemical feedstock**, where the fossil fuels are chemically inseparable from the process, often via a chemical reduction process (which usually means the carbon molecule in the fossil fuel is part of the final product).

Important Nuance: Some other industrial processes, such as the production of cement, release carbon via the processing of a carbon-containing mineral (for instance, in cement, the decomposition of limestone during the production of clinker releases CO_2). Strictly speaking, this is a mineral-based process, not fossil fuel-derived, and cannot be addressed with electrification or substitution of fuels. However, emergent technologies to replace limestone calcination exist and are under research now.

For the purposes of this summary, industrial electrification is treated as a discrete pathway from the use of green hydrogen, although they are often performing the same function (i.e., serving as an alternative source of heat). Green hydrogen is produced via electrolysis of water with green electricity, and so it is a second-order product of electricity, not electrification itself.

As a rule of thumb, it is generally technologically feasible to replace **energy carrier applications** for fossil fuels with electrification, although cost competitiveness may remain a barrier. Similarly, combustion of green hydrogen produced via electrolysis is often a technically viable (but costly) substitute for combustion of fossil fuels.

On the other hand, when fossil hydrocarbons are **chemically integral** to the final product (e.g., petroleum-based feedstocks in plastics or chemicals) decarbonization via electrification is unviable. However, green hydrogen often also finds potential applications here as a substitute for fossil fuels, particularly as a reducing agent in chemicals production.

For scenarios where fossil fuels are chemically inseparable from the production process, the typical alternative options to consider are:

1. **Carbon Capture and Utilization/Storage (CCUS):** Capture the emitted CO2 and sequester it, or use it as a feedstock for industrial production (like synthetic fuels).
2. **Material Substitution:** Replace fuel-based products with bio-based alternatives (like algae-based bioplastics).

In some cases, decarbonization of the industry can be achieved in phased steps, where electrification allows for some gains, introduction of green hydrogen improves those gains, and carbon capture accounts for the last few percentage points. In other cases, the most reasonable approach is to commit entirely to carbon capture from the outset, because the gains possible via electrification or green hydrogen aren't impressive enough to warrant the cost.

In many or even most cases, China pursues an "all of the above" approach to decarbonization and cleantech innovation. Thus, it would not be surprising to see multiple pathways to decarbonizing the same industrial process under research or even piloting commercially at the same time, advanced by different companies and all enjoying the benefit of state funding and resource support. The most successful and economic options will see mass deployment in the end, but not until all the potentially viable pathways have been explored.

Table 4: Fossil Fuel Applications and Substitutability of Electricity or Hydrogen Across China's 8 HECIs

Industrial Segment	Fossil Fuels Application	Opportunities for Substitution with Electricity	Opportunities for Substitution with Green Hydrogen	Comments
Power Generation	Combustion of coal or natural gas to produce heat, boil water, and spin a turbine	Yes – with power produced from wind, solar, hydropower, nuclear, geothermal, etc.	Hydrogen may find some limited application in the power sector as an alternative storage medium but is likely better used in other sectors.	
Petrochemicals	Fossil fuels are used both as feedstock and as energy carriers for heat via combustion.	High-temperature applications using fossil fuels can be substituted with electric steam crackers, but the technology is very new and relatively unproven. The medium/low-temperature operations can be substituted with electric boilers and infrared heating.	Gret hydrogen can be replaced with green hydrogen in many processes, including hydrotreating, hydrocracking, catalytic reforming. Hydrogen can also provide heat for production of aromatics and alkenes.	Hydrocarbons used as feedstock are irreplaceable in the current production processes of petrochemicals. In the long term, CCUS and/or alternative materials like bioplastics may be the only way to fully decarbonize petrochemicals.
Other Basic and Fine Chemicals	Fossil fuels are used both as feedstock and as energy carriers for heat via combustion.	Depends on product. Energy carrier applications for fossil fuels can be substituted with electrified heat and/or hydrogen. Products with no carbon molecules in the final product like ammonia often have alternative production processes using hydrogen. However, products with a carbon molecule in the final product like methanol are currently chemically inseparable from the use of carbon-bearing inputs (most commonly fossil fuels) as a feedstock.		Long-term, carbon produced via CCUS can be used as a feedstock for alternative production of carbon-containing chemicals like methanol.
Building Materials	Fossil fuels are used primarily as energy carriers for heat via combustion	High-temperature applications for glass manufacturing can substitute fossil fuels in glass furnaces with electricity or hydrogen, which account for most of the fossil fuel use in glass manufacturing. High-temperature applications for cement manufacturing can substitute fossil fuels for electricity or hydrogen, but emissions from limestone calcination remain.		Cement's production also relies on a process called limestone calcination, which leads to unavoidable emissions via the decomposition of CaCO3. This process must either be substituted for an alternative process, or CCUS implemented, to decarbonize cement production.
Steelmaking	Fossil fuels are used both as energy carries for heat, and as a reducing agent for iron ore processing.	Electric Arc Furnaces (EAF) can enable steel producers to utilize a different production process called direct reduced iron (DRI) instead of reliance on the traditional blast furnace – basic oxygen furnace (BF-BOF) process. This eliminates the use of coking coal but introduces the use of natural gas as a reducing agent at a later stage in the process. EAFs can also be used to produce secondary steel from scrap, offsetting demand for primary steel, but this pathway is limited by the supply of scrap.	If the steel plant is using the DRI process instead of the BF-BOF process, the natural gas typically used for reduction in this process can be almost entirely replaced with hydrogen with only trace emissions remaining. However, the cost and requirements for the grade of iron ore are higher. Hydrogen can also be cofired with coking coal in the BF-BOF process, reducing the demand for coke, but the reduction of demand is limited.	Steel plants must convert fully to 100% DRI and substitute hydrogen in the reduction process to realize decarbonized steel. If the BF-BOF process is still used, implementation of CCUS will be needed to achieve higher decarbonization levels for steel production.

Non-ferrous metals	Fossil fuels are primarily energy carriers in the production of non-ferrous metals, but some processes also rely on fossil-fuel based reduction.	Partially yes. Electricity already dominates production of these metals, particularly aluminum, but some chemically inseparable fossil fuels remain (carbon anodes for aluminum; coke for zinc or copper).	The use of coke as a reducing agent in pyrometallurgical production of zinc, and the use of coke or gas in pyrometallurgical smelting of copper could substitute hydrogen instead, but the technological and cost barriers are still very large.	Aluminum production uses carbon anodes (made from petroleum coke). Producers are exploring substitution of carbon anodes for inert anodes, which eliminate process-related emissions, but cost is a barrier.
Papermaking	Fossil fuels are energy carriers in the papermaking process, but most energy use is electricity.	Most energy use in paper production is used for drying, which can be met by electrified heating.	Combustion of hydrogen can be considered as an alternative heat source, but cost is a barrier.	Unlike many other industries, papermaking has a relatively high penetration of biomass combustion for its energy use, which creates biogenic carbon emissions and would necessitate use of CCUS to mitigate.
Aviation	Fossil fuels are chemically integral to the production of aviation fuel	Electric aircraft are a potential pathway, but battery energy density limits the application of electric-battery aircraft to short ranges only.	Hydrogen-powered aircraft are a potential pathway, but the cost of hydrogen limits their application.	Sustainable Aviation Fuels (SAF) are an emergent alternative pathway to production of jet fuel with lower emissions, although the release of CO2 is still part of their production process and would require CCUS to fully decarbonize.

Note: Some recent Chinese planning documents have started to include data centers/digital computing as a new/unofficial HECI, although it is categorized as being part of the tertiary industry sector, rather than the secondary industry sector. Data center operation can be virtually 100% decarbonized with electricity if green power is used, so while it IS a HECI, it is not a particularly problematic one to decarbonize from a technological perspective.

3.1.1. Chinese HECI Decarbonization Potential and Progress Assessment

A detailed assessment of electrification potential for ALL major carbon-emitting segments is worthy of extensive and detailed research but is outside of the scope of this exercise. Here, only an estimate of decarbonization potential via electrification for selected segments is provided, along with the additional incremental benefits of using green hydrogen or CCUS. Often these numbers represent very speculative numbers from academia or the results of just a single demo/pilot project. If a demonstration project exists somewhere in the world that can be referred to, it is usually deployed in Europe, China, or Japan.

For most industrial segments, Chinese research institutions and academic bodies are already at the forefront of decarbonization research (using electrification, green hydrogen, efficiency advancements, and/or CCUS) and have been for several years. The Chinese Academy of Sciences (CAS) has been particularly prolific in furthering industrial low-carbon research, supported by the full resource backing of the Chinese state. The role and ambition of the CAS is well summarized by a 2022 bulletin which established **CAS Strategic Action Plan for Science and Technological Support to Achieve Carbon Peak and Carbon Neutrality.** This action plan highlights eight Major Initiatives and 18 Priority Tasks, all revolving around research and deployment for industrial decarbonization.[29]

The academic and research efforts of the CAS, SOEs, private companies, universities, and various research institutes across both the public and private sector have yielded obvious fruit in the last decade. According to analysis from Nikkei, by 2024, Chinese companies held nearly half of the global total of patents related to CCUS, with issuance of patents in the cleantech and decarbonization space rising by 4x vs. 2015.[30] In a separate analysis, Nikkei reviewed research papers on Elsevier published between 2015 and 2020 across 18 cleantech-related sectors and found Chinese institutions led all other countries in 16/18 technical areas (for the last two, the United States led in paper count, barely, for research into geothermal and energy-efficient semiconductors).[31] Additionally, while not all these papers were necessarily categorized as high-quality papers, it is telling that China has also consistently led for energy research output in the Nature Index (a ranking system weighted for high-quality academic research in credible journals, and which also considers how often the research is cited by other papers).[32] By most available metrics, Chinese cleantech research, including for industrial decarbonization, is dominating in the world.

However, the commercial deployment of these technologies in China has lagged theoretical research a bit more and has only started to pick up in the last 2-3 years. While nearly every major energy-consuming industrial segment in China has at least a few demonstration low-carbon projects (either recently completed, or under construction now) their technological success or failure remains to be seen — and economic

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[29] He, Jingdong, Daquan Cao, Duan Xiaonan, et al., "Give Full Play to National Strategic S&T Force to Provide Vigorous Support for Carbon Peak and Carbon Neutrality Goals." *Bulletin of the Chinese Academy of Sciences*, April 6, 2022. http://bulletin.cas.cn/BCAS_CH/doi/10.16418/j.issn.1000-3045.20220324004

[30] "中国脱碳技术崛起，碳捕集专利数居首." Nikkei.com. June 18, 2024. https://cn.nikkei.com/industry/scienceatechnology/55675-2024-06-18-05-00-40.html.

[31] Misumi, Yuki. "China Hot on Heels of US in Cutting-edge Green Tech Research." *Nikkei Asia*, June 11, 2021. https://asia.nikkei.com/Spotlight/Environment/Climate-Change/China-hot-on-heels-of-US-in-cutting-edge-green-tech-research.

[32] "Asia Leads Rise in Clean-energy Research." *Nature* 639, no. 8055 (March 19, 2025): S24. https://doi.org/10.1038/d41586-025-00744-6.

viability is likely still years or decades away. When it comes to commercial deployment of low-carbon or zero-carbon industrial process technology (not just theoretical research) the closest peers to Chinese companies are typically European.

From a timing perspective, targeting completion of these demo projects in the late 2020s is reasonable. Even if they are successful, batch deployment of these technologies will not be strictly necessary for hitting decarbonization goals until post-2030, after the carbon peaking deadline is hit. Industrial decarbonization at scale is not necessary to peak carbon in China, but it will certainly be necessary to decrease emissions after 2030 and achieve carbon neutrality by 2060.

3.1.2. Decarbonization Potential in China for Selected Industrial Segments

Note these estimates for decarbonization potential focus entirely on technological feasibility, not economic feasibility. The percentage refers to the extent to which fossil fuels can be replaced via the indicated decarbonization pathway.

Petrochemicals

- **Electrification:** 30-40%

Electric motors can replace steam turbines and are more energy efficient as well. High-temperature cracking still relies on fossil fuels for now, but electrification can meet low-temperature heat applications and partial steam cracking via electric boilers. Electric steam cracking technologies are piloting at a BASF demonstration plant in Germany but are still very early-stage. BASF's electric steam cracking pilot in Germany targets 90% CO2 reduction, but this has not been demonstrated yet.

- **+ Green hydrogen:** 50-60%

Green hydrogen replaces fossil-based hydrogen in steam methane reforming (SMR) and feedstock production. Pilot projects show 23% emission reductions in ethylene cracking with incorporation of green hydrogen. Green hydrogen can replace grey hydrogen in production of various other alkenes and aromatics.

- **+ CCUS:** 80-90%

CCUS captures any remaining process emissions from cracking and SMR.

Situation in China: Chinese petrochemical firms and research universities are close to the technological frontier of petrochemical electrification and innovation, and lag only a few European companies in the whole world when it comes to track record for commercial deployment.

Electric steam cracking technology has been under research at the State Key Laboratory of Heavy Oil Processing at the China University of Petroleum for several years already.[33] In January 2025, The Tarim Phase II Ethylene Project announced it would be powering its triple ethylene units (cracked gas compressor, ethylene refrigeration compressor, and propylene refrigeration compressor) with electric motor drives, instead of steam turbines powered by fossil fuels. Additionally, the power for the site would be sourced from

[33] Gao, Jinsen, Xiaogang Shi, Xingying Lan, and Chunming Xu. "A Technical Roadmap for China's Petrochemical Industry Upgrading to Achieve Carbon Neutrality." *Engineering* 29 (August 25, 2023): 55–58. https://doi.org/10.1016/j.eng.2023.05.021.

renewable energy, and the site's remaining carbon emissions would be captured via CCUS and used as feedstock for the integrated production of synthetic urea and ammonia.[34] This is a first-of-a-kind project in China.

Steel

- **Electrification:** 25-50%

Swapping the Blast Furnace-Basic Oxygen Furnace (BF-BOF) production process for Direct Reduction Iron DRI with an Electric Arc Furnace (EAFs) can cut emissions associated with steel production by 25-50%. Use of coking coal in the blast furnace is eliminated, but natural gas is introduced as a reduction agent.

- **+ Green hydrogen:** 75-95%

Hydrogen DRI replaces natural gas as a reduction agent in the DRI process, eliminating the associated emissions. ArcelorMittal's Sestao facility in Spain claims ~75% decarbonized steel using hydrogen DRI and EAF.[35] Up to 95% is theoretically possible.

Alternatively, green hydrogen may be injected into the BF-BOF process as a substitute for coking coal.

- **+ CCUS:** 90-100%

If using hydrogen DRI with EAFs, there should be very few emissions left to capture, perhaps only some process emissions associated with additives. However, carbon capture can help to eliminate any remaining unabated emissions.

Situation in China: Multiple Chinese steel producers are establishing production of low-carbon or zero-carbon steel. For instance, Baowu Group has announced plans to invest 730M USD at its Zhanjiang site, using a hydrogen-fed shaft furnace in place of fossil fuels, with an annual capacity of 1.8 metric tons of "green steel".[36] This site will produce steel sheets for automobiles as well as electrical steel and was recently named a National Demonstration Project.

Cement

- **Electrification:** 30–40%

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34 中国石油网. "国内首套全电气化驱动的百万吨乙烯机组将应用于独山子石化项目." January 28, 2025. https://mp.weixin.qq.com/s/ig3cxucGiREkkYgft669cg.

35 Ricardo, and Ricardo. "Policies to Accelerate Steel Decarbonization in Europe 'Critical' in 2025: ArcelorMittal CEO - EUROMETAL." *EUROMETAL - The Voice of European Steel, Tubes and Metal Distribution Representing All Types of Steel Intermediation.* (blog), February 7, 2025. https://eurometal.net/policies-to-accelerate-steel-decarbonization-in-europe-critical-in-2025-arcelormittal-ceo/.

36 "Baosteel Zhanjiang Steel to Invest RMB 5.2046 Billion in Zero-carbon High-grade Sheet Plant," Steelorbis. March 20, 2024. https://www.steelorbis.com/steel-news/latest-news/baosteel-zhanjiang-steel-to-invest-rmb-52046-billion-in-zero-carbon-high-grade-sheet-plant-1332837.htm.

Electric kilns and plasma torches can replace fuel combustion (albeit very cost-ineffectively). Process emissions from limestone calcination remain.

- **+ Green Hydrogen**: 60–70%

Hydrogen combustion in kilns can reduce fossil fuel use but would also be very cost ineffective.

- **+ CCUS:** 85–90%

CCUS is needed to address unavoidable process emissions (60% of sector emissions) and is more promising as a pathway compared to the electrification or hydrogen routes. Demo projects like Heidelberg Materials' net-zero cement project in Norway validate the potential of this pathway.[37]

Situation in China: Several Chinese cement producers have targeted CCUS as the decarbonization pathway of choice for cement and launched pilot/demonstration projects.

The Baima Cement Plant of Conch Group launched its carbon capture project at the cement kiln flue gas outlet in 2018. At the time, it was the world's first demonstration project in the cement industry for flue gas capture and purification using chemical absorption technology. It was designed with an annual output of 50,000 tons of liquid CO2 for use in other industrial applications. In 2021, Conch Group developed a new generation of low-energy, high-efficiency chemical absorbents for cement kilns, further reducing capture energy consumption to 2.1 GJ per ton of CO_2.[38]

In 2024, Qingzhou Zhonglian Cement launched a CO2 oxy-fuel combustion enrichment and purification demonstration project. It is currently the largest CCUS project in China's cement industry, producing 150,000 tons of industrial-grade CO2, 45,000 tons of food-grade CO2, and 5,000 tons of dry ice annually. The project adopts several technological innovations to significantly increase CO2 concentration in flue gas and reduce overall capture energy consumption to below 1.6 GJ per ton of CO2, substantially lowering operating costs.[39]

Due to the limited number of large-scale operational CCUS projects in China's cement industry and the early stage of development and application, operational models are still under exploration and optimization. As a result, carbon utilization by cement enterprises remains relatively limited, and the construction of CCUS industry clusters (to use the captured CO2 onsite) has not yet been prioritized.

Aluminum

- **Electrification**: 65-70%

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[37] HM Group. "Pioneering the Transformation to Net Zero: Brevik CCS Project in Norway Reaches Mechanical Completion." Heidelberg Materials, December 2, 2024. https://www.heidelbergmaterials.com/en/pr-2024-12-02.

[38] Current Status and Outlook of CCUS Development in China's Cement Industry. China Building Materials Foundation. http://www.nrdc.cn/Public/uploads/2024-12-16/675f8b7c57920.pdf

[39] Ibid.

The Hall-Héroult aluminum smelting process itself is already fully electric, which means it can be abated by using green electricity. The remaining 30% of unaddressed emissions can be attributed to the use of carbon anodes, which are essential components of the Hall-Héroult process, and which are made from petroleum. Replacing carbon anodes with inert anodes can eliminate almost all process emissions.

- **Hydrogen:** N/A

There's little obvious role for green hydrogen in primary aluminum production; however, it can replace fossil fuels in the melting process of aluminum recycling to produce secondary aluminum. This has been trialled with some success at a demo project in Spain.

- **+ CCUS:** N/A

CCUS would not typically be applied for alumnium process decarbonization; however, it could be applied on a fossil-fuels power plant that is powering an aluminium smelter, in lieu of using green electricity.

Situation in China: The Action Plan for Carbon Peaking and Carbon Neutrality of Aluminum Corporation of China Limited calls for the sector to reach peak carbon emissions five years ahead of the national schedule (2025) and to reduce carbon emissions by 40% by 2035, aiming to become the first sub-sector in the non-ferrous metals industry to achieve carbon neutrality.[40] Besides hydropower-backed aluminum projects, there are several "green aluminum" demonstration projects using wind and solar, for instance the 350,000 ton capacity Zhahanuo'er Green Aluminum project in Inner Mongolia, which plans to obtain 80% of its power from wind and solar.

To date, there are not yet any instances of inert anode demonstration projects in China, but they are explicitly named as key research areas in the Electrolytic Aluminum Industry Energy Conservation and Carbon Reduction Special Action Plan released in July 2024.[41]

Ammonia

- **Electrification:** 20-30%

Traditional ammonia production involves the use of fossil-derived hydrogen in the Haber-Bosch process, so the direct gains achievable by electrification of ammonia production are relatively limited.

- **+ Green hydrogen:** 70-90%

Green hydrogen produced via electrolysis replaces fossil-based hydrogen. Pilot projects have shown up to 90% emissions reduction using this pathway and is the pathway currently showing the most commercial activity.

- **+ CCUS:** 90-95%

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40 "铝冶炼低碳清洁智能化创新发展研究丨中国工程科学." 中国工程科学. December 20, 2024. https://mp.weixin.qq.com/s/S08vZNZaLZoplKJbqsztNA.

41 "Electrolytic Aluminum Industry Energy Conservation and Carbon Reduction Special Action Plan", National Development and Reform Commission, July 2024. https://www.ndrc.gov.cn/xwdt/tzgg/202407/P020240723623280665889.pdf

In this scenario, CCUS would be applied to a traditional ammonia production facility (producing "blue ammonia" via steam methane reforming of natural gas) rather than as an additive measure to a green ammonia facility producing green ammonia from green hydrogen.

Situation in China: China has many green hydrogen and green ammonia projects under development nationwide, especially in the north and northwest of the country, where the cheap and abundant renewable resources can be found. A recent list of national low-carbon demonstration projects included an experimental carbon capture + green hydrogen + ammonia + oxamide production facility in the Xinjiang UAR with 200,000 tonnes of annual green ammonia production capacity.

Summary Comments

A comprehensive and detailed whole-of-industry assessment of the potential for electrification to abate fossil fuel usage would be well outside of the scope of this report. However, based on the typical figures for some of the highest energy-consuming segments shown above, a rough estimate of the percentage of fossil fuels in heavy industry that can be replaced by electrification alone (with no consideration of cost) might be somewhere in the 40% range, **leaving the hard-to-electrify portion at 60%.**

After accounting for the further introduction of green hydrogen, the percentage of fossil-fuels removed could be in the 60% range, **leaving a final 40% of hard-to-abate fossil fuel use**. For this final 40%, CCUS or alternative production processes may be considered.

4. OTHER KEY TRENDS

Chinese renewable energy integration into industrial supply chains has been supported by many different policy and economic features, but at least two major ones are worth closer evaluation:

1. **Ultra-High Voltage Network**: China employs world-leading UHVDC technology to transmit power thousands of miles from the resource-rich regions of north, northwest, and southwest China to industrial bases in central, eastern, and southern China. This allows industrial producers in those areas to enjoy low-cost hydropower, coal-power, and renewables generated on the other side of the country. Even after accounting for the transmission costs, the power is often cheaper and cleaner than the alternatives for local power generation.

2. **Industrial Clusters**: China has leveraged industrial clusters to great effect, reducing energy, raw materials, and logistics costs by constructing integrated heavy-industry hubs in one area. For instance, a green hydrogen producer might be co-located with a pre-existing coal-fired power plant and a wind farm in the Gobi Desert. Green hydrogen is produced from co-located wind power, while carbon capture is employed to secure carbon feedstock. The green hydrogen and carbon feedstock may then be combined onsite to produce green methanol or urea, along with green hydrogen and coal-fired power. With a single company or single joint venture entity financing the entire endeavor, the facility diversifies its revenue into multiple sectors, decarbonizes multiple industrial segments (urea is a critical component of fertilizers) and complies with national mandates, earning access to additional resources, funding, subsidies, and other forms of support from provincial or national bodies.

5. POLICY RECOMMENDATIONS

5.1. Jump-Start Domestic Investment

Recommendation:

Accelerate U.S. Investment Support for Deployment of Next-Gen Industrial Cleantech

Rationale:

While China leads in industrial decarbonization and cleantech research output, the United States is still a strong contender in the research space and still performs very well when it comes to *high-quality* research. The gap, therefore, is not in quality of R&D output, but in support for commercial deployment of demonstration projects, particularly consistent and reliable federal support.

Actions:

- **Expand federal funding for R&D in hard-to-abate sectors** (e.g., cement, steel, aviation) with programs modelled on the Inflation Reduction Act's provisions supporting EVs and clean energy deployment.
- Create and/or enhance **incentive programs for pilot projects** employing U.S.-developed demonstration clean technology (green hydrogen, CCUS, electric steam cracking, etc.) to partially derisk the initial commercial deployment of demonstration/pilot facilities.
- Investigate establishment of public-private partnerships to establish power sources for green hydrogen production and smooth grid integration.

5.2. Enhance International Collaboration

Recommendation:

Strengthen U.S.-China Collaboration in Cleantech Deployment

Rationale:

China's industrial decarbonization achievements, particularly in scaling renewables, grid infrastructure, and piloting emerging technologies, offer lessons for global climate action. A partnership of equals, predicated on mutual respect and the leveraging of complementary strengths, can accelerate progress for both nations while advancing global climate goals.

Actions:

- Co-develop open-access platforms for industrial decarbonization R&D, perhaps a kind of "U.S.-China Clean Industrial Innovation Hub", focusing on the hardest-to-abate sectors. This would marry U.S. strengths in foundational research/AI-driven solutions with China's rapid prototyping and manufacturing scale.
- Launch reciprocal technology demonstration zones, allowing U.S. and Chinese firms to pilot industrial decarbonization technologies in each other's countries, or in a third country (see next item).
- Align incentives for joint ventures or joint investments in third countries, particularly in developing nations also seeking to decarbonize heavy industry.

- Harmonize carbon accounting methodologies through a bilateral working group, creating standards for tracking emissions across integrated industrial supply chains. This will help to prevent "green trade" fragmentation while respecting each nation's policy autonomy.

5.3. Improve Understanding of Cross-Border Clean Technology Innovation Progress

Recommendation:

Improved information-gathering on China's industrial advancements and other activities creates opportunities for mutual learning, accelerates climate progress, and helps align international decarbonization efforts. Real and actionable insights into technological developments benefit all nations pursuing sustainable growth, while ensuring that any remaining suggestions for improvement are accurate, sensible, and likely to be received as thoughtful and reasonable constructive critiques.

Actions:

- Establish a U.S.-China Clean Energy Research Coordination Initiative. This could be a congressional effort, or alternatively a multi-agency program (Energy, State, Commerce) to analyze publicly available technical developments, like peer-reviewed studies from the Chinese Academy of Sciences, corporate sustainability reports, lists of demonstration projects under deployment in China, etc., for use in congressional briefings. Special emphasis should be placed on technologies with cross-border or collaborative climate applications.
- Create technical exchange programs for low-carbon industries. Specialists with appropriate language and technical skills should be deployed to strengthen cross-cultural understanding of clean/low-carbon industrial transformation strategies and enhance understanding of progress, barriers, and intentions on both sides.
- Leverage the insights of U.S. firms already working in China (e.g., Tesla, GE, ExxonMobil) to share observations on industrial trends in the cleantech sector, like the uptake of electric arc furnaces or retirements of small-capacity coal-fired power plants.

I would like to thank Chak Wa Li for research and editing support.

OPENING STATEMENT OF ERICA DOWNS, SENIOR RESEARCH SCHOLAR, CENTER ON GLOBAL ENERGY POLICY, COLUMBIA UNIVERSITY

DR. DOWNS: Members of the Commission, thank you for inviting me to testify today. Right, sorry. Better? Okay. In my remarks I will address three issues: China's slowing oil demand growth, changes to China's oil imports, and developments that probably have enhanced the country's security of oil supply.

I will now turn to China's oil demand.

China's demand for oil, long an important driver of global oil demand growth, is decelerating. Between 2003 and 2023, China accounted for more than half of the increase in world oil demand, growing at an average annual rate of 5.8 percent. However, China's oil demand grew more slowly last year, with industry sources estimating a growth rate between -2 to 2 percent, and these same sources expect China's oil demand will continue to grow more slowly this year.

There are several factors contributing to this slowdown. These include increasing sales of new energy vehicles, the property sector slump, increasing deployment of trucks powered by LNG, and the continued buildout of China's high-speed rail network and subway systems. And I will say a few quick words about each of these.

First, turning to new energy vehicles or NEVs. These are displacing demand for gasoline. New energy vehicles include battery-electric vehicles, plug-in hybrids, and fuel-cell electric vehicles. China's national oil companies estimate that NEVs contributed to a decline in China's gasoline consumption last year and that they will contribute to a decline in China's gasoline consumption this year.

Second, China's property sector downturn is almost certainly displacing diesel demand because diesel is used to fuel construction equipment and transport construction materials.

Third, the increasing deployment of trucks powered by LNG is displacing diesel demand, and here again, China's national oil companies estimate that LNG's contributed to a decline in China's diesel consumption last year and will do so again this year.

And finally, the continued buildout of China's high-speed rail and subway systems and the increasing use of them is also displacing oil demand. The International Energy Agency recently estimated that oil displaced by NEVs, LNG trucks, high-speed rail, and subways allowed China to avoid 1.2 million barrels per day of oil demand growth since 2019.

I will now turn to the second topic of my remarks, which is changes to China's oil imports. Last year, China imported 11.1 million barrels per day, accounting for more than 70 percent of the country's oil consumption. China's top five suppliers provided two-thirds of China's oil imports last year, and the five countries, in descending order, are Russia, Saudi Arabia, Malaysia, Iraq, and Oman. China imports oil by land and by sea, and last year about 90 percent of China's oil imports were seaborne, and Russia accounted for almost all of China's overland oil imports.

A number of changes have occurred to China's crude oil import portfolio over the past decade, and especially the past few years, and I will highlight five of them.

The first is that crude oil subject to U.S. and Western sanctions probably accounted for more than a fifth of China's oil imports last year, and this pool of crude oil includes barrels from Iran and Venezuela as well as oil arriving from Russia on sanctioned tankers. And the main buyers of these crudes are small, independent refineries known as "teapots." The teapots operate on thin margins, and they are attracted by the discounts they can obtain on crude subject to sanctions.

Second, the emergence of Malaysia as China's third-largest oil supplier last year reflects oil imports from Iran, and to a lesser extent Venezuela, which are rebranded as Malaysian in origin. Last year, China imported 1.4 million barrels per day from Malaysia, but Malaysia only produced 565,000 barrels per day, and the difference is due to oil from third countries that are delivered to China via ship-to-ship transfers in the water off of Malaysia.

Third, Western sanctions have helped make Russia an even larger supplier to China than it was before the start of the war in Ukraine because of the discounts available on Russian crudes. Between 2021 and 2024, China's imports of Russian oil increased by about 38 percent, and Russia's share of China's crude oil imports expanded from 17 to 20 percent.

Fourth, the growth of China's imports of sanctioned crudes almost certainly contributed to the 10 percent decline in Saudi Arabia's oil exports to China between 2021 and 2024, as well as the reduction in Saudi Arabia's share of China's crude oil imports, from 17 percent to 14 percent.

And fifth, Africa's importance as a crude oil supplier to China has declined over the past decade, with its share of China's crude oil imports falling from 19 percent in 2015 to 9 percent in 2024, and this is primarily the result of reduced imports from Angola, Sudan, and South Sudan, all of which have seen their oil output decline.

I will now turn to the third and final section of my remarks, developments that have probably enhanced China's oil supply security. Now, to be sure, oil supply security remains a concern for China because of its high level of import dependence, but there are several developments that may be cause for some comfort in Beijing.

First, China's domestic oil production is increasing, and this growth is actually rooted in a decline in China's oil output between 2015 and 2018. In the summer of 2018, Xi Jinping issued an instruction calling for stepped-up efforts to find and produce more oil. China's oil companies respond, and they invested heavily in production, and China's oil production grew by 500,000 barrels per day, to 4.3 million barrels per day in 2024, which was close to that 2015 level.

Second, the rapid growth of new energy vehicle sales means that China's oil demand may peak earlier than expected. China National Petroleum Corporation, for example, now thinks China's oil demand could peak as early as this year.

Third, China can store a large quantity of oil in its commercial stocks and its strategic petroleum reserve. Specifically, China has the capacity to store about 2 billion barrels of oil, which would provide it with about six months of import coverage at the 2024 level, and at the end of the first quarter of this year China probably had about three months of import coverage at the 2024 level in storage.

And I see that my time is about up, so I will stop there. Thank you.

PREPARED STATEMENT OF ERICA DOWNS, SENIOR RESEARCH SCHOLAR, CENTER ON GLOBAL ENERGY POLICY, COLUMBIA UNIVERSITY

April 24, 2025
Erica Downs
Senior Research Scholar, Center on Global Energy Policy, Columbia University
Testimony Before the U.S.-China Economic and Security Review Commission
Hearing on "China's Domestic Energy Challenges and Growing Influence over International Energy Markets"

China's Oil Demand, Imports and Supply Security

Members of the Commission, thank you for inviting me to testify. In my remarks, I will address three issues: China's slowing oil demand, changes to China's oil imports, and developments in recent years that probably have enhanced the country's oil supply security.

China's Slowing Oil Demand

China's demand for oil, long an important driver of global oil demand, is decelerating. Between 2003 and 2023, China accounted for more than 50 percent of the growth in world oil demand, with an average annual growth rate of 5.8 percent and an average annual increase of 542,000 barrels per day (bpd).[1] However, the country's demand for oil increased by less in 2024, with industry estimates of the growth rate ranging from ranging from -1.6 percent to 2 percent and the volume ranging from -242,000 bpd to 320,000 bpd. These sources expect slower growth to continue in 2025 (See Table 1).

Table 1: Estimates of China's Oil Demand in 2024 and 2025

	IEA	OPEC	CNPC	Sinopec
2024				
Demand (million bpd)	16.62	16.68	15.19	15.02
Demand growth (bpd)	150,000	320,000	10,000	-242,000
Growth rate (%)	1	2	0	-2
2025				
Demand (million) bpd)	16.78	16.95	15.36	15.46
Demand growth (bpd)	160,000	270,000	171,000	443,000
Growth rate (%)	1	2	1	3

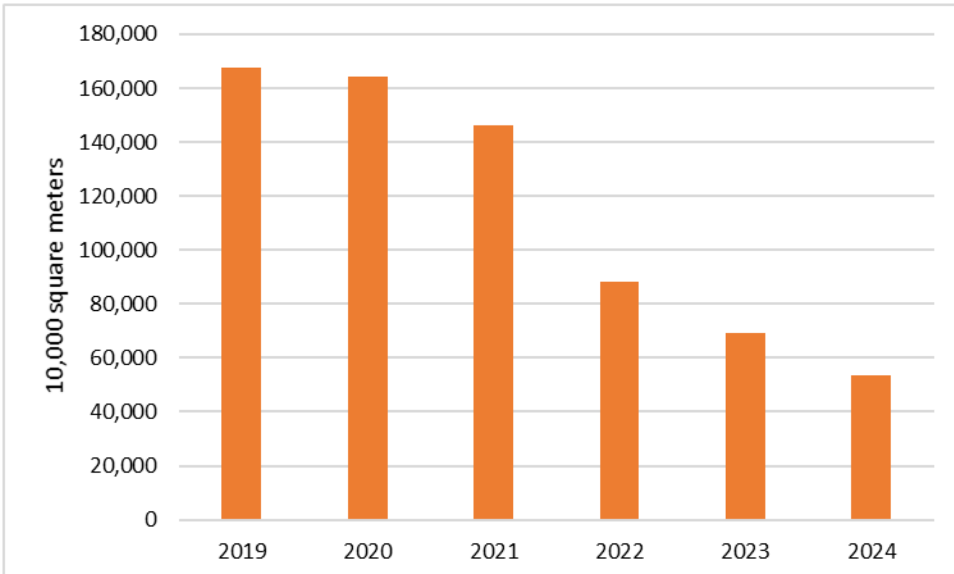
Sources: International Energy Agency, OPEC, China National Petroleum Corporation, Sinopec[2]

China's oil demand is growing more slowly because of increasing sales of new energy vehicles (NEVs) (a category that includes battery-electric vehicles, plug-in hybrids, and fuel-cell electric vehicles), a property sector slump, the growing popularity of LNG trucks, and the buildout of China's high-speed rail network.

NEVs are reducing China's demand for gasoline. According to China National Petroleum Corporation's Economics and Technology Research Institute (CNPC), in 2024, NEVs displaced 28 million tons of gasoline in China, contributing to an estimated 3.1 percent decrease in gasoline consumption.[3] Sinopec, China's largest refiner, expects NEVs to reduce China's gasoline consumption by 2.4 percent in 2025.[4]

China's property sector slump and the deployment of trucks powered by liquefied natural gas (LNG) are weakening China's demand for diesel. The floor space of new home starts in China decreased by more than 68 percent between 2019 and 2024 (see Figure 1). This almost certainly had a negative impact on diesel demand because diesel is used to fuel construction equipment and transport construction materials.[5] The increased use of LNG trucks in 2024 also took a bite out of diesel demand. According to CNPC, the distances driven by LNG trucks increased by more than 50 percent in 2024, displacing 25 million tons of diesel and contributing to an estimated 4.8 percent decline in diesel consumption.[6] Sinopec expects LNG trucks to reduce China's diesel consumption by 5.5 percent in 2025.[7]

Figure 1: Floor Space of New Home Construction Starts in China



Source: National Bureau of Statistics of China[8]

The use of public transportation is also curbing China's oil demand. The continued buildout of China's high-speed rail network, an increase in the number of miles traveled by long-distance rail passengers, and greater use of urban subway systems likely reduced China's demand for oil last year by 1.5%, according to the International Energy Agency (IEA).[9]

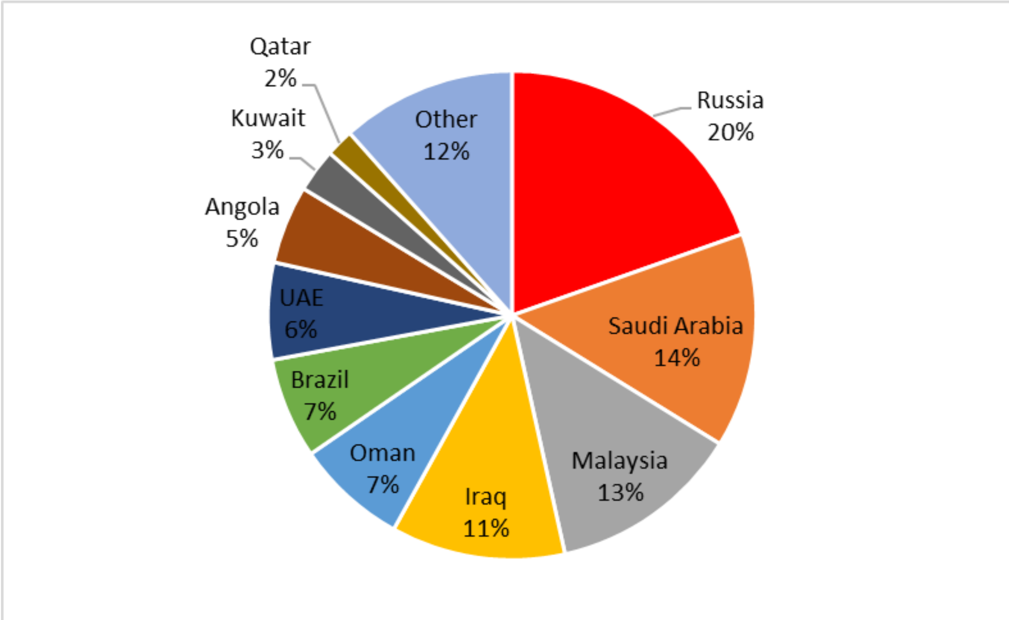
The IEA estimates that NEVs, LNG trucks and the development of China's high-speed rail network and subways systems has avoided oil demand growth of 1.2 million bpd since 2019.[10]

With China's consumption of gasoline and diesel in decline, petrochemicals are now the primary driver of China's oil demand growth.[11] Private and state-owned refineries looking for ways to thrive in a China where road transportation consumes less oil are pivoting to the production of high-end chemicals, including those used in green technologies such as solar panels and lithium ion batteries.[12] This shift advances other goals of the central government, including reducing China's dependence on imports of higher-end chemicals, lessening overcapacity in lower-end chemicals, and investing in high technologies – which use high-end chemicals – to drive economic growth.[13]

Changes to China's Oil Imports

In 2024, China imported 11.1 million barrels per day of crude oil, accounting for 74 percent of the country's apparent oil consumption.[14] China's five largest crude oil suppliers provided two-thirds of China's crude oil imports. The five countries are Russia, Saudi Arabia, Malaysia, Iraq and Oman (See Figure 2).

Figure 2: China's Crude Oil Suppliers in 2024



Source: General Administration of Customs of China

China imports oil by land and by sea. Last year, roughly 90 percent of China's crude oil imports were seaborne. The remainder arrived overland from Russia, Kazakhstan and Mongolia. Russia accounted for almost 95 percent of China's overland oil imports last year, delivering oil to China via pipelines from Russia and Kazakhstan.[15]

China's crude oil imports have experienced a number of changes over the past decade:

Crude oil subject to US and western sanctions probably accounted for more than one-fifth of China's oil imports in 2024. This includes 1.4 million bpd from Iran, 268,000 bpd from Venezuela, and 821,000 bpd of Russian oil shipped on sanctioned tankers.[16] The main buyers of these crudes in China are independent refineries known as "teapots", which are concentrated in Shandong province. The teapots, which operate on thin margins and are highly opportunistic crude buyers, are motivated by the discounts on sanctioned crudes.[17]

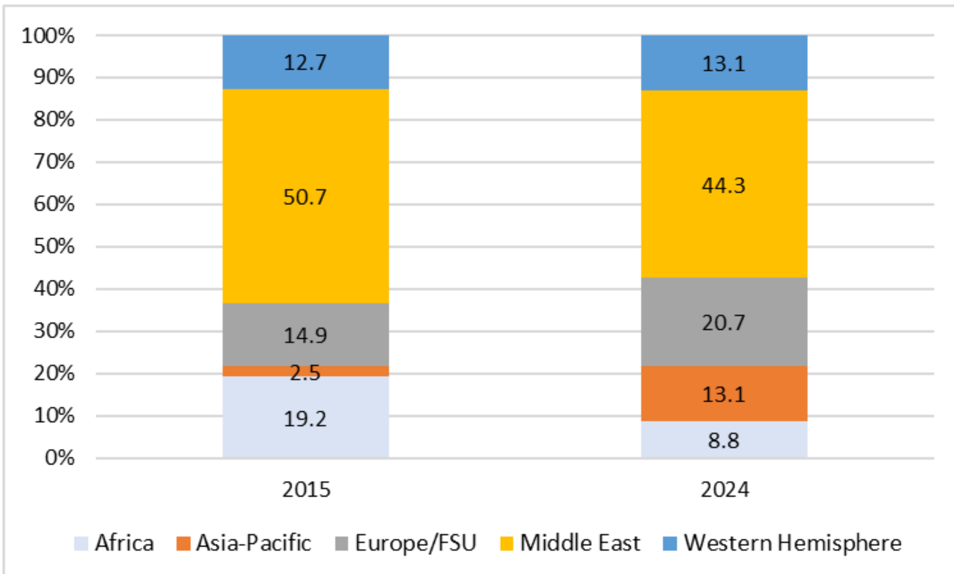
The emergence of Malaysia as China's third largest oil supplier last year almost certainly reflects oil imports from Iran and Venezuela which are rebranded as Malaysian to evade US sanctions. China's imports of crude oil from Malaysia grew from just 5,400 bpd in 2015 to 1.4 million bpd in 2024. However, Malaysia only produced 565,000 bpd last year.[18] The difference is probably due to oil exported from Iran and – to a lesser extent -- Venezuela that is delivered to China via ship-to-ship transfers in the waters off of Malaysia.[19]

Sanctions imposed on Russia by the United States and partner countries have made Russia an even larger supplier of oil to China than it was before Russia began its war in Ukraine because of the discounts available. Russian oil deliveries to China increased from 1.6 million bpd in 2021 to 2.2 million bpd in 2024.[20] As a result, Russia's share of China's crude oil imports last year was nearly 20 percent, the highest level since Saudi Arabia supplied 19.1 percent of China's crude oil imports in 2013.[21]

The increase in China's imports of crudes subject to US and western sanctions probably has contributed to a reduction in Saudi Arabia's oil exports to China. Saudi crude deliveries to China decreased by about 10 percent between 2021 and 2024 (from 1.8 million bpd to 1.6 million bpd). Saudi Arabia's share of China's crude oil imports declined from 17 percent to 14 percent.[22]

Increased oil deliveries from Russia and Malaysia help explain some of the big changes over the past decade in China's reliance on different parts of the world for oil supplies, according to Chinese customs data (See Figure 3).

Figure 3: China's Oil Imports by Region, 2015 and 2024



Source: General Administration of Customs of China

- Russia is responsible for the increase in the Europe and the Former Soviet Union's share of China's crude oil imports from 15 percent to 20 percent.

- The emergence of the waters off the coast of Malaysia as a large hub for ship-to-ship transfers of crude oil originally exported from Iran and Venezuela accounts for the expansion of the Asia-Pacific region's share of China's crude oil imports from 2 percent to 13 percent

- The decline in the Middle East's share of China's crude oil imports from 51 percent to 44 percent is largely due to the fact that China's General Administration of Customs recorded zero shipments from Iran in 2024.

- The increase in the Western Hemisphere's share of China's crude oil imports is primarily due to the growth in Brazil's exports to China, which grew by 164 percent.

- The decline in Africa's importance as a crude oil supplier to China is largely the result of declines in deliveries from Angola, Sudan and South Sudan. All three countries' oil production and exports have fallen over the past decade.[23]

Saudi Arabia and Russia are likely to remain top suppliers to China. Saudi Aramco is investing in petrochemical complexes in China, a move that aligns with China's emphasis on producing less diesel and gasoline and more chemicals as peak oil demand looms.[24] Russia's ability to deliver large volumes of oil to China via pipeline should ensure that it remains one of China's most important oil suppliers given Beijing's longstanding preference for diversifying its oil imports away from the sea lines of communication.

China's Oil Supply Security

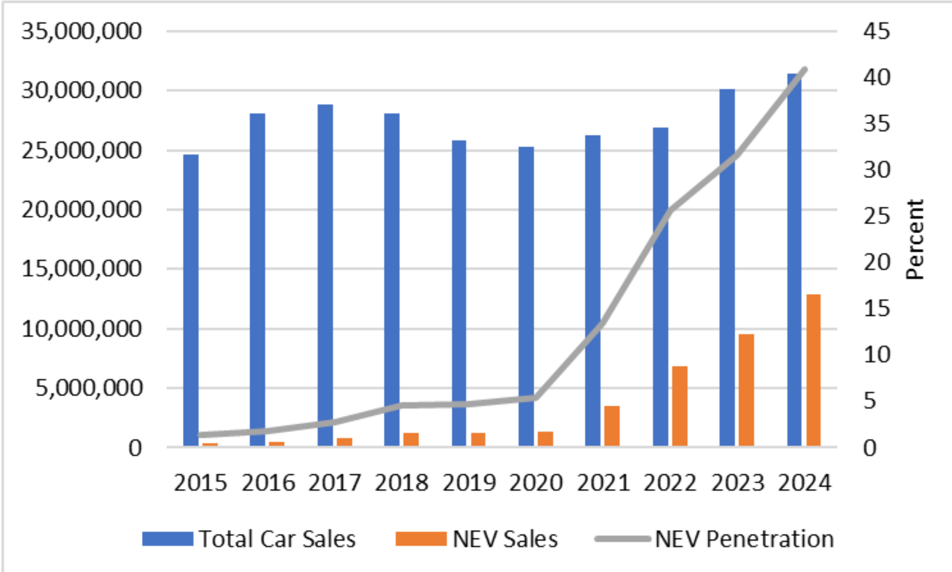
Beijing remains concerned about China's oil supply security because of China's heavy reliance on oil imports in general and seaborne oil imports in particular, as discussed above. China's leader Xi Jinping himself has expressed concern over China's dependence on imported oil in recent years. In 2021, while visiting Shengli oilfield, he indicated that the key to bolstering China's oil supply securities lies in expanding domestic output. He told oil workers that "oil and energy construction is very significant to our country. As a major manufacturing power, China has to secure its energy supply in its own hands."[25] He also said that "solving the core demand for oil and gas is an important task we face."[26]

That said, there several developments over the past decade may lessen Beijing's concerns about China's high level of dependence on imported oil:

Increases in domestic production: In 2024, China produced 213 million tons (4.27 million bpd) of crude oil, virtually equaling the historical peak of 215 million tons (4.32 million bpd) in 2015.[27] After setting that production record, China's oil output fell to 189 million tons (3.8 million bpd) in 2018.[28] This decline appears to have alarmed China's leader Xi Jinping. In July of that year he issued an instruction to "vigorously increase exploration and development efforts to ensure national energy security."[29] China's national oil companies subsequently developed their first-ever seven-year action plans to increase domestic reserves and production for the period 2019-2025.[30] To this end, the companies invested heavily in exploration and production.[31] China's oil output grew by almost 500,000 bpd.[32]

More NEVs on the road: Rapid growth in NEV sales is leading to projections that China's oil demand will peak earlier than expected. The number of NEVs sold in China grew from 331,000 in 2015 to 129 million in 2024, increasing the NEV penetration rate from one percent to 41 percent over the same period (See Figure 4). In the process, China achieved its 2025 NEV penetration target of 20 percent in 2022.[33] A former minister of industry and information technology expects China to hit its 2035 NEV penetration target of more than 50 percent as early as 2025.[34]

Figure 4: China's Increasing New Energy Vehicle Sales



Sources: China Association of Automobile Manufacturers and Ministry of Industry and Information Technology[35]

The rapid deployment of NEVs has prompted China's NOCs to move up their projections of China's peak oil demand date. Sinopec now expects China's oil demand to peak at no more than 16 million bpd.[36] Last year, the company projected oil demand would peak at the same level in 2026-2030.[37] CNPC now says China's oil demand could peak at 15.4 million bpd in 2025.[38] In 2023, the company projected China's oil demand peaking at 15.6 to 16 million bpd by 2030.[39]

Expanding strategic and commercial oil stocks: China's strategic petroleum reserve (SPR) and commercial stocks enhance its oil supply security. The combined volume of strategic and commercial stocks provides China with at least 96 days of crude oil import coverage at the 2024 level. According to Kayrros, a geospatial analytics company, as of March 31, 2025, China held 401 million bpd in above-ground SPR facilities and 668 million bpd in above-ground commercial stocks.[40] China also has five underground SPR facilities with a combined operating capacity of 130 million barrels.[41] If filled to operating capacity, these underground locations provide China with an additional 11.7 days of crude import coverage.

China had room in its SPR and commercial tanks farms for more oil. According to Kayrros, as of March 31, 2025, China had only filled 56% percent of its above-ground strategic and commercial storage facilities. If China were to fill these facilities and the five underground SPR location to capacity, then China would have enough crude oil in storage to cover 183 days of imports at the 2024 level.[42]

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PANEL I QUESTION AND ANSWER

COMMISSIONER GOODWIN: Great. Thank you very much.

Turning to Q&A, we'll go in alphabetical order, but taking the prerogative of the Chair, I'll kick us off.

Dr. Meidan, you had mentioned the unique pricing mechanisms in China, and in some respects they're administratively set and others, they're informed by the market. Curious as to how that works in practice, and then how price informs, influences, or even undercuts stated policy.

DR. MEIDAN: I think we probably need a whole day to talk about the pricing mechanisms. But the point I was trying to make also is that we do not know enough about exactly how they work. We know that there are state-set prices for oil products. Natural gas is set sort of at the city gate level. But within that there are market fluctuations and sales that sort of take that as a benchmark and can move up or down. The state-owned companies have, again, these city gate benchmark prices. They can sell above contract or beyond contract. There is a hybrid system of state-set prices and then prices that are allowed to fluctuate in and around that.

So the point is that it is very complicated and it changes, depending on oil products, on sort of natural gas power. Imported volumes can be negotiated directly. Some of the, sort of, the LNG, for instance, is negotiated directly between seller and buyer. Pipeline flows have the city gate cap prices.

The point is that we need to understand these, because I think then we can understand what are the fuel switching levels. The LNG markets have been looking all last year at sort of which price point do Chinese buyers come in, and at what point is that fuel switching. And it is different for diesel and LNG and in the power sector. So at what price point does gas displace coal and vice versa.

But that's also where we need to understand the power pricing mechanism as it feeds the industrial system. What is the price of electricity that industries are paying? And they vary, and they can be subject to incentives and support measures.

But the short answer is we don't have a good understanding of these pricing mechanisms, and I think we should.

COMMISSIONER GOODWIN: Thank you. Let me ask a question about the grid in China and grid reliability. All this investment and innovation in new technologies, new energy technologies, might not matter if you can't efficiently store, distribute, and transport the power. So what are the biggest challenges facing transportation and distribution of electricity in China?

DR. MEIDAN: As I mentioned in my remarks, I think there are institutional barriers that are the most formidable. You can talk about limited physical grid infrastructure, which China is building and adding, but not fast enough. You can talk about the inadequacy of storage. Again, China has a lot of battery storage, pump storage, that it is investing in and building out, although they may not be enough. But it is the institutional barriers. I's the limited price reforms. It is the fact that every province has long-term coal contracts, long-term power contracts that are based on coal, and this disincentivizes the use of renewables, on a sort of pricing and market basis.

Now, every so often we get increased curtailment. The government comes in and sets mandates to increase the use of renewables. It sort of tweaks the signals and the pricing mechanisms to offset different losses. So right now there is a new pricing mechanism that will come in in June, that will price renewables slightly differently. Essentially the aim is to give the grid a bit more money to invest in more of these physical bottlenecks.

So again, there are physical bottlenecks and there are institutional bottlenecks. I would argue that the institutional bottlenecks are the biggest concerns. But sort of in response to that, China is overbuilding, and every province is overbuilding capacity. I mean, we are seeing Guangdong province, which has a lot of renewables, adding a lot of coal capacity that it doesn't need in terms of peak demand. But every province and every leader wants to have energy supplies that are sort of guaranteed. And so there are those two elements that come in together, but there are solutions in this kind of whack-a-mole of policies that try and deal with inefficiencies.

COMMISSIONER GOODWIN: Thank you. One more quick question for the panel. As we alluded to at the beginning, there is some questions that some commentators are curious about whether China will be able to meet its international commitments to peak emissions in five years, in 2030, and then become carbon neutral by 2060. I want to invite reaction from all three of you as to the likelihood that they'll be able to meet those commitments.

DR. MEIDAN: Maybe I'll start. They are likely to meet certainly the 2030 commitment because they've pledged to peak emissions. They haven't said at which level. They haven't set an absolute cap for emissions. There used to be talk about earlier peak, but their ability to sort of reach a threshold and then start to slow it afterwards is highly likely.

The 2060 targets of net zero, of reaching carbon neutrality, I think are much more complicated, and just this week President Xi said that they would look at all forms of emissions, not just carbon. That is much more complicated by the use of the current predominance of coal in the energy mix. But here, too, the metrics are quite vague, so there's a bit of room to play around with what carbon neutrality actually looks like.

But in terms of the renewables that they've added to the grid, they should be able to meet sort of power demand, for instance, through renewables. It then comes down to the mechanisms and some of the additional measures that, that David Fishman was talking about.

COMMISSIONER GOODWIN: I am already over my time, but Mr. Fishman, Dr. Downs, anything to add?

MR. FISHMAN: Yeah, sure, I could jump in here. Look, in 2024, China added about 650 terawatt hours of new power consumption. That's a lot of electricity. They added an entire Germany, and then some, of new power consumption, and about 85, 86 percent of that was met by clean sources, you know, wind, water, solar, nuclear. And again, a massive amount, 500 terawatt hours, and yet it's not enough. Even adding 500 terawatt hours in one year of new clean generation was not enough to meet the demand of the Chinese economy and the Chinese people for more electricity.

And, of course, they're the largest power consumers in the world. On a per capita basis it's average. It's not especially notable how much the average Chinese citizen consumes for electricity purposes. Which is just to say there's so much space to use more electricity still, and going forward they will. It will get a little bit easier to meet all of that new power consumption with clean sources. The base is getting larger, the actual amount that's growing each year. Their real estate sector is not going to be demanding as much. Hopefully coal chemical slows down a little bit.

And then, overall, we get to a point where clean energy is able to meet 100 percent, and that's how you get to the peak, right, that was mentioned. Yeah, peaking, no problem. How do we stop peaking from becoming a plateau and actually start declining? That's really, I think, the key question that both internationally should be asked and China domestically is asking itself. And that's where we get into some of the things where I was talking about the industrial decarbonization.

DR. DOWNS: I agree with my co-panelists that peaking by 2030 is likely. And I will just add that China typically tends to set targets that they expect to be able to meet or exceed, and in this case they certainly know that the rest of the world is watching.

COMMISSIONER GOODWIN: Thank you. Commissioner Brands.

COMMISSIONER BRANDS: Thank you. Dr. Meidan, I wonder if we just come back for a moment to the issue you mentioned about the need for reliable data, and if you could just say a little bit more about what the source of the problem is. Is it that there is too little data and it is too opaque? Is there too much data and we are swimming in it? And what would we need to do to get a better handle on the issues that you are talking about?

DR. MEIDAN: So for some of the issues there is too little data, and it is imperfect. I know that the IEA is working with the Chinese authorities, the Chinese National Bureau of Statistics, of getting better quality data. I mean, the data is available, and they're pretty good at publishing supply side data on a monthly basis. But what it actually means is a question, so some of that needs clarification.

Demand data is limited. There are a few consultancies, so there's a few paid-for datasets that are available. But they're inconsistent. Again, you don't know what they entail and what they mean.

So for all of these things, (A) establishing a baseline, even when you look at gasoline demand in China, different institutes have a different baseline, let alone the decline rate. We don't even agree on where China is today in terms of it's demand. So some of it is improved data out of China, triangulating with other sources of data.

But making data more free and available, especially, I think, in the critical minerals space, for pricing and for the flow and trade of commodities would be very helpful.

COMMISSIONER BRANDS: You also mentioned in your statement the need for the U.S. to cooperate with third parties if it's to compete effectively with China in these areas. Could you just say a bit more about that? What are the key areas, who are the key players, and where do things stand at the moment?

DR. MEIDAN: And if we are talking about new energy supply chains they are very vast, and I think there has to be a choice here, in which supply chains. If you look at battery and electric vehicle supply chains, they go all the way from a variety of nickel, cobalt, manganese, lithium, all the way to the processing the anodes, the end products. Similar story for solar panels and wind turbines. I put a very simplified kind of schematic representation in my testimony, and even that's simplified.

So I think the first decision is which industries should the U.S. and allies compete in. Maybe some are not worth sort of all that investment. Then, because they are so deeply integrated, these supply chains, the collaboration has to go from the upstream, I think, through the midstream, and to the end market. So again, if you look at battery chemistries, for instance, if the leading battery chemistry is going to be NMC or LFP, that determines which of the minerals and the commodities are going to be needed. So miners need to know what the demand market is looking like. It needs to have the pricing information and the knowledge of what's happening, but also the midstream infrastructure, which is all in China.

I mean, the U.S. has a lot of the attributes, or the potential, for China with these integrated and sort of manufacturing hubs and industrial clusters. The U.S. is perhaps the only country that has the land mass, the resources, the skill base, the talent to do these sort of very big industrial clusters. But partnering with other countries and thinking through that supply chain and where are the comparative advantages, to at times collaborate with China but also create new and diverse supply chain sources, I think there have to be certain choices that are made.

COMMISSIONER BRANDS: Thanks. Dr. Downs?

DR. DOWNS: Yeah. I would like to come in on the data issue. I spend most of my time looking at data for China's oil and natural gas in terms of demand, production, imports. I certainly agree with what Michal said, that there is not as much data out there, I think, as we would like on the demand side, that China's government every month publishes data on oil and natural gas production. They publish data on imports. But there's no official number for oil demand.

And to Michal's point about different actors in China having different baselines and different numbers, in my written testimony I include projections from several entities inside and outside of China, of China's oil demand in 2024 and 2025, and there you can see that the two biggest oil companies in China have slightly different numbers.

I will also add that one area where there has been, I guess, a decline in data availability is a breakdown of China's pipeline natural gas imports by country. China's General Administration of Customs used to publish this monthly breakdown of volumes on its website, and they stopped doing that after December 2021. I think you can still get an aggregate number. You can get the dollar value. But in terms of figuring out how much is coming from Russia and how much is coming from Turkmenistan, that's no longer available.

COMMISSIONER BRANDS: Thank you very much.

COMMISSIONER GOODWIN: Commissioner Friedberg.

COMMISSIONER FRIEDBERG: Thank you very much. Good morning, everyone. Dr. Meidan, I wonder if I could start with you. You make the observation towards the end of your written testimony that China didn't start out, or didn't at the outset have a strategy to dominate the mineral supply chains that they currently dominate. Could you give a little insight into the evolution of Chinese thinking on this question? Did they, at some point, decide that, in fact, that was a desirable objective for strategic reasons? When was that?

DR. MEIDAN: I think the evolution of these different supply chains, as I mentioned, started off in very different ways. So solar was built as an export industry, whereas wind turbines were built as a domestic industry. Electric vehicles and batteries had sort of energy security in mind. And they were started off by different ministries, different actors as a vision, and I think there was a vision of, sort of, strategic emerging industries and industries of the future, back then, that China would like to lead in and maybe leapfrog Western competitors, because it knew it couldn't compete with ICE vehicles so it went to electric vehicles. It knew in telecoms it couldn't compete in 2G and 3G. It went to 5G.

So there were different policy strands for developing these industries over time, and at the same time there were policies for minerals. But China doesn't have a list of critical minerals, for instance. It has strategic emerging industry minerals. Sort of the way it classifies it is slightly different. It also has advantageous minerals, which are minerals that it possesses that other countries need.

So it did recognize pretty early on that it had an advantage there and a potential for leverage. But over time, as these industries emerged, gradually China was doing rare earth extraction and then there was a desire to capture more of the value add, so they moved into the midstream. There was a progressive move by both government and companies to become central in these supply chains.

I think the realization that this is a powerful tool is quite recent. I think, sort of, ever since there was a perception that relations with the U.S. are in decline there has been a greater ability to coordinate among industry, among ministries, and to look at how to use this sort of policy tool book.

But here, too, I think we do need better understanding and more analysis of where is the policy tool book and where is the corporate tool book. Like we know that Chinese companies can impact lithium prices when they are big investments that are coming online, and therefore disincentivize Western investments. Now, is that a corporate strategy or a central government strategy? Probably a corporate, but we need to understand it better. But there is now, I think, an emerging sort of tool book that the Chinese are starting to practice and fine tune.

COMMISSIONER FRIEDBERG: Thank you. Dr. Meidan and Mr. Fishman, I would like to ask you the same question. Dr. Meidan, you used the term "leapfrogging." Would it be a correct summary of a very complicated situation to say that China has effectively dominated the first wave of green technologies, gotten an early start, focused on this, deployed subsidies, and so on, and that it would be very difficult or impossible for the United States or other advanced industrial countries to catch up. First, is that accurate?

And secondly, a next wave, a coming wave of green technologies, Mr. Fishman, you referred to that. Are there opportunities there for the United States or other advanced industrial democracies to leapfrog? Are there areas where we should focus? If we can't catch up, are there areas where we could get ahead in the next couple of decades?

So Mr. Fishman, maybe I could start with you.

MR. FISHMAN: Sure. Right. So none of these technologies, or very few of these technologies originated in China, right? When we talk about going from zero to one, the zero to one sometimes happened five decades ago in the United States or in Europe. But when it got to one, maybe that's where it got stuck. And then China took it from one and they iterated it to 10, and then 50, and then 100, and that's where we stand now with solar panels, perhaps, or lithium ion batteries.

And because of the way that has been constructed and because of the early lead that in some cases I would argue was squandered, I would consider it to be very difficult to catch up in batteries, for example, or solar panels.

When we talk about the next wave, we are on the edge of that. So when we talk about whether or not ethylene crackers or green hydrogen or whatever it is, is going to be competitive, in most cases there is a European company that's doing it right now, there are 10 Chinese companies that are doing it, and there is an American academic institute that wrote a fantastic paper about it but they can't find the funding to deploy it. That's what I see playing out many, many times.

So I think the United States absolutely has the fundamental research to catch up, or to keep up, not to catch up, but right now it is not getting the right ecosystem that it would need to de-risk some of that early stage deployment.

COMMISSIONER FRIEDBERG: I don't know if we have time for Dr. Meidan to give a very brief response.

DR. MEIDAN: I would just add to that, I think there is a question of leapfrogging might be hard, but growing the pie, right. There is demand for a lot of these industries and these industrial products, and there is room for many other countries to produce them. And critically, we need diversification of supply chains. Geographic concentration is not a good thing, and therefore more of everything is important.

What we are seeing is that China has led in what we call sort of manufacturing-intensive technologies, so things that need to be scaled up. There's been a lot of process innovation, and with that China has been very good at reducing cost and by growing scale.

Design-intensive technologies are a bit more complex, things like hydrogen and the more complicated systems. There are areas to work with China but also to lead the efforts in design and innovation, as David was also saying. There is a point where you have a breakthrough technology and you need to scale it up. China is typically the market where you can scale it up.

So there is, I think, growing the pie and then there is leapfrogging, but there is certainly room for more innovation and more of everything.

COMMISSIONER FRIEDBERG: Thank you very much.

COMMISSIONER GOODWIN: Thank you. Commissioner Kuiken.

COMMISSIONER KUIKEN: Thank you very much, Commissioner Goodwin. Dr. Fishman, I want to go back to the one point you just made about innovation and thinking about Europe and the companies there, China and the companies there, and then the American academic. Have we seen anything in the space of joint ventures or forced acquisitions or anything like that? The reason I ask the question is during the last hearing I think we had, on space, one of the witnesses talked about this company called KUKA Robotics, which is this German advanced manufacturing company that had this incredible technology, and over the course of a series of years the Chinese basically bought a portion of the company and then did a hostile takeover.

So are we seeing anything similar in this space on solar panels or any of the other advanced technologies in the sort of next wave that you just talked about?

MR. FISHMAN: Out of respect to my fellow panelists, I will correct and say that I am not a doctor, so I can't claim that one.

But yes, the current wave of technologies, or rather the next wave, the next big thing so to speak, they exist mostly in academic form. So for Chinese companies to be referring to something, they are developing alongside the existing European companies, and they are all drawing from theoretical and academic work, that there wouldn't be much to grab from or to requisition when it comes to looking at, I don't know, electrifying ethylene crackers. No one's done it yet. The first one maybe is happening in Europe, and the second one is happening in China, and they're happening at the same time, because we have gone past the point where we have preexisting technology where you could even consider some type of corporate espionage or ill-gotten goods, something like that. It is just happening now. It is new now. Everybody has got it new now. And China is developing it because they are throwing tons and tons of money and state support and smart people at it, and so is Europe. Sometimes in partnership, more often independently, from what I've seen.

COMMISSIONER KUIKEN: Thank you, Dr. Fishman. Dr. Downs. The data issue that you talked about. While it's opaque to us, I assume the Chinese have near perfect data on their side of the curtain. Is there anything that we can assume or extrapolate through their actions that we couldn't see in the data?

DR. DOWNS: Do you have an example in mind?

COMMISSIONER KUIKEN: No, I do not have an example in mind. But if I have perfect data and you have bad data, there are actions that I'm going to take that are going to drive me to make certain investments and certain actions. They're obviously not going to be reflected in the data you see, but they might be reflected in other places, in investments we are making, perhaps what Dr. Fishman talked about.

But it just seems that if you have a data advantage, you would be driving certain industries to go a specific way, on some of the grid switching issues, on price points. Dr. Meidan was talking about where that switch point is and things like that.

DR. DOWNS: I'll have to think about that.

COMMISSIONER KUIKEN: All right. That's fine. I'll keep moving. Don't worry.

DR. DOWNS: I will turn the floor over to my fellow panelists if they have something to add, and then maybe something will come to me.

DR. MEIDAN: I don't think they have perfect data. I think certain people within the system have data. CNPC, in their reports, they use NBS data, and internally they use their own internal data. But they don't coordinate with Sinopec and CNOOC and their peers. They're actually really interested to talk to people who talk to all three, because they don't have each other's data.

I don't think that data is systematically transmitted to the government either. That's why you have a lot of various consultancies in China that make a lot of money selling to U.S. corporates. There is absolutely no way to validate where that data comes from.

COMMISSIONER KUIKEN: Fascinating. That's helpful.

MR. FISHMAN: I could make a comment here about data in the electricity sector, because that's my sector. I'm in electricity. And the data in the electricity sector is incredibly siloed. It's very much on a need-to-know basis. And whether you don't know the data doesn't mean no one knows the data. When it comes to, for example, power trading entities, if you are a power generator or a wholesale power buyer you have access to tons of power pricing data in the power exchanges that I can't access because I'm not a trader in the power markets.

And so when a developer chooses to build a solar farm or a wind farm in a certain location, that to me looks like it should be a really bad call -- I try to do my napkin math and I think it looks like a bad investment -- and they are seemingly going ahead with it. I, in those cases, assume that they have more data than I do, and it is driving them to act in a way that I can't understand.

COMMISSIONER KUIKEN: Mind if I get one more question in? Dr. Meidan, you, at the end of Dr. Friedberg's questions, said that there are areas where the U.S. and the West should consider not competing. You stopped short of saying what they were. I have my own ideas, but I'd be fascinated to hear yours. And then as we think about this sort of next wave, and other sort of subcomponent technologies, are there areas where we should think about doubling down in terms of our investments, our research and development activities? I'd be interested in you sort of finishing off that line of thought.

DR. MEIDAN: That's a really difficult one. I can give you an example from Europe, not so much from the U.S. I think for Europe, for instance, investing in solar panels makes little sense. U.S. has an offshore wind industry. It has an auto and battery industry, with limited funds, and the limited ability to de-risk, and there is going to have to be some government support. The solar industry doesn't make sense anymore. I think for the U.S. it does make sense to invest in the solar industry because there is a big and thriving solar industry. The auto sector is big. Maybe the offshore wind or wind is not a priority sector, sort of when you think about sort of domestic energy demands and the domestic energy outlook.

So I think that's one way to look at it, of how do you triangulate the areas where you are going to need the energy, you are going to have the demand, but also have already expertise, and it is worth investing in more.

Again, in terms of technologies, I think there's electrolysis, electrolyzers in hydrogen are an area that is still -- I don't like it when people say, "Is the race already won?" or "Is the race over?" because again, the market is growing and there is demand for these technologies, and there is room for a lot of innovation, and a lot of growth. And I think also we need to differentiate between the different sectors and what we need. Disruptive technologies are great for, you know, AI and for military defense.

I think in a lot of the energy space good enough technology that is low cost is impactful -- solar panels that can be deployed quickly, electric vehicles that compete with ICE vehicles or that can encourage mobility. That's good enough. You don't have to be at the frontier of technology. And again, what we are seeing from China is that a lot of the innovation happens through scale, manufacturing hubs, industrial clusters that are able to have this sort of feedback loop between producer and consumer.

So I think it does merit more in-depth thinking about which technologies and which sectors of priority.

COMMISSIONER KUIKEN: Thank you very much.

DR. DOWNS: May I come back on the data question?

COMMISSIONER KUIKEN: That's up to Commissioner Goodwin.

COMMISSIONER GOODWIN: Quickly.

DR. DOWNS: Okay. I just wanted to add that in the oil sector, I agree with Michal there is imperfect data. And I think one of the reasons for that is if you look at what is going on in the refining sector, you have a lot of players. Like the big national oil companies do control a majority of the refining capacity, but you have a lot of other refineries in this space. You have large plants, but you also have a lot of small "teapot" refineries. And over the years it's been very difficult to get a handle on exactly sort of how much capacity they have, how much throughput they have. And I think in some cases some of these smaller refineries probably have had an incentive to conceal some of that information.

So I basically just wanted to elaborate on the point that even in China not everybody necessarily has access to all of the data that they would like to see.

COMMISSIONER GOODWIN: Thank you. Commissioner Miller.

COMMISSIONER MILLER: Thank you all for your excellent testimonies. I would like to look a bit into the future right now. Mr. Fishman, you mention a number of innovations in your testimony, including injecting green hydrogen into steelmaking. Can you explain to us how that process works and also what potential hydrogen overall has in terms of China's energy mix. And any of the rest of you are welcome to contribute to the second part, hydrogen discussion.

MR. FISHMAN: Sure. So looking at process emissions, you know, and trying to figure out where the fossil fuels are and where they can and cannot be substituted, the ones that are easier, at least from a technological standpoint, to substitute are your heat processes. Anything where you are combusting something, because you just needed the heat for high temperature or medium temperature applications, you could be either electrifying that with electric boiler, or in the case of green hydrogen, you can be combusting hydrogen in place of the fossil fuels or co-firing with fossil fuels to get your heat.

So when we are talking about extremely high temperature applications, for steel, for example, of course, one avenue is to go for electric arc furnaces, but you could also choose to keep your blast furnaces and instead co-fire with hydrogen instead. And if that hydrogen was produced through electrolysis, from green electricity, then you have green hydrogen, and therefore you have green steel. So as long as you are introducing it into the blast furnace pathway, then you have the opportunity to introduce hydrogen to steelmaking.

COMMISSIONER MILLER: We can move on if no one else has a hydrogen point.

We read earlier this year about the artificial sun that China has created. I'm curious, because fusion has been mentioned relatively little in this conversation in the testimonies, and I was wondering what you think, what all of you think, about the future of the fusion sector in China. What is the significance of the artificial sun project? Is it something that's high-profile propaganda, or is it something that's really meaningfully moving to something in the near term?

Anyone is welcome to start.

MR. FISHMAN: I was asked to try to be ready to answer some questions about fusion, so I did take a little bit of a look into that.

So yeah, the artificial sun, out of one of the institutes of the Chinese Academy of Sciences, they have been a support institute for the International Thermoelectrical Reactor Project out of Europe for about 20 years now. They've been one of the member countries and been contributing a lot to that project over the decades. But they have also had their own domestic exercises. And with what was referred to in the news as the "artificial sun," I believe that was a plasma containment exercise I think is what it was being referred to there, and in that case they successfully contained plasma for 18 minutes, I think was the number at the time, which was quite a milestone at the time. It was the longest containment of plasma ever. I believe since then it has been exceeded by a French institute that did it for two minutes longer, or something like that.

China does have fusion in its long-term energy strategy, but it's a long shot. It's not written in there until 2030 or 2040, perhaps even. There are no promises to develop fusion in the next three years or five years. I know there are some commercial developers in the United States that have a much more aggressive timeline. China takes a much more long-term view on the potential for fusion, and whether or not it will eventually be part of the energy mix right now is far too early to say.

But I would say at the moment it doesn't look like it's put into the blueprint for the energy transition. It is just something that is interesting. We will see if it works. We will invest in it, quite significantly. They are spending supposedly over $1 billion a year in R&D on their fusion projects. But that is certainly not a core part of the energy transition at this point.

COMMISSIONER MILLER: Thank you. I see my time is ticking down, but I wanted to have one last question. Most of the projections that we are talking about are based linearly on what we know from what China is doing. What is the most out-of-the-box development you can envision that would affect China's energy mix in the future, realistic but out-of-the-box that may change everything we are talking about today? Dr. Meidan.

DR. MEIDAN: That is a really good question, a really hard one. I think, as you have been saying, all of the projections are based on what we already know, but we're not keeping up with the trends. If we look at electric vehicle penetration, and you look historically at some of the renewable deployment, every year the IEA and others were revising up, because the scale of deployments and penetration was faster than we expected. Which is why I am also saying that electric vehicle penetration, if we keep it current trends or even slightly accelerate, then gasoline displacement would be faster than anticipated. Renewable deployment could very well be faster than anticipated.

And so these fundamental sort of systematic changes that I tried to sort of lay out are based on sort of extrapolating to maybe last year's trend and not five- to ten-year trends, and that is where a lot of the models do struggle. And I am not even talking about disruptive change. There are disruptive changes on the demand side. There are other scenarios that we can think about, if the Chinese system became efficient, sort of in terms of incorporating market efficiencies or demand side efficiencies. There's lots of gains there.

But I think one important message is that the past is not a good enough indicator already.

COMMISSIONER MILLER: I'm over my time, but, I don't know, anyone else has a particularly interesting zinger for out-of-the-box developments? All right.

COMMISSIONER GOODWIN: We'll come back to the zingers. Chair Price.

CHAIR PRICE: Thank you all very much for participating today. This is very interesting.

The most important thing we do is create recommendations for policymakers, so I want to go back to that. Several things have been alluded to. Mr. Fishman, you have recommendations in your written testimony. I'm going to start with you and ask you to pull out what you think is the most important of those three recommendations that you've made.

And to Drs. Downs and Meidan, you have alluded to certain things that you would do, in answer to other questions. I'm going to ask you to give me what your recommendations would be or your priority, moving forward.

So Mr. Fishman?

MR. FISHMAN: I will briefly mention the third one, just to set up the first one. The third one is involving gathering better intelligence on what China is doing currently, what its current capabilities, intentions, strengths, and weaknesses are. I think there is a persistent gap in what is available and knowable, even from public sources, and what is known and how that is incorporated into strategic thinking on the U.S. side.

And then building upon that, which was my third recommendation, my first recommendation that there has to be an acceleration of U.S. infrastructural, ecosystem-level support for the next gen industrial clean tech deployment, getting it out of that R&D phase, getting it out of academia and into deployment, and crucially, providing the right levers and the right systems that de-risk these efforts. Because if you leave it up to our financialized world of short-term returns, of asset managers, of investment banks looking for certain returns on certain time frames, these things will never get built. They'll never get done. It needs a certain de-risking in order for the zero to become the one and then the one to become the ten, to use my metaphor from before.

That's my key recommendation. Enhance the environment to allow builders who want to try out some of these projects, to try out some of these technologies, to build a demo and see if they can't get it going.

CHAIR PRICE: Thank you. Dr. Downs or Dr. Meidan?

DR. DOWNS: I'm happy to come in. So one recommendation that I have is to monitor changes in China's oil demand and imports and how those changes impact China's relationships with its key oil suppliers. So as China's demand for oil and its oil imports peak, plateau, start to decline, who among China's major suppliers are the big winners and the big losers, and what does it mean for China's relationship with these countries, and then what does it mean for the United States.

So thinking about who might win in the future. One country I would point out is Saudi Arabia, that Saudi Aramco has been not only investing in more petrochemical projects in China, with an eye to producing some of those materials needed for the energy transition, and that's also a way to lock in demand in China, but we're also seeing the energy relationship between these two countries broaden beyond oil, to include renewable energy technologies, especially solar. But there also have been big investments announced last year between Chinese companies and the Saudi Sovereign Wealth Fund for the manufacture of wind turbines and solar panels and storage in the Kingdom.

I will stop there, but basically I do think it is worth paying attention to how these changes in oil demand and imports impact China's relationships with other countries in the world and what all of that means for the United States.

DR. MEIDAN: Thank you. I'd like to reiterate the point about understanding and knowledge. Our conversation just now also highlighted issues of data and price. We spend our time looking at the data, at the issues, and we spend a lot of time on it, and we're nowhere near understanding it completely. That has to continue, sort of those efforts, both to get better data from China but also to triangulate from external sources, including from perhaps the corporate and the business sector. It's not just the data. It is also the information about how things work and the different interests and the different stakeholders.

Different parts in the business community, the policy community, have interactions with counterparts in China and overseas, and understanding how that all fits together is really important. It does, perhaps, lend itself to sort of whole-of-government approach or a better coordination internally within the U.S.

Sort of going back to that data issue, some of the issue with independent refiners that we have bad data is because they are doing tax evasion, and this is a challenge for the Chinese government, as well. But we all need to figure it out. So better understanding.

I think when the U.S. thinks about infrastructure support, which sectors to de-risk, I think there has to be, as I sort of started saying earlier, a more holistic view of what is feasible, what is realistic, which areas are worth sort of keeping, saving, and leading.

And I think there is a difference between leadership and scaling up in deployment. There are certain sectors, again, which are to be sort of discussed, because there are tradeoffs, right. You can't have everything. You can't have infrastructure for everything and leadership in everything. So which are the sectors that the U.S. can lead on, and perhaps hydrogen and next generation of some of these clean technologies. But there is also a race to just have these infrastructures and technologies.

I just want to point out that scale and size and cost reductions matter. If you look back at the history of solar panels, it was thin film technology in the U.S., and China came in, scaled up, polysilicon. Now that is the dominant technology. Battery technology started as NMC. Then China came and is doing LFP. That is the dominant technology.

So what is the race, or sort of what are we getting to? What are we trying to get to? And then what are the tradeoffs, because not everything is achievable.

CHAIR PRICE: Thank you very much.

COMMISSIONER GOODWIN: Thank you. Commissioner Shmavonian.

COMMISSIONER SHMAVONIAN: Thank you. Dr. Meidan, you note in your written testimony that China's industrial sector makes up a large share of their energy use, and we have also heard that China is seeking to rapidly towards industrial decarbonization. Can you talk about the interaction between those two items and what that might mean long-term, over the next five to ten years, for China's energy mix and use and dependency?

DR. MEIDAN: I think the priority now has gone from, if we were to rank sort of decarbonization, that is now much lower in the ranking because it's all about economic growth, but also economic resilience and the ability to compete with the U.S. and potentially with the West. And that will happen, I think in Beijing's view, through the leadership in these industries and technologies. So that is the main focus. It is making sure that these industries are fueled by whatever it takes, be it coal, be it renewables. But over time, because renewables are also an industry and they contribute to economic growth and activity within China, and they are a way to deal with decarbonization, the European Carbon Border Adjustment Mechanism might be watered down a little bit now, but it's still there. So that threat of carbon tariffs exists and is pushing for steel sector decarbonization and other efforts at decarbonization.

So over time I do think we will see greater decarbonization in the mix, so a reduction of coal, much more wind and solar. It's an open question about how much nuclear and how much hydro. But the question is really wind, solar, and coal. And probably China will electrify much more rapidly than it decarbonizes, but it is laying the groundwork for a system that is low carbon, that is quite low emission, and also can deliver on this industrial growth.

COMMISSIONER SHMAVONIAN: Thank you. I noted that there wasn't a lot of discussion in the testimony around nuclear, green hydrogen, geothermal, geologic hydrogen, some of the other energy sectors where the United States has competitive advantage or where we're investing heavily, such as in green hydrogen. A lot of these technologies and sectors also draw from the oil and gas industry, and a lot of the technologies of the oil and gas industry. So we have indigenous and inherent expertise in those areas.

Dr. Downs, Dr. Meidan, can you talk through both China's interest in those sectors and also where we might have competitive advantage, and what that can mean long-term?

DR. DOWNS: Sure. I'm happy to start. I've looked at geothermal and green hydrogen through work that I've done examining how China's national oil companies are preparing for a future in which less oil is consumed. Geothermal is one area where they have been active. They are planning to do more in this space. And this is also true for green hydrogen. Sinopec, which is China's largest oil refiner, back in 2021, set the goal of becoming China's leading green hydrogen company. It's worth noting that Sinopec is already a leading hydrogen company, but most of its hydrogen production is from fossil fuels. But they do have some big projects that they are working on, both in terms of producing green hydrogen, in terms of a pipeline.

And I think sort of a big question for the company is does it have what it takes to be the leader in green hydrogen. This is a wide-open space. It's a new industry, so you have a lot of companies rushing in. And there are renewable energy companies in this space that may be better positioned to succeed. But certainly it's an area where a lot of companies in China are interested in becoming bigger players.

DR. MEIDAN: I can just add very briefly, I agree with everything that Erica said. I guess when you look at the kind of systemwide picture -- these are small parts of the picture, but they're not absent. I think the Chinese policy is sort of all of the above, and invest in all of these, and it had a lot of geothermal activity and investments happening that are continuing.

In terms of hydrogen, there has been more policy support since 2021, 2022. I mean, there's been a longstanding hydrogen policy for fuel-cell vehicles, that has sort of been ongoing in tandem with electric vehicles, but electric vehicles sort of won out. The shift in 2021, 2022, became more focused on hydrogen as a tool of decarbonization, with a focus on green hydrogen. And with the availability of excess renewable capacity that is curtailed in some provinces, those are being redirected into green ethanol, green hydrogen. I think there is a lot of potential there. It might not be spoken about because it's a variety of companies.

But these are, as I mentioned earlier, these are sort of design-intensive technologies, so not the easiest for China to take and scale. I mean, they're already quite advanced in alkaline electrolyzers, so in the industrial component of it, but not in PEM electrolyzers, where there is hope (A) for the U.S. to remain a leader. And if we think about these industrial hubs and clusters, well then hydrogen clusters in the U.S. are potentially worthwhile sort of pursuing and advancing.

COMMISSIONER SHMAVONIAN: Thank you.

COMMISSIONER GOODWIN: We can kick off a second round. Mr. Fishman, I have a question about the role of AI in data center construction in increasing demand. Obviously seen a lot of press coverage about the growth of AI in China and around the world and the impact that that has on consumption and demand, with some commentators indicating that it's set to quadruple in China over the next ten years, and suggesting it's growing at an alarming rate.

My sense, from your testimony, was that you didn't seem very alarmed, given the overall growth of their capacity in China. So wanted you to react to that. And then also, just for context, provide some comparison to the growth of AI and data center construction here in the U.S. relative to our capacity.

MR. FISHMAN: Yeah, sure. When it comes to the challenge posed by the rise of electricity consumption for AI, the key thing to remember is that China has had year-on-year power consumption growth of 6, 7, 8, 10 percent for many, many years. And so when it comes to this new driver of power consumption growth, keeping power consumption growth high, keeping it at, well, these days it's maybe 5 percent or 6 percent, it's just another thing that makes you need more electricity.

By contrast, I think the response in the United States has been a little bit more of consternation because for many years power consumption growth rates have been very, very minimal, or maybe even flat. And so when data centers mean we need to rise by 1.5 percent or 2 percent year-on-year, this becomes a considerable challenge, whereas in China's case, it's just another thing. Now, of course, it's a big thing, and it means that electricity consumption will keep growing when maybe it would have flattened out a little bit more.

But the mechanisms in place to ensure that those data centers are going to be using as much green electricity as possible are also already going into place. So putting those data centers into the renewable portfolio scheme means you can only locate them, in some cases, in a few provinces. Sometimes they have to be close to the compute center, but the ones that can be put far from -- they don't have to be so reliant on being close to the compute cluster, those can be out in Inner Mongolia or Gansu. They can be happily soaking up some of those extra renewables that we were just talking about.

China has, indeed, quadrupled -- I've seen numbers saying anywhere from 500 terawatt hours to 1,000 terawatt hours by 2030, going solely to data centers. Now again, for context, 500 terawatt hours, that's a Germany, and 1,000 terawatt hours, that's a Japan. So between a Japan and a Germany of power consumption going just to data centers, but in China's world, in the scale that China is working with already, it's manageable. It's doable. It's just another thing that you have to prepare for.

So I do think they're handling it a little bit differently, and they're more prepared to be able to scale up in that way.

COMMISSIONER GOODWIN: Thank you. Let me switch gears and talk a little bit about super-critical coal-fired power plants that you discussed in your testimony. As you described them, these plants are more efficient and subject to stricter emission standards than comparable coal-fired power plants here in the U.S. Wanted you to talk a little bit more about what those stricter standards are and what they actually govern in terms of emissions.

And then you also suggest that putting more of these super-critical plants online could actually reduce emissions. Now, that presupposes a lot of things, about the grid mix, what else is available. So would like to hear you expand on that.

MR. FISHMAN: Yeah, sure. I'm having trouble with my mute button. Right. So when it comes to those ultra-super-critical plants, they're being built in the last five to ten years, really. They are the newest technology. And they are being expected to operate in the reality of the new power mix, which is one that increasingly is using solar power during the day and maybe has wind power in the evenings, and it needs coal to be able to fill in all the gaps, and to be able to operate, as was mentioned before, a lot like we would operate natural gas-fired power plants in the United States. China doesn't have a lot of gas. It has lots of coal, so it's going to operate its plants as if they were gas plants.

These new, newer, newest plants, the ultra-super-critical plants, are the culmination of many, many years of iterating and improving the efficiency of the existing fleet. And what it comes down to is that when all of those coal plants are competing for dispatch, competing to sell electricity and to be load followers and to complement the wind and solar, they're going to be competing with each other. They're going to be competing for capacity markets, against batteries and nuclear and other coal plants. And in the end, the ultra-super-critical plants will be more efficient and operating at lower cost, and they'll beat out the sub-critical plants.

So that's the future that looks like it's a dog-eat-dog world for coal plants in China, and the ultra-super-critical ones will surely be best positioned to win.

COMMISSIONER GOODWIN: Thank you. Anybody else for a second round? Commissioner Kuiken.

COMMISSIONER KUIKEN: Thank you very much, Commissioner Goodwin. I don't usually get a bunch of energy experts and electricity experts in front of me, so let me talk through a scenario and then I'd just love to hear the reaction of all of you.

So China is reportedly going to have about a terawatt or more of solar panels coming off the line every year. They're also building nuclear power plants. We're trying to build power plants. I was recently told that nuclear power plants are sort of a critical piece of any sort of electrical grid, as we think about data centers and sort of the challenges of the future.

If China is building a terawatt of solar panels, Dr. Meidan, and we go back to your point about saying maybe it's not worth investing in solar, how should we think about the Chinese power grid and the American power grid and what that mix looks like. Should we go all in on everything? Should we prioritize where those investments are made as we sort of invest in data centers, and we see this continued race to artificial general intelligence, or should we go all in on one particular solution?

And I am sorry, I said Dr. Meidan. I don't intend you to be the only person to answer the question. Everyone's welcome to chip in. And zingers remain welcome for my friend, Commissioner Miller.

DR. MEIDAN: I mean, the Chinese and U.S. grids are very different. I have to profess, I know very little about the U.S. grid. So the starting point is different and, therefore, what you're trying to achieve is very different. My understanding of the U.S. needs, saying about AI rising, there's a lot of transmission infrastructure. There's a lot of sort of the physical stuff. There is adding nuclear, adding gas, adding any form of energy that will allow firm, dispatchable capacity. And so how you decide on those investments, I think they have to include the physical infrastructure and the grid infrastructure to be able to deliver on that.

China is doing an all-of-the-above approach, where nuclear is a small part of what it will be able to deliver in the future. It's doing also battery storage to be able to fuel that growth. But it is a very different sort of mix, and it's a very different, I guess, provincial layout, because in some of these industries, as David was saying, they are going where the energy supply is.

So I think that the U.S. should be looked at on its own merit, with a few to resilience, flexibility, and I think down the line a lower emission grid, because the world is going towards more carbon tariffs and carbon accounting on industrial products.

COMMISSIONER KUIKEN: Anyone else?

MR. FISHMAN: I'll jump in here. The United States has a fragmented grid. We have RTOs. We have not one grid but rather eight to ten grids, sometimes regional, sometimes individual states. And that is going to continue to define how each region meets its electricity needs.

I am from New England. We can't expect to ever be having a solar-powered NEISO. It's just not going to happen. We can maybe expect to have a solar- and wind-powered ERCOT or CAISO, but it's never going to happen up in the Northeast. So as long as we continue to have a very fragmented national grid, or no national grid like that, every region is going to need to be defined by what makes sense for that region.

China, on the other hand, is hoping to build a national, unified grid. It will take a very long time, and it will be very difficult, both for the physical and commercial mechanisms to be put in place. But someday when that's all built, you can imagine that coastal needs for electricity are met by wind power generated on the other side of the country, and transmitted to the coasts where they're needed.

So China will be also taking a different approach, where we are saying we can do all of the above, we can build everywhere all at once, but we're also going to send it everywhere that it could theoretically be needed. It's going to be monstrously difficult, larger than any grid anyone has tried to build before, a huge, huge challenge. But they're looking at it quite differently.

The United States, I don't think, is moving towards having an integrated national grid any time soon, so it's going to continue to be restricted by regional capacity for what makes sense in the region where you're located.

COMMISSIONER GOODWIN: Chair Price.

CHAIR PRICE: Thank you. I have just two quick clarifying questions. The role of hydropower, does anyone want to comment on it? It was mentioned once, I think, briefly. But I'd love to hear that. Mr. Fishman, maybe? You're shaking your head.

MR. FISHMAN: I've been talking a lot so I wanted to give a chance for some of the other commenters to speak. But yeah, hydropower, there's a lot of hydropower, in southwest China especially. As long as it can be transported out of southwest China into other places where it's needed, of course it will be very useful elsewhere.

Currently a lot has been built. So while we're not exhausted, necessarily, while China hasn't built all the hydropower it possibly could, it's probably getting pretty close. There's at least a few more very large projects that will be on the 10- to 15-year horizon. And then at that point it seems like most of the accessible, readily developable hydropower resources will be exhausted. That being said, it's still on the order of hundreds of gigawatts, so quite a lot, but getting close to exhaustion.

CHAIR PRICE: Thank you. Yes, Dr. Meidan.

DR. MEIDAN: Just to add on the hydropower point, it is very vulnerable to climate change. So we've seen droughts and issues in Yunnan and some of these provinces that are rich in hydropower, that are building back up capacity of renewables and other because of the concerns of the impacts of climate change on the availability of hydropower.

CHAIR PRICE: Thank you. I want to go back, Dr. Meidan, to one thing you also said, switching to coal, in response to Commissioner Goodwin's first question, and institutional barriers on coal. You mentioned something about long-term contracts, but is that the sole institutional barrier, or is there something else that's keeping them in the coal business?

DR. MEIDAN: The power contracts are an important part of this because there's a guaranteed revenue, but local governments also know that they can rely on the coal industry, and the coal industry is a big employer and a big political stakeholder. So it is important well beyond the sort of market contracts. It is able to maintain a strong role. And increasingly, as the world is looking geopolitically more volatile, then China's leaders fall back on coal because it is domestically produced, and it is locally available. So I think it is obviously much deeper than contractual terms.

CHAIR PRICE: Thank you.

COMMISSIONER GOODWIN: Well, thank you all for your time and testimony today. We're going to take a quick break, and we will return at 10 after the hour for our second panel. Thank you.

PANEL II INTRODUCTION BY COMMISSIONER HAL BRANDS

COMMISSIONER BRANDS: Our next panel will explore the risks to the United States and its allies' national security from reliance on Chinese components and materials and critical energy infrastructure.

We'll start with Ms. Kate Logan, Director of Climate Diplomacy at the Asia Society Policy Institute, and Fellow in the Center for China Analysis. Ms. Logan will discuss how Chinese energy-related lending is being eclipsed by investments in overseas manufacturing and exports of clean energy technologies.

Next we'll hear from Mr. Patrick Miller, President and CEO of Ampyx Cyber. Mr. Miller will address recent Chinese cyber operations against the U.S. power grid and risks from both cyber actors and reliance on Chinese energy equipment.

Then we'll hear from Mr. Brian Menell, Chairman and CEO of TechMet. Mr. Menell will speak to how China became the global leader in critical mineral mining and refining and the challenges Chinese control of mineral processing poses to U.S. attempts to diversify supply chains.

Finally we'll hear from Mr. Cory Combs, Associate Director for Climate, Energy, and Industrial Policy at Trivium China. Mr. Combs will discuss how China uses its asymmetrical leverage in critical materials over the United States and strategies for the U.S. to loosen China's hold on the American economy.

Thank you all very much for your testimony. The Commission is looking forward to your remarks. And I ask that all of our witnesses please keep their remarks to seven minutes.

So Ms. Logan, we'll begin with you.

OPENING STATEMENT OF KATE LOGAN, DIRECTOR OF CLIMATE DIPLOMACY, ASIA SOCIETY POLICY INSTITUTE; FELLOW, CENTER FOR CHINA ANALYSIS

MS. LOGAN: Commissioners Goodwin and Brands, distinguished members of the Commission and staff, thank you for the opportunity to testify at today's hearing.

My remarks will focus on China's overseas energy footprint, including its infrastructure, exports, and manufacturing investments. I'll focus on three key points, followed by policy recommendations for Congress.

First is that the crux of China's overseas energy engagement has shifted from public lending for traditional energy infrastructure to commercially driven exports and manufacturing of new energy technologies, especially solar, electric vehicles, and batteries, which China collectively refers to as the "New Three."

For many years, China's global energy footprint was defined by large-scale, state-financed infrastructure projects under the Belt and Road Initiative. However, since 2021, sovereign lending by China's two main policy banks for energy has dropped sharply, amounting to just $737 million from 2021 to 2023. This is less than 1 percent of the total value of all loans from when the BRI was launched in 2013, through 2020.

In addition, President Xi Jinping's 2021 pledge to halt financing for new coal-fired power abroad has largely held up. While there are a few loopholes for coal developments that are still proceeding, no major new projects have been announced, and over 40 gigawatts of proposed coal capacity has been cancelled since the pledge, avoiding roughly 4.5 billion tons of cumulative emissions.

By contrast, in 2024, China exported 177 billion USD worth of new energy technologies and committed 58 billion USD to build overseas manufacturing facilities for these products. These factories have a potential annual output value of 111 billion USD once they are complete.

This pivot reflects a deeper structural transformation within China's economy. New energy industries, most of which are private enterprises, have become key growth engines, comprising over 10 percent of China's GDP in 2024, and driving more than a quarter of its economic growth.

Second, as the U.S. and other countries adopt trade restrictions, China will increasingly seek markets that impose lower or no barriers, many of which are in the Global South. China's overcapacity in new energy industries is a structural feature of China's economic policymaking that is unlikely to be resolved through external pressure alone. While this has made clean energy incredibly cheap, it has also caused challenges for companies to turn a profit. As a result, companies will increasingly court international markets to stay afloat, especially in the Global South where demand is growing and trade barriers are less prevalent. For instance, last year the value of EV exports from China to Global South overtook those to the EU.

Trade restrictions have also accelerated China's foreign direct investment into overseas manufacturing capacity. Initially, many companies were looking to circumvent tariffs by producing their new energy products in third countries, but this FDI is increasingly pouring into countries that are also looking to leverage China's clean energy knowhow and technology while deriving economic benefits and creating local jobs.

Third, the rising influence of China's new energy industries is now driving Beijing's political and diplomatic priorities. For instance, in a special address at the World Economic Forum this January, Vice Premier Ding Xuexiang emphasized China's dominance in new energy supply chains while extensively promoting green products and technologies. And at last year's COP29 climate conference, China cited over $24 billion in climate-related finance to developing countries since 2016, breaking from precedent to frame China as a constructive global player. China is also growing its contributions to multilateral development banks, thus elevating its influence in these global institutions. These actions all support expanding markets for China's new energy companies.

Now let me turn to three policy recommendations for Congress to consider, which aim to enhance U.S. resilience and prosperity in light of China's new energy dominance.

First, Congress should commission an updated report assessing the risks and tradeoffs of decoupling supply chains from China for critical new energy technologies that U.S. states and other countries are looking to source, given their economic and energy transition goals. By understanding the level of dominance of Chinese companies, extent of supply chain leverage, and resources that may be required to compete with Chinese enterprises, the U.S. could better cater its economic and industrial policies.

Second, based on this analysis, the U.S. should adopt targeted incentives toward technologies where U.S. companies may still have a cost-competitive opportunity to rise into key market players globally, such as advanced geothermal, solid-state batteries, and energy software. Existing tools like DOE national labs and the Battery Workforce Initiative should be strengthened, with additional resources put toward R&D as well as demonstration and deployment, especially in global markets.

Where U.S. domestic production would be prohibitively expensive, a different approach may be needed. Policymakers could reconsider trade barriers while investing in strategic rainy-day manufacturing reserves that could be activated during supply disruptions. Platforms like the Minerals Security Partnership could be leveraged to expand processing capacity for critical resources toward which the U.S. is working to secure greater access.

At the same time, the U.S. should consider where and how Chinese investment might benefit the U.S. economy. Streamlining the vetting process for Chinese FDI in new energy manufacturing, especially when paired with robust technology transfer agreements and other conditions, could help the U.S. benefit from China's expertise, create local jobs, and foster innovation.

Third, to remain a credible player in the global energy transition, the U.S. must not cede multilateral spaces to China. Staying in the IMF and the World Bank is not enough. Congress must continue supporting their investments in new energy, otherwise risk relinquishing ground to Chinese-led MBBs like the AIIB and NDB. Reauthorizing the Development Finance Corporation and expanding its equity investment authority could help bring U.S. new energy companies into emerging markets and support the nearshoring and friendshoring of critical new energy supply chains. This is vital for maintaining a constructive U.S. presence in regions where China is becoming more active.

Thank you, and I look forward to your questions.

COMMISSIONER BRANDS: Thank you. Mr. Miller.

PREPARED STATEMENT OF KATE LOGAN, DIRECTOR OF CLIMATE DIPLOMACY, ASIA SOCIETY POLICY INSTITUTE; FELLOW, CENTER FOR CHINA ANALYSIS

Testimony before the
U.S.-China Economic and Security Review Commission

Hearing on
"China's Domestic Energy Challenges and Its Growing Influence over International Energy Markets"

Testimony by Kate Logan
Director of Climate Diplomacy, Asia Society Policy Institute
Fellow, Center for China Analysis

April 24, 2025

Engagement by Chinese actors is shaping the future trajectory of global energy production and consumption. Examples of such activities include, but are not necessarily limited to, the construction of energy-related infrastructure, the export of new energy technologies produced in China, and foreign direct investment (FDI) in overseas manufacturing capacity of energy products. Discerning the trends, drivers, and impacts of China's global energy engagement is critical for helping countries achieve their objectives for energy security, economic development, and reducing emissions. A nuanced understanding is also a prerequisite for any country or business that desires to effectively compete with Chinese energy providers in overseas markets.

Much of the research agenda on China's overseas energy has focused on state-driven lending for large-scale infrastructure projects carried out under the banner of China's so-called Belt and Road Initiative (BRI), which was first proposed by Chinese President Xi Jinping in 2013.[1] However, a more accurate picture of China's engagement in recent years requires looking at a broader set of activities. As infrastructure lending has declined, exports of Chinese low-carbon energy technologies and the establishment of overseas production capacity for these products by Chinese companies have risen dramatically. These are largely commercially driven activities that have received a boost as China's clean energy companies have become major drivers of China's domestic economy, but also experienced overcapacity, thus prompting them to seek new markets abroad.

In recent years, the value of China's exports of clean energy products and FDI in new manufacturing capacity have far outstripped sovereign loans for energy infrastructure overseas.

[1] "President Xi Jinping Delivers Important Speech and Proposes to Build a Silk Road Economic Belt with Central Asian Countries," Ministry of Foreign Affairs, The People's Republic of China. 7 Sep 2013. https://www.fmprc.gov.cn/eng/gjhdq_665435/2675_665437/3180_664322/3182_664326/202406/t20240607_11410011.html.

On one hand, energy-related lending from China's two major state-sponsored development finance institutions – the Export-Import Bank of China (CHEXIM) and the China Development Bank (CDB) – has slowed dramatically. Only four loans totaling $737 million were recorded from 2021-2023, all in non-fossil energy.[2] This compares to an annual average of $14.8 billion in energy-related lending annually from 2013 when the BRI was launched through 2020, indicating that commitments from 2021-2023 comprised less than 1% of the total sum of loans from 2013-2020.

By comparison, in 2024, China exported a total of $177 billion in clean energy technologies.[3] In other words, total energy lending by China's policy banks in the *entire decade* since the BRI was launched was still only two-thirds the value of China's clean technology exports in *just last year alone*. Deals for overseas manufacturing facilities for these products in 2024 were worth $58 billion, with a potential annual output value of $111 billion once these facilities are completed.[4] Hence, while sovereign lending for energy infrastructure may rise somewhat and continue trending cleaner in the coming years, China's overseas energy footprint is much larger and more complex than just public finance.

These figures reflect a fundamental set of shifts that are defining, and will continue to shape, the nature of China's overseas energy footprint going forward:

- The extent of China's clean energy exports and overseas manufacturing investments is surpassing that of its energy infrastructure engagement. This shift, which is largely driven by economic factors, means that clean energy industries have become more significant to Beijing's political and foreign policy interests.
- The economic model that cultivated these clean energy industries in China and drove down costs, but also led to their overcapacity, is unlikely to change. Therefore, other countries should focus their efforts on navigating global markets in light of China's economic structure, rather than attempting to compel Beijing to change it.
- As the U.S. and some other countries adopt trade restrictions as means of navigating China's clean energy industry dominance, China will increasingly seek other markets that impose lower or no barriers, many of which are in the Global South. While it will be difficult to compete against Chinese energy on price alone in these markets, these countries may still have an appetite for certain energy technologies that provide comparative benefits to those products where China is currently dominant.
- Meanwhile, countries that figure out how to learn from and leverage China's clean energy innovation, such as through technology transfer and joint ventures, may lower the costs of their energy needs and derive greater economic benefits.

As such, this testimony aims to shed light on recent trends in China's overseas energy engagement, the factors that are driving these shifts, and their implications for the global energy

[2] "China's Global Energy Finance Database," Boston University Global Development Policy Center. Accessed Apr 2025. https://www.bu.edu/cgef/.

[3] Asia Society Policy Institute analysis.

[4] Ibid.

sector. It concludes by putting forth a series of recommendations to the U.S. Congress and policymakers based on the analysis within.

I. China's sovereign lending for energy infrastructure abroad has slowed dramatically as commercial deals have trended greener

Breaking down Chinese overseas energy into three core categories – infrastructure, exports, and manufacturing facilities – can help to distill differences in their drivers and impacts on recipient countries. The first category, energy infrastructure, includes power plants, transmission, pipelines, and other facilities and equipment used to produce, transmit, store, and distribute energy. Such infrastructure typically requires an influx of labor during the period when projects are being built, with construction contracts often favoring Chinese workers. Infrastructure projects can also provide local benefits by way of energy security and, when cleaner energy sources are deployed, emissions reductions. In cases where infrastructure projects consume fuel or resources to operate, they can provide economic benefits to the providers of these fuels. Yet, infrastructure deals generally do not provide significant long-term employment or major economic returns. Moreover, they are typically financed with a combination of equity and debt, often requiring the host country to pay back the debt financiers over the course of decades.

Lending for energy infrastructure by China's core state-sponsored policy banks, CHEXIM and CDB, has fallen off dramatically since the pandemic and essentially stayed that way. The value of loans from these two players has yet to return to anywhere near its post-2013 peak in 2016 of $28.1 billion in BRI countries and $34.1 billion across all geographies.[5] Lending from CHEXIM and CDB had already been declining steadily since then, before hitting a nadir with no new energy loans recorded in 2022. The average size of commitments was also much smaller, with the average loan in 2023 worth $167 million as compared to the $574 million average for energy-related loans committed between 2000 and 2022.[6] With only $0.5 billion in new loans recorded in 2023, the policy banks have shifted away from their previous role in shaping the contours of China's global energy footprint. While sovereign lending for energy projects may tick back up following a lull during the pandemic, broader challenges, including debt distress in host countries and the need for policy banks to fund domestic stimulus, make it unlikely they will return to previous levels of activity seen in the BRI's early years.

Despite this, when commercial investments in energy infrastructure are considered together with construction deals[7], the overall value of Chinese energy deals in BRI countries has recovered post-pandemic to the highest levels since its previous peak in 2017, during the heyday of the BRI's political momentum. Such deals approached a total value of $40 billion in 2024, representing the largest overall share of China's BRI engagement by sector.[8]

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[5] "China's Global Energy Finance Database," Boston University Global Development Policy Center.

[6] Jiaqi Lu and Diego Morro, "'Small' Belt, 'Beautiful' Road," Boston University Global Development Policy Center. Nov 2024. https://www.bu.edu/gdp/files/2024/11/GCI-PB-24-CGEF-2024-FIN.pdf

[7] These include deals with a range of corporate players, including state-owned enterprises (SOEs), publicly listed companies, and privately-owned companies.

[8] "China Belt and Road Initiative (BRI) Investment Report 2024," Green Finance & Development Center, Fudan University. 27 Feb 2025. https://greenfdc.org/china-belt-and-road-initiative-bri-investment-report-2024/.

Engagement across all sectors in BRI countries was also the highest since the BRI's launch in 2013, totaling just over $70 billion in construction contracts and $51 billion in investments. Notably, energy-related deals skew heavily toward construction, which comprised about 90% of the overall value of projects in 2024, with investments making up only around 10%; previously, construction deals had made up around a third of overall energy engagement in the period since 2013. This means that only about $4 billion of China's BRI energy engagement in 2024 was in the form of actual investments, indicating a much smaller portion of the overall total. Only one of these investments exceeded $1 billion in size: a $3.18 billion investment by China's CNOOC in the Whiptail offshore oil project in Guyana, representing a 25% stake of the $12.7 billion project.[9, 10]

China's engagement in overseas energy infrastructure is also the greenest it has been in relative terms. In September 2021, Chinese President Xi Jinping delivered a speech at the UN General Assembly, where he stated that "China will step up support for other developing countries in developing green and low-carbon energy, and will not build new coal-fired power projects abroad."[11] Since then, no new loans to fossil fuel projects have been approved by China's policy banks, though the overall volume of loans has also remained minimal as noted above. More broadly, the share of China's construction and investment deals in energy in BRI countries has seen its highest percentage share of "green" projects in solar, wind, and biomass, which totaled $11.8 billion or 30% of China's total energy engagement in 2024, or $8 billion when biomass is excluded.[12] Another 11% of energy engagement went toward distribution systems, such as substations and power lines, and an additional $0.64 billion went into hydropower projects, although this represented the lowest overall volume and share of engagement in hydropower since 2013.

Nevertheless, despite no new fossil loans from policy banks, fossil fuel investments are still a prominent part of Chinese energy engagement in BRI countries. While over half of the record 24 GW of new power capacity installed in these countries by Chinese companies in 2024 was for solar, wind and hydropower, nearly half still went toward fossil projects.[13] Approximately two-thirds, or around $27 billion, of the total value of BRI energy engagement in 2024 – including both investments and construction contracts together – went toward oil, gas, and coal projects. Cumulatively since 2013, China has completed 94 GW of such fossil power projects overseas in BRI countries.[14]

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[9] "China Global Investment Tracker," American Enterprise Institute. Accessed Apr 2025. https://www.aei.org/china-global-investment-tracker/.

[10] "ExxonMobil Guyana moves forward with sixth offshore development," ExxonMobil. 12 Apr 2024. https://corporate.exxonmobil.com/news/news-releases/2024/0412_guyana-offshore-development-whiptail.

[11] "Bolstering Confidence and Jointly Overcoming Difficulties To Build a Better World," Ministry of Foreign Affairs, The People's Republic of China." 22 Sep 2021. https://www.mfa.gov.cn/eng/xw/zyjh/202405/t20240530_11341561.html.

[12] "China Belt and Road Initiative (BRI) Investment Report 2024," Green Finance & Development Center, Fudan University.

[13] "Record year for Chinese overseas power projects: 24 GW installed in Belt & Road countries," Wood Mackenzie. 27 Jan 2025. https://www.woodmac.com/press-releases/china-br-2025/.

[14] Ibid.

Given Xi's high-level pledge in 2021 to stop building new coal-fired power abroad, the share of coal is worth examining further. Xi was ambiguous as to whether projects already in the pipeline would be included in his pledge. Many of these have thus moved ahead, with a total of 26.2 GW of coal power capacity becoming operational between then and October 2024[15] – thus signifying that the original pledge was intended to exclude those projects that had already been announced. However, when assessed against the interpretation that Xi's announcement only applied to projects that were not already in the pipeline, China has largely abided by its high-level commitment, albeit with a few loopholes – mostly for captive coal power plants at industrial facilities and expansions of existing facilities with new coal-fired units. In 2024, at least 3.4 GW of previously unannounced coal-power projects advanced into construction and 4.9 GW entered the pre-permit phase.[16] Chinese actors were also involved in coal mining, with PowerChina providing construction contracts for projects in Mongolia and Bangladesh and another company purchasing stock in a coal mine in Indonesia.[17] Still, a total of 42.8 GW of coal-fired projects abroad have been cancelled since Xi's pledge, which has avoided 4.5 billion tonnes of cumulative carbon emissions that would have been produced over these plants' lifetimes.

These changes in China's engagement in overseas energy infrastructure are shaped by a combination of domestic "push" factors and foreign "pull" factors. The rebound in energy infrastructure investments in BRI countries with projects trending greener reflects many of the same economic incentives that are driving China's clean energy exports, but also the different nature of clean energy projects as compared to large-scale fossil infrastructure: they are smaller in size and oftentimes hampered by local policy challenges, such as inflexible power pricing on the grid or a lack of sufficient transmission infrastructure, leading to widespread curtailment if new power is installed. This could be a factor in why China's policy banks have yet to move in earnest on green lending, as they are ill-suited and inexperienced with lending to these types of projects. At the same time, the trend toward a greater overall volume of construction contracts compared to investments may reflect developers taking advantage of China's technical know-how gained from its own domestic renewable installation success. China's ongoing fossil projects also reflect vested domestic interests, such as a need to secure oil and gas supplies internationally given lack of domestic resources, or China's coal mining companies searching for economic viability in the face of the energy transition.

While political signals and guidance on China's overseas energy infrastructure have reinforced economic factors and global incentives, they have typically followed market influences rather than shaped them in the first place. Starting even before the Covid-19 pandemic, China's lending for overseas energy had begun to decline as many host countries increasingly struggled with debt. Dirtier projects, such as coal-fired plants, were also being challenged legally and by civil society on a local level.[18] Thus, when President Xi began deploying the phrase "small and

[15] Daniel Nesan, "Three years later: Impacts of China's overseas coal power ban," Center for Research on Energy and Clean Air. Oct 2024. https://energyandcleanair.org/publication/three-years-later-impacts-of-chinas-overseas-coal-power-ban/.

[16] Ibid.

[17] "China Belt and Road Initiative (BRI) Investment Report 2024," Green Finance & Development Center, Fudan University.

[18] "Kenya halts Lamu coal power project at World Heritage Site," BBC. 26 Jun 2019. https://www.bbc.com/news/world-africa-48771519

beautiful" to guide the direction of BRI investments, this political framing served as means of hedging against China's declining capacity and interest to invest in large-scale, polluting projects, and to cater to the needs and desires of host countries, while providing cover for the smaller overall volume of lending.

China has also been leveraging its greener overseas finance to boost its global reputation within multilateral spaces and on climate change action. Notably, at the COP29 UN climate conference in Baku, Azerbaijan in November 2024, China's vice premier Ding Xuexiang stated that "since 2016, China has provided and mobilized more than RMB 177 billion yuan of project funds in support of other developing countries' climate response."[19] This statement was the first time that a Chinese official referred to its climate finance for developing countries using the same framing applied to developed countries' contributions – a significant step, as China is still classified as a "developing" country within the UN climate regime. It also reflects China's interest to deploy more of its clean energy in markets abroad, including by financing projects. The figure put forth, which roughly equates to $24.5 billion – or approximately $3.1 billion per year – places China's climate finance contributions on par with, if not higher than, those of many developed countries.[20] While China did not disclose how this figure was calculated, it presumably includes a wide range of finance from China's policy banks and other actors, rather than just South-South aid related to climate, which had previously been benchmarked by officials at 1.2 billion RMB ($170 million).[21]

China's pivot within this context demonstrates how China may take active steps to bolster its multilateral reputation when they align with its existing objectives. Ding's strategic announcement set the stage for China to come across as a constructive player in negotiations, especially after having received pressure from the U.S., EU and other developed countries to make active contributions on global climate finance. Ultimately, China broke from existing precedent in the final outcome of subsequent negotiations on a new UN goal for global climate finance by agreeing for the first time to count its multilateral development bank (MDB) contributions alongside those from developed countries. Notably, despite lower bilateral lending by its policy banks, China had been ramping up its contributions to MDBs for clean energy and climate lending, which had grown from around $1.2 billion in 2017 to nearly $4 billion in 2022 after averaging around $0.5 billion per year from 2013–2016.[22] China's consistent support for multilateral lending and potential backing of further reforms to expand MDB lending on clean energy in the face of U.S. retreat could further enhance the world's perception of China as a constructive player. China has also expanded its climate and clean energy aid projects since

[19] "Full Text: Address by Chinese Vice Premier Ding Xuexiang at World Leaders Climate Action Summit," The State Council, The People's Republic of China. 14 Nov 2024. https://english.www.gov.cn/news/202411/14/content_WS67352200c6d0868f4e8ecea3.html.

[20] "COP29: Key outcomes agreed at the UN climate talks in Baku," CarbonBrief. 24 Nov 2024. https://www.carbonbrief.org/cop29-key-outcomes-agreed-at-the-un-climate-talks-in-baku/.

[21] "丁薛祥在"77 国集团和中国"气候变化领导人峰会上的致辞（全文）," 中华人民共和国中央人民政府. 3 Dec 2023. https://www.gov.cn/yaowen/liebiao/202312/content_6918225.htm.

[22] "China's international climate-related finance provision and mobilization for South- South cooperation," World Resources Institute. Sep 2024. https://doi.org/10.46830/wriwp.24.00036.

establishing a standalone aid agency, the China International Development Cooperation Agency (CIDCA), in 2018.

II. Exports of Chinese clean energy products have surged on the back of these industries' rise to prominence

The relative greening of China's overseas energy infrastructure engagement reflects a much more fundamental game-changer: China's clean energy companies have risen to prominence as a major force helping to keep its domestic economy afloat amidst relative economic stagnation otherwise. Beginning around 2023, the term *xin san yang*, or the "new three," began appearing in Chinese media and policy discourse to refer to the three major clean energy products where China had come to dominate the global market: solar panels, electric vehicles (EVs), and lithium-ion batteries.[23] In 2024, clean-energy technologies contributed over 10% of China's total GDP, with sales and investments worth over $1.9 trillion.[24] By way of comparison, this figure is on par with total global investment in fossil fuels in 2024 from all sources. China's clean energy sectors also grew three times as fast as the overall Chinese economy, driving over a quarter of China's GDP growth in the same year. To place this in context, without the growth from these technologies, China's economy would have only risen by 3.6% and thus would have missed its 5% growth target.[25]

These industries' success has been spurred by myriad factors. It can be attributed in part to policy support for these sectors, including the "Made in China 2025" initiative in 2015 that aimed to secure China's leadership in high-tech manufacturing industries. In contrast to traditional energy sources, which are largely state-dominated, most new energy companies are private enterprises, accounting for over half of China's "new three" exports and more than 92% of China's high-tech enterprises overall. While subsidies and targets contributed to their development, policy support extended well beyond this to encompass consistent investment signals, spending on R&D, and support for integrated industrial clusters.[26] Innovation has also played a role. While some of this occurred through technology transfer, other factors – including entrepreneurship, human capital, and supply chain interactions – have also been important, leading to coevolution of technologies between manufacturers, component providers, and customers.

At the same time, these sectors have also experienced hyper-competition, or "involution," leading to overcapacity and intense price wars. On one hand, China is installing the world's highest capacity of renewable energy by far domestically in 2024 – including 277 GW of solar

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[23] Xiaoying You, "The 'new three': How China came to lead solar cell, lithium battery and EV manufacturing," Dialogue Earth. 7 Nov 2023. https://dialogue.earth/en/business/new-three-china-solar-cell-lithium-battery-ev/.

[24] Lauri Myllyvirta, Qi Qin, and Chengcheng Qiu, "Analysis: Clean energy contributed a record 10% of China's GDP in 2024," CarbonBrief. 19 Feb 2024. https://www.carbonbrief.org/analysis-clean-energy-contributed-a-record-10-of-chinas-gdp-in-2024/.

[25] Ibid.

[26] Anders Hove, "Clean energy innovation in China: fact and fiction, and implications for the future," Oxford Institute for Energy Studies. Jul 2024. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/07/CE14-Clean-energy-innovation-in-China-Final.pdf.

and nearly 80 GW of wind power – and, as of 2024, installs more solar panels than it exports.[27] Yet, the country's manufacturers still possess an excess supply of clean energy products. For instance, at the end of 2024, China's solar PV manufacturing capacity was estimated to be 1.2 TW, or about twice the current market demand.[28] While this has made solar panels incredibly cheap, it has also caused challenges for companies to turn a profit. Solar modules and batteries have seen year-on-year price drops of 60% and 50% respectively, while lithium prices have decreased by 80%.[29]

China's glut of clean energy products has led to a sharp uptick in exports of these technologies. In contrast to overseas energy infrastructure, exporting energy products from China to other countries often poses more immediate benefits to the Chinese companies making these technologies. Products that require installation and maintenance also spur local job creation, though many associated positions are temporary rather than long-term. While exports are scalable and low risk compared to long-term lending for infrastructure or investments in manufacturing capacity, they may be susceptible to pushback if dumping is perceived.

The total value of China's low-carbon energy exports in recent years far exceeds its energy infrastructure engagement. In 2024, China exported a total of $177 billion in clean energy technologies, including $66 billion in solar panels, $48 billion in new energy vehicles (NEVs), $62 billion in batteries, and $1.2 billion in wind turbines.[30] Put another way, for China's "new three"[31] clean energy products – solar panels, EVs, and batteries – total global exports of *each respective product* exceeded the total value of all Chinese energy investments and construction contracts in BRI countries. Exports of these respective products were also greater than total energy lending from China's two main policy banks at their peak in 2016, when these banks committed $34.1 billion in loans across all geographies.[32] In recent years, the Global South has become a major market for China's cleantech exports, with the value of EV exports from China to the Global South overtaking those to the EU last year in 2024, for instance.[33]

The impact of these exports is amplified when one considers the projects where they are being deployed. The estimated value of overseas solar power generation projects that are using Chinese panels exported in 2024 is $210 billion, which is triple the value of the panels alone.[34] Only approximately $9 billion of these projects, or less than 5%, involve Chinese overseas

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[27] Dave Jones and Libby Copsey, "Guest post: Saudi Arabia's surprisingly large imports of solar panels from China," CarbonBrief. 31 Mar 2025. https://www.carbonbrief.org/guest-post-saudi-arabias-surprisingly-large-imports-of-solar-panels-from-china/.

[28] Yujie Xue, "China to erase excess solar-panel capacity by 2027, UBS forecasts," South China Morning Post. 6 Jan 2025. https://www.scmp.com/business/article/3293592/china-erase-excess-solar-panel-capacity-2027-ubs-forecasts.

[29] "Green capital tsunami: China's >$100 billion outbound cleantech investment since 2023 turbocharges global energy transition," Climate Energy Finance.

[30] Asia Society Policy Institute analysis.

[31] Xiaoying You, "The 'new three': How China came to lead solar cell, lithium battery and EV manufacturing," Dialogue Earth. 7 Nov 2023. https://dialogue.earth/en/business/new-three-china-solar-cell-lithium-battery-ev/.

[32] "China's Global Energy Finance Database," Boston University Global Development Policy Center.

[33] Lauri Myllyvirta and Hubert Thieriot, "Why China's clean energy need not fear US tariffs," Dialogue Earth. 9 Jan 2025. https://dialogue.earth/en/energy/why-chinas-clean-energy-need-not-fear-us-tariffs/

[34] Asia Society Policy Institute analysis.

financing or construction contracts.[35] This implies that most power sector projects using Chinese technologies are not actually invested in or constructed by Chinese actors. In short, the sheer economic clout and dominance of China's clean energy industries has become more significant as a driver of China's overseas energy footprint than its engagement in energy infrastructure, let alone fossil fuels. This economic influence makes these industries central to China's political interests and diplomacy.

As the U.S. and other countries have adopted policies to limit imports of Chinese-produced clean energy, Chinese companies have turned to other global markets, especially those in the Global South that may not have the same concerns about importing cheap Chinese products undercutting domestic industries.[36] The availability of such markets means that Chinese companies may be relatively resilient to the adoption of trade barriers by the U.S., EU, and other markets. Furthermore, while it is likely still too early to understand the full impact of the latest series of tariffs announced by U.S. President Donald Trump, signals indicate that China's clean energy industries will manage to cope by continuing to pursue such alternate markets, a process that had already started following restrictions that the U.S. had already put in place under former President Joe Biden. "Pull" factors from recipient countries are also driving imports of Chinese clean energy technologies. Since the Paris Agreement was adopted in 2015, nearly all countries globally have adopted climate targets to reduce emissions, thus necessitating their energy sectors to transition from fossil fuels to clean energy. Economic considerations are also playing a role in some markets, such as surging electricity prices that far exceed the cost of purchasing and installing affordable, Chinese-produced solar panels.

Country-specific case studies illustrate the variation in how "pull" factors are shaping China's overseas energy footprint. Solar panels provide one example to interrogate. Pakistan, which was the third largest importer of Chinese solar panels in 2024 after rising from 12th place in 2022, imported 17 GW of panels just last year.[37] The main reason Pakistan's imports surged is due to the spiking cost of electricity and unreliability of the grid due to regular power outages. Distributed installations of low-cost, Chinese-produced solar panels, coupled with battery storage and paid for by consumers, have become a cheaper and more reliable energy source and are helping to drive down electricity generation from fossil fuels, even as electricity demand is still growing. The overwhelming majority of these installations are not grid-connected and are instead located on-site on rooftops or next to factories for direct use. In a somewhat ironic twist, a major reason electricity prices are so high is due to the increasing lack of financial viability of Chinese-financed coal plants built in recent years.[38]

By contrast, Saudi Arabia, which also imported 17 GW of Chinese solar panels last year – thus rising to fourth in 2024 from 26th in 2022 – has been deploying Chinese panels in large-scale

[35] Ibid.

[36] Lauri Myllyvirta and Hubert Thieriot, "Why China's clean energy need not fear US tariffs," Dialogue Earth.

[37] Dave Jones and Libby Copsey, "Guest post: Saudi Arabia's surprisingly large imports of solar panels from China," CarbonBrief. 31 Mar 2025. https://www.carbonbrief.org/guest-post-saudi-arabias-surprisingly-large-imports-of-solar-panels-from-china/.

[38] Humza Jilani, "Chinese solar panel boom threatens Pakistan's debt-ridden grid," Financial Times. 18 Sep 2024. https://www.ft.com/content/69e4cb33-3615-4424-996d-5aee9d1afe19.

solar parks located in its vast deserts.[39] These solar installations have achieved the lowest reported electricity prices in the world of 1.3 cents per kilowatt hour. The construction of these solar parks will help Saudi Arabia achieve its target of 50% electricity generation from renewable energy by 2030, up from almost no renewable electricity generation in 2020.

As clean technology industries have grown in prominence and thus significance for China's economic health, Chinese leaders have also boosted their emphasis on these sectors in high-level speeches and documents. For instance, in a special address at the World Economic Forum in January 2025 – delivered the day after Donald Trump's inauguration – vice premier Ding Xuexiang emphasized China's dominance in new energy supply chains, while stating that the "green transition is a prevailing trend of global development and the fundamental solution to climate change. The international community should work together to accelerate the energy transition in an equitable, orderly and just manner, keep the new energy industrial chain stable, and promote green products and technologies."[40] Meanwhile, recent pushback from Chinese leaders against trade restrictions for green products may also be aimed at ensuring stable overseas markets for Chinese goods while managing political pushback toward China's perceived dumping as means of addressing domestic overcapacity. For instance, the 2025 Government Work Report stated that China will "actively respond to green trade barriers,"[41] and new narratives from Chinese thought leaders have emerged calling for free trade on green goods, including by leveraging existing trade frameworks such as the Regional Comprehensive Economic Partnership (RCEP).[42]

III. In the face of trade-related challenges, Chinese companies have ramped up investment in overseas manufacturing for clean energy technologies

As China's exports of clean energy technologies have skyrocketed, related factors – including pushback against alleged dumping and trade restrictions – have accelerated China's foreign direct investment into overseas manufacturing capacity for these products. As more countries have limited their imports of Chinese energy technologies, Chinese companies have looked to circumvent tariffs by manufacturing their clean energy products in other countries where such policies might not apply. In other cases, such as in Brazil, countries have adopted their own tariffs toward Chinese clean energy technologies, while at the same time encouraging Chinese companies to invest in building factories within their borders. An incentive to this approach is the desire to derive greater domestic economic benefits from Chinese companies, such as by creating local job opportunities and contributing to domestic GDP growth. Companies may also establish factories abroad as means of courting new markets, securing supply chains, and to further globalize and extend their influence.

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[39] Dave Jones and Libby Copsey, "Guest post: Saudi Arabia's surprisingly large imports of solar panels from China," CarbonBrief.

[40] "Davos 2025: Special address by Ding Xuexiang, Vice-Premier of the People's Republic of China," World Economic Forum. 21 Jan 2025. https://www.weforum.org/stories/2025/01/davos-2025-special-address-ding-xuexiang-vice-premier-china/.

[41] "Report on the Work of the Government," The State Council, The People's Republic of China. 12 Mar 2025. https://english.www.gov.cn/news/202503/12/content_WS67d17f57c6d0868f4e8f0c0d.html.

[42] Jun Ma, "Regional Green Trade Bloc to Fight Both Climate Change and Protectionism, Forum on Trade, Environment & the SDGs. 28 Mar 2025. https://tessforum.org/latest/regional-green-trade-bloc-to-fight-both-climate-change-and-protectionism.

Examining the drivers of Chinese FDI in clean energy manufacturing capacity across different geographies and over time can help unpack how China is applying their merits. As compared to infrastructure and exports, FDI in manufacturing facilities for clean energy products, such as solar panels or batteries, can provide longer-term economic gains through local employment and technology transfer. Especially following the U.S. adoption of the Inflation Reduction Act, more countries globally looked to leverage industrial policy as means of deriving greater economic and social benefits from the global energy transition, thus creating more incentives for manufacturing FDI in many markets. However, these projects may involve evaluating and navigating a complex set of considerations, such as risk of industrial espionage or security concerns. The incentives that facilitate these projects, such as subsidies and tariffs, could also change suddenly because of shifts in local policies.

Similarly to clean energy exports, China's outbound foreign direct investment in manufacturing facilities for clean energy technologies in all countries now exceeds the value of its commercial engagement in energy infrastructure across the BRI. In 2024, China proposed and confirmed approximately $58 billion in factories for key clean technology sectors, including wind, solar, batteries, and new energy vehicles.[43] Over half of these investments, or around $35.4 billion, were for facilities to make batteries. Beyond this, approximately $15.3 billion was for capacity to produce new energy vehicles, and the remaining $7.2 billion was for solar and wind manufacturing combined. These investments are flowing to a range of geographies, but especially Global South regions across greater Asia, Africa, and Central and Eastern Europe; overall Chinese FDI in these regions has far outpaced investment from the US.[44] More broadly, when overseas investment across all clean energy projects by Chinese companies overseas is considered – including renewable power plants and transmission projects – over 130 new projects totaling over $100 billion were proposed and confirmed in 2023 and 2024.[45]

Furthermore, the potential output from these factories already rivals the value of China's cleantech exports. For manufacturing deals announced in 2024, the value of their annual output in products could reach over $110 billion, or more than 60% of the annual value of last year's exports.[46] For some technologies, the expected value of overseas production could actually be even higher than that of exports: the potential output from electric vehicle factories abroad is estimated to be 3 million units per year, which is greater than the 2.2 million units of EVs exported in 2024. Thus, in the future, the total value of clean energy products manufactured by China-invested factories abroad may overtake that of China's exports – reflecting the potential for China to help other countries produce more than it sells to them.

New energy vehicles provide a useful case study to better understand how local policies, as influenced in part by Chinese exports and industrial policy, are shaping Chinese FDI in overseas

[43] Asia Society Policy Institute analysis.

[44] Raphael Minder, "China 'dwarfs' US investments in EU neighbourhood countries," Financial Times. 15 May 2024. https://www.ft.com/content/bf9132d1-09c7-4604-b972-043f44812eaa?emailId=e04273d7-0394-407f-90c8-d8e445db994e&segmentId=60a126e8-df3c-b524-c979-f90bde8a67cd.

[45] "Green capital tsunami: China's >$100 billion outbound cleantech investment since 2023 turbocharges global energy transition," Climate Energy Finance.

[46] Asia Society Policy Institute analysis.

manufacturing capacity. Amidst the value of Chinese battery EVs surging by 18 times over the course of 2023 and Brazil surpassing Belgium as the top export market for China's EVs in April 2024, the Brazilian government opened several probes into China's potential dumping. It also adopted a 10% tariff on EV imports (not just from China), which will ratchet up to 35% by 2026.[47] However, Brazilian President Lula has welcomed foreign investment as part of his push to reindustrialize Brazil. As a result, global auto companies invested $19 billion in Brazil from 2023-24, of which $3 billion was from Chinese carmakers Great Wall and BYD.

A second example is playing out in Thailand, which has become a production hub for Chinese carmakers and battery companies. Alongside Thailand's role as a regional auto export hub, the country has adopted a target for auto production to reach 30% of electric vehicles annually by 2030[48], which has attracted more Chinese companies to build factories there. The strategy is also impacting Thailand's local EV penetration, with domestic NEV sales quadrupling in 2023 and reaching 10% of the domestic market; Chinese EVs account for over half of Thai NEV sales. At the same time, given the increasing political importance of these industries, China's leaders are encouraging Chinese companies to avoid investing in manufacturing FDI in overseas markets that might threaten China's interests or be seen as a political concession.[49]

IV. Implications and recommendations to U.S. Congress

The future trajectory and implications of China's overseas energy engagement will likely be shaped by several important factors. First, as researchers have noted, China's overcapacity in clean technology industries – as well as other industries – is "a feature, not a bug, of Xi's new economic policymaking and ideology as the party state prioritizes self-reliance and economic security at all costs, even at the erosion of profitability, return on investment, and efficiency."[50] Thus, other countries may have few levers to compel China into actively addressing its overcapacity, which is likely to persist as a factor shaping the global energy economy.

Second, if enacted, the latest round of U.S. tariffs on China announced by President Trump may prompt a fundamental rethinking of trade relationships by China and other countries affected. As the U.S. closes its doors to Chinese products due to prohibitive prices when tariffs are applied, China will need to look to both its own domestic market as well as other markets overseas to sell and deploy those products. The ability of these markets to absorb China's clean energy goods, as well as how these countries navigate potential U.S. pressure to follow its lead in decoupling from China, will shape China's global energy influence.

[47] "Green capital tsunami: China's >$100 billion outbound cleantech investment since 2023 turbocharges global energy transition," Climate Energy Finance.

[48] Stella Nolan, "Thailand: A Global Hub for Electric Vehicle Production," EV Magazine, 9 Aug 2024. https://evmagazine.com/news/thailand-a-global-hub-for-electric-vehicle-production.

[49] Gloria Li and Cheng Leng, "China delays approval of BYD's Mexico plant amid fears tech could leak to US," Financial Times. 18 Mar 2025. https://www.ft.com/content/36ae6f78-aadb-47bb-a5cd-ec69b420cbe1.

[50] "Beyond overcapacity: Chinese-style modernization and the clash of economic models," MERICS. 1 Apr 2025. https://merics.org/en/report/beyond-overcapacity-chinese-style-modernization-and-clash-economic-models.

Finally, regardless of unilateral U.S. action and diplomacy on trade, other countries will be compelled to decide how they approach their individual trade relationships with China as a function of ensuring these ties benefit their own economies and contribute to industrial development. Developed and developing nations alike will need to determine the extent to which they let in Chinese clean energy imports and their appetite for Chinese FDI in cleantech manufacturing, in light of their relative ability to foster and develop homegrown industries in the same technologies. These responses may also be shaped by whether non-Chinese competitors can provide the same products at a commensurate quality and price, and the extent to which countries might be willing to pay a premium for non-Chinese energy.

There are several actions that the United States and its legislative branch could pursue to better advantage U.S. interests in light of China's overseas energy footprint. Firstly, Congress could commission an updated report on the state-of-play of Chinese industries and policies across a broad range of critical new energy technology products that U.S. states and other countries are looking to source given their energy transition and economic goals. Specifically, this report should analyze the risks and tradeoffs countries would face if and how they move to decouple their supply chains from China for new energy technologies. By understanding the level of dominance of Chinese companies, extent of supply chain leverage, and level of funding and expertise that may be required to cultivate homegrown industries that could compete with Chinese enterprises on both quality and price, the U.S. could better cater its economic and industrial policies toward technologies where U.S. companies may still have a cost-competitive opportunity to rise into key market players globally – such as advanced geothermal energy and solid-state batteries, as well as software and other services. For these areas, the U.S. should ramp up R&D funding, and couple this with additional resources to support demonstration, deployment, and dissemination of these technologies, especially in international markets. As part of this, funding for existing resources should be maintained and enhanced, including for DOE's national laboratories, energy innovation hubs, and battery workforce initiative.

For energy technologies where competing with China may be prohibitively expensive, the U.S. could consider lowering tariffs and other barriers to trade, or ensuring there is a definitive plan to "sunset" such restrictions when appropriate. This should be paired with investing in sufficient "rainy day" manufacturing capacity across the entire value chain of those products, such that the U.S. could procure the full supply chain domestically or from allies and partners for a set capacity should supply chains become volatile or deemed to threaten U.S. interests. As part of this, the U.S. could leverage platforms such as the Minerals Security Partnership (MSP) to expand processing capacity for critical mineral resources toward which the MSP is already working to secure greater access. At the same time, U.S. policymakers should consider reducing barriers to foreign direct investment, including by streamlining the vetting process for key new energy technologies, while promoting technology use and transfer agreements with Chinese firms that are interested to invest in the U.S. This would enable the U.S. to learn from China's expertise and know-how, while ensuring that China's companies benefit the U.S. domestic economy by providing jobs, accelerating local innovation and dissemination, and reducing import dependencies.

The U.S. Congress should also leverage existing tools for ensuring the U.S. has a stake in shaping the global new energy future by maintaining and enhancing its presence in multilateral financial institutions such as the International Monetary Fund and the World Bank. By doing so, the U.S. can leverage their investment activities to ensure that the U.S. has a presence in markets where China is involved bilaterally, while avoiding ceding such multilateral spaces to China. In tandem, the U.S. should also reauthorize and expand the Development Finance Corporation, which is an important mechanism for investing in new energy projects that promote U.S. security, including by nearshoring or friendshoring supply chains, facilitating access to foreign markets for U.S. companies, and maintaining a constructive U.S. presence in critical areas of the world that may otherwise turn to Beijing. Increasing DFC's investment portfolio cap could also enable it to make better use of equity in investments.

OPENING STATEMENT OF PATRICK MILLER, PRESIDENT AND CEO, AMPYX CYBER

MR. MILLER: Co-Chairs Goodwin, Brands, Commissioners, thank you for the opportunity to testify. I am Patrick Miller, President and CEO of Ampyx Cyber. For more than 25 years I have worked in cybersecurity for critical infrastructure, focusing primarily on the electric grid. I have worked extensively with electric utilities of every size and function, in addition to collaborating with key Federal and state agencies, as well as major industrial hardware and software suppliers. I was one of the original contributors to the NERC Critical Infrastructure Protection, or CIP, standards, and the first CIP auditor with delegated Federal authority in the U.S. My remarks today draw from direct field experience assessing and mitigating cyber threats across the energy sector.

Let me start with a clear message. The cybersecurity threat from China to the U.S. energy grid is real, growing, and strategically motivated. This is not about isolated intrusions or espionage. It's about a persistent effort to position for potential disruption in a time of crisis. China is preparing the digital battlefield.

Over the past several years, threat reporting has consistently pointed to Chinese state-sponsored groups targeting critical infrastructure. These actors are not just stealing data. They are embedding themselves into our operational systems. The FBI and Intelligence Community have repeatedly warned that these groups are laying the groundwork to wreak havoc on American communities if and when the Chinese government chooses to escalate a geopolitical conflict.

Chinese-linked groups like Volt Typhoon use what we call "living off the land" techniques, by blending into normal system operation and exploiting legitimate administrative tools already built into operating systems. While larger utilities have stronger defenses, their complexity presents more opportunities for adversaries to hide, to maneuver, or escalate. Smaller utilities may be seen as testing grounds, places where threat actors can refine techniques or explore indirect paths to higher-value targets through shared systems, contractors, or communications infrastructure.

Part of the challenge lies in the age and complexity of our grid. Much of the infrastructure was built decades ago, long before modern connectivity or cybersecurity were considerations. These legacy systems are reliable by design, but upgrading or replacing them is costly and operationally disruptive. Such work requires carefully coordinated outages, even as the grid is engineered for continuous uptime.

The risk isn't limited to software or connectivity. Many critical grid components, transformers, inverters, batteries, and monitoring devices now come from Chinese manufacturers and run remotely updatable embedded software. This creates potential vectors for surveillance or sabotage. Simply put, we are increasingly dependent on foreign technologies across every layer of grid functionality and resilience.

Concerns go beyond the domestic risks. China has exported its energy technology to other nations through the Belt and Road Initiative. They have built and deployed SCADA systems, grid control platforms, and communication infrastructure around the world, often using proprietary software subject to PRC intelligence laws. This creates back doors into foreign infrastructure and potentially gives Beijing leverage over our allies during a crisis. To put it plainly, China is playing a long game by using technology and infrastructure as tools of influence and potential coercion. The U.S. cannot afford to ignore that reality.

So what can we do about it? First, we need to recognize that a complete rip-and-replace of all Chinese-made components is not feasible in the near term. We need to prioritize. We should start by identifying the most critical and vulnerable assets, those with remote access, updatable firmware, or high operational impact. Once identified, these components need to be isolated, monitored, and then when possible, replaced.

We should adopt a cyber-informed engineering, or CIE, approach. That means designing systems from the start to limit the impact of a cyberattack. It includes manual overrides, system isolation, segmentation, and operational redundancies. This approach is already being promoted by the Department of Energy and national labs and it should be mandated for all of the highest risk infrastructures.

We also need transparency across the digital supply chain. Vendors supplying hardware or software in grid operations should be required to provide a hardware or software bill of materials along with disclosures about the development process, code provenance, and sourcing of third-party components.

We must continue to expand and modernize our regulatory frameworks. The NERC CIP standards provide a baseline for bulk power system reliability and cybersecurity, but they only apply to larger generation and transmission assets. As our grid evolves, new classes of risk are emerging in distributed energy aggregators, edge-connected devices, and vendor-controlled assets, well outside the traditional utility compliance footprint.

Some voluntary standards are gaining ground, but currently there is a patchwork of governance mechanisms across the spectrum of grid systems and participants. Addressing these gaps may require new regulatory or compliance frameworks for the creation of modern, fit-for-purpose standards that reflect the complexities and interdependencies of today's electric grid.

Investing in domestic manufacturing is essential, but to build in America we must also secure the raw materials necessary for production. Critical minerals are the foundation of semiconductors and control boards, the essential components in everything from transformers to inverters. Without reliable access to these minerals, our supply chains will remain at risk.

We also need to test what we already have, particularly the systems and devices already deployed across our infrastructure that may pose hidden risks. There are thousands of currently fielded devices in substations, control centers, and edge environments whose software and hardware origins are poorly documented or understood. The Federal Government should fund programs to reverse engineer and thoroughly analyze these systems, especially where foreign-developed components are involved.

Another essential pillar of resilience is planning for failure. We need to practice what to do when things go wrong by simulating worst-case cyberattacks and mapping the key interdependencies. Resilience exercises should include options like temporarily islanding critical systems to keep them running rather than shutting them down.

In conclusion, the security of our energy infrastructure is foundational to national security, economic competitiveness, and global leadership. Emerging technologies like artificial intelligence, quantum computing, and advanced manufacturing all depend on reliable, secure electricity. If our grid is compromised, our future is constrained.

China has made its intent clear. The United States must respond with clarity, urgency, and coordination. That includes smarter regulation, greater transparency, public-private collaboration, and strategic investment in trusted technologies.

Thank you for your time.

PREPARED STATEMENT OF PATRICK MILLER, PRESIDENT AND CEO, AMPYX CYBER

WRITTEN TESTIMONY of Patrick C. Miller

President & CEO, Ampyx Cyber

before the

U.S.-CHINA ECONOMIC and SECURITY REVIEW COMMISSION

concerning

"*China's Domestic Energy Challenges and Its Growing Influence over International Energy Markets*"

APRIL 24, 2025

Co-Chairs Commissioner Carte Goodwin and Commissioner Hal Brands, and members of the committee, thank you for the opportunity to testify on a topic critical to our nation's security. My name is Patrick Miller, and I am the President and CEO of Ampyx Cyber, a consulting firm specializing in cybersecurity for critical infrastructure, particularly energy systems. For more than 25 years, I have worked directly with every size and function of electric utility, as well as federal and state agencies, Information Sharing and Analysis Centers, and industrial technology hardware and software manufacturers to assess and mitigate cyber risk. I was one of the original contributors to the North American Electric Reliability Corporation Critical Infrastructure Protection, or NERC CIP, security regulations for the electric power sector. Further, I was the first auditor with delegated federal authority to monitor and enforce the NERC CIP regulations in the country. Most of my professional career has been dedicated to protecting the critical energy sector. I appreciate the opportunity to provide testimony on the threats posed by Chinese energy policy and technology practices. My testimony is based not only on public intelligence and open-source threat reporting, but also on direct field observations during my career.

Background

The cybersecurity of the United States power grid has emerged as one of the most urgent national security issues of the 21st century. As the grid becomes increasingly digitized and interconnected, it is also becoming more vulnerable to sophisticated cyberattacks—particularly those orchestrated by state-sponsored actors. Among these, Chinese state sponsored actors and criminals stand out as the most persistent and capable adversaries, with a clear strategic interest in targeting US critical infrastructure. Over the past several years, a growing body of evidence from federal agencies, congressional testimony, industry reports, and investigative journalism has revealed the scale, seriousness, and urgency of this threat.

China's cyber operations against the US power grid are not isolated acts of espionage or theft; rather, they are part of a broader campaign to pre-position disruptive capabilities within American networked infrastructure. The goal appears to be to create options for China to sow chaos and impede US military responses during a future crisis, especially one involving Taiwan. Just last year, Former FBI Director Christopher Wray warned Congress that these actors are actively "positioning on American infrastructure in preparation to wreak havoc and cause real world harm to American citizens and communities if and when China decides the time is right to strike"[1] and that Beijing's resources dedicated to cyber warfare was bigger "than every other major nation combined." [2] The US House Committee on Homeland Security has documented more than 60 instances of Chinese espionage on US soil in recent years, spanning cyber intrusions, intellectual property theft, and even transnational repression.[3]

The scope of China's targeting is vast. While the electric grid is a documented target, Chinese cyber actors have also probed and penetrated water treatment plants, oil and natural gas pipelines, transportation systems, and telecommunications networks. These attacks are not limited to the largest utilities; smaller organizations with limited cybersecurity resources are often compromised first, serving as steppingstones to larger and more critical targets.[4]

One of the most active and concerning groups in this space is Volt Typhoon. This Chinese state-sponsored advanced persistent threat (APT) group has been active since at least 2021, focusing on cyber espionage and pre-positioning for potential disruptive attacks. Volt Typhoon is particularly notable for its use of "living off the land" (LOTL) techniques, which involve leveraging tools and applications which are not introduced by the attacker, but are legitimate components of the operating system, commonly used for administration, automation, or troubleshooting. By using these native tools, Volt Typhoon is able to blend in with normal or expected activity, making detection much more difficult and allowing the group to maintain persistent access for extended periods.[5]

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[1] Robert Walton, China-linked hackers primed to attack US critical infrastructure, Utility Dive (Jan. 31, 2024), https://www.utilitydive.com/news/fbi-china-hackers-us-critical-infrastructure/706423/

[2] Gareth Evans, FBI says Chinese state hacker group targeted US infrastructure, BBC News (Jan. 31, 2024), https://www.bbc.com/news/world-asia-68163172

[3] U.S. House Comm. on Homeland Sec., Threat Snapshot: CCP Espionage, Repression on U.S. Soil is Growing (Feb. 12, 2025), https://homeland.house.gov/2025/02/12/threat-snapshot-ccp-espionage-repression-on-us-soil-is-growing/

[4] Cybersecurity and Infrastructure Security Agency, National Security Agency & Federal Bureau of Investigation, PRC State-Sponsored Actors Compromise and Maintain Persistent Access to U.S. Critical Infrastructure, CISA Alert AA24-038A (2024), https://www.cisa.gov/news-events/cybersecurity-advisories/aa24-038a

[5] Cybersecurity & Infrastructure Security Agency, Nat'l Security Agency & Fed. Bureau of Investigation, PRC State-Sponsored Actors Compromise and Maintain Persistent Access to U.S. Critical Infrastructure, Joint Cybersecurity Advisory AA24-038A (Feb. 7, 2024), https://www.cisa.gov/news-events/cybersecurity-advisories/aa24-038a

A case that illustrates the sophistication and stealth of Volt Typhoon's operations involved the Littleton Electric Light and Water Departments (LELWD) in Massachusetts. The group infiltrated the utility's operational technology (OT) systems and, although operations were not disrupted, they remained embedded in the environment undetected for over 300 days, collecting data that could potentially facilitate future disruptive attacks. The breach was only discovered after the FBI alerted the utility, highlighting the importance of federal-private sector collaboration and the challenges of detecting advanced adversaries.[6]

The vulnerabilities exploited by Chinese actors are often rooted in the long operational lifespan of grid devices and the availability of outdated equipment. Many components in the US power grid were designed and installed decades ago, before modern cybersecurity standards were established. Some devices stay in service for decades and still run outdated software or systems that were never designed with cybersecurity in mind. Attackers exploit these weaknesses, especially in devices that are difficult or costly to upgrade or replace. The growing use of Chinese-manufactured components in the grid supply chain further complicates the risk landscape, raising concerns about potential backdoors or hidden vulnerabilities.[7,8]

In response to these threats, federal agencies have issued a series of urgent advisories and guidance documents. The Cybersecurity and Infrastructure Security Agency (CISA), National Security Agency (NSA), and Federal Bureau of Investigation (FBI) have published joint advisories warning of the tactics, techniques, and procedures (TTPs) used by Volt Typhoon and other Chinese threat actors. These advisories urge critical infrastructure organizations to implement robust network segmentation, monitor for anomalous use of legitimate admin tools, and share incident information promptly with federal authorities. Congressional testimony has emphasized the need for improved information sharing between the private sector and government,[9] as well as the importance of modernizing legacy infrastructure to reduce vulnerabilities.[10]

International collaboration has also played a key role in the US response. The United States has worked closely with allies to share threat intelligence and best practices for defending critical

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[6] Michael Kan, Chinese Hackers Sat Undetected in Small Massachusetts Power Utility for 300 Days, PCMag (Mar. 12, 2025), https://www.pcmag.com/news/chinese-hackers-sat-undetected-in-small-massachusetts-power-utility-for

[7] U.S. Dep't of Energy, DOE Leads Effort to Improve the Cybersecurity of Energy Supply Chains (June 18, 2024), https://www.energy.gov/articles/doe-leads-effort-improve-cybersecurity-energy-supply-chains

[8] Harry Krejsa, Sun Shield: How Clean Tech & America's Energy Expansion Can Stop Chinese Cyber Threats, Carnegie Mellon Inst. for Strategy & Tech. (Jan. 2025), https://www.cmu.edu/cmist/tech-and-policy/sun-shield/krejsa-jan2025.html

[9] Helena Fu, Director, Office of Critical & Emerging Technology, U.S. Dep't of Energy, Testimony Before the S. Comm. on Energy & Nat. Res. (Sept. 12, 2024), https://www.energy.gov/sites/default/files/2024-09/SENR%20Hearing%20HF%20AI%20Testimony_Final.pdf

[10] Robert Walton, China-linked hackers primed to attack US critical infrastructure, Utility Dive (Feb. 1, 2024), https://www.utilitydive.com/news/fbi-china-hackers-us-critical-infrastructure/706423/

infrastructure.[11] This collective approach is essential, given the global nature of supply chains and the transnational reach of cyber adversaries.

Private sector and academic organizations have contributed valuable insights and recommendations. Cybersecurity firms have published technical analyses of Volt Typhoon's operations, underscoring the importance of foundational cyber defense capabilities and rapid incident response.[12] Academic white papers, such as the "Sun Shield" report from Carnegie Mellon University,[13] argue that the ongoing clean energy transition presents both risks and opportunities for grid cybersecurity. While the adoption of digitally-native, software-defined technologies can improve resilience, heavy dependence on Chinese-manufactured components introduces new supply chain vulnerabilities.

Global Trends and Threat Evolution

The cyber threat landscape targeting critical infrastructure has shifted dramatically over the past decade. Chinese state-aligned actors have moved from broad-spectrum cyber espionage campaigns to targeted pre-positioning within critical national infrastructure (CNI), indicating a strategic pivot from intelligence collection to the preparation of sabotage capabilities. This evolution aligns with China's broader doctrine of integrated warfare, in which cyber operations are used to shape the battlespace long before conventional conflict arises. This "access now, exploit later" strategy marks a dangerous escalation in China's global cyber posture.

Globally, countries such as Australia, Japan, the United Kingdom, and several NATO members have issued public warnings regarding increasing Chinese cyber intrusions into their energy, telecommunications, and transportation networks. The European Union Agency for Cybersecurity (ENISA) and the U.K. National Cyber Security Centre (NCSC) have both identified the PRC as a significant source of cyberattacks on infrastructure, often masked as supply chain compromises or remote service exploits.[14]

China's Belt and Road Initiative (BRI), particularly its Digital Silk Road component, has facilitated the global proliferation of potentially compromised infrastructure. By offering subsidized deals and attractive financing, Chinese state-linked firms such as Huawei and ZTE

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[11] Cybersecurity and Infrastructure Security Agency, National Security Agency & Federal Bureau of Investigation, PRC State-Sponsored Actors Compromise and Maintain Persistent Access to U.S. Critical Infrastructure, CISA Alert AA24-038A (2024), https://www.cisa.gov/news-events/cybersecurity-advisories/aa24-038a

[12] Mandiant, Volt Typhoon Brief (Jan. 9, 2024), https://static.carahsoft.com/concrete/files/1417/1198/7095/Mandiant-Volt-Typhoon-Brief-Public.pdf

[13] Harry Krejsa, Sun Shield: How Clean Tech & America's Energy Expansion Can Stop Chinese Cyber Threats, Carnegie Mellon Inst. for Strategy & Tech. (Jan. 2025), https://www.cmu.edu/cmist/tech-and-policy/sun-shield/krejsa-jan2025.html

[14] Eur. Union Agency for Cybersecurity (ENISA), ENISA Threat Landscape 2023 (Oct. 19, 2023), https://www.enisa.europa.eu/publications/enisa-threat-landscape-2023

have exported telecommunications systems, SCADA platforms, and digital control equipment to countries across Africa, Southeast Asia, Latin America, and Eastern Europe. These deployments often include bundled managed services, cloud platforms, and firmware update mechanisms controlled by PRC-affiliated vendors, thereby creating avenues for persistent access under the guise of legitimate operations. This strategy has raised significant concerns among international security experts regarding espionage risks, data sovereignty, and the potential for embedded surveillance capabilities within critical infrastructure.[15]

In parallel, Chinese hacking groups have continued to harvest large volumes of personal and organizational data from commercial breaches. The 2015 U.S. Office of Personnel Management (OPM) breach, the 2023 Microsoft email server breach, and the 2024 Salt Typhoon attack on major telecom firms illustrate an enduring interest in exploiting identity infrastructure and personal metadata as auxiliary targets. These datasets, among others available through criminal channels, can be aggregated and mined, then correlated with infrastructure operator credentials or leveraged for social engineering operations, reinforcing the strategic value of long-term surveillance.

Finally, the advent of generative artificial intelligence has accelerated both the speed and scale of potential cyber operations. Chinese cyber actors are now believed to be using AI to automate reconnaissance, exploit development, and social engineering campaigns at unprecedented scale. In testimony to Congress, senior intelligence officials have emphasized the risk that AI-enhanced intrusions will undermine the ability of defenders to detect and respond in real time.[16]

The combination of these trends paints a clear picture: the Chinese government is refining a full-spectrum, globally scalable cyber capability with the express purpose of undermining adversaries' infrastructure before, during, or even in lieu of conventional hostilities. Western nations must adapt by treating these digital threats with the same urgency and strategic foresight as kinetic threats, recognizing that infrastructure pre-positioning is not theoretical, but operationally underway.

Espionage and Sabotage Susceptible Equipment

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[15] Council on Foreign Relations, Assessing China's Digital Silk Road Initiative, https://www.cfr.org/china-digital-silk-road/; 3GIMBALS, China's Telecommunications Infiltration: A Growing Security Risk in Latin America, https://3gimbals.com/insights/chinas-telecommunications-infiltration-a-growing-security-risk-in-latin-america/

[16] Emma Stewart, Chief Power Grid Scientist, Idaho Nat'l Lab., Written Testimony Before the U.S. House Select Committee on the CCP, 118th Cong. (2024), https://democrats-selectcommitteeontheccp.house.gov/sites/evo-subsites/democrats-selectcommitteeontheccp.house.gov/files/evo-media-document/opening-statement-emma-stewart-final.pdf

The electric grid and broader energy infrastructure contain a range of components that are susceptible to exploitation for intelligence-gathering purposes. These include smart meters, supervisory control and data acquisition (SCADA) systems, remote terminal units (RTUs), energy management systems (EMS), intelligent electronic devices (IEDs), and other digital sensors and controllers that communicate across operational networks.

While traditional grid components such as transformers may not seem digitally sophisticated, many are now equipped with embedded digital control systems and auxiliary devices that collect operational data and relay it back to asset owners or service providers. For instance, load tap changers (LTCs), dissolved gas analysis (DGA) sensors, and digital relays have become standard for monitoring and optimizing equipment performance. If these digital subcomponents are compromised or covertly transmitting data, they may provide adversaries with operational insights about grid configuration, load characteristics, asset health, and control patterns.[17]

The risk is exacerbated when these devices are sourced from foreign entities with known affiliations to adversarial governments. Data exfiltration could be disguised as routine telemetry or system health reporting. Once collected, such information could be used to develop highly tailored attack plans, map out grid topology, or identify targets for disruption in a crisis scenario. Espionage at this level enables adversaries to understand not just what infrastructure exists, but how and when it operates—turning infrastructure visibility into operational leverage.[18]

These risks are not theoretical. Intelligence officials have testified to Congress that Chinese state-sponsored groups such as Volt Typhoon and Salt Typhoon are known to exfiltrate operational information to support broader strategic objectives, including pre-positioning and targeting of critical infrastructure.[19] In 2024, according to both the Wall Street Journal and Google Cloud's Mandiant unit, Chinese cyber actors gained access to SCADA networks across multiple sectors, including energy, using vulnerabilities in edge devices and misconfigured remote access tools.[20]

In addition to the risk of espionage, Chinese-manufactured components present credible risks of remote sabotage—particularly during periods of geopolitical crisis. The types of equipment most vulnerable to sabotage include devices with embedded software, remote access capabilities, firmware updaters, or connectivity to cloud management portals. This category spans from

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[17] Federal Energy Regulatory Commission (FERC), *Cybersecurity of Electric Transmission Control Devices*, 2022, https://www.ferc.gov.

[18] Stewart, Emma, *Written Testimony Before the U.S. House Select Committee on the CCP*, March 5, 2025, https://democrats-selectcommitteeontheccp.house.gov/sites/evo-subsites/democrats-selectcommitteeontheccp.house.gov/files/evo-media-document/opening-statement-emma-stewart-final.pdf

[19] Ibid

[20] Volz, Dustin and Strohm, Chris. "In Secret Meeting, China Acknowledged Role in U.S. Infrastructure Hacks," *Wall Street Journal*, March 8, 2025, https://www.wsj.com/politics/national-security/in-secret-meeting-china-acknowledged-role-in-u-s-infrastructure-hacks-c5ab37cb; Gallagher, Sean. "China Acknowledges US Infrastructure Hacks in Leaked Cybersecurity Report," *WIRED*, March 8, 2025, https://www.wired.com/story/china-admits-hacking-us-infrastructure/

digital protective relays and programmable logic controllers (PLCs) to industrial firewalls, communications gateways, and battery energy storage systems (BESS).

Transformers, while traditionally seen as passive equipment, often include auxiliary systems that may have digital interfaces—especially load tap changers (LTCs), which regulate voltage output. Modern LTCs include motor drive units, relay logic, and control boards, which in some cases are network-connected or remotely configurable. A solution here could be only using manual control for critical transformers or engineering out the use of vulnerable components.

Battery energy storage systems are another concern. A 2022 study sponsored by the Department of Energy's Office of Cybersecurity, Energy Security, and Emergency Response (CESER) found that over 90% of grid-scale BESS deployed in the U.S. contain critical components manufactured in China, including battery management systems (BMS), power conversion systems (PCS), and supervisory interfaces. These components are capable of firmware updates and telemetry reporting. If malicious firmware is pre-installed or remotely deployed, it could cause sudden outages, physical damage to energy assets, or even thermal runaway events in batteries.[21]

Sabotage risks are not limited to generation and storage. Substation automation systems, industrial routers, and remote terminal units—particularly those sourced from high-risk suppliers—can serve as pivot points to manipulate field devices or issue unauthorized control commands. Remote sabotage may not require sophisticated malware: it may simply involve leveraging a preconfigured access path, hard-coded credentials, or a dormant exploit awaiting activation.

U.S. officials and cybersecurity researchers have warned that Volt Typhoon and other Chinese groups have specifically sought to identify these "choke point" devices—small, often-overlooked components that can yield outsized control over grid operations. Once access is gained, even limited disruption can ripple across transmission networks, impair restoration efforts, or delay military deployments in a crisis.[22]

Reducing our dependence on foreign-manufactured grid components requires not only reshoring production capacity but also securing the upstream materials essential for that production Critical minerals are the foundational inputs for semiconductors and control boards—the essential components required to domestically manufacture transformers, inverters, battery management systems, and other core elements of grid infrastructure. Without secure and diversified access to

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[21] Emma Stewart, Written Testimony Before the H. Select Comm. on the CCP, 118th Cong. (Mar. 5, 2025), https://democrats-selectcommitteeontheccp.house.gov/sites/evo-subsites/democrats-selectcommitteeontheccp.house.gov/files/evo-media-document/opening-statement-emma-stewart-final.pdf

[22] Robert Joyce, Testimony Before the H. Select Comm. on the CCP, 118th Cong. (Mar. 5, 2025), https://www.congress.gov/event/118th-congress/house-event/116479

these minerals, any effort to reshore the manufacturing of energy technologies will face severe constraints.

Mitigation of these risks requires an urgent shift from component-level testing to system-level risk modeling, with particular emphasis on country-of-origin sourcing, software assurance, and remote access pathways. Until the supply chain is more trusted and transparent, resilience must rely on active monitoring, strict segmentation, firmware verification, and the ability to operate in degraded modes without reliance on remote services.

U.S. Reliance on Chinese Energy Equipment

The United States' reliance on Chinese-manufactured energy equipment—particularly within critical infrastructure—presents a long-term strategic vulnerability. This dependency spans multiple layers of the electric power system, including grid components such as transformers, inverters, protective relays, industrial control devices, and energy storage systems. In many cases, these components are either wholly manufactured in the People's Republic of China (PRC), assembled from PRC-made subcomponents, or integrated with firmware and software developed by PRC-affiliated firms.

A significant concern lies with high-voltage power transformers (HVPTs), which form the backbone of bulk power transmission. Roughly 10–15% of HVPTs operating in the U.S. today are imported directly from China, including units deployed at critical substations and interconnects between regional grids.[23] Given the limited domestic manufacturing capacity for HVPTs and the long lead times associated with their replacement, any compromise of these assets—whether via embedded digital components or sabotage during manufacture—could have widespread consequences.

Another area for consideration is the widespread adoption of distributed energy resources (DERs), such as solar photovoltaics and associated inverters, which are frequently sourced from Chinese manufacturers. Inverter-based resources introduce bidirectional power flows and dynamic grid interactions. Many Chinese inverters include remote management capabilities, cloud-connected diagnostics, and over-the-air firmware updates—all potential vectors for exploitation or disruption if these systems are compromised.[24]

As the grid modernizes, energy management systems, smart meters, and advanced metering infrastructure (AMI) are also increasingly sourced from Chinese vendors. These systems collect

[23] U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, Large Power Transformers and the U.S. Electric Grid (Apr. 2014), https://www.energy.gov/sites/prod/files/2014/04/f15/LPTStudyUpdate-040914.pdf

[24] Megan J. Culler et al., BESSIE: Battery & Energy Storage Supply Chain Analysis, Mitigation Deployment, and Tools, INL/MIS-24-82394-Revision-0, Idaho Nat'l Lab. (Dec. 2024), https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_65687.pdf

granular usage data, interface with control networks, and serve as gateways for utility-customer interactions. The presence of foreign-developed software in these tools, particularly if updated or serviced remotely, may enable long-term data harvesting or command injection.

Further, Chinese dominance in the battery energy storage market—estimated at over 70% of global supply—has led to large-scale deployment of PRC-made control systems in energy storage units nationwide.[25] These devices, now essential for peak shaving, black start operations, and renewable integration, represent both a cybersecurity and resilience risk if not properly isolated, monitored, and tested.

Continued reliance on untrusted foreign equipment creates opportunities for embedded threats, difficult-to-detect supply chain tampering, and coercive leverage during geopolitical crises. Reducing this risk requires a national strategy that includes repatriating key manufacturing capabilities, diversifying trusted suppliers, and ensuring full software and firmware transparency for all energy infrastructure components.

Risks in Third-Country Infrastructure

The cybersecurity risks posed by Chinese involvement in the infrastructure of third-party nations represent a significant and growing threat to U.S. national security and global energy stability. Through investment, technology transfer, and strategic partnerships, the People's Republic of China (PRC) has become a dominant force in the global buildout of energy and telecommunications infrastructure across Africa, Southeast Asia, Latin America, and parts of Eastern Europe. This international footprint allows China not only to extend its economic and diplomatic influence, but also to embed technologies that may carry security vulnerabilities or enable future remote access.

Much of this expansion occurs under the umbrella of the Belt and Road Initiative (BRI), which includes significant energy-sector investments such as power generation, substation automation, high-voltage transmission systems, and grid control platforms. Chinese state-owned enterprises (SOEs), such as State Grid Corporation of China and China Southern Power Grid, often lead these projects, deploying equipment and supervisory control and data acquisition (SCADA) systems that are developed domestically. The embedded software in these systems frequently lacks third-party vetting, relies on proprietary protocols, and is subject to PRC cybersecurity laws requiring cooperation with Chinese intelligence services.[26]

[25] Global Top 10 Power and ESS Battery Shipments Announced, Six Chinese Companies Hold Nearly 70% Market Share, Metal.com (Mar. 19, 2025), https://news.metal.com/newscontent/103195500/Global-Top-10-Power-and-ESS-Battery-Shipments-Announced-Six-Chinese-Companies-Hold-Nearly-70-Market-Share
[26] Michael R. Pompeo, Sec'y of State, Comm'n on Unalienable Rts., Safeguarding Our Freedom in the Digital Age (July 2020), https://it.usembassy.gov/secretary-pompeo-speech-at-the-national-constitution-center-july-16-2020/

This pattern creates two primary concerns. First, countries adopting PRC-supplied energy systems may unknowingly introduce persistent surveillance or remote-access risks. Second, these platforms can serve as launch points for lateral attacks or intelligence collection on U.S. allies and partners. For example, a compromised SCADA system in a foreign substation may offer visibility into regional grid flows, load patterns, or interconnection statuses that are relevant to U.S. diplomatic, military, or commercial activities in the area.

Recent cybersecurity advisories have highlighted that Chinese state-sponsored actors such as Volt Typhoon. These campaigns have been linked to anomalies in network traffic and operational disruptions, raising concerns about potential backdoor access facilitated through foreign infrastructure projects.[27] The United States and allied intelligence services have also expressed concern over Huawei's role in the deployment of smart grid communications infrastructure in strategic regions, particularly where those deployments coincide with military installations or sensitive resource corridors.

Beyond surveillance and cyber exploitation, Chinese investments in energy infrastructure also pose risks of operational coercion. The PRC has, in prior geopolitical disputes, restricted exports of rare earth materials or critical components. A similar leverage model could be applied to maintenance contracts, software updates, or spare parts necessary for grid reliability in third-country systems.

Risk Mitigation When Alternatives Are Limited

In certain segments of the energy sector, avoiding the use of Chinese-made components may be infeasible in the short term. Mitigation strategies must therefore account for existing dependencies while pursuing longer-term goals of supply chain diversification and domestic manufacturing capacity expansion.

1. A layered defense approach begins with rigorous supply chain risk assessments. Utilities and energy developers should identify all Chinese-origin components within their critical systems and evaluate their network exposure, remote access potential, and firmware update paths. Components with remote connectivity should be segmented on isolated networks, with strict firewall rules and no outbound internet access unless absolutely necessary.[28]
2. When foreign-manufactured components cannot be removed immediately, entities should implement cyber-informed engineering (CIE) practices. This proven approach, advocated by Idaho National Laboratory and the Department of Energy, focuses on designing grid systems

[27] U.S. Cybersecurity & Infrastructure Sec. Agency, PRC State-Sponsored Actors Compromise and Maintain Persistent Access to U.S. Critical Infrastructure (Feb. 7, 2024), https://www.cisa.gov/news-events/cybersecurity-advisories/aa24-038a
[28] Nat'l Inst. of Standards & Tech., NIST Special Publication 800-82 Rev. 3, Guide Operational Technology (OT) Security (Sep 2023), https://doi.org/10.6028/NIST.SP.800-82r3

that limit the potential impact of cyber-initiated failures by incorporating fail-safes, manual overrides, and operational redundancies.[29]

3. Utilities should mandate firmware integrity checks and behavior baselining for field-deployed equipment. Any deviations from expected device behavior—such as unusual data transmissions, time drift, or reboots—should trigger alerts and forensic review. Modern network monitoring platforms that include asset fingerprinting, passive traffic inspection, and anomaly detection can help detect compromised devices operating within normal parameters.
4. Utilities and regulators should demand full transparency from suppliers regarding the origin and development of software and firmware. Where full software bill of materials (SBOM) disclosure is not available, utilities should treat such equipment as untrusted and isolate accordingly.
5. National programs should fund the development and deployment of Trusted Energy Infrastructure Zones (TEIZs)—pilot projects or demonstration areas where only hardware and software from vetted domestic or allied suppliers are allowed. These zones can serve as proving grounds for high-trust architectures and highlight the operational benefits of secure-by-design principles.
6. Several partner nations—such as India, Australia, and several EU member states—have begun excluding PRC vendors from critical infrastructure procurements. The United States has a strategic interest in supporting these decisions through technical assistance, capacity building, and the promotion of secure-by-design alternatives. Moreover, ensuring that regional partners adopt strong supply chain risk management practices—including source-code review, firmware validation, and contract enforcement mechanisms—can further reduce systemic exposure.
7. Where full replacement is not possible due to cost or availability constraints, the government should support compensating controls, such as hardened perimeter defenses, restricted control logic, physical separation, and tamper detection. These measures do not eliminate risk but can reduce the likelihood and impact of exploitation.

While perfect security is unattainable, meaningful reduction of systemic risk is achievable. Doing so requires a holistic strategy that combines technical safeguards, rigorous oversight, and policy coordination—especially where Chinese technologies remain embedded in the energy supply chain.

Policy Recommendations

To counter the growing risks posed by reliance on Chinese-manufactured equipment and state-sponsored cyber operations, the United States must adopt a comprehensive and sustained policy

[29] Emma Stewart et al., Applying Cyber-Informed Engineering to Grid Modernization, INL/EXT-21-63527, Idaho Nat'l Lab. (Aug. 2021), https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_147023.pdf

response. This response must span procurement, regulation, public-private coordination, and international engagement. Below are several recommended policy actions, rooted in both current threat intelligence and infrastructure realities:

1. **Reduce Exposure to High-Risk Components and Mandate Cyber-Informed Engineering.**
   Acknowledging that full-scale "rip and replace" is infeasible in the near term, the U.S. should focus on isolating, segmenting, and monitoring Chinese-manufactured components most susceptible to compromise. In parallel, Congress should mandate the application of Cyber-Informed Engineering (CIE), at a minimum for systems integrating foreign-sourced digital components. CIE ensures operational safety and mission continuity even if digital compromise occurs. While more resource-intensive, CIE offers a realistic path to resilience and should be funded accordingly.[30]
2. **Modernize Regulatory Frameworks for a Changing Grid.**
   We must continue to expand and modernize our regulatory frameworks. The NERC CIP standards provide a baseline for bulk power system reliability and cybersecurity, but they only apply to larger generation and transmission assets. As our grid evolves, new classes of risk are emerging in distributed energy aggregators, edge-connected devices, and vendor-controlled assets outside the traditional compliance footprint. Some voluntary standards are gaining ground, but currently, there is no top-level governance mechanism to bring many of these technologies under a unified security model. Addressing these gaps may require new regulatory or similar compliance frameworks for the creation of modern, fit-for-purpose standards that reflect the complexities and interdependencies of today's electric grid.
3. **Require Transparency in Firmware and Software Codebases.**
   Vendors supplying digital equipment to the bulk electric system or major distribution systems should be required to provide attestation of secure development practices, code origin audits, and third-party software composition analysis. Standards developed by NIST's Secure Software Development Framework (SSDF) and DOE's Cyber-Informed Engineering principles offer a strong foundation for these requirements.[31]
4. **Incentivize Domestic and Allied Manufacturing.**
   To reduce long-term dependence, Congress should expand tax incentives, loan guarantees, and public-private partnerships for domestic manufacturing of grid components. Coordinated industrial base strategies—such as those outlined in the CHIPS and Science Act—should be extended to transformer cores, HV relays, grid-scale inverters, and battery control systems.[32]

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[30] Emma Stewart, Chief Power Grid Scientist, Idaho Nat'l Lab., Written Testimony Before the U.S. House Select Committee on the CCP, 118th Cong. (2024), https://democrats-selectcommitteeontheccp.house.gov/sites/evo-subsites/democrats-selectcommitteeontheccp.house.gov/files/evo-media-document/opening-statement-emma-stewart-final.pdf
[31] Nat'l Inst. of Standards & Tech., Secure Software Development Framework (SSDF) Version 1.1 (Feb. 2022), https://csrc.nist.gov/pubs/sp/800/218/final
[32] CHIPS and Science Act of 2022, Pub. L. No. 117-167, 136 Stat. 1392

5. **Enhance International Engagement and Standards Harmonization.**
   The U.S. should lead international efforts to develop aligned cybersecurity standards for energy equipment. Through organizations such as the International Electrotechnical Commission (IEC) and the International Energy Agency (IEA), the U.S. can push for common security requirements that reduce PRC influence in developing economies and Belt and Road recipient nations.
6. **Fund Targeted Testing and Reverse Engineering of Suspect Devices.**
   The Department of Energy, in coordination with National Laboratories, should assess the feasibility of developing and deploying trusted, open-source firmware for commonly used Chinese-manufactured energy equipment. In cases where hardware permits firmware replacement, this approach could mitigate embedded software risks while preserving utility investments in physical infrastructure. The National Labs could also lead firmware reverse engineering, behavioral baselining, and secure re-implementation, coupled with firmware provenance monitoring and code audits. Findings should inform regulatory action, public alerts, and real-time risk mitigation strategies.
7. **Prepare Consequence-Based Contingency Planning.**
   Recognizing that some legacy equipment will remain in place, DOE, FERC, and NERC should develop operational contingencies and tabletop exercises simulating hostile exploitation of embedded Chinese devices. These exercises must test not only system restoration but also interagency coordination and attribution procedures.

The PRC has demonstrated its willingness and capability to integrate coercive cyber tools into the energy domain. The response from the U.S. government must be equally strategic and preemptive—matching the technical sophistication of the threat with institutional resolve and regulatory foresight.

Summary

The security of the United States' energy infrastructure is not merely a technical concern—it is a foundational pillar of national strategy, economic competitiveness, and global leadership. In an era defined by great power competition, the electric grid has emerged as a strategic asset whose security underwrites every other critical capability, including military readiness, artificial intelligence advancement, and quantum computing development. These emerging domains will require unprecedented energy availability, reliability, and resilience—none of which can be assured while adversarial access to grid infrastructure remains unchecked and unmitigated.

Chinese state-aligned cyber actors have evolved from opportunistic information theft and espionage to persistent pre-positioning within U.S. energy systems and other critical infrastructures. Their ability to exploit vulnerabilities in control systems, firmware, and supply chain dependencies enables both intelligence collection and disruptive potential in future conflicts. This testimony has documented the extent to which such risks are no longer hypothetical. From Volt Typhoon's infiltration of power and water systems to the global dissemination of PRC-controlled technologies via the Belt and Road Initiative, China's strategic intent to compromise energy infrastructure has become unmistakable.

Concurrently, the United States is at a strategic inflection point. The renewed emphasis on energy dominance—a cornerstone of recent national policy—recognizes that energy independence alone is insufficient if the technologies underpinning the grid are compromised by foreign control. Securing the grid against Chinese influence is now a prerequisite for sustaining leadership in AI, quantum science, and advanced manufacturing, all of which depend on secure, high-capacity power delivery. A compromised grid is a constrained future.

At present, the U.S. lacks a unified, actionable strategy to detect, isolate, and mitigate these embedded risks. Regulatory frameworks like the NERC CIP standards have laid a foundation, but they require enhancement, modernization, and continued enforcement to match the evolving threat landscape. Policy solutions must embrace both the near-term need for Cyber-Informed Engineering and the long-term necessity of reshoring manufacturing, auditing firmware integrity, and harmonizing international standards.

And finally, how do we fund the kinds of improvements discussed in this testimony? The reality is, the mechanisms for financing grid security investments are complex and uneven. The electric grid is subject to a variety of regulators, oversight models, and cost recovery rules. It's a difficult and important conversation—and one that needs to happen if we want real, sustainable progress.

To delay action is to cede advantage. The United States must marshal a coordinated national response—combining legislative clarity, regulatory reach, industrial mobilization, and international alignment—to secure its energy infrastructure against adversarial compromise. Only then can the U.S. claim true energy dominance: not just in supply, but in sovereign control over the technologies that sustain the nation's most critical functions.

OPENING STATEMENT OF BRIAN MENELL, CHAIRMAN AND CEO, TECHMET

COMMISSIONER BRANDS: Mr. Menell.

MR. MENELL: Commissioner Goodwin, Commissioner Brands, Chair Price, and members of the Commission, thank you for your invitation to testify here today. I'll keep my remarks brief to allow as much time as possible for Q&A, and we have submitted testimony which elaborates on some of my points.

As the world electrifies and automates, demand for the critical minerals required for these core technologies is growing at an unprecedented scale. China has established an imposing presence in the mining, refining, and processing of many of these minerals, and now holds significant control over their supply chains. This dominance, in the context of broader geopolitical tensions, could pose a major risk to the economic and national security of the United States and the world.

TechMet is a critical minerals investment company that I founded in 2017. We've built projects that produce, process, and recycle the critical minerals needed to secure competitive, China-free supply chains to feed American industry and national defense. TechMet is unique in that we are partially owned by the U.S. government through a series of equity investments by the International Development Finance Corporation, the first of which was in 2020, and the two follow-ons in '22 and '23.

The definition of a critical mineral has two components. The first is that the mineral is deemed essential in the manufacturing of a product or application without which there would be serious implications for the economic or national security of the U.S. For example, lithium, nickel, cobalt, and manganese are the main components of lithium-ion batteries which power handheld devices, electric vehicles, robotics, and energy systems. Rare earth elements, as we know, are crucial in permanent magnets, electric motors, and defense equipment.

The second criterion of a critical mineral is that its supply chain is highly vulnerable to disruption, including through foreign political risk. Of the 50 minerals included in the 2022 Final List of Critical Minerals, the U.S. relied on imports in 2024 to meet 100 percent of its apparent consumption for 12 of these minerals, and had over 50 percent import reliance for another 28. China was the largest producer of at least 30 of the minerals on the list.

China has spent over two decades strategically positioning itself as the leading player in critical minerals. Upstream mining projects, often owned by Chinese entities outside of the country, feed domestic processing facilities to refine the products used in local economy, and local industry and globally.

From 2000 to 2021, China deployed $57 billion in aid and subsidized credit for critical minerals projects, and beyond this over $100 billion in related infrastructure debt facilities to countries to secure this dominant position over the minerals that they have built control globally over.

One example is the rapid buildout of nickel processing capacity in Indonesia over the past decade, fueled by Chinese investment. Recent analysis suggests that over 75 percent of Indonesia's nickel refining capacity and mining capacity is now controlled by Chinese stakeholders.

There are strong indications that China is consolidating its hold over critical minerals and is prepared to use its position as geopolitical leverage amid escalating trade tensions. They are placing increasingly stringent controls on the export of critical minerals, components, and technologies, citing national security concerns as the reason for doing so. In addition, China continues to deploy capital and cement its dominance, taking advantage of continuing divestment by Western companies.

Looking ahead, current low spot prices of many critical minerals are threatening the ability to meet future demand projections. The U.S. faces many challenges in trying to balance China's control of critical mineral supply chains. Ultimately it boils down to time and money. Critical minerals projects can take over a decade to develop, are capital intensive, and highly technical. In the U.S., private investors are often risk averse or seek more immediate returns on their capital than critical mineral projects offer. This has created a financing gap for Western-aligned projects and made it more difficult to compete with Chinese projects that have access to sources of cheap, long-term funding.

The U.S. will need to work with industry to identify and address the barriers to building new production and processing capacity. Access to financing, vulnerability to price manipulation, slow public sector support, speed of permitting, and other regulatory hurdles are just some of the key challenges facing U.S. projects.

To diversify supply chains away from Chinese control and build capacity both in the U.S. and across allied nations, the government needs to move much more quickly and invest much more. The U.S. already has many of the tools required to address these issues, both at home and abroad, but they need to be well-resourced, deconflicted, and reformed to address the unique challenges of the critical minerals sector.

Reauthorizing the DFC, our shareholders, for a longer period, correcting how equity investments are scored, increasing their investment cap, and expanding the countries in which they can operate would allow us to have a much greater impact. Similarly, reauthorization of U.S. EXIM for a longer period, lifting the current 2 percent default cap, addressing statutory restrictions, and adding technical capacity could unleash significant support for the critical minerals sector.

The Department of Defense has several initiatives and offices that could be utilized to direct funding and purchasing towards areas that would secure American critical mineral supplies and expand production and processing capacity. Likewise, the Department of Commerce, Energy, Interior, State, and Treasury also have programs that could be optimized to secure portions of the supply chain and crowd in more private sector investment.

China's dominant position in critical minerals is the result of a dedicated, unwavering strategy implemented over many years, almost 20 years. Substantial capital deployment in overseas mining projects, combined with consolidation of a hugely competitive domestic refining and manufacturing base has given China formidable control of global supply chains which countries around the world are now reliant on, and are very overexposed to.

Increasing signs that this position could be used as geopolitical leverage mean that the need to diversify away from China is stronger than ever. This is possible, despite the scale of the challenge, but it will require the U.S. to fine tune and optimize the tools at its disposal to efficiently build out Western-aligned supply chains. Without urgent action, the U.S. could face severe disruption to its economic stability and national security.

Thank you.

COMMISSIONER BRANDS: Thank you. Mr. Combs.

PREPARED STATEMENT OF BRIAN MENELL, CHAIRMAN AND CEO, TECHMET

TESTIMONY BEFORE THE U.S.-CHINA ECONOMIC

AND SECURITY REVIEW COMMISSION

HEARING ON: China's Domestic Energy Challenges and Its Growing Influence over International Energy Markets

PANEL II: The Risk of Chinese Components and Critical Minerals

in Global Energy Infrastructure

How the U.S. can counter China's dominance of critical mineral supply chains

Brian Menell

Chairman & Chief Executive Officer of TechMet

April 24, 2025

I. Introduction

Commissioner Goodwin, Commissioner Brands, and members of the Commission, thank you for your invitation to testify here today. As the world electrifies and automates, demand for the critical minerals required for these core technologies is growing on an unprecedented scale. China has established an imposing presence in the mining, refining and processing of many of these minerals, and now holds significant control over their supply chains. This dominance, in the context of broader geopolitical tensions, could pose a major risk to the economic and national security of the United States and the world. In this testimony I will address how China built up its position as the leader in the critical minerals space, and the challenges and opportunities that the U.S. faces in reducing its supply chain vulnerability.

TechMet is a critical minerals investment company founded in 2017. We build projects that produce, process, and recycle the critical minerals needed to secure competitive, China-free supply chains to feed American industry and national defense. Our portfolio currently includes ten companies across four continents, including four in the United States. We focus on seven critical minerals – lithium, nickel, cobalt, tin, tungsten, vanadium, and rare earth elements.

TechMet is unique in that we are partially owned by the U.S. Government through a series of equity investments by the International Development Finance Corporation (DFC), the first of which was in 2020. The investments by the DFC have been transformational for TechMet, as they have allowed us to invest in more projects, accelerate their development, and attract additional private sector investment and partnerships. It has also meant that U.S. taxpayers are able to benefit from the success of our projects. In addition to our partnership with the DFC, we are engaging in other funding processes with various agencies, both at the TechMet and project levels.

While U.S. efforts to combat Chinese dominance in this area have progressed significantly in recent years, there remains much more to be done.

II. An overview of current critical minerals supply chains

The *Energy Act of 2020*'s definition of a critical mineral has two key criteria[1].

The first is that the mineral is deemed essential in the manufacturing of a product or application, without which there would be serious implications for the economic or national security of the U.S.

Today, many critical minerals are the integral ingredients for burgeoning electrification and energy storage technologies. Lithium, nickel, cobalt and manganese are the main components of lithium-ion batteries which power handheld devices, electric vehicles (EVs), robotics and energy storage systems that provide stabilisation for renewable energy. Rare earth elements are crucial in permanent magnet electric motors in wind turbines and defense equipment. Tin is the solder in circuit boards, underpinning all electronics. All of these applications are at the very centre of an industrial shift in the U.S., fuelling future economic growth and maintaining national security.

As adoption of these technologies accelerates, so too will the demand for these critical minerals. Global lithium demand is forecast to reach nearly 3.8 million tonnes of lithium carbonate equivalent (LCE) in 2034, up from 1.1 million tonnes LCE last year[2], and approximately 10x demand in 2020[3]. Demand growth rates in the U.S. alone are projected to be similarly strong over the next five years[4], as EV penetration – which currently lags other key markets such as China and Europe – ramps up.

The second component of the definition of a critical mineral is that its supply chain is highly vulnerable to disruption, including through foreign political risk.

Of the 50 minerals included in the *2022 Final List of Critical Minerals*[5], the U.S. relied on imports in 2024 to meet 100% of its apparent consumption for 12 of these minerals and had over 50% import reliance for another 28. China was the largest producer of at least 30 of the minerals on the list[6].

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[1] *116th Congress.* "Consolidated Appropriations Act 2021". Pub. L. No. 116-260, 134 Stat. 2564 (2020). https://www.congress.gov/bill/116th-congress/house-bill/133/text

[2] *Benchmark Mineral Intelligence.* "Battery minerals deficits continue to be expected within a decade" (7 January 2025). https://source.benchmarkminerals.com/article/battery-cathode-material-deficits-continue-to-be-expected-by-the-end-of-decade

[3] *U.S. Geological Survey.* "2021 Minerals Yearbook: Lithium" (January 2025). https://pubs.usgs.gov/myb/vol1/2021/myb1-2021-lithium.pdf

[4] *Fastmarkets*. "US lithium demand predicted to grow nearly 500% by 2030; Fastmarkets steps in to provide regional price transparency" (3 April 2024). https://www.fastmarkets.com/insights/us-lithium-demand-to-grow-fastmarkets-provide-regional-price-transparency/

[5] *U.S. Geological Survey.* "2022 Final List of Critical Minerals" (February 2022). https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/2022%20Final%20List%20of%20Critical%20Minerals%20Federal%20Register%20Notice_2222022-F.pdf

[6] *U.S. Geological Survey.* "Mineral commodity summaries 2025" (March 2025). https://pubs.usgs.gov/periodicals/mcs2025/mcs2025.pdf

Chinese dominance over the production of many of these critical minerals stretches across their supply chains. The control also extends downstream into the end-use products – China produces 80% of the world's lithium-ion batteries[7].

There are embedded risks to dependence on raw materials from overseas. Extreme geopolitical fragmentation could cut off sources of critical minerals and leave domestic industries desperately short of feedstock. Even without tensions, compounding demand growth could lead to scarcity, prompting countries to prioritise their own manufacturing bases at the expense of exports. Either way, this would lead to severe consequences for economic and national security.

III. How China tightened its grip on critical minerals

China has spent over two decades strategically positioning itself as the leading player in critical minerals. Upstream mining projects, often owned by Chinese entities outside of the country, feed domestic processing facilities to refine the products used in local industry.

China hosts substantial resources of many critical minerals in country and is highly protective over their exploitation and processing. Foreign investment in the exploration, mining and beneficiation of rare earths and tungsten is prohibited[8].

Their playbook has been to invest huge amounts of capital in securing resources and developing projects outside of China. From 2000 to 2021, China deployed nearly $57 billion in aid and subsidized credit for "transition" (i.e., critical) mineral projects in 19 low- and middle-income countries participating in the Belt and Road Initiative[9].

This scale of investment is perhaps most evident in the Democratic Republic of Congo (DRC), which is responsible for three-quarters of global mined cobalt supply[10]. In 2020, it was reported that 15 of the 19 mines producing cobalt in the DRC were owned or financed by Chinese companies[11]. Chinese firms last year commenced a $7 billion infrastructure project as part of

[7] *Benchmark Mineral Intelligence (LinkedIn)*. "China and the rise of lithium-ion battery dominance" (24 March 2024).
https://www.linkedin.com/posts/benchmark-mineral-intelligence_lithiumion-energytransition-activity-7309914573942194177-SP1a/

[8] *CW CPA*. "China Promulgated the Negative List 2024 for Foreign Investment Access at National Level" (2 November 2024).
https://www.cwhkcpa.com/china-promulgated-the-negative-list-2024-for-foreign-investment-access-at-national-level/

[9] *Escobar, B., Malik, A. A., Zhang, S., Walsh, K., Joosse, A., Parks, B. C., Zimmerman, J., & R. Fedorochko.* "Power Playbook: Beijing's Bid to Secure Overseas Transition Minerals". Williamsburg, VA: AidData at William & Mary (January 2025).
https://docs.aiddata.org/reports/china-transition-minerals-2025/FULL_REPORT_Power_Playbook.pdf

[10] *Cobalt Institute*. "Quarterly Cobalt Market Update Overview 2024 Q4" (27 January 2025).
https://www.cobaltinstitute.org/wp-content/uploads/2025/01/Cobalt-Institute_Q4-2024-cobalt-market-report.pdf

[11] *The New York Times*. "A Power Struggle Over Cobalt Rattles the Clean Energy Revolution" (20 November 2021).
https://www.nytimes.com/2021/11/20/world/china-congo-cobalt.html

a long-disputed and revised deal surrounding the operation of the Sicomines copper and cobalt joint venture project in the country[12].

The rise of China's control over cobalt mining in the DRC included the high-profile acquisition of the Tenke Fungurume operation in 2016 and the Kisanfu project in 2020 from major U.S. miner Freeport-McMoRan[13,14]. These deals are symptomatic of China's approach to securing access to critical minerals, with Western players often ceding control for shorter-term strategic or financial reasons.

The result is that China holds a commanding share of the DRC's cobalt supply. By 2030, it is estimated that China will control over 53% of DRC cobalt production, and 46% of global supply[15]. Most of this supply, in the form of cobalt hydroxide, is shipped to China for processing into higher-value cobalt metal or chemicals.

A similar example of China's influence in critical mineral supply chains is the rapid buildout of nickel processing capacity in Indonesia over the past decade, fuelled by Chinese investment. Recent analysis suggests that over 75% of Indonesia's nickel refining capacity is controlled by Chinese stakeholders, many of whom have ties to the CCP[16]. There are serious ESG concerns associated with Indonesian nickel production, including forced labour[17] and deforestation[18].

TechMet is the majority shareholder of Brazilian Nickel, which is developing a nickel mine in Piauí state and is committed to production with high ESG credentials. The DFC has issued a Letter of Interest to Brazilian Nickel for a $550m loan towards the construction of the project[19].

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[12] *Argus Media*. "China starts $7bn road-building project in DRC" (1 August 2024).
https://www.argusmedia.com/en/news-and-insights/latest-market-news/2593779-china-starts-7bn-road-building-project-in-drc

[13] *Freeport-McMoRan.* "Freeport-McMoRan Completes Sale of Interest in TF Holdings Limited for $2.65 Billion in Cash" (16 November 2016).
https://investors.fcx.com/investors/news-releases/news-release-details/2016/Freeport-McMoRan-Completes-Sale-of-Interest-in-TF-Holdings-Limited-for-265-Billion-in-Cash/default.aspx

[14] *CMOC.* "CMOC Announces Acquisition of Kisanfu Copper-cobalt Deposit in DRC" (13 December 2020).
https://en.cmoc.com/html/2020/News_1213/39.html

[15] *Benchmark Mineral Intelligence.* "How much cobalt production is owned by Chinese companies?" (17 October 2024).
https://source.benchmarkminerals.com/article/how-much-cobalt-production-is-owned-by-chinese-companies

[16] *Center for Advanced Defense Studies,* "Refining Power" (4 February 2025).
https://c4ads.org/commentary/refining-power/

[17] *U.S. Department of Labor*. "List of Goods Produced by Child Labor or Forced Labor" (September 2024).
https://www.dol.gov/agencies/ilab/reports/child-labor/list-of-goods

[18] *Financial Times.* "Nickel miners linked to devastation of Indonesian forests" (8 October 2023).
https://www.ft.com/content/cd1fd7f3-b3ea-4603-8024-db75ec6e1843

[19] *Brazilian Nickel.* "U.S. International Development Finance Corporation Issues Letter of Interest to Brazilian Nickel for up to US$550 Million Loan as Part of Overall Financing Package for Piauí Nickel Project" (9 December 2024).
https://www.braziliannickel.com/u-s-international-development-finance-corporation-issues-letter-of-interest-to-brazilian-nickel-for-up-to-us550-million-loan-as-part-of-overall-financing-package-for-piaui-nickel-project/

IV. Current trends suggest China shows no signs of abating

There are strong indications that China is consolidating its hold over critical minerals and is prepared to use its position as geopolitical leverage amid escalating trade tensions. The implementation of export restrictions poses a significant risk of near-term scarcity, while rapid supply growth from Chinese-subsidised operations is suppressing prices and stifling the development of projects which are needed to meet longer-term demand.

China is placing increasingly stringent controls on the export of critical minerals, components and technologies, citing national security concerns as the reason for doing so. In December 2024, an immediate ban on exports of antimony, gallium and germanium to the U.S. was enforced in retaliation to restrictions on sales of advanced technology from the U.S. to China[20]. Gallium and germanium are essential components of semiconductors. This year, China has levied export controls on various critical minerals, including most recently on several rare earth elements as a countermeasure to U.S. tariffs[21].

Similar export controls on processing technologies threaten the ability of projects outside of China to extract and refine critical minerals. It was reported in February that a Chinese manufacturer of sorbents – a key component of direct lithium extraction (DLE) technology – has stopped exports of the material after restrictions on exports of technological processes were proposed[22]. This conveys the importance of developing supply chains which are not reliant on foreign control and susceptible to disruption. TechMet is the largest shareholder of EnergySource Minerals (ESM), whose subsidiary ILiAD Technologies has developed its own DLE technology with a resilient supply chain unbeholden to China. ESM is looking to deploy the technology at a geothermal lithium project on the Salton Sea in California.

The risks associated with concentrated supply chains are clearly greater than ever, leaving those exposed scrambling for new sources of their components. Skydio, a leading U.S. drone manufacturer, rushed to find alternative battery suppliers late last year after China placed sanctions on the company[23].

Despite its already commanding lead, China continues to deploy capital and cement its dominance, taking advantage of continued divestment by Western companies. Recent transactions include Appian's sale of Mineração Vale Verde (MVV – the owner of the Serrote copper-gold project in Brazil) to Baiyin Nonferrous[24], and Anglo American's sale of its nickel

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[20] *Reuters*. "China bans export of critical minerals to US as trade tensions escalate" (3 December 2024). https://www.reuters.com/markets/commodities/china-bans-exports-gallium-germanium-antimony-us-2024-12-03/

[21] *Reuters.* "China hits back at US tariffs with export controls on key rare earths" (4 April 2025). https://www.reuters.com/world/china-hits-back-us-tariffs-with-rare-earth-export-controls-2025-04-04/

[22] *Reuters*. "Exclusive: Chinese lithium company halts tech exports as trade tensions build" (19 February 2025). https://www.reuters.com/technology/chinese-lithium-company-halts-tech-exports-trade-tensions-build-2025-02-18/

[23] *Financial Times.* "Chinese sanctions hit US drone maker supplying Ukraine" (31 October 2024). https://www.ft.com/content/b1104594-5da7-4b9a-b635-e7a80ab68fad

[24] *Appian Capital Advisory.* "EXIT: Appian completes sales of MVV to Baiyin Nonferrous for US$420 million" (2 April 2025). https://appiancapitaladvisory.com/exit-appian-completes-sale-of-mvv-to-baiyin-nonferrous-for-us420-million/

assets in Brazil – including producing assets and highly prospective deposits – to MMG[25]. Chinese EV maker BYD also took over a manufacturing plant in Brazil in 2023 from Ford, which was to the detriment of the workers amid abusive labour claims[26].

Looking ahead, current low spot prices of many critical minerals are threatening the ability to meet future demand projections. Lithium, nickel, rare earth element and cobalt prices are currently trading near multi-year lows due to oversupply, brought about by rapid supply growth stemming from the previous price cycles. Much of this growth has come from Chinese-associated operations, including those producing nickel in Indonesia, and lithium concentrate in Africa[27] and China[28]. In the DRC, CMOC's surging cobalt production has weighed heavily on prices, but the miner plans to continue increasing output[29].

These metal markets are now at an impasse – the need to diversify supply and boost future production means that new projects need to be developed now, but the rise in prices needed to incentivize private investment in these projects is unlikely to happen presently. If this continues, the risk of a widening supply/demand dislocation in the future will continue to grow.

V. The challenge facing the U.S.

The U.S. faces many challenges in trying to balance China's control of critical minerals supply chains, which it has been building over the last 20 years. Ultimately, it boils down to time and money.

Critical minerals projects can take well over a decade to develop – the U.S. is ranked as having some of the longest mine development times in the world, taking over 19 years from first discovery to first production[30]. The projects are also capital intensive, and highly technical. The long timelines, combined with regulatory issues and market uncertainties, mean that they are challenging to finance. China has overcome these challenges by using state-backed money to finance high-risk projects to establish control over supply.

In the U.S., private investors are often risk averse or seek more immediate returns on their capital than critical mineral projects offer. Private Equity funds and other institutional investors

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[25] *Anglo American.* "Anglo American agrees sale of nickel business for up to $500 million" (18 February 2025).
https://www.angloamerican.com/media/press-releases/2025/18-02-2025a

[26] *Reuters.* "Exclusive: Chinese workers in BYD Brazil factory signed contracts with abusive clauses, investigators say" (31 January 2025).
https://www.reuters.com/business/autos-transportation/chinese-workers-byd-brazil-factory-signed-contracts-with-abusive-clauses-2025-01-31/

[27] *CRU*. "Lithium floods out of Africa as artisanal miners exploit old tin workings" (3 July 2024).
https://www.crugroup.com/en/communities/thought-leadership/2024/lithium-floods-out-of-africa-as-artisanal-miners-exploit-old-tin-workings/

[28] *Fastmarkets*. "Shining a light on lepidolite producers" (21 February 2024).
https://www.fastmarkets.com/insights/china-lepidolite-producers-andrea-hotter/

[29] *Bloomber*g. "World's No. 1 Cobalt Miner Sees 2025 Output Approaching Record" (23 January 2025).
https://www.bloomberg.com/news/articles/2025-01-23/world-s-no-1-cobalt-miner-sees-2025-output-approaching-record

[30] *S&P Global.* "From 6 years to 18 years: The increasing trend of mine lead times" (11 April 2025).
https://www.spglobal.com/market-intelligence/en/news-insights/research/from-6years-to-18years-the-increasing-trend-of-mine-lead-times

have not been active in the critical minerals space, as it does not fit within their typical investment structures. This has created a financing gap for Western-aligned projects and made it more difficult to compete with Chinese projects that have access to sources of cheap, long-term funding.

In addition, investment in a critical minerals project is often tied to the price of that material during the fundraising period. Currently, low prices are hindering the financing of many projects, with investors more concerned about short-term bearishness than longer-term fundamentals. Meanwhile, Chinese projects can continue to operate and increase supply, which limits the potential for price recovery. For example, Chinese rare earth miners can maintain strong margins well below the incentive price for new projects outside of the country[31].

Chinese processing and manufacturing are also inherently lower cost domestically than outside of the country. Lithium-ion battery cell manufacturing is approximately 20% cheaper in China than in the U.S.[32] As long as China controls feedstock supply, it will be able to support its lower-cost manufacturing base. This is evident in the destination of Chinese funding – of the previously mentioned $57 billion provided to 19 low- and middle-income countries, 92% was deployed to upstream mining projects, and just 8% to midstream processing projects[33].

The U.S. will need to work with industry to identify and address the barriers to building new production and processing capacity. Access to financing, vulnerability to price manipulation, slow public sector support, speed of permitting, and other regulatory hurdles are just some of the key challenges facing U.S. projects.

VI. Recommendations

To diversify supply chains away from Chinese control and build capacity both in the U.S. and allied nations, the Government will need to move much more quickly and invest much more money. The U.S. already has many of the tools required to address these issues, both at home and abroad, but they need to be well-resourced, de-conflicted, and reformed to address the unique challenges of the critical minerals sector. The DFC, U.S. EXIM Bank, and the DOD all have existing funding mechanisms that can be utilized for this purpose.

In 2018, President Trump signed the BUILD Act, creating the DFC. In 2020, the Trump Administration used it to invest in our company. This has had an outsized effect on TechMet's ability to attract additional private investment and build more projects free from Chinese control while providing a return to U.S. taxpayers. However, the DFC's authorization is currently set

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[31] *Benchmark Mineral Intelligence.* "Why higher prices are needed to develop ex-China rare earths supply" (30 April 2024).
https://source.benchmarkminerals.com/article/higher-prices-needed-to-develop-ex-china-rare-earths-supply

[32] *International Energy Agency.* "Global EV Outlook 2024: Trends in electric vehicle batteries" (April 2024).
https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-vehicle-batteries

[33] *Escobar, B., Malik, A. A., Zhang, S., Walsh, K., Joosse, A., Parks, B. C., Zimmerman, J., & R. Fedorochko.* "Power Playbook: Beijing's Bid to Secure Overseas Transition Minerals". Williamsburg, VA: AidData at William & Mary (January 2025).
https://docs.aiddata.org/reports/china-transition-minerals-2025/FULL_REPORT_Power_Playbook.pdf

to expire in October of this year. In addition, it is rapidly approaching its investment cap, forced to score equity investments as grants, and required to notify Congress of every transaction over $10 million, which impacts both its speed and risk threshold. Reauthorizing the DFC for a longer period, with a higher investment cap, correcting the equity scoring, lifting the Congressional notification threshold, and expanding the countries in which it can operate would allow it to have a much greater impact.

Similarly, the EXIM Bank has a series of tools that could be impactful in the critical minerals sector. These include the Make More in America Initiative (MMIA), the China and Transformational Exports Program (CTEP), and the recently established Supply Chain Resiliency Initiative (SCRI). However, EXIM is also coming up against a reauthorization window as its current mandate expires at the end of 2026. In addition, it is bound by a 2% default cap that means it is forced to be risk averse in its lending. Extensive bureaucracy and limited human resources extend its timelines and restrict deal pipeline, which minimize its impact. Reauthorizing EXIM for a longer period, addressing the statutory restrictions, and adding technical capacity could unleash significant support for the critical minerals sector.

The Department of Defense has several initiatives and funding mechanisms that could support critical minerals projects, including the Defense Logistics Agency (DLA), the National Defense Stockpile (NDS) and the recently created Office of Strategic Capital (OSC). In addition, the fleets of vehicles, equipment, and materials owned by the DOD represent a significant potential recycling opportunity with resource grades that would rival many mines. With a more focused approach, DOD can utilize these tools to direct funding and purchasing toward areas that would secure American critical mineral supplies and expand production and processing capacity.

The departments of Commerce, Energy, Interior, State, and Treasury also have programs that could be optimized to secure portions of the supply chain and crowd in greater private sector investment. Strengthening the enforcement and monitoring of Foreign Entity of Concern provisions, the targeted and strategic use of tariffs, and implementing incentives for production domestically and among closely allied nations will also mobilize the private sector.

VII. Conclusion

China's dominant position in critical minerals is the result of a dedicated, unwavering strategy implemented over many years. Substantial capital deployment in overseas mining projects, combined with consolidation of a hugely competitive domestic refining and manufacturing base, has given China formidable control of global supply chains which countries around the world are reliant on, and now, are overexposed.

Increasing signs that this position could be used as geopolitical leverage mean that the need to diversify away from China is stronger than ever. This is possible, despite the scale of the challenge, but it will require the U.S. to finely tune and optimize the tools at its disposal to efficiently build out Western-aligned supply chains. Without urgent action, the U.S. could face severe disruption to its economic stability and national security.

OPENING STATEMENT OF CORY COMBS, ASSOCIATE DIRECTOR FOR CLIMATE, ENERGY, AND INDUSTRIAL POLICY, TRIVIUM CHINA

MR. COMBS: Good morning. I would like to thank the Commission, Commissioner Brands, Commissioner Goodwin, Chair Price, for the opportunity to testify today, and thank you to the staff for ushering the witnesses through the process.

We are here because the U.S. today finds itself in a position of supply chain insecurity decades in the making. At the same time, these are decades, in some cases up to half a century of development, China maintains a position of strength with regard to many of the key critical mineral supply chains of interest today.

Over the past two years, in particular, Beijing has sought new forms of material leverage through which to retaliate against and counteract U.S. trade controls, in particular, and it has found that leverage in the case of critical minerals.

As of now, export controls on critical minerals are a central part of Beijing's playbook for applying that leverage, to the extent that it feels its economic interests are threatened. Since 2022, it has instituted export controls, either licensing requirements in some cases, or outright bans on exports to the U.S. in other cases, on a total of 16 distinct sets of critical minerals, noting that one of those contains seven distinct rare earth elements, along with associated production equipment.

This process began in mid-2023, under former President Biden's institution of tech controls on China, to limit access to certain chip technologies. The response was export controls on gallium and germanium, chip materials, chip minerals.

This has accelerated recently, most notably in response to the Trump administration's imposition of tariffs against China, and now is a much more broad-based set of mineral controls. China maintains significant leverage in stock for future retaliation, and it will continue to use it.

The situation has rattled global markets and directly threatened both the supply chains of American producers and key American trading partners, putting businesses' growth, jobs, and overall national security in jeopardy.

Now, critical minerals, in terms of their importance, they're unique in the breadth of their importance, in many ways, compared to other parts of the supply chain. They underpin both energy security and the industries of the future, and as the previous panelists noted, these are future industries that are increasingly industries of today, as the actual growth drivers globally. These include advanced semiconductors, which have proportionally more critical mineral requirements than legacy chips, for example, batteries, electric vehicles, and new energy applications of all sorts, as discussed today.

They are also vital to national security applications, as noted, from remote sensing equipment, guided missile systems, to munitions and high-strength alloys for vehicles and aircraft. The same sources supply both sides of the equation.

Now, with regard to the form of the energy and industrial applications, China's export controls threaten strategic commercial and industrial interests in a variety of directions, both contemporary and emerging interests, and with regard to the latter they drive unsustainable military vulnerabilities.

At present, the U.S. government has to decide how will it adapt to ensure the country's energy, industrial, economic, and national security.

The long and short is, I think, widely agreed upon, that the U.S. needs to diversify critical mineral supply chains away from pure China dependence. The question, however, is how. There are many opportunities here. There is a rich discourse around this question. But I would pose that the best answer has two parts.

First is a coordinated industrial development that supports both downstream demand to incentivize private investment in the upstream supplies, which is something we've seen China, in its most successful cases, begin to do, and its least successful cases it has failed to do. We need [unclear] the demand side to enable the supply side.

Second is through strategic partnerships with allies and strategic economic partners that can not only diversify the access to the geological resource but also leverage their capabilities, their unique and distinct capabilities, while minimizing the necessary subsidies required to get similar efforts here in the United States and thereby lowering the cost to taxpayers.

Diversification of the full set of critical mineral supplies in question is not an easy task. There are 50 critical minerals recognized by the USGS. There are 72 that my team tracks across the EU, China, Japan, South Korea, and many other countries, that are considered critical and are treated as such in geopolitical considerations. Most of these have unique geological sources, unique processing production chains, and also require different amounts of expertise. Some are not mined at all. Some are produced as byproducts of other industrial processes. For example, in the case of gallium, germanium from zinc and bauxite processing, which means, in some cases, you have a second order production issue that you must address.

The degree of subsidization required to completely onshore all of this is not exactly calculated, but the short answer is a baffling degree of subsidization. That is not a sustainable way to move forward. However, the U.S. does have certain resources, certain expertise, and a certain degree of subsidization possible, and its partners have many of the pieces to help fill the gap. The U.S. and its partners stand to significantly support each other's diversification efforts through strategic coordination and cooperation.

Two pieces of that, I will reiterate. The first is that the U.S. must incentivize the private sector to build the projects and develop the expertise where we don't have it, for more upstream production and processing of minerals, and that ultimately requires, in the medium to long term, the unleashing of industries that will create downstream demand. And again, I would highlight that the military applications are significant, but they are not financially enough to incentivize the wholesale buildout of supply chains that the United States needs for its full set of interests. That is why we need the private sector involved, as well.

In terms of commercial applications, the global trajectory is moving increasingly toward new energy applications, and it is precisely why China has succeeded in many of its contemporary industrial policy, where it has failed in past industrial policy. Mainly, it is applying more of what more countries want, which, in effect, is a form of energy security in the form of renewables. Most countries are not as oil rich as the United States, Russia, and a few others, and so for them the ability to have solar panels, et cetera, has been critical to ensuring their interests. China is supplying what they need. That is where the demand side is coming from, and that is now increasingly supporting and decreasing the pressure on the state upstream, as well.

The U.S. will find different avenues, certainly, I hope, than China to develop this ecosystem, but this is the end goal to which it must pursue.

The second is to balance the scales against China. The U.S. must leverage not only its domestic mineral resources, which are significant but not sufficient. It must leverage all of its resources, and I consider its greatest resources to be its allies and other economic partners. And again, the U.S. alone cannot hope to compete on any particular minerals or downstream growth industries, for a variety of issues, including the price issues just alluded to earlier, but alongside the U.S.'s many mineral-rich, highly, and importantly, differently skilled allies and partners, many of whom are also very keen to diversify those supply chains away from China. There we have an opportunity to reduce supply chain risks, seize some of the growth opportunities in the meantime, and address national security risks in the meantime, ideally at the minimal cost to taxpayer dollars through a big tent of trading cooperation with our strategic partners.

Thank you for your time.

PREPARED STATEMENT OF CORY COMBS, ASSOCIATE DIRECTOR FOR CLIMATE, ENERGY, AND INDUSTRIAL POLICY, TRIVIUM CHINA

Testimony before the U.S.-China Economic and Security Review Commission

Hearing on "China's Domestic Energy Challenges and Its Growing Influence over International Energy Markets"

Security Holism: Strength through Diversification, Upstream and Downstream

Testimony by:

Cory J. Combs

Head of Supply Chain Research and Associate Director for Climate, Energy, and Industrial Policy

Trivium China

April 24, 2025

Introduction

My thanks to the Commission, the Commissioners, the Co-chairs and their staff for holding this hearing and for extending the opportunity to testify today.

The US today finds itself in a position of supply chain insecurity decades in the making. For reasons both strategic and serendipitous, and even longer in the making, China finds itself in a position of strength vis-à-vis many of the world's most vital mineral and metal supply chains. These include irreplaceable materials on which the energy and industrial ecosystems of the future are being built, and on which many US national security interests already depend. As evolving global markets increase these commodities' demand, and bilateral tensions risk disruption of their supply, the US must decide: how will it adapt to ensure the country's energy, industrial, economic, and national security?

The future of American economic security hinges on its competitiveness in the emerging industries driving global growth – in many of which China leads the world. Competitiveness is a product of many interrelated variables; the security and cost effectiveness of critical mineral supply chains are among the most fundamental for competitive manufacturing in emerging industries. Meanwhile, critical minerals are also inherently tied to national security interests. As such, Chinese critical mineral export controls pose direct economic and security risks.

Today I examine the strategic logic of China's expanding critical mineral export controls and offer recommendations for effective and sustainable long-term risk mitigation. Chinese export controls are already reshaping global supply chains and the logic of upstream investment, with business-critical implications for American and allied countries' companies across energy, mining, tech, aerospace, and many other industries. Critically, many of the same supply chains of concern for civilian industry are irreplaceable in national security applications, from munitions to remote sensing equipment. Markets alone will not resolve all the simultaneous risks at hand.

Policy discussions of mineral supply chains and export controls are complicated not only by the sheer range of minerals at risk – including 72 that my team actively tracks[a] – but by: each mineral's criticality to myriad, often unrelated downstream interests, both civilian and military; their often unique processing requirements and uneven geological concentrations; and associated market idiosyncrasies that will make it difficult for US supplies to become competitive, absent heavy government involvement. These complications preclude "one-size-fits-all" solutions.

Nonetheless, a coordinated US government response is essential. Many Chinese export control announcements have taken affected entities by surprise, driving supply and price disruptions. Most companies seek to diversify supplies, but they often have few good options

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[a] The US Geological Survey officially recognizes 50 "critical minerals." Trivium tracks these 50 along with all other minerals and materials the EU, Japan, South Korea, China, and other countries designate as "critical" or "strategic."

outside of China. Meanwhile, for most minerals there is no simple, swift, or cost-effective path to onshoring production in time to avoid extreme costs to companies and consumers.

In export controls, China has found a materially impactful means of retaliation against US trade actions, and it still has significant leverage in stock. A sound US response to China's export controls requires integrated understanding of China's advantages and disadvantages, its objectives and the costs of pursuing them, and the US's practical options given its constraints. Together, these considerations make clear that the US requires a coordinated, "big tent" approach to overall supply chain development to compete with China. Joint action with strategic partners would truly and cost-effectively advance US energy, industrial, economic, and national security.

1. Status quo

The big picture

For decades, US producers and consumers alike have reaped the economic benefits of low-cost Chinese upstream production – and the absence of associated negative environment and social impacts – with comparatively little fanfare. The US market decided on its suppliers as expected and, for investors, desired: it optimized investments to maximize profitability. With aggregate advantages in geological resource endowments, decades of industrial policy, and – especially since the 1980s – process innovation, Chinese companies were often the most competitive mineral suppliers. Global supply chains, including the US's, shifted accordingly.

Today, however, the status quo of general Chinese mineral industry dominance poses salient and rapidly escalating supply chain risks. Since mid-2023, the PRC has leveraged US supply chain insecurities to retaliate against US tech controls, tariffs, and related actions that impede Chinese economic interests. Ongoing escalatory trade actions and reactions now pose direct threats to US and allied countries' commercial, industrial, and national security interests. With economic and trade tensions being structural features of the bilateral relation, the associated risks will persist.

The logic of Chinese export controls

Export controls are a key part of China's broader – and increasingly sophisticated – playbook for retaliation against foreign provocations.[1] [b] This playbook also includes reciprocal tariffs, sanctions (e.g., via the Unreliable Entity List), and industrial competitiveness investigations, among other tools. In general, China maintains a defensive posture with respect to trade, responding to foreign threats to its economic and security interests with what it intends to be symbolically and materially tit-for-tat retaliation. For example, in July 2023, it met US-led semiconductor export controls with export controls on minerals used to make semiconductors.

[b] It is important to note that not all Chinese export controls are retaliatory. Many reflect internationally standard restrictions on hazardous, dual-use, and/or illegal goods. This analysis pertains only to weaponized export controls.

In the case of the recent tariff war, China began by exactly matching US tariffs – symbolically reciprocal. However, because China is a more significant exporter to the US than the US is to China, US tariffs on China have a proportionally greater material impact on Chinese exports than vice versa. So, to make up for the differential in material impacts, China also incorporated other tools – most significantly including the April 4 export restrictions on seven (of seventeen) rare earth elements.[c] This is in line with the expected logic and intended signaling behind China's trade retaliation measures over the past several years.

The next question is why export controls on *critical minerals* have become such a staple of Chinese trade retaliation. In brief, they provide Chinese policymakers a rare degree of asymmetrical leverage: they are highly effective at causing material risks and impacts for the US and other offending actors with comparatively little domestic harm from their implementation.

This is in stark contrast to blanket tariffs, which cause direct, significant economic harm to both sides' consumers and producers alike. Beijing has matched mutually harmful tariffs for direct reciprocation, but otherwise prefers more favorably asymmetric measures. Export controls also contrast with sanctions on US defense contractors, which have limited impact on either country.

Chinese critical mineral export controls are effective leverage for (at least) three key reasons:

1. Geologically, China has a greater volume of commercially viable reserves of more different minerals than the US, which both the central and local governments – and recently, private downstream companies – have spent decades developing
2. Technically, China has significant advantages in both talent development and institutional knowledge, which is especially vital for mineral processing – the key bottleneck for supply chains, more so than raw ore extraction
3. Industrially, Chinese companies enjoy numerous domestic supply chain synergies, upstream and downstream, with many enjoying efficiency gains from vertical integration, further increasing competitiveness

Importantly, critical mineral export controls pose three materially distinct risks to the US:

1. Direct supply disruptions, wherein the US may become unable to obtain non-substitutable inputs to products it manufactures (like American carmakers)
2. Indirect supply disruptions, wherein other countries that produce goods then sold to the US may become unable to obtain non-substitutable inputs to products they manufacture (like Japanese permanent rare earth magnets)
3. Global price shocks, wherein the US may be able to secure both upstream supplies and their key products, but Chinese controls increase global market prices, inhibiting industrial and/or commercial operations (as for standard and legacy semiconductors)

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[c] Namely, samarium, gadolinium, terbium, dysprosium, lutetium, scandium, and yttrium. Samarium is a light rare earth; the other six are heavy rare earths.

It is also worth noting the less tangible, but still impactful, effect of sheer uncertainty. Enormous amounts of both government and corporate resources have been diverted to mapping out the potential risks of each control, and potential future controls. Many industries' supply chains are so complex that few companies have complete mappings of who supplies their suppliers (or *their* suppliers); whether a particular controlled compound is critical to their operations; and whether they ultimately obtain applicable compounds from China. Meanwhile, many controlled and at-risk goods used in national security applications are not used in large quantities – theoretically limiting the potential economic impacts of their restriction. But the impact is of course massively amplified by the sensitivity of these applications. Uncertainty and fear remain powerful tools.

Key actions to date

Below are presented key actions – both foreign triggers and Chinese retaliation – in the evolution of China's export control landscape. The timeline makes clear that Beijing's export controls typically follow triggering actions, from tech controls to industry investigations to tariffs. In a few cases, they more generally reflect periods of rising tensions, intended to serve as warning signals to dissuade further action. Also notably, early export controls saw longer delays between trigger and retaliation, as the policy infrastructure and customs enforcement both took time to develop. However, recent controls – likely prepared in advance, ready for appropriate triggers, and streamlined by unified regulations in late 2024 – would come in as little as one to two days.

Timeline: Key waypoints in China's critical mineral export control regime development

Date	Action
August 13, 2018	**The US launches sanctions against Chinese tech firms** The US bans the sale and import of communications equipment made by five Chinese brands, including Huawei and ZTE.[2]
December 1, 2020	**China implements cornerstone Export Control Law** It provides China's first consolidated legal basis for export controls – something Western countries have had in place for decades – to "safeguard national security and interests."[3]
October 7, 2022	**The US restricts China's access to high-end chips** President Biden's "small yard, high fence" strategy extends to both high-end chips and their means of production.[4]
March 31, 2023	**Japan moves to restricts China's access to chip equipment** Japan, a top producer of high-end chips, finalizes strict high-end chip production equipment controls, in line with US policy.[5]
June 30, 2023	**The Netherlands moves to restricts key chip equipment exports** It blocks ASML, maker of the world's top chip manufacturing equipment, from selling to China, in line with US policy.[6]
July 3, 2023	**China imposes gallium and germanium restrictions** The restrictions, which take the form of licensing requirements that give Beijing the ability to deny exports, threaten chip production.[7]

October 4, 2023	**The EU launches electric vehicle (EV) investigation** The investigation targets Chinese EVs, with the expectation – borne out on October 31, 2024 – of additional tariffs.[8]
October 17, 2023	**The US tightens export restrictions on chips, chip-making tech** In a second round of tech controls, the US blocks Nvidia from selling best-in-class advanced AI chips (e.g., the H800) to China.[9]
October 20, 2023	**China imposes graphite export restrictions** The controls, analogous in form to those on gallium and germanium, threaten EV battery and semiconductor production.[10]
December 21, 2023	**China blocks exports of REE processing equipment** To protect domestic industry, Beijing prohibits exports of rare earth element (REE) processing equipment, impeding foreign adoption.[11]
September 15, 2024	**China implements export restrictions on antimony** As a warning sign amid rising tensions, Beijing adds new controls on key antimony products and antimony separation equipment.[12]
October 19, 2024	**China releases Dual-Use Item Export Control Regulations** The regulations, structured similarly to Western models, consolidate prior export controls under a unified dual-use list – and establishes a "Control List" similar to the US Entity List.[13]
December 2, 2024	**The US announces third round of chip export controls** President Biden expands controls on 24 upstream manufacturing tools to inhibit Chinese advanced chip development.[14]
December 3, 2024	**China escalates gallium, germanium, graphite controls to bans** Beijing announces an "in principle" export ban on the three previously restricted minerals, along with "superhard materials."[15]
January 2, 2025	**China unveils draft strategic tech export restriction list update** In a *non*-retaliatory export control update, instead designed to protect future Chinese industrial competitiveness, the draft strategic tech catalog adds select pre-commercial LFP and LFMP batteries.[16]
January 16, 2025	**China warns then President-elect Trump of mineral leverage** The Ministry of Commerce publicly signals it stands ready to implement further mineral export controls to defend its interests.[17]
February 1, 2025	**President Trump adds 10% additional blanket tariffs on China** With respect to China, the tariffs (which separately include add 25% additional tariffs on Canada and Mexico) focus on fentanyl.[18]
February 4, 2025	**China imposes five more dual-use mineral export restrictions** Namely, **tungsten**, **tellurium**, **bismuth**, **molybdenum**, and **indium** – the most cross-cutting controls to date, mirroring US tariffs.[19]
April 2, 2025	**President Trump initiates escalating tariffs** President Trump imposes global tariffs, followed by further tariff increases on China for each round of its reciprocal retaliation.[20]
April 4, 2025	**China imposes export restrictions on seven rare earth elements**

	The specific controls prioritize impacts on defense and aerospace rather than general commercial and industrial interests.[21]
April 9-10, 2025	**China signals accelerated development of export control regime** At its annual export control conference – held six months earlier than last year – the Ministry of Commerce signaled it will expedite the build-out of its still-nascent regulatory framework "in the face of the current complex and challenging international landscape."[22]

Comprehensive policy analysis makes clear that the central government has intended its export controls to serve as defensive, reactionary responses to foreign action, including as signals to warn against further action – though this is not likely the general perception in the US.

Officially, all export controls have non-retaliatory justifications – typically as dual-use controls to prevent use in military applications, though only a moderately sized subset of the specific controls reasonably meet dual-use criteria. That said, officials in Beijing have grown increasingly direct in acknowledging the controls' retaliatory function. Discussing the December 3, 2024 "in principle" bans on gallium, germanium, and graphite exports at a press conference the same day, the Ministry of Commerce (MofCom) stated[23]:

- *"In recent years, the United States has generalized the concept of national security, politicized and weaponized economic, trade and technological issues, abused export control measures, unreasonably restricted the export of relevant products to China, and included a number of Chinese companies in the sanctions list for suppression and containment, seriously undermining international trade rules, seriously damaging the legitimate rights and interests of companies, and seriously undermining the stability of the global industrial chain and supply chain."*

In effect, the rising mutual sense of supply chain insecurity is proving a self-fulfilling prophecy. Now that the current trajectory has been established, though, it will prove difficult to redirect – necessitating a sound long-term risk mitigation strategy.

2. Drivers and trajectory

Origins of China's upstream advantages

China's historical mineral resource investments, dating back to the immediate aftermath of the Chinese Civil War, were anchored in two basic drivers: the central government's efforts to shore up national security and local governments' efforts to drive local economic development. It took decades of winding, often contentious, and even more often wasteful state-led investment to develop China's foundational natural resource extraction capabilities.[d] With few exceptions, coordination was poor, driven and shaped by local interests often in tension with national goals. One consequence was low prices, which incentivized global supply chain migration to China.

But this is not the end of the story. Over the past decade, two new drivers have reshaped and realigned both the political interests and industrial investment in many critical minerals: first, the increased focus on technological upgrading, and second, the emergence of the "new energy" industry. Both support supply chain demand growth, which both the state and private sectors have direct, high-priority interests in meeting. Both have redirected investment toward goods used in higher-value applications. And both are making China more difficult to compete with.

The central government's long-term economic security strategy hinges on moving China up the value chain. That, in turn, requires wholesale industrial upgrading, with specific focuses on "high-end, intelligent, and green" applications.[24] To that end, central authorities are actively pushing for innovation through both supply- and demand-side industrial policies. Among the results has been massive growth in the "new energy" industry, including:

- New energy vehicles (NEVs), e.g., electrics, hybrids, and hydrogen fuel cells vehicles – and now also electric autonomous vehicles and eVTOLS (including "flying cars")
- Renewable energy equipment, e.g., solar cells, wind turbines, and associated systems
- Batteries, both for transportation and energy storage (both closely tied to electrification and renewable energy development)

These industries are now among China's top growth drivers, both domestically and in terms of exports. Local governments have jumped on the chance to ride the wave. Companies – most, and the most competitive of which, are private – have mobilized vast resources to seize market share.

The rapid growth of these industries – supported by concerted central and local policy supports and private investment alike, on both the supply and demand sides – has also massively increased the projected market demand for critical mineral inputs, compared to prior levels required for traditional industries. More chips for intelligent manufacturing, NEVs, and electrified energy systems. More permanent rare earth magnets for motors, including for NEVs

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[d] Based on the unique characteristics of different minerals, regions, and local governments, the historical development paths of China's upstream mineral industries are in many cases highly idiosyncratic. Local governments in regions with limited industrial opportunities often – both in the past and still today – turned to extractive industry, driving expansion efforts that were generally not well coordinated and often frustrated central planning efforts. The buildout was often neither efficient nor, in some cases, even strategic; for example, the rise of township and village enterprises (TVEs) during the Mao era was one of several trends that drove massive overcapacity that ironically undercut strategic industry development. Yet, where the central government attempted to right the ship, it in many cases struggled to enforce its goals, given the local economic and political dependencies that had already formed. It took decades to consolidate many industries, which still struggle from overcapacity. Indeed, such issues still plague the modern steel and rare earth element industries, among others. This is the context in which many Chinese upstream industries evolved – and which Beijing has more recently turned to its advantage.

and wind turbines. More batteries, containing lithium, nickel, cobalt, manganese, and other minerals. And so on.

Today, it is not only the historically large but inefficient, primarily state-led investment that drives China's upstream advantages. Now, ambitious and innovative private companies have also jumped into upstream investment, seeking to secure their own supply chains. Chinese companies have developed significant synergies through vertical integration across high-value production chains, e.g., battery-makers making major lithium investments. The trend has introduced new capital and competitive pressure to make upstream investment more efficient. State investments remain critical, given the decades of prior capital expenditure – and indeed, the state has made it a clear priority to ensure industry has the supplies it needs to grow. But rising mineral demand itself has driven competition between companies and regions, adding profit motives to invest and improve operational efficiency beyond what the central government alone would achieve.

All this is to say, industrial upgrading efforts extend upstream, in mining, as well as downstream, in manufacturing – and the two sides are essential to enabling each other's progress. This is one key lesson for the US: as much as the downstream depends on upstream supply security, an *efficient* buildout of upstream supply chains requires robust downstream demand.

Industrial drivers of national security leverage

The question remains: how does domestic upgrading tie into the emergence of China's export control regime? In brief: it has significantly bolstered China's mineral dominance and the outlook for its persistence – giving China a substantive, durable mode of retaliation beyond the likes of tariffs. The leverage is multiplied by certain compounds' national security applications.

Many of the critical mineral products central to China's industrial and economic upgrading are also critical in national security applications, from munitions to remote sensing equipment. While some dual-use applications are clear-cut – e.g., antimony trisulfide used mainly for munitions – there exist ample gray areas – for example, spheroidized graphite used in batteries, which are predominantly used to power commercial autos, but also military equipment.

To be clear, China has weaponized critical mineral export controls for trade retaliation, targeting many compounds that lack clear dual-use applications. But the strategically targeted controls also cover enough genuine dual-use applications to also create real non-commercial threats.

But weaponization was not a driving, much less a primary, goal behind most mineral investment. The Chinese government would undoubtedly maintain a certain level of production of key minerals for domestic national security purposes, but it would have far less economic ability to maintain its current extreme degrees of overall mineral dominance absent the widespread and growing industrial demand that currently incentives it. By meeting the domestic industrial and commercial demand the state helped spur – driving down costs and thereby maintaining global competitiveness – the government inherently also boosts its leverage vis-à-vis dual-use minerals.

China's contemporary export control regime

Like all major economies, China has legitimate need of a baseline export control regime for the likes of nonproliferation. It arguably went too long with a fragmented system, which until 2020 remained spread across the Customs Law (1987), Foreign Trade Law (1994), and myriad regulations since (including those on exports of arms, nuclear components, and biological items).

Today, China's unified export control regime is built around its cornerstone Export Control Law, which was implemented on December 1, 2020. The landmark legislation provided a unified legal foundation for all Chinese export controls, past and present. Notably, it also laid explicit claim to long-arm jurisdiction authority, which has yet to be meaningfully tested. On October 19, 2024, China released regulations on dual-use item export controls that consolidated prior controls and streamlined the process for implementing new controls, insofar as they are deemed dual-use.

China now maintains two key lists to manage export controls[25]: the set of goods subject to export controls, which include restrictions (requiring export license approvals) and prohibitions, and the Control List for companies specifically barred from importing listed goods (even if the goods are not otherwise prohibited from exports). The latter generally covers entities legitimately involved in military or other sensitive applications; e.g., it includes many foreign defense contractors. However, the weaponization of export controls comes from the former list, with China adding even critical mineral products that are not generally considered to be dual-use to the list.

The regime continues to evolve. China's December 3, 2024 announcement escalating gallium, germanium, and graphite export restrictions to outright bans includes the first explicit invocation of the country's claimed authority to take legal action against "any organization or individual," including foreign entities, for violating Chinese export controls. Two key points remain unclear: the extent to which Beijing is practically *able* to enforce this form of long-arm jurisdiction with respect to any given set of products, and the extent to which Beijing might *attempt* to enforce it.

Strategically, at present, the best outcome for Beijing remains that third countries, fearing retaliation, voluntarily comply with Beijing controls and prohibit through transit, transshipment, through-transportation, and re-export *without* the need for any tangible action by Beijing. This way, China would face no risk of failures that could undermine its position. The worst outcome would be that third parties enable circumvention of Chinese controls and Beijing proves unable to enforce its claimed long-arm jurisdiction. However, given widespread industry and, to our knowledge, foreign government belief in the credibility of the Chinese threat, there is an extremely low chance of the latter case. Many countries are likely to preemptively comply.

Global industry's positioning

Since the initial shock of the gallium and germanium controls in mid-2023, many industry actors have grown proactive in anticipating and preparing for further Chinese export controls. Indeed, not only has the continuation of export controls been anticipatable, but specific targets were anticipated.[26] Some large-scale producers have stockpiled key minerals dominated by Chinese production, and most with significant exposure have actively sought to diversify their sourcing. However, China's advantages in many critical minerals put it a decade or more ahead of most competitors – and even where alternative supplies exist, they may not be available at similar qualities or costs. This is precisely what makes the controls an effective retaliatory tool.

Beyond such high-level information, however, inquiries into the international business community's responses are complicated, A central problem is that, in the current context, most businesses are not in a position to share much information regarding their supply chains. To the extent they *are* at high risk of supply disruptions, they cannot advertise their vulnerabilities, lest competitors seize the advantage and investors flee. To the extent they are *not* at high risk – e.g., companies that have secured stable, cost-effective non-Chinese supplies of Chinese-dominated goods – they cannot risk making themselves a target for other forms of political reprisal.

Overall, though, it is fair to say that, based on the author's engagements with multinational companies – American and otherwise, across the mineral, energy, auto, tech, and aerospace industries, among others – most producers remain very highly concerned about both short-term risks and long-term costs. Moreover, while none are in a position to make such statements directly, there exists a very high degree of doubt that the US is in a position to effectively offset the risks of export controls driven by US-China trade conflicts in the near future.

Strategic trade partners' positioning

US strategic trade partners are likewise in an increasingly difficult position. This is a problem for the US not only diplomatically, but logistically: even in cases where the US has low direct dependencies on specific Chinese mineral imports, it often has high indirect dependencies through trading partners, whose goods may be difficult to substitute. While many key trading partners are politically and economically aligned with the US, there are stark limits to many of their industries' ability to operate without stable flows of minerals extracted and/or processed in China. Most economies are also less diversified than the US and China, meaning they may be unable to manage overt disruptions to critical manufacturing industries – giving China leverage.

The semiconductor, permanent rare earth magnet, and battery industries in Japan and South Korean are important cases. For both countries, these are strategic industries, each with significant Chinese mineral dependencies. In turn, the US is dependent on Japan and South Korea for significant portions of these goods (in different product categories). This means that Japan and South Korea are potential vectors through which China could seek punitive action against the US – where the US would have limited ability to mitigate the impacts, absent de-escalation with China.

Beijing has already engaged with both countries and well understands their positions. In late October and mid November 2024 – just weeks before unveiling its consolidated dual-use export control mechanism, announced in December – China held separate consultations with Japan and South Korea to discuss its evolving export control regime.[27] [28] In both cases, MofCom's readouts sent two clear messages: first, practically, that Beijing is keen to ensure key trading partners fully understand China's export control regime and specific policies; and second, politically, that China will retaliate against provocative actions, presumably such as (in Japan's case) further US-led tech controls. The subtext is, credibly, that China will still make no preemptive or instigative moves, including critical mineral export controls, but will maintain a strong defensive posture.

In short, Beijing has been – and will continue – placing key midstream trading partners in increasingly dire strategic positions vis-à-vis US-China trade and economic conflicts. Where the US has historically relied on economic and trade partners to help enforce its China policies – through diplomacy and pressure alike – China has established a strong capacity to further complicate their alignment and/or compliance with US efforts.

Among the most salient cases today is chip controls: were the US to attempt to align partners on new chip equipment controls today as it did in 2023, it would likely face far greater resistance, given the greater potential costs of Chinese retaliation.[e] There is simply a limit on the degree to which most countries' industries can manage the (highly credible) risk of losing access to critical Chinese supply chains that fuel strategic, high-value industries – including chips, rare earth magnets, batteries, and other energy equipment.

This is all to say that the Chinese threat is credible, well calculated, and essential to factor into broader trade strategy, not only for sake of direct US access to Chinese minerals, but for supplies of the broader array of intermediate goods produced by US allies and partners that depend on Chinese minerals.

Still, it essential to confirm that the Chinese government's demonstrated preference remains, by far, a stable trade status quo that supports both upstream and downstream exports, to the US and elsewhere, as required for its economic upgrading strategy. It still treats export controls as one of relatively few tangible means to defend itself against threats to its economic interests, to the point that it is willing to incur a degree of financial and economic harm to deploy them against material threats – but only where the threat really is material, lest the costs outweigh the benefits.

The upshot is that, with China maintaining a defensive posture, the US is ultimately in a position to decide the extent to which it is willing to accept further supply chain risks in pursuit of its own restrictive trade actions. In the meantime, there is no near-term solution to completely undermine China's leverage over critical minerals. Risk mitigation will necessarily be a long-term project – although it can be made far, far more efficient through strategic partnerships, as discussed next.

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[e] Nor would it necessarily be in the US's near-term economic or industrial interest for them to do so, even if the US saw their compliance as valuable for tactical objectives. So far, the US has weathered Chinese mineral export controls with comparatively few major disruptions precisely because it produces so few of the energy, tech, and other goods that use them. Instead, it largely imports goods containing the affected minerals. If the US's overseas suppliers were to lose access to Chinese minerals, the US would likely face sudden and serious material shortages with little near-term recourse.

3. Securing the future

China's approach

China will continue to deploy export controls – notably on critical minerals, and gradually expanding to other materials and upstream inputs – as long as it feels threatened by foreign trade actions. It remains in a comparatively weak position with respect to tariffs and sanctions, and thereby has relatively few materially impactful alternatives. It could, say, begin to punish larger and larger US companies – but doing so would significantly harm domestic economic interests. Hence, export controls are likely to remain a favored retaliatory mechanism for some time.

Meanwhile, China is not implicitly threatened by foreign minerals competition. Indeed, it continues to partner with and import from many international mineral producers, including US allies and partners. It is chiefly threatened by the weaponization of trade – and acts accordingly.

China's future export control targets will likely depend largely on the action it is retaliating against. Where symbolic reciprocity is possible, it is likely. Where a perceived provocation is more harmful to Chinese interests, China is likely to consider more impactful controls. And in all cases, naturally, risks to specific goods are higher where China has greater market dominance.

The US's approach

Economically, the US is not in a position to develop its own mines for each of the dozens of critical minerals over which China has significant global market influence. It can onshore certain supplies, but onshoring will be woefully insufficient to address the broad, complex set of risks at hand. Economically, free and open trade remains the single best solution for US consumers and producers alike. However, to the extent that bilateral security concerns continue to inhibit stable free trade, the US needs to diversify supplies. It can do so, but it cannot expect to do so alone.

The first challenge is the sheer up-front capital expenditure required. Domestic private sector interest in production development is rising but still very small compared to what is required to substantially offset Chinese supplies of many minerals. Meanwhile, it is structurally limited by the limited demand side in the US. As noted in the above, the US is heavily dependent on imports of intermediate goods as well as upstream supplies; i.e., it does not produce many of the goods that use many critical minerals of concern. US domestic demand is currently too limited to support large-scale production, necessitating revenue from exports. But the US cannot produce at a price point amenable to the global market, given Chinese production costs and overcapacity.

The second challenge is the fact that it takes years to develop a mine – even ignoring the time for permitting, much less financing. No degree of regulatory simplification will make construction alone less than a years-long effort. Key supply risks already exist and will persist in the interim.

The third challenge concerns *processing*. Mine production is only the first step; significant processing is required to make the extracted ores useful. Some minerals are not technically challenging to process, but still require significant knowledge and skilled labor the US does not currently have in any abundance. Other minerals are incredibly complex to process effectively, especially where required in highly purified forms (such as rare earths). Where it does not produce such goods domestically, the US largely relies on upstream processing in China and intermediate good processing in China, Japan, South Korea, and elsewhere.

The fourth challenge concerns a subset of minerals that are not mined, but primarily recovered as byproducts of other industrial activities. For instance: gallium (for which the US is entirely import-dependent) is largely recovered as a byproduct of aluminum production (from alumina); germanium and indium largely from zinc production; tellurium from copper refining; and many platinum groups metals from nickel and copper refining. In some of these cases, the US has capabilities and even some production capacity; these are promising cases for domestic expansion, given significant government subsidization. Some have alternative (if more costly) production methods. Overall, however, there will remain numerous minerals for which US production is not likely to be feasible, absent incredibly high degrees of subsidization – and even then they may not be technically viable, much less useful for mitigating real near-term risks.

But there are solutions – and they necessitate that the US look outward as well as inward.

Recommendations

In the near term, the US should seek to negotiate targeted critical mineral supply chain agreements with key allies and partners, whose existing upstream capabilities can help wean the US from Chinese critical mineral supplies.

The US should onshore where it can and "friendshore" where it must. In the near term, many minerals will fall into the latter category. Even if the US were to seek total mineral independence, its best path forward – by far – would be to build a robust supply chain network with partners who have the necessary resources and expertise. At minimum, the US can secure supply agreements that ensure immediate economic and national security. Beyond that, it could pursue joint investments in new supply lines, domestically or overseas, as geological reserves allow – reducing the burden on US taxpayers while increasing the total benefits for US interests.

In February, the President established the National Energy Dominance Council, which, among other responsibilities, is tasked with "reestablishing American leadership in manufacturing," and to that end, coordinating the use of national resources, including critical minerals. In principle, it should be well positioned to convene interagency planners – drawing on the federal government's vast array of valuable expertise, including at the Department of Energy (including the National Laboratories), the Department of State, and the United States Geological Survey (within the Department of the Interior) – to map out a network of agreements to shore up critical mineral supply chains.

In the medium term, the US should couple upstream investments with reinvigoration of downstream demand development efforts – particularly in fast-growing emerging industries.

The President has already demonstrated support for large-scale government subsidization to support energy, industrial, and broader economic security. In particular, he has authorized use of funds via the Defense Production Act to "[bring] back" the domestic coal industry.

The challenge here is that coal is not a growth industry, domestically or globally, and it will not become one again regardless of the degree of government subsidization; the comparative advantages of alternatives are too great for it to return to competitiveness. As such, the returns on this government subsidization will be low – even, in the medium term, to coal mining communities, compared to other industry opportunities that could be subsidized to support them.

Meanwhile, emerging industries – in most of which China currently leads not only on cost, but in technological innovation – continue to see significant long-term growth outlooks globally. Even amid China's ongoing economic challenges, its companies' leadership in emerging industries is boosting both investment and manufacturing growth, both of which the US is increasingly missing out on. That downstream industry growth, in turn, is proportionally increasing total returns to strategic critical mineral industries further upstream – industries the US would also benefit from developing, for strategic and security purposes, even more so if it requires less extreme degrees of government subsidization than the pursuit of independence would require.

Above all, US policymakers should proceed with three principles in mind:

1. **Industrial, economic, and national security are all best served by the pursuit of leadership in emerging industries.** China's mineral advantages began with historical state-led development, wasteful and inefficient as it was. But its true – and actually replicable – advantage, now and moving forward, is its support for emerging industry leadership. The US cannot fixate on traditional industries whose growth windows are over. It must look to the future to secure new advantages. Else, it will fall further behind.
2. **Holistic economic security requires balanced upstream and downstream investment.** Without the upstream, the downstream suffers from supply chain insecurity; without the latter, the former depends entirely on government subsidization. Together, though, a balanced equation enables significant growth opportunities. China's NEV industry offers an instructive case study. Thanks to concerted supply- and demand-side supports, NEVs now represent *over 50%* of new auto sales in the world's largest auto market. More broadly, NEVs have become the future of the global auto market (regardless of the US trajectory). Currently, Chinese companies (along with Tesla, although it is losing its advantages) are easily the favorites to seize global growth opportunities – even without access to the US market. The other side: this growth has spurred private Chinese investment in lithium extraction and processing – diversifying China's supplies and reducing risks for its NEV industry with less need for further government subsidization.

3. **The US's ability to resist Chinese supply chain and other trade threats is stronger when it convenes partners than when it pursues total independence.** In the case of critical minerals, it has neither the geology, nor the technical capabilities, nor the market incentives to onshore *everything* it needs to diversify away from China. It *does* have a healthy number of critical minerals it could focus on developing domestically – and which partners and allies could also purchase to diversify away from China. And it *does* have trusted, skilled, resource-rich trading partners who could diversify their own risks by jointly investing with and exporting to the US. For example, Australia is well positioned in many resources, and Japan and South Korean have unparalleled processing and intermediate goods production capabilities, particularly for permanent rare earth magnets. Similarly with Canada. Potential partners across Latin America and Southeast Asia – some of which are already engaged with other mineral-producing US partners – also have exceptional capabilities and could be valuable links in a "big tent" critical minerals arrangement.

Overall, the US will be most holistically secure within a network of trusted trade and investment partners, which would amplify available capital, open up more economical investment opportunities, provide for a wider range of comparative advantages, and diversify financial, technical, and other key risks all around. It will be most industrially and economically secure when it is focused on leveraging such partnership for pursuit of global growth industries, advancing American competitiveness.

In the present context, there is no better means than convening strategic partnership to mitigate the risks posed by an evolving US-China economic conflict – or to promote genuine American leadership in such times of trouble.

Appendix A: Chinese critical mineral export controls

Product (English)	Affected HS Codes
Antimony products	
Antimony ore and raw materials, including but not limited to lumps, granules, powders, crystals and other forms	2617101000, 2617109001, 2617109090, 2830902000
Antimony metal and its products, including but not limited to ingots, blocks, beads, granules, powders, etc.	8110101000, 8110102000, 8110200000, 8110900000
Antimony oxide, purity greater than or equal to 99.99%, including but not limited to powder form	2825800010
Trimethylantimony, triethyl antimony and other organic antimony compounds, with purity (inorganic element benchmark) >99.999%	2931900032
Antimony hydride, purity >99.999% (hydride containing antimony diluted in inert gas or hydrogen)	2850009020
Indium antimonide with single crystals with a dislocation density of less than 50 pcs/cm² and polycrystals with purity >99.99999%, including but not limited to ingots (rods), blocks, sheets, sputtering targets, granules, powders, scraps, etc.	2853909031
Gold-antimony smelting and separation technology	N/A
Bismuth products	
6C001.a. Bismuth metal and products not controlled under 1C229, including but not limited to ingots, blocks, beads, granules, powders and other forms	8106101091, 8106101092, 8106101099, 8106109090, 8106901019, 8106901029, 8106901099, 8106909090
6C001.b. Bismuth germanate	2841900041
6C001.c. Triphenylbismuth	2931900032
6C001.d. Tri-p-ethoxyphenyl bismuth	2931900032
6E001 Technology and data for production of 6C001 items (including process specifications, process parameters, processing procedures, etc.)	N/A
Dysprosium products	
1C905.a Dysprosium metal	2805301200
1C905.a (continued) Dysprosium-containing alloys: • Dysprosium ferroalloys • Terbium dysprosium ferroalloys	Not listed
1C905.a (continued) Dysprosium-containing targets: • Dysprosium targets • Terbium dysprosium ferroalloy targets	3824999922, 8486909110
1C905.a (continued) Dysprosium-containing NdFeB permanent magnet materials	Not listed
1C905.b Dysprosium oxide and its mixtures	2846901500, 2846901993, 3824999922

1C905.c Dysprosium-containing compounds and their mixtures	2846902200, 2846902810, 2846903200, 2846903910, 2846904300, 2846904820, 2846909400, 2846909920, 3824999922
Gadolinium products	
1C903.a Gadolinium metal	2805301910
1C903.a (continued) Gadolinium-containing alloys: • Gadolinium-magnesium alloys • Gadolinium aluminum alloys	2805301910
1C903.a (continued) Gadolinium-containing sputtering targets: • Gadolinium sputtering targets • Gadolinium ferroalloy sputtering targets • Gadolinium cobalt alloy sputtering targets	3824999922, 8486909110
1C903.b Gadolinium oxide and its mixtures	2846901930, 2846901993, 3824999922
1C903.c Gadolinium-containing compounds and their mixtures	2846902810, 2846902910, 2846903910, 2846904820, 2846904910, 2846909920, 3824999922
Gallium products	
Gallium metal (elemental)	8112929010, 8112929090, 8112999000
Gallium nitride (including but not limited to wafers, powders, scraps, etc.)	2850001901, 3818009001, 3825690001
Gallium oxide (including but not limited to polycrystalline, monocrystalline, wafer, epitaxial wafer, powder, scrap and other forms)	2825909001, 3818009002, 3825690002
Gallium phosphide (including but not limited to polycrystalline, monocrystalline, wafer, epitaxial wafer, etc.)	2853904030, 3818009003, 3825690003
Gallium arsenide (including but not limited to polycrystalline, monocrystalline, wafer, epitaxial wafer, powder, scrap and other forms)	2853909026, 3818009004, 3825690004
Indium gallium arsenic	2853909028, 3818009005, 3825690005
Gallium selenide (including but not limited to polycrystalline, monocrystalline, wafer, epitaxial wafer, powder, scrap and other forms)	2842909024, 3818009006, 3825690006
Gallium antimonide (including but not limited to polycrystalline, monocrystalline, wafer, epitaxial wafer, powder, scrap, etc.)	2853909029, 3818009007, 3825690007
Germanium products	
Metal germanium (elemental, including but not limited to crystals, powders, scraps, etc.)	8112921010, 8112921090, 8112991000
District melt germanium ingot	8112921090
Zinc germanium phosphate (including but not limited to crystals, powders, scraps, etc.)	2853904040, 3818009008, 3825690008
Germanium epitaxial growth substrate	8112921090
Germanium dioxide	2825600002, 3818009009, 3825690009

Germanium tetrachloride	2827399001, 3818009010, 3825690010
Graphite products	
High-purity (purity >99.9%), high-strength (flexural strength >30Mpa), high-density (density >1.73 g/cm³) artificial graphite materials and their products thereof	3801100030, 3801909010, 6815190020
Natural flake graphite and its products (including spheroidized graphite, expanded graphite, etc.)	2504101000, 2504109100, 3801901000, 3801909010, 3824999940, 6815190020
Indium products	
3C004.a. Indium phosphide	2853904051
3C004.b. Trimethylindium	2931900032
3C004.c. Triethylindium	2931900032
3E004 Technology and data for production of 3C004 items (including process specifications, process parameters, processing procedures, etc.).	N/A
Lutetium products	
1C906.a Lutetium metal	2805301910
1C906.a (continued) Lutetium-ytterbium alloys	Not listed
1C906.a (continued) Lutetium sputtering targets	3824999922, 8486909110
1C906.b Lutetium oxide and its mixtures	2846901800, 2846901993, 3824999922
1C906.c Lutetium-containing compounds and their mixtures	2846902810, 2846902910, 2846903910, 2846904820, 2846904910, 2846909920, 3824999922
Molybdenum products	
1C117.b. Molybdenum powder with: molybdenum content (by weight) greater than or equal to 97%, particle size less than or equal to 50×10^{-6} m (50μm), used in the manufacture of missile parts of molybdenum and alloy grains	8102100001
1E101.b. Technology and data for production of 1C117.b (including process specifications, process parameters, processing procedures, etc.)	N/A
Samarium products	
1C902.a Samarium metal	2805301910
1C902.a (continued) Samarium-containing alloys: • Samarium cobalt alloys • Samarium-iron alloys • Samarium-nickel alloys • Samarium aluminum alloys • Samarium-magnesium alloys	Not listed
1C902.a (continued) Samarium-containing sputtering targets: • Samarium sputtering targets • Samarium cobalt alloy sputtering targets • Samarium-iron alloy sputtering targets	3824999922, 8486909110

1C902.a (continued) Samarium cobalt permanent magnet materials	Not listed
1C902.b Samarium oxide and its mixtures	2846901940, 2846901993, 3824999922
1C902.c Samarium-containing compounds and their mixtures	2846902810, 2846902910, 2846903910, 2846904820, 2846904910, 2846909920, 3824999922
Scandium products	
1C907.a Scandium metal	2805301800
1C907.a (continued) Scandium-containing alloys: • Scandium aluminium alloys • Scandium-magnesium alloys • Scandium-copper alloys	Not listed
1C907.a (continued) Scandium targets	3824999922, 8486909110
1C907.b Scandium oxide and its mixtures	2846901980, 2846901993, 3824999922)
1C907.c Scandium-containing compounds and their mixtures	2846902810, 2846902910, 2846903910, 2846904820, 2846904910, 2846909920, 3824999922
Tellurium products	
6C002.a. Tellurium metal	2804500001
6C002.b. Tellurium compound monocrystalline or polycrystalline products (including substrates or epitaxial wafers) of: 1. Cadmium telluride 2. Zinc cadmium telluride 3. Mercury cadmium telluride	1. 2842902000, 3818009021 2. 2842909025, 3818009021 3. 2852100010, 3818009021
6E002 Technology and data for the production of 6C002 items (including process specifications, process parameters, processing procedures, etc.).	N/A
Terbium products	
1C904.a Terbium metal	2805301300
1C904.a (continued) Terbium-containing alloys: • Terbium cobalt alloys • Terbium cobalt-iron alloys	2805301300
1C904.a (continued) Terbium-containing sputtering targets • Terbium sputtering targets • Terbium cobalt alloy sputtering targets	3824999922, 8486909110
1C904.a (continued) NdFeB permanent magnet materials containing terbium	N/A
1C904.b Terbium oxide and its mixtures	2846901600, 2846901993, 3824999922
1C904.c Terbium-containing compounds and their mixtures	2846902100, 2846902810, 2846903100, 2846903910, 2846904200, 2846904820, 2846909300, 2846909920, 3824999922
Tungsten products	
1C117.d. Tungsten-related materials:	1. 2841801000

1. Ammonium paratungstate 2. Tungsten oxide 3. Tungsten carbide not controlled under 1C226	2. 2825901200, 2825901910, 2825901920 3. 2849902000
1C117.c. Solid tungsten with the following characteristics: 1. Solid tungsten (excluding granules and powders) with any of the following characteristics: a. Tungsten alloy not controlled under 1C226 and 1C241 and tungsten alloy with tungsten content greater than or equal to 97% (by weight) b. Tungsten doped with copper with tungsten content greater than or equal to 80% (by weight) c. Tungsten silver doped with tungsten content greater than or equal to 80% (by weight) (silver content greater than or equal to 2%) 2. Can be machined into any of the following products: a. Cylinders with a diameter greater than or equal to 120 mm and a length greater than or equal to 50 mm b. Pipes with an inner diameter greater than or equal to 65 mm, a wall thickness greater than or equal to 25 mm and a length greater than or equal to 50 mm c. Blocks with dimensions greater than or equal to 120 mm× 120 mm×50 mm	1.a. 8101940001, 8101991001, 8101999001 1.b. 8101940001, 8101991001, 8101999001 1.c. 7106919001, 7106929001 2.a., 2.b., 2.c. N/A
1C004 Tungsten-nickel-iron alloy or tungsten-nickel-copper alloys with all of the following characteristics: • a. Density >17.5 g/cm^3 • b. Elastic limit > 800 MPa • c. Ultimate tensile strength >1270 MPa • d. Elongation >8%	8101940001, 8101991001, 8101999001
1E004 and 1E101.b. Technology and data for the production of 1C004, 1C117.c, and 1C117.d items (including process specifications, process parameters, processing procedures, etc.)	N/A
Superhard materials	
Six-sided top press equipment, with all the following characteristics: specially designed or manufactured X/Y/Z three-axis six-sided synchronous pressurized large hydraulic press, bore size greater than or equal to 500 mm or designed to use pressure greater than or equal to 5 GPA	8479899956
Special key components for six-sided top press, including hinge beam, top hammer, and high-pressure control system with a combined pressure greater than 5 gigapascals	8479909020, 9032899094
Microwave plasma chemical vapor deposition (MPCVD) equipment with all the following characteristics: specially designed or manufactured with a microwave power of 10 kilowatts or more, microwave frequency of 915 MHz or 2450 MHz	8479899957
Diamond window materials, including curved diamond window materials, or planar diamond window materials with all of the following characteristics:	7104911010

• Monocrystalline or polycrystalline with a diameter of 3 inches or more • Visible light transmittance of 65% or above	
Synthetic diamond single crystal or cubic boron nitride single crystal process technology with six-sided top press	Not listed
Technology used to manufacture the six-sided top press equipment listed above	N/A
Yttrium products	
1C908.a Yttrium metal	2805301700
1C908.a (continued) Yttrium-containing alloys: • Yttrium-aluminum alloys • Yttrium-magnesium alloys • Yttrium-nickel alloys • Yttrium-copper alloys • Yttrium-iron alloys	Not listed
1C908.a (continued) Yttrium-containing sputtering targets: • Yttrium targets • Yttrium-aluminum alloy targets • Yttrium-zirconium alloy targets	3824999922, 8486909110
1C908.b Yttrium oxide and its mixtures	2846901100, 2846901993, 3824999922
1C908.c Yttrium-containing compounds and their mixtures	2846902600, 2846902810, 2846903600, 2846903910, 2846904600, 2846904820, 2846909690, 2846909920, 3824999922

Appendix B: Chinese and US strategic/critical minerals

	Chinese Strategic Minerals List[29]	US Critical Minerals List[30]
Aluminum	✓	✓
Antimony	✓	✓
Arsenic		✓
Barite		✓
Beryllium		✓
Bismuth		✓
Cesium		✓
Chromium	✓	✓
Coal	✓ *	
Coalbed methane	✓ *	
Cobalt	✓	✓
Copper	✓	✓ DOE list only
Fluorite/fluorspar	✓	✓
Gallium		✓
Germanium		✓
Graphite	✓ Crystalline	✓
Gold	✓	
Hafnium		✓
Indium		✓
Iridium		✓
Iron	✓	
Lithium	✓	✓
Magnesium		✓
Manganese		✓
Molybdenum	✓	

Natural gas	✓ *	
Nickel	✓	✓
Niobium		✓
Palladium		✓
Petroleum oil	✓ *	
Phosphorus	✓	
Platinum		✓
Potash	✓	
Rare earth elements	✓ All 17	✓ 16, ex promethium
Rhodium		✓
Rubidium		✓
Ruthenium		✓
Shale gas	✓ *	
Tantalum		✓
Tellurium		✓
Tin	✓	✓
Titanium		✓
Tungsten	✓	✓
Uranium	✓ *	
Vanadium		✓
Zinc		✓
Zirconium	✓	✓

** China's strategic minerals list includes fuels, while the US's critical minerals list explicitly excludes fuels.*

[1] The Washington Quarterly: China's New Economic Weapons
[2] U.S. Congress: H.R.5515 - John S. McCain National Defense Authorization Act for Fiscal Year 2019
[3] MofCom: 《中华人民共和国出口管制法》全文
[4] BIS: Commerce Implements New Export Controls on Advanced Computing and Semiconductor Manufacturing Items to the People's Republic of China (PRC)
[5] METI: 西村経済産業大臣の閣議後記者会見の概要
[6] Overheid.nl: Staatscourant van het Koninkrijk der Nederlanden
[7] MofCom: 商务部 海关总署公告 2023 年第 23 号 关于对镓、锗相关物项实施出口管制的公告
[8] European Commission: Commission launches investigation on subsidised electric cars from China
[9] BIS: Commerce Strengthens Restrictions on Advanced Computing Semiconductors, Semiconductor Manufacturing Equipment, and Supercomputing Items to Countries of Concern
[10] MofCom: 商务部 海关总署公告 2023 年第 39 号 关于优化调整石墨物项临时出口管制措施的公告
[11] MofCom: 商务部 科技部公告 2023 年第 57 号 关于公布《中国禁止出口限制出口技术目录》的公告
[12] MofCom: 商务部 海关总署公告 2024 年第 33 号 关于对锑等物项实施出口管制的公告
[13] Gov.cn: 中华人民共和国两用物项出口管制条例
[14] BIS: Commerce Strengthens Export Controls to Restrict China's Capability to Produce Advanced Semiconductors for Military Applications
[15] MofCom: 商务部公告 2024 年第 46 号 关于加强相关两用物项对美国出口管制的公告
[16] MofCom: 关于《中国禁止出口限制出口技术目录》调整公开征求意见的通知
[17] MofCom: 商务部新闻发言人就两用物项出口管制有关问题答记者问
[18] The White House: Fact Sheet: President Donald J. Trump Imposes Tariffs on Imports from Canada, Mexico and China
[19] MofCom: 商务部 海关总署公告 2025 年第 10 号 公布对钨、碲、铋、钼、铟相关物项 实施出口管制的决定
[20] White House: Regulating Imports with a Reciprocal Tariff to Rectify Trade Practices that Contribute to Large and Persistent Annual United States Goods Trade Deficits
[21] MofCom: 商务部 海关总署公告 2025 年第 18 号 公布对部分中重稀土相关物项实施出口管制的决定
[22] MofCom: 2025 年全国出口管制工作会议在京召开
[23] MofCom: 商务部新闻发言人就加强相关两用物项对美出口管制应询答记者问
[24] CSIS: "New Industrialization": The Industrial Upgrading Theory Driving China's Advanced Manufacturing Policy
[25] Gov.cn: 中华人民共和国国务院令
[26] Trivium China: Gaming out China's next export controls on critical minerals
[27] MofCom: 中日出口管制对话机制第三次会议及政企交流活动在东京举行
[28] MofCom: 中韩出口管制对口磋商及政企交流活动在无锡举行
[29] MNR: 国土资源部：我国将 24 种矿产确定为战略性矿产
[30] DOI: 2022 Final List of Critical Minerals

PANEL II QUESTION AND ANSWER

COMMISSIONER BRANDS: Thank you. We will now move to questions, and we'll go in reverse alphabetical order. But as usual, the Co-Chairs will hop the line.

Mr. Combs, you have a great timeline in your written testimony of the various coercive measures that the PRC has rolled out. And so we've seen, really over a series of years, the development and deployment of this coercive toolkit. And so could you just say a little bit more about the evolution of that toolkit over time, how Beijing assesses its effectiveness. And you mentioned that there is a lot of leverage left to be deployed, so what are the next places this coercive toolkit might go?

MR. COMBS: Absolutely. Several pieces there. First, I would confirm that for China, the mineral strategy in China has evolved. It's very complex. It is different by industry. In the case of rare earths it started during the Mao era. It was involved with Soviet mining processes. Others are very new. Lithium was not really in major demand until the last 20 years or so, maybe 30.

Increasingly, what China was looking to do, and local economies in particular, especially in inland provinces that had few development opportunities, they said, "What can we do?" Well, we can leverage our natural resources, build more. So a supply-led system in that case. And now, in the contemporary strategic environment, Beijing has said, "What is our form of leverage? What else do we have besides tariffs," which are disproportionately effective from the U.S. side compared to the other way around, and then sanctions, et cetera. And so China, at a national level, has built on these existing advantages in a variety of ways, but most importantly in the export control side.

So a brief background on the export control regime. China's export control regime is, in its modern form, quite nascent. The Export Control Law of 2020 was the first of its kind. Before that there was a patchwork of different sometimes agreements with international partners on, for example, nonproliferation, in some cases there was a direct block on a particular technology to maintain a strategic advantage in one industry, but very, very narrow, not something that was particularly market distorting.

Now it is a consolidated framework that includes two different lists of controls. One is a list of goods whereby goods can be very quickly and efficiently added to the list to say if you produce this we must track it, and you have to give us all the information about the end user, and we can approve or deny that license. In other cases it is completely banned. The other side is a list of entities to which the Chinese authorities will not approve, and this is mostly defense contractors.

In many ways a lot of what Chinese export controls look like, in terms of the processing, is not dissimilar from a lot of the ways that the U.S. and other economies manage. The difference is in the degree of weaponization, driven by the degree of control that they have.

So right now the critical minerals lists are, I mean, effectively, when we call minerals critical, it is a political and technical determination. So it's basically a roadmap to what every economy deems critical, so that's why we look at these first. And Beijing has done likewise, and looking to materially retaliate is effectively a roadmap for how to have material impact.

Now it's also a signal to markets of where investment is needed, of where the demand will lie. And so that is the flip side of the equation, I do want to highlight in talking about critical minerals as a concept.

But beyond that I would note that we're basically moving down the list of minerals over which China has the most control and are most impactful. And so one of the challenges now is that future controls are getting increasingly complex. We look at the most recent ones. Bismuth is used in just a staggering array of everything from Pepto-Bismol to military applications. It is very difficult to trace all of the supplies of that and all of the applications, and to strategically say we'll make one investment to support, especially given -- I have a very extensive appendix here. I apologize for the page count. But just to list out the degree and the variation in the particular minerals and materials controlled. We expect the complexity of these controls to get even more significant over time.

And I would note that there were two different dimensions of impacts, in my personal view, of the controls. One is very obvious. If you need tungsten to make an airplane, and you can't get tungsten, the impact is very obvious.

The other side, though, is the uncertainty. When we see certain controls like tellurium or bismuth or others that are not necessarily household names, in many cases it took weeks of corporate and government time, energy, and money to figure out where the supply chains are and what they're needed for. And so that uncertainty itself is a major market driver and a major form of retaliation in itself, and something I would like to flag as a potentially increasing issue moving forward. Thank you.

COMMISSIONER BRANDS: And is it fair to say, just briefly, that Beijing is learning as it goes. It's learning about how these controls work. It's understanding. It's becoming more sophisticated. And so we should expect China to become a more adept, sophisticated user of these controls in the future.

MR. COMBS: I would agree with that assessment.

COMMISSIONER BRANDS: Thank you. Commissioner Goodwin.

COMMISSIONER GOODWIN: Thank you, Commissioner Brands. Ms. Logan, in your testimony you talked a little bit about China being able to prove somewhat resilient to some trade barriers that the U.S. has put up, shifting some of these clean energy products and excess capacity to other markets, especially in the Global South.

Provide a little bit more context on the ability of those markets to absorb that excess capacity. How big are these markets? How much can they take? And then, of course, what can the U.S. do to educate our partners in those regions on the risks?

MS. LOGAN: Thank you very much for the question. So first of all, the overall share, as I mentioned, of China's clean technology exports to the Global South has been growing as compared to that going to developed countries. And I think I referenced the example of EVs in particular now eclipsing those going to the EU, that are going to the Global South.

This is to say that some of the Global South countries are, of course, also concerned about the impact of exports toward their domestic economies and China's alleged dumping in terms of how that impacts their ability to drive economic benefits from some of those industries. So you are seeing, in the Global South, some examples of countries also adopting trade barriers toward some of the exports, including Turkey, India, and Brazil.

But I want to draw a distinction between exports and foreign direct investment and manufacturing capacity, because I think those are two different stories. And I referenced in some of my remarks the idea that initially a lot of the FDI was perhaps driven more by attempts to circumvent some of the trade restrictions. But now we're seeing trends where Global South countries are increasingly open to FDI and Chinese companies also as they want to grow their global presence in markets that are mostly, as I mentioned, private enterprises desiring to actively invest in overseas manufacturing capacity beyond just trying to circumvent some of those trade restrictions. And you see other countries welcoming that and not having the same sort of concerns that perhaps we see in some of the developed countries about welcoming that FDI. So for instance, I referenced in my longer testimony, Brazil, where there have been significant investments from electric vehicle manufacturers and manufacturer capacity domestically, despite some of the restrictions on trade.

So I will say, still, the developed markets are higher end markets compared to the Global South markets, but the demand in the Global South markets for new technologies is growing. And I think a really interesting example, as well, is how some of these markets are importing products because of reasons related to their electricity prices in the first place. I also reference in my testimony the example of Pakistan, where they imported 20 gigawatts of solar panels from China last year, largely as a result of energy prices from the grid being so high, which, in part, has to do with Chinese investment in coal-fired power plants in the first place, that it's more economical for small and medium-sized enterprises in Pakistan to import Chinese solar panels to power their small and medium-sized businesses, largely through off-grid power than to continue to offtake from the grid.

So overall I would emphasize that the demand is growing from third markets, though some of them may have concerns from a trade perspective. I would say that the trend then shifting toward FDI will continue, and Chinese companies also have an interest being private enterprises and continuing in that direction.

COMMISSIONER GOODWIN: Great. Thank you.

Mr. Combs, I want to return to your discussion about investing upstream and downstream, and effectively creating demand, or investing in demand. In your testimony you talk about this in the context of the EV industry in China, and note that investments in the electric vehicle industry in China also created a market and attracted private investment, or investment, into upstream inputs -- lithium extraction and processing. And I've heard everyone on the panel say we need a dedicated and comprehensive strategy to respond to what has been a comprehensive and dedicated strategy on the part of the PRC.

Does that include investment in the downstream, in creating demand, and recognizing the tension. Just recently the news noted the cancellation of a billion-dollar battery manufacturing facility in a U.S. state. And if you go back through some of the press coverage you'll note some of the same people that applauded the initial investment noted and observed that investing in the EV industry, and in battery manufacturing, was a matter of economic and national security. At the same time, when the question is raised about incentivizing downstream demand for EVs, the response was, "We don't want to distort the market. Consumers should make that choice."

How do we reconcile that tension if we intend to craft this sort of comprehensive strategy that you say we need?

MR. COMBS: Excellent. Thank you.

COMMISSIONER GOODWIN: In 30 seconds.

MR. COMBS: In 30 seconds. Consumers are intelligent. Consumers go toward the best options at the best prices, and there is a balancing point there.

What China's most successful, I would argue, industrial policy -- let's keep it in the EV silo -- was not picking a winner. It was specifically saying that the reason we talk about new energy vehicles is because China did not say we will have lithium-ion powered electric vehicles. They said we will have new energy vehicles, because that is the future. But we don't know which piece of that is the future, so there's a competition around that.

And now we have a flood, absolutely with state support and with state guidelines and kind of encouragement. But what that did was create a demand signal, saying we will help with licensing, we will help with the processing of the factory paperwork, all of these things, tax write-offs, whatever it is, fairly standard in many cases, localized in some other cases.

But effectively they incited a competition, one that is still fierce and one that obviously has driven overcapacity issues which are related and a separate topic. And now we see, finally, the consolidation of China's electric vehicle industry, from 300 down to 100 to now about 40, maybe 35 real companies left. It'll come down to 10, and the winners will be the most battle-tested of the electric vehicle side. Hydrogen has largely, but not entirely, lost that battle. We've consolidated toward lithium-ion.

And now BYD, as of this past week, is opening the battle on sodium-ion batteries. Beijing did not designate any of these pieces. What they said is this is the direction of travel, and encouraged the competition, and the market went out and consumers picked the winners. I think that is the balance of management, from the government side, incentive from the government side, and enabling constructive competition. Historically, when China has failed to enable that, and more often than not, frankly, China's industrial policy has suffered because it doesn't lead to constructive competition. The SOEs are not competitive in most industries. This is where, I think, the private sector in the U.S. has a better opportunity.

COMMISSIONER GOODWIN: Thank you.

COMMISSIONER BRANDS: Commissioner Shmavonian.

COMMISSIONER SHMAVONIAN: Thank you. Building off that line of questioning, the United States is really seeking to build out our critical minerals recycling, and we are investing heavily in that, both through funding through the Loan Program Office and other grant-making entities within the government, and also through demand side, through the foreign entity of concern requirements with respect to the 30D electric vehicle credit and other measures.

So Mr. Menell, I would like to start with you, and then Mr. Combs, if you'd like to chime in, or anyone else on the panel. Can you just talk through whether the work that we have done so far is sufficient to give investors the level of confidence they need to make the types of investments we want in that space, given the fact that China, as we have seen over and over again, can just turn the dial a little bit and crash the cost of a specific product?

MR. MENELL: Certainly China's present market manipulation and oversupply of some of these metals into an already temporarily short-term, weak market environment has made building capacity that much more difficult. Certainly financing support for critical minerals, and particularly lithium-ion battery recycling on behalf of a number of government agencies, has been enormously valuable. And recycling is certainly an important part of the ecosystem that we have to build to secure resilience and critical mineral supply chain security for the United States.

So that's a part of the answer but it's not the answer. It's a very difficult industry to make commercial in the short term. Even though there are technical solutions for recycling lithium-ion batteries, they're relatively expensive and require fairly substantial volumes of feedstocks in order to build scale that makes them competitive.

The landscape for lithium-ion battery recycling have become very crowded and fragmented, partially as a result of the availability of Department of Energy loan program and other support mechanisms, as a result of which the commercial viability, and hence, scalability is that much more challenging.

But even when it does succeed, which it will succeed and must succeed in terms of a fully developed recycling ecosystem for these critical minerals, it'll still only provide a maximum of 20 percent -- this is in 10 years' time -- 20 percent of battery metals and rare earth metal inputs into the manufacture of new batteries and electric motors and other essential components.

So it's important, and that does have environmental benefits, it has cost benefits, and it has benefits in displacing reliance on newly mined materials, which are overwhelmingly dominated by China. But it's not the solution. It's a bit of the solution.

MR. COMBS: Thank you, I'll make a couple of brief additions. Completely agree. One of the issues is there's a severe distinction in the tolerance for low margins between the up- and downstream. I mean, that leads to your point. When we're talking about upstream industries in China, there is a combination of private, hybrid, and state-owned support, but where it's state-owned they can tolerate the low to zero margins. In many cases, Beijing has actually been attempting to increase prices by restricting, for example, the illegal mining of rare earths, which continues to be a perennial problem after 20 years, Beijing has been trying to deal with this issue. But it's the local economies. It's entrenched. No local leader wants to cut off revenue and jobs in a relatively low-growth, low-income environment.

And so Beijing, even internally, I would like to recognize has many issues with price. The infamous quote that rare earths are being sold at "earth or dirt cheap prices" as opposed to "rare prices" is something that has driven Beijing's concerns about upstream low margins for a long time. And the state basically absorbs a lot of that cost.

On the flip side, where we see private investment, it's in vertical supply chain integration, and that's in the case of CATL and BYD, these battery and electric vehicle leaders, as you referenced earlier, investing in lithium. It's okay for them because the value is not the marginal financial value of that product. It's the risk mitigation they get through that investment. That's the value to those companies. And that's where I say in some, this is why all the minerals are very distinct in how they operate. But in the case of lithium, for example, there is certainly a state interest in ensuring supply, but there is also a very commercial interest. And they are willing to absorb that cost because it lowers their risk.

So there are a couple of different ways you can come at a tolerance for low margins, but in our case, if we do not have either massive state subsidization or companies interested in investing at these low margin, top end in the supply chain, it is very difficult to move forward.

COMMISSIONER SHMAVONIAN: Thank you.

COMMISSIONER BRANDS: Chair Price.

CHAIR PRICE: Thank you all for your participation today. I have a couple of quick questions. Ms. Logan, in your recommendation number three you talk about not ceding the space at international institutions. But you didn't go into a whole lot of detail about where we might be falling behind. Can you talk a moment about what you're trying to make sure doesn't happen?

MS. LOGAN: Sure. Thank you very much for the question. So in my longer written testimony I reference the fact that China has been increasing its contributions to multilateral development banks significantly in recent years. I believe in earlier years it was about half a billion per year, but then in recent years as high as 4 billion per year. This is for climate-related financing specifically, but that just reflects a broader trend.

And part of what I'm getting at is that these banks are lending in the projects that lead to development for those host countries, and in many cases those projects focus on new energy technologies, energy transition. So if the U.S. stays within these institutions and wants to lead the way, they need to continue their investments in these new energy technologies and climate investments. Otherwise, China will continue to seek opportunities through other multilateral development banks. But also if the U.S. cedes the ground in these spaces China will continue to leverage these spaces for its own aims, as well.

CHAIR PRICE: Thank you. Mr. Miller, very sobering testimony. So rip-and-replace not being possible, your testimony was very much at the 40,000-foot level. Where would you start?

MR. MILLER: Thank you for the question. Yeah, the place to start is essentially, the cyber-informed engineering is one of the first places I would look at when we're designing new systems. The legacy problem is a much different situation. So new systems going forward, we need to look at ways to make them more reliable, more resilient, so that we don't have to shut them down. We can continue operating them. We can do that through cyber-informed engineering, which puts in additional controls that are not necessarily cyber in some cases. They're analog, for example, or just a different design.

One of the examples in a water system is if, let's say you hack the control system, the digital components that you control the system with, to 10 billion parts per million. Well, the pipe that delivers the chlorine is teeny, tiny. It just physically can't do that, even though you set it to that setting, for example. So designing the system in ways like that is one example for future systems.

Rip-and-replace in legacy environments is challenging because for the power grid you have to take the system down, which is the reason you don't want it to go down. So taking it down to avoid it from going down is the crux of the problem.

Designing systems alongside the existing environments, which means you have to have basically two systems, test them, make sure that they work reliably, peel off the old system, that's pretty much how we do this traditionally to keep the system running, maximum efficiency all the time. We're running our transmission system at roughly 90 to 95 percent continuously, all the time. There's very little additional capacity there. And there's three basic different systems -- distribution, transmission, and generation -- so there'll be different approaches for each one of those verticals.

Does that come close?

CHAIR PRICE: It comes close. I was looking for specifics -- water, electrical grid.

MR. MILLER: Yeah. It's replacing individual components, or since we can't rip-and-replace, the challenge is isolating the ones that we have. There is a good friend of mine that calls this living on a diet of poison fruit. We have to continue, but we can't basically just rip everything out.

So in those cases you want to isolate the individual devices so that they can't communicate outbound. They can only communicate locally, if they do. And there's even been some discussion around taking what we currently have, reverse engineering it and finding out if we can actually replace the Chinese software with our own version, so that we can continue to use that machine, that piece of equipment, but not with their software, with ours instead.

CHAIR PRICE: Helpful. Thank you very much.

For Mr. Menell and Combs, both of you refer to leveraging partners and allies as we move forward. What would that look like?

MR. COMBS: There are many opportunities, the most basic of which I think would be strategic trade relationships. One of the issues, as we talk about on the investment side, is if investors do not see a reasonable rate of return possible on a project, they're not going to pursue it. And so part of the issue is locking off a market where you have other incentives to trade. That is not simply -- a kind of generalized tariff regime is probably not going to do the trick because that's really helpful for moving one source of supply to another, but the other has to exist for that to work.

And so what we're talking about more is agreements that are very targeted, say, if we say with X partner, we will provide you the tungsten that we can produce in, say, Nevada. In return we want certain guarantee on imports of cobalt or something, just things of that much more specific nature. And that's something that makes this much more complicated. There are probably better multilateral regimes for this, but in the short term, very specific, designated partnerships could be a first step toward understanding.

And I have to note, the complexities of supply chains continues to be an issue, certainly at a high level but also for many individual companies that are currently doing this at a small scale all over the country. I have dozens of clients who are trying to figure this out right now, which countries, which companies do they talk to.

And so part of the issue is information sharing. They're all kind of doing, in some ways, duplicative work. And I think there is a chance for kind of, maybe the government with a bigger view, and also other strategic interests such as national security, to support in that effort.

But long and short, there's a challenge of overprescribing versus leaving it entirely to the market. Neither is quite efficient or effective, as far as we can tell. And so finding that balance is definitely tricky, but I would suggest starting with specific supply agreements.

MR. MENELL: Yeah, I mean, there's no question that domestic production processing alone can't possibly secure adequate supply of these critical minerals to feed U.S. national security and industrial competitiveness. It has to be a global initiative to secure these feeds.

In my view, the solutions are not Mineral Security Partnership type solutions, which is an initiative launched and promoted by the State Department, which is really a diplomatic, feel-good exercise. You know, efforts to build global supply chains to support the United States have to be driven by incentivizing or enforcing allied supply chains rather than relying on goodwill.

It's certainly the case that Europe has similar problems, vis-à-vis Chinese control, that the United States has, and it's certainly the case that the United States is similarly positioned globally and ideologically to Europe with respect to fear of the rise of Chinese dominance and wish to protect sort of freedoms and democracy. However, we're entering into a period of structural short supply of these materials globally, beyond this present short-term market weakness. Two, three, four years out there's going to be major global structural short supply, China aside, of lithium, nickel, rare earth metals. And therefore, the United States, United States national defense industry, United States industry in general, is going to be competing for scarcer sources, not only with China but with Europe and allies. And that's a reality we have to accept.

And therefore, who gets the cobalt out of the Congo, between industry in Germany, feeding the creation of growth in jobs in Germany, relative to industry in Detroit, creating jobs for American workers, is going to be determined now by what the United States does in the Congo with respect to cobalt, or in Brazil with respect to what we're trying to do in nickel to counter Chinese control of global supply out of Indonesia. And that requires a much more robust use of carrots and sticks than has been the case historically.

So if we take the cobalt in the Congo as an example, they are the overwhelmingly dominant global producers of cobalt. While everybody else was sleeping over the last 15 years, China has built up an overwhelmingly dominant position with respect to control of primary resource and control of processing capacity to take cobalt hydroxides and other materials out of the Congo, to China, where they produce high-purity battery metal chemicals going into battery manufacturing and everything else. That requires cobalt, including high-performance alloys for aerospace and defense.

And how do we counter that? We counter that by going to ensure that U.S.-aligned interests have preferential access to these resources and flow of product out of the Congo. And we do that with leverage, like the ability to sanction, the ability to provide military and intelligence support in conflicts such as the Eastern DRC, and we do that by creating mechanisms for aligned industry partners to be able to fund, which means offtakes to provide price floors for critical minerals by the National Critical Minerals Stockpile in the Department of Defense. It means what the DFC, our shareholders can do with respect to financing project development and political risk cover.

It's a multiplicity of programs that are, in many instances, there, but need to be accelerated and expanded in order to achieve those ends. And it's not just cobalt in the Congo. It's lithium in Argentina and Australia, and it's nickel in Brazil and elsewhere, and rare earth metals, which are overwhelmingly dominated by both Chinese mining and processing.

CHAIR PRICE: Thank very much. Sorry.

COMMISSIONER BRANDS: All good. Commissioner Miller.

COMMISSIONER MILLER: Thank you. I'd like to build off Chair Price's line of questioning. Mr. Miller, your testimony was rather scary. Well, all your testimonies were very scary. Mr. Miller, your testimony was particularly scary, I thought. You had a section on U.S. reliance on Chinese energy equipment.

MR. MILLER: Yes.

COMMISSIONER MILLER: And you highlighted a significant concern lies with high voltage power transformers, which form the backbone of bulk power transmission, widespread adoption of distributed energy resources such as solar photovoltaics and associated inverters, which are frequently sourced from Chinese manufacturers. As the grid modernizes, energy management systems, smart meters that advance metering infrastructure are also increasingly sourced from Chinese vendors. PRC-made control systems and energy storage units nationwide. This is quite a list.

You also describe them as long-term, strategic vulnerabilities, which of course they are.

MR. MILLER: Yes.

COMMISSIONER MILLER: And we have never been good, as the United States, has never been good at getting our ducks in a row to get a strategy on these long-term strategic vulnerabilities.

But what I'd like to ask you about are the short-term potential crisis points around this. If we're to look at this not as a long-term plan, which we should have also, but as the potential for this decade there could be a serious confrontation with China, and these things could crash down right away, how should we think through what our options are? I know you laid out a priority or two to Chair Price in terms of what we should be doing. But if we were on a much shorter timeline, and actually had a secondary game plan that was focused on worst case scenario, what do we do to make sure that if something bad happens in the next several years that we are doing all we can in order to mitigate these problems? How would you redirect our attention?

MR. MILLER: Thank you for the question. That's a complex question. I'm going to divide it into two parts. There is the Chinese threat that is coming in to the utilities to take control of the systems that they have. Those systems may or may not be already Chinese-manufactured. They may be manufactured anywhere else. Most of the control systems are manufactured in Europe and some here in the U.S., in terms of where the code is written, for example. Some of the equipment itself is also manufactured here in the U.S., like Schweitzer gear, for example. So that's one set of problems.

The second set of problems is the Chinese-made equipment that makes it easier for the PRC to take over that equipment or misuse that equipment. So those are two separate issues.

The first one, where we have Chinese gear, we have to live with it. We have to, as I mentioned earlier, isolate it as much as possible and monitor it extensively, so that we know if it's misbehaving in any way. If we can, we can do things like try to repurpose it or reverse engineer it, to better understand it. Those are things we can do right now.

Now, there are larger installed bases of certain types of equipment, so start with those. Obviously, the smaller numbers, worry about those when you can get to them. That's the equipment that's manufactured and made in China that we have to worry about. That's that issue.

The part where the Chinese actors are actually accessing our systems and can possibly control our systems, different issue. That is helping those utilities in some way discover that this is someone in their environment, which can be, as I mentioned in the earlier testimony, for the larger utilities they're very complex. There are a lot of seams, a lot of silos. Smaller utilities, they have lower funding. They typically have lower defenses. Not always, but they typically do. They are often seen as training grounds, but they are connected to the other utilities in lots of ways.

So the way you approach those two different organizations will be different. Giving them assistance is a good thing, because they're currently trying to do things like keep the power on all the time, 24/7, and at a very diversified funding streams for how they can do things. Cooperatives, municipals, investor-owned utilities all have very different types of funding for how they can fund their security. So some of those options would be useful, as well.

That's kind of the two situations I would look at going into immediately. The third leg of the stool is going to be assuming the worst. Just in case things go wrong, we need to be able to continue to operate, even if it means operating in something like a degraded or limp-along kind of fashion, but restarting an area of the grid is incredibly difficult. So keeping as much of it lit as you can in islands, in ways, makes it a lot more useful in terms of its ability to resync and -- we call it black start, but reenergize areas of the grid.

COMMISSIONER MILLER: Thank you. Let's continue our theme of scary, scary, scary. Mr. Menell and Mr. Combs, you ran us through some also scary figures about import reliance on the top 50 or so critical minerals. Thinking short-term again, two to five years, this decade, assuming you were given a high budget and unlimited authority, what would you do in order to secure these critical minerals, and as a big-picture look -- so from 40,000 feet -- what's doable? What share of these minerals could we reshore or friendshore through some sort of new supply chain, in which are we probably going to be screwed? And if we're screwed, then we, of course, have to think about the other side of the equation, which is we have to possibly have offensive capabilities in order to create pain on our adversaries, because everybody's going to be in a bad situation.

But how would you look through the next two to five years in terms of the short-term vulnerabilities, critical minerals, what can we do?

MR. MENELL: Firstly, talking about scary, the situation is, despite increasing analysis and prioritization in the U.S. since the first Trump administration and growing under Biden and now the new administration of critical mineral supply chain security and the increasing proliferation of government programs to support U.S.-allied supply chains, the situation continues to get worse every day.

Every day, in this present, weak, China-oversupplied market, projects aligned with U.S. interests are being slowed down or scrapped, and therefore medium-term shortages, two years out, three years out, are growing every day. And Chinese control over all of these global supply chains is growing every day, because they're not slowing down their programs. They're accelerating their investment in nickel production in Indonesia and lithium production in Australia and Argentina, and cobalt production in the Congo. So the situation is becoming more urgent and more of a pressing imperative to deal with literally every day.

What we do about it is the key, and what we do about it with the two- to five-year time horizon is an enormously big challenge because of the long-term nature of a lot of the projects that we need to build in order to supply United States defense and industry in a manner that's not beholden to China, with their 20-year head start.

And we can't realistically out-Chinese the Chinese. They're very good at being Chinese in terms of cheap government money, in terms of lower environmental licensing standards at home, in terms of the economies of scale and process technology experience that they've built up while everybody else was sleeping, and as was mentioned by Cory earlier, their capacity or willingness to subsidize low-margin elements of the supply chain in order to control the supply chain, which we don't really have the capacity to do.

So in my view the answers are not to try and be China but what we can do is out-innovate China. We can out-innovate China like what we're doing in heap leaching of nickel laterites in Brazil to counter reliance on Chinese Indonesia production, like what we're doing with building direct lithium extraction technologies so we can produce all of the lithium the United States needs from lithium brines in the Salton Sea in California, from the Smackover in Arkansas and Texas.

So that we need to support and accelerate, and that's where government funding and support needs to go in doing things differently, where we can build quicker, cleaner, better, rather than just trying to do what the Chinese are doing in America, which is really difficult to compete with.

The other thing we can do, and this might sound improbable, but we could outspend the Chinese, not necessarily with state funding but by state incentivization or regulation or encouragement of private sector sources of funding, the Blackstones and the BlackRocks of this world, to deploy capital in areas such as critical minerals that are ones of national strategic imperative. And we're not doing that. These big institutions are ignoring our industry, because historically it's been considered to be an ESG and PR risk, and therefore best left to somebody else, i.e., the Chinese. And that's irresponsible.

We also need to find ways to incentivize or regulate or encourage U.S. industry to support the supply chains. The GMs of this world who need to secure critical minerals, inputs to ensure their industrial competitiveness, to ensure jobs and growth in the United States and their future existence relative to Chinese and European competition, are doing very little to take equity risk in the supply chain to secure preferential access to product, because they're conservative, big organizations who don't move as quickly as the United States needs them to move, to play the role they need to play for the United States' future success and growth and security.

And, therefore, there's a lot we need to do differently --

COMMISSIONER MILLER: Mr. Menell, maybe I might just ask you to wrap up briefly, and maybe, Mr. Combs, just a very brief answer, and we can come back to it in a second round if we need to.

MR. COMBS: Thank you. Ultimately, the United States does not need nearly the same degree of mineral resource as China, because it is not a manufacturing-led economy in the same way. It is not a sizeable domestic economy in terms of production of these goods, because it's a smaller population and needs.

So in many ways one thing I would encourage is that the U.S. does not need access to the places with the greatest reserves. They need access to the lowest-risk reserves, and they need access to partners who can help with the integration of supply chains, to reduce the costs of mitigating those risks. This does not mean the U.S. has to go to the cobalt in the DRC, can go other places where there are lower risks. There are costs associated with risks. So one is that piece.

The other is to recognize that these goods are, by and large, undifferentiated. One of the issues, whether that really means, is that these are unusual markets but they are markets. I am not concerned, ultimately, about China trying to cut off the world. What China is interested in, primarily, with these markets, is to ensure that its downstream industry has what it needs at low cost to be competitive. And it'll weaponize it to the extent that it needs. But also there are other producers, there are other suppliers, and China itself benefits from having some competition, as well.

So recognizing this ecosystem we're in is very market oriented, even with the state backing. We need to operate in that ecosystem, looking for the lowest risks, not necessarily the highest yield in terms of total value.

And then that goes for innovation, too. We can create innovative methods, but if they're not low cost, they're not competitive. And so that's the key, is all power to the innovation, but we need low-cost sources, and I think that comes from partners.

COMMISSIONER BRANDS: Commissioner Kuiken.

COMMISSIONER KUIKEN: Thank you, Commissioner Brands, and thank you to the witnesses for being here today.

Ms. Logan, I think I heard in your opening statement that you recommended the idea of a commission, or Congress direct a report on a number of things. I love reports. My question would be to you, do we already know the answers, and what do you think the answers should be?

MS. LOGAN: Thank you for the question. Yes. So what I was recommending is that Congress commission an updated report specifically on the risks of decoupling from China on new energy technologies. I think that we have commissioned a number of reports on the dominance of Chinese industries, how they got there. We have a pretty good understanding of China's domestic economy, the different drivers, whatnot. But I think where we're uninformed is on the risks of the path that we're taking in terms of de-risking and/or decoupling, and what that looks like in practice and how that plays out in the near term.

COMMISSIONER KUIKEN: Thank you, Ms. Logan. You've been listening to the other witnesses, and I've noticed you've been nodding your head and shaking your head. I always enjoy witnesses and the nonverbals. I'd love to sort of hear your reaction to the other panelists and your neighbors here and some of the things they're saying. Because I think a lot of people agree with what they're saying. I'd be interested in just your view and whether or not you share those views on critical minerals, on the energy crisis, dependence on Chinese for a variety of other goods. What's your view?

MS. LOGAN: Thanks again for the acknowledgement of my reactions. I agree that we're in a really challenging situation in terms of China's dominance of a lot of supply chains for critical new energy technologies, and that the pathway to de-risking and protecting American interests in both the near term and the long term is really difficult, really challenging, and that we're not doing enough to invest specifically in some of what's needed, especially from the processing perspective for critical minerals and rare earths. I think that we've put a lot of attention on sourcing in the first place, but not enough attention on the full supply chain.

For instance, also there was a report yesterday, or earlier this week, in *The New York Times*, about a rare earths mine, I believe in Brazil, that was invested by Americans in part, but they couldn't basically get contracts for their exports to be processed by U.S. or allied facilities because China had basically already locked in the processing for a number of years into the future, even though that mine, I believe, was invested by Americans, in part.

So I think all things considered, the strategy in the near term, as it relates to some of these risks, needs a lot more attention. At the same time, I also think that we need to right-size where there are critical security risks as it relates to the tradeoffs with other goals such as the energy transition as well as economic priorities and job creation. And I think that there are ways to do that, that could, in part, leverage some of the techniques that China has used to adopt technology transfer for their benefit, in reverse for our own benefit, as well.

COMMISSIONER KUIKEN: Thank you. Mr. Combs and Ms. Logan, I think you partly just answered this, Ms. Logan, but I'm going to ask the question anyway, just to give you another chance and give Mr. Combs an opportunity.

Do we have a critical mineral, rare earth crisis, like where we can't find them, we're running out of them, China has them all? Or do we have a refining crisis? Or maybe both. Actually, let's go Mr. Combs and then Ms. Logan.

MR. COMBS: There are layered risks on different time horizons, and I think this is why we'll hear some people say, "No, we're fine, because we are still producing a lot of the things" --

COMMISSIONER KUIKEN: Hold on. Hold on. What are the layers?

MR. COMBS: Layers, yes. Immediate term, there are stockpiles. We're good for a few months. Medium term, a lot of the things that we need we actually don't import directly and then produce. Permanent rare earth magnets mostly flow through Japan, South Korea, especially Japan, and some China, but we can get that elsewhere, as well.

Longer term, if things escalate to the point where Beijing attempts to enforce long-arm jurisdiction, which would mean, in this case, for example, prohibiting Japanese, or retaliating against Japan and South Korea for exporting said intermediate goods containing Chinese minerals, that would be a much bigger risk.

Now there are a lot of reasons that are very clearly against Beijing's interest to do that, except in an extreme case of very intense trade and economic conflict. That is basically what they've been warning is the ultimate sign, and they've very clearly indicated they do not want to reach that. But that is ultimately the end.

COMMISSIONER KUIKEN: Do I have a mineral crisis or a refining crisis?

MR. COMBS: Right now, primarily refining. The processing is the worst.

COMMISSIONER KUIKEN: Ms. Logan?

MS. LOGAN: Don't have much to add. I also agree that it's more of a refining crisis, if you had to pick, at the end of the day, rather than a supply crisis.

COMMISSIONER KUIKEN: Okay. That's helpful.

My dear friend, Mr. Miller, asked a question about giving you unlimited resources to solve the problems. I'm going to constrain you by saying it's highly unlikely that Mr. Miller's scenario becomes true, or Commissioner Miller's scenario becomes true. It's much more likely that you are able to take a number of small, incremental steps, some that the executive branch can take unilaterally and some that require congressional action.

Ms. Logan and Mr. Combs, what are the baby steps that we could make, either through executive action or through congressional legislation, that don't require sort of, you know, running into political headwinds, but where people across the aisle can sort of hold hands and jump into the swimming pool together?

MR. COMBS: I think if there were easy solutions we would have taken them. I think if there were solutions that didn't face massive political headwinds we would have taken them. So obviously I would like to give a constructive answer, but I want to be realistic about the issues there.

COMMISSIONER KUIKEN: That's a dark answer, Mr. Combs.

MR. COMBS: I know.

COMMISSIONER KUIKEN: Ms. Logan, let's get some optimism here, for some like five baby steps.

MS. LOGAN: So I'm afraid that I also don't have much optimism, as well. But I think where we've gotten to in terms of the current trade situation with China, I think at the end of the day I would say that China is interested in coming to some sort of constructive resolution, from a trade perspective. And in that regard, one of the aspects to consider from that is what I referenced earlier, in terms of how we leverage this opportunity to benefit the U.S. domestic economy and take advantage of some of China's knowhow and technology where we don't necessarily have that ability yet to do so domestically. So in that sense I am supportive of reverse tech transfer requirements for Chinese foreign direct investment in the United States, and I think that's something that could potentially see support.

COMMISSIONER KUIKEN: Thank you, Commissioner Brands.

COMMISSIONER BRANDS: Commissioner Friedberg.

COMMISSIONER FRIEDBERG: Thank you very much. Mr. Miller, I would like to start with you. Does the Federal Government currently have the legal authority to mandate corrective measures of the sorts that we've been discussing, those steps be taken by power companies around the country? Does it have the power to do that?

MR. MILLER: Thank you for the question. Short answer is yes, but only for a limited number of utilities. Currently, through the Energy Policy Act of 2005, Section 215, that gives FERC the authority to create the Electric Reliability Organization and create mandatory and enforceable cybersecurity standards for what's known as the bulk electric system. That bulk electric system is 100 kV and higher, which is transmission, and then in the generation space it's going to be 75 MVA aggregate at a point of interconnection. So those are generally larger transmission and larger generation companies. And that was done to protect the bulk system.

We're looking at a situation where there are many other aspects to the power grid now that go beyond just those bulk elements. So the short answer is yes, but only for some players.

COMMISSIONER FRIEDBERG: Okay. Thank you. Mr. Combs, you've described how China might use, or has used, its control of supply chains for certain critical minerals to respond to or to retaliate against the United States or other countries that are doing things it doesn't like. Have you considered the possibility that China, at some point, might use its control for offensive or coercive purposes? Have they not done that yet simply because the occasion hasn't arisen, or do you think there's some reason why they would just not do that under any circumstances, to be the first mover?

MR. COMBS: My sense right now is that Beijing is in a very defensive position in two regards. One is that its economy is still struggling. It cannot afford to start conflicts that will inherently undercut its economic interests and growth.

And the other is as a much broader, more strategic pivot. It's trying to move up the value chain. It has a massive ongoing economic upgrading effort, the central piece of which is industrial upgrading. Effectively, the more trade for China, the better. And so anything that cuts off trade, namely when it cuts off trade, there are retaliatory measures to it, for example. I think when I speak of it being defensive it's that ultimately it wants more trade, not less, so it'll use trade as a tactic when it thinks basically when the downsides of that are less bad than the threats it's already facing.

So there are certainly circumstances, but it is down the list of possibilities by a significant way.

COMMISSIONER FRIEDBERG: Okay. Ms. Logan, I wanted to ask you about the manufacturing part of China's activities, particularly in the developing world. What kinds of manufacturing facilities have they been building there? To what extent are the countries in which those facilities are located gaining value from those facilities, and to what extent is China actually transferring knowledge and technology to the countries in which it's building those facilities?

MS. LOGAN: Thank you for the question. So I believe there were three parts. I'll start with the first part, which is what types of facilities are those. So what I've looked at in my research so far are critical new energy technologies which include solar, electric vehicles, batteries, as well as wind technology. And the figures that I raised were that last year China committed approximately, I think, $58 billion in terms of direct investments in manufacturing facilities just last year. And those facilities, as they'll be built, could have a potential output value of around $111 billion in total, which, to make the point that rivals what we're seeing already in terms of the value of exports from China domestically on those new energy technologies.

The second part of the question and third parts in terms of whether countries are deriving any sort of value from those investments and then also in terms of requirements that they may be imposing. I would say first of all, one of the notable aspects of these investments as compared to Belt and Road investments and engagement is that many of them employ, vast majority local labor, 80 to 90 percent, as compared to the Belt and Road, where if you looked at the overall engagement figures for last year for energy, 90 percent, if you combine investments with construction contracts, 90 percent of the value of engagement of the $40 billion that went to energy was for construction contracts, which is basically China exporting its labor. So it's not basically contributing to value-added manufacturing in those economies. So in terms of creating local jobs and other benefits for those economies, I would say yes, these facilities are playing a role in that.

The question of reverse tech transfer I think is something that we have not yet seen sort of from a broad perspective, and that's a remaining question. I think, whether or not Chinese companies are willing to do that as well as whether or not the Chinese government may place restrictions on that are also open questions, and we've seen an example with China, the government stepping in on a BYD proposed investment in Mexico from that perspective. So I would say those are still open questions, as well.

COMMISSIONER FRIEDBERG: Okay. Thank you very much.

COMMISSIONER BRANDS: We have a few minutes left. Does anybody have a second round question? All right. In that case I will turn it over to Commissioner Goodwin to close us out.

COMMISSIONER GOODWIN: Thank you, Commissioner Brands. He said he had to defer to me for the closing since the gavel is on this side of the microphone.

But in closing, thank you all again for your excellent testimony today. You can find those testimonies as well as a transcript and recording of today's hearing on the Commission's website.

I'd like to note that the Commission's next hearing on "Key U.S. Supply Chain Vulnerabilities and the Impact of a Second China Shock" is scheduled to place on Thursday,

[June] 5th.

With that we stand adjourned.

[Whereupon, the above entitled matter went off the record at 12:55 p.m.]