Competing *for Fuel*

Benchmarking the US-China Energy Competition

force distance times

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Executive Summary

Both the US and China acknowledge that energy shapes global economic development and security – and, accordingly, assess their national power based on their energy status. This report seeks to assess the current US-China competitive playing field in the energy domain, benchmarking US and Chinese standing in the field.

The analysis finds that writ large, the US and China prioritize similar areas in energy, and measure themselves relatively similarly within those. But they differ in competitive approach to the energy sector and in the scope of their focus on it. First, Beijing treats energy not only as a matter of security but also a competitive domain, one in and through which to project power, acquire leverage, and exact concessions. By contrast, the US tends to place more emphasis on defending and cooperating in energy. Second, in defining its energy priorities, layout, and capacity, China tends to prioritize the entire scope of industry chains, from the upstream to the downstream. China's energy-related policy discourse, legislation, and firm-level investments have long prioritized vertical integration of energy supply chains, connecting upstream to downstream. The US approach tends to focus more on downstream capacity, especially in new energy domains.

These differences in focus and approach are particularly acute, and relevant to today's US-China competition, when it comes to new energy domains and the energy revolution more broadly. China and the United States are both adjusting their approaches to energy in response to – and anticipation of – an energy revolution. But while Chinese discourse and policies suggest that Beijing sees the energy revolution as a competitive opportunity and is positioning accordingly, the United States tends to treat it more as a matter of security and a domain of international cooperation. This difference in orientation, paired with Beijing's dedicated industrial policy, already manifests in outsized Chinese capacity in new energy fields that could position it to leapfrog, or establish strategic positions of leverage over, the United States. Compounding that asymmetry, Beijing has shown itself willing to weaponize climate cooperation for competitive gain, an approach that directly targets a US vulnerability.

Accounting for the particularities of the US and Chinese approaches to the energy sector, this analysis breaks its assessment of energy standing into three parts, roughly mapped onto the upstream, midstream, and downstream segments of the energy industry.

Raw materials are considered "fundamental" inputs at the uppermost point of the supply chain. Both the US and China have, in official policy, identified advanced high-performance materials as strategic emerging fields of science and technology focus areas.[1] As such, this

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[1] "S.1260: United States Innovation and Competition Act of 2021," accessed August 1, 2021. https://www.congress.gov/bill/117th-congress/senate-bill/1260/text

analysis considers the importance of high purity quartz as a strategic input in the 21st century global economy, and draw comparisons to its role as a strategic material in the 20th century.

Distribution of energy to end users, or energy infrastructure, forms the “synthetic” section of the energy value chain. With the US being the world’s largest producer of natural gas and China being the world’s largest importer, the analysis takes a comparative look at the domestic and cross-border transportation capacities of gas pipelines in the two countries.

Meanwhile, **high-tech applications** that harness and amplify the value accrued in the up- and midstream sections can spur dramatic advances in the transformation of energy systems. These are considered the “downstream” element of the energy competition.

This analysis finds that:

- In **strategic and critical minerals**, China is, broadly speaking, less dependent on the US than the US is on it. Moreover, China defines strategic and critical minerals in terms of their offensive as well as defensive implications. The US only includes in its list of strategic and critical minerals those for which supply is at risk. This not the case for China. This suggests that Beijing sees strategic and critical minerals, and the fundamental points of the energy sector more broadly, as areas through which to develop and project offensive power, not simply points of potential vulnerability. That said, this analysis also finds that the US does still maintain leverage over China in some critical and strategic minerals, including high-purity quartz, that could provide competitive advantage – especially considering Beijing’s sensitivity to such leverage.
- In **energy infrastructure**, this analysis finds that the US continues to enjoy an advantage over China in conventional energy infrastructure. But China is overtaking, or has overtaken, the US in infrastructure for emerging energies – a reality that could neutralize the competitive advantage that the US currently enjoy based on its established lead in legacy fields. The outcome of that asymmetry could depend on US decisions with respect to the make-up of its energy portfolio and global energy norms. At the same time, even in conventional energy, China’s power as the world’s major energy importer could give it leapfrog potential to shape global pricing and markets, and Beijing may be actively working to that end, with relevant initiatives including the Petroyuan and potential efforts to establish a natural gas trading hub.
- In **high-tech applications,** this analysis finds that China’s approach orients around establishing a full supply chain and actively coordinating both vertical and horizontal linkages in prioritized high-tech applications. For example, in rare earth permanent magnets, China’s competitive approach hinges not only on acquiring and deploying advanced technology, but also on doing so leveraging relative supply chain control. That supply chain control also facilitates Beijing’s efforts to acquire and deploy technology. This approach demands competitive assessment that looks beyond just technological capacity and rather at the full supply chains behind those – and, from the US, frameworks that take into account dangers of supply chain vulnerability in prioritized high-tech energy applications.

Introduction

Oil is often pointed to as a casus belli contributing to the loss of life and treasure in critical battles of World War I and II as well as every struggle that has formed the modern Middle East. Oil has fueled the economies, power, and national prestige of countries ranging from Norway to Bahrain to Saudi Arabia. The world may well move on from fossil fuels. But energy – even if derived from new sources – will continue to shape global economic development and security.

Both the US and China acknowledge as much, and assess their national power based on their energy status. Then-president George W. Bush hailed the US Energy Policy Act of 2005 as "an economic bill, but…also a national security bill" designed to both fuel economic growth and reduce reliance on foreign sources of energy.[2] Former president Donald Trump described his administration's energy philosophy as "energy dominance,"[3] a concept that orients around developing US energy resources to provide American households with cheap energy prices, building leverage over foreign adversaries, and protecting against "foreign regimes that use energy as an economic weapon."[4] The Biden administration takes a more nuanced approach to energy: Rather than explicit dominance, it seeks to project American power by re-establishing US leadership in tackling the climate crisis and driving global innovation and deployment of clean energy technologies.[5] From the Chinese perspective, Beijing's 2014 energy development strategy action plan stated, "Energy is the basis and driving force of modernization. Energy supply and security is a matter of the overall situation of China's modernization."[6] And Chinese policy documents directly link the successful emergence of a post-1949 New China under the leadership of the Communist Party (CCP) to China's rise as the world's largest producer and consumer of energy.[7]

Both governments have developed their national and industrial policies accordingly. The US Department of Energy consistently receives one of the largest shares of research and

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[2] President Signs Energy Policy Act," The White House, August 2005. https://georgewbush-whitehouse.archives.gov/news/releases/2005/08/20050808-6.html

[3] "Remarks by President Trump at the Unleashing American Energy Event," The White House, June 29, 2017. https://trumpwhitehouse.archives.gov/briefings-statements/remarks-president-trump-unleashing-american-energy-event/

[4] "President Trump Vows to Usher in Golden Era of American Energy Dominance," The White House, June 30, 2017. https://trumpwhitehouse.archives.gov/articles/president-trump-vows-usher-golden-era-american-energy-dominance/

[5] "Executive Order on Tackling the Climate Crisis at Home and Abroad," The White House, January 27, 2021.

[6] 国务院办公厅关于印发能源发展战略行动计划（2014-2020 年）的通知 [Notice of the General Office of the State Council on Issuing the Energy Development Strategic Action Plan (2014-2020)], State Council, November 29, 2014.

[7] See, for example: 新时代的中国能源发展 (2020) [China's Energy Development in the New Era (2020)], State Council, December 21, 2020.

development funding among federal agencies.[8] China's Belt and Road Initiative places strong emphasis on securing energy supplies.[9] Both the US and China also measure their national power based on the results of these efforts.

The report that follows seeks to assess relative US and Chinese energy power and influence. To that end, it presents comparative metrics reflecting US and Chinese energy consumption, production, and capacity profiles, across both traditional and emerging energy sectors. The report also leverages authoritative strategic discourse to survey the two sides' different attitudes toward today's energy transition and the opportunities, as well as vulnerabilities, it creates. The chapter concludes with a discussion of US and Chinese approaches to energy-relevant industrial policy, namely Beijing's emphasis on integrated value chains, before presenting an outline of the benchmarking to follow.

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[8] "Total R&D by Agency, FY 1976-2020," American Association for the Advancement of Science. https://www.aaas.org/sites/default/files/2020-10/Agencies.xlsx

[9] See, for example: 国家能源局综合司关于建立"一带一路"能源合作伙伴关系合作网络的通知 [Notice of the General Department of the National Energy Administration on the Establishment of the "Belt and Road" Energy Partnership Cooperation Network], National Energy Administration (NEA), June 10, 2021.

Comparative Metrics

While the US and China take differing competitive approaches to energy, the two countries share significant overlaps in energy priority domains (see table).

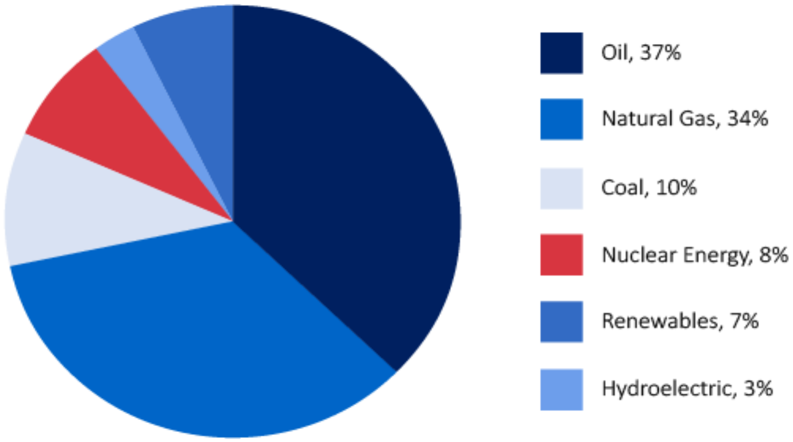
14th Five-Year Plan	China's Energy Development in the New Era	US Infrastructure Investment and Jobs Act	US Energy Act of 2020	US Executive Order 14008
Energy intensity	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency
Carbon emissions	.	Carbon capture, storage, removal	Carbon capture, storage, removal	.
Security of energy supply	Security of energy supply	Energy security; energy independence	.	.
Modern energy system; digital transformation of traditional energy system	Energy revolution to drive industrial upgrading	.	.	Building a new American infrastructure and clean energy economy
Energy storage	Energy storage and peaking	Energy storage	Energy storage; emerging alternative fuel infrastructure	.
Security & resilience of electric grid; intelligent grid	.	Grid infrastructure security and resiliency	Grid modernization	.
New energy	Energy technology	Advanced energy manufacturing	Energy technology	Clean energy technologies and infrastructure
New energy vehicles	.	Electric vehicles	.	.
Hydrogen energy and storage	Clean hydrogen; hydrogen storage and transport; hydrogen fuel cells	Hydrogen energy; clean hydrogen; hydrogen fueling infrastructure; hydrogen vehicles	Blue hydrogen; hydrogen and fuel cell technologies; hydrogen transport	.
Modernize strategic global industrial chains	Innovation across whole industry chains	Supply chains for clean energy technologies	.	Supply chain resilience
Strategic mineral resources	.	Critical minerals supply chains and reliability	Critical minerals including rare earths	.
Oil and gas production, reserves, and imports	.	Secure energy networks including electricity, oil, and gas	Fossil fuel energy research & development	.
Nuclear energy	.	Nuclear energy	Nuclear energy	.

Energy sector market reforms; China-centered pricing and trading mechanisms; promote use of yuan	Energy sector market reforms	.	.	.
Military-civil fusion in the energy sector		.	.	.
.	Global energy governance	,	,	Climate diplomacy
.	Addressing the global climate crisis	.	.	International collaboration to drive clean tech development

Consumption Profiles

The US and China have vastly different energy consumption profiles. Oil and gas constitute the bulk of US energy consumption, while coal is China's primary energy source. Chinese coal consumption is not expected to peak until 2025.[10] The share of natural gas in China's energy consumption is expected to grow by nearly 50 percent to reach 12 percent by 2030, and increase "significantly" from 2030 to 2035.[11] For electricity generation, the US primarily relies on natural gas (41 percent) and China on coal (63 percent).

Figure 1: US primary energy consumption by fuel, 2020[12]



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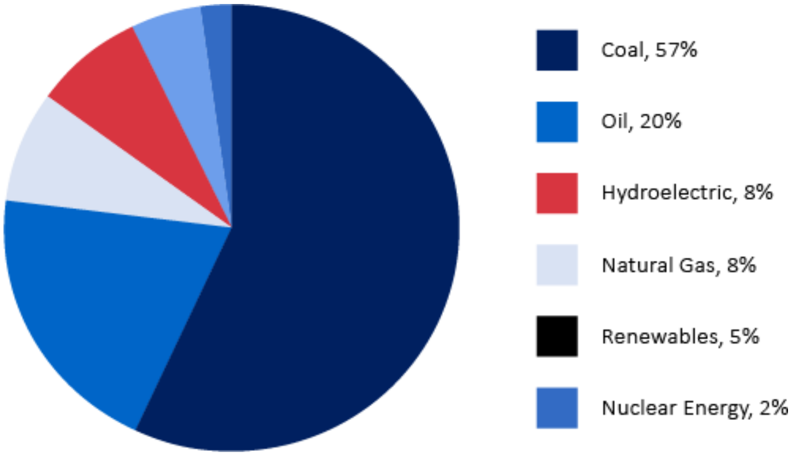
[10] David Stanway and Cate Cadell, "President Xi says China will start cutting coal consumption from 2026," Reuters, April 22, 2019. https://www.reuters.com/world/china/chinas-xi-says-china-will-phase-down-coal-consumption-over-2026-2030-2021-04-22/

[11] "China to use more natural gas in energy mix to 2035 – CNPC," Reuters, June 24, 2021. https://www.reuters.com/business/sustainable-business/china-use-more-natural-gas-energy-mix-2035-cnpc-2021-06-24/

[12] BP Statistical Review of World Energy, 2021

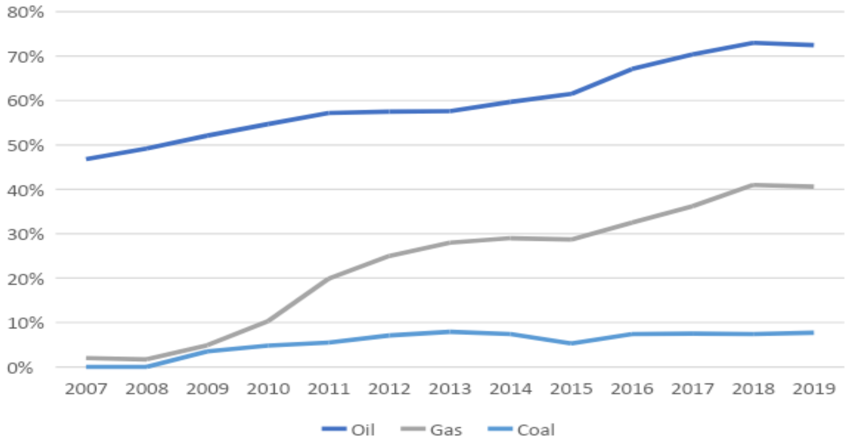
Figure 2: China primary energy consumption by fuel, 2020[13]



Energy Dependencies

Since China's reform and opening began in 1978, the country has become the world's largest energy consumer and producer, securing its role as a dominant consumer of critical inputs like coal and oil and shaping global energy production and trade flows. The corollary is that China has significant import dependencies for its oil and gas consumption. By contrast, in 2019, US gross energy exports exceeded gross energy imports for the first time since 1952.[14]

Figure 3: China's oil, gas, and coal import dependency[15]



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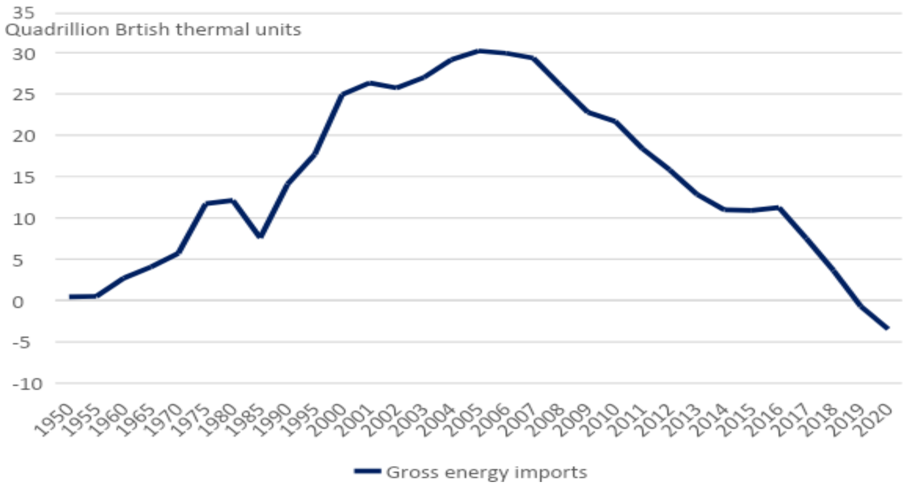
[13] BP Statistical Review of World Energy, 2021

[14] "U.S. total energy exports exceed imports in 2019 for the first time in 67 years," US Energy Information Agency, April 20, 2020. https://www.eia.gov/todayinenergy/detail.php?id=43395

[15] "Oil, gas and coal import dependency in China, 2007-2019," International Energy Agency, https://www.iea.org/data-and-statistics/charts/oil-gas-and-coal-import-dependency-in-china-2007-2019

Figure 4: US gross energy imports, 1950-2020[16]



Rate Statistics: Energy Intensity and Per Capita Consumption

One key metric that has informed China's energy strategy – and where China continues to lag behind the US and other developed countries – is energy intensity, a measure of how much energy is needed for each unit of GDP growth. In 2020, China expended 0.145 kilograms of oil equivalent in energy to achieve one unit of GDP growth, compared with 0.107 kilograms of oil equivalent for the US. The Chinese government has set a target of cutting energy intensity by 13.5% by 2025 from 2020 levels.[17]

Another metric of note, used by the Chinese government to benchmark its development against other nations, is per capita energy consumption. Here, Chinese discourse features explicit comparisons with the US. A 2011 report on China's medium and long-term energy development strategies published by Du Xiangwan, former vice president of the Chinese Academy of Engineering, stipulates that China must "establish the strategic idea that 'per capita energy consumption should be controlled at a level significantly lower than that of developed countries such as the United States.'"[18]

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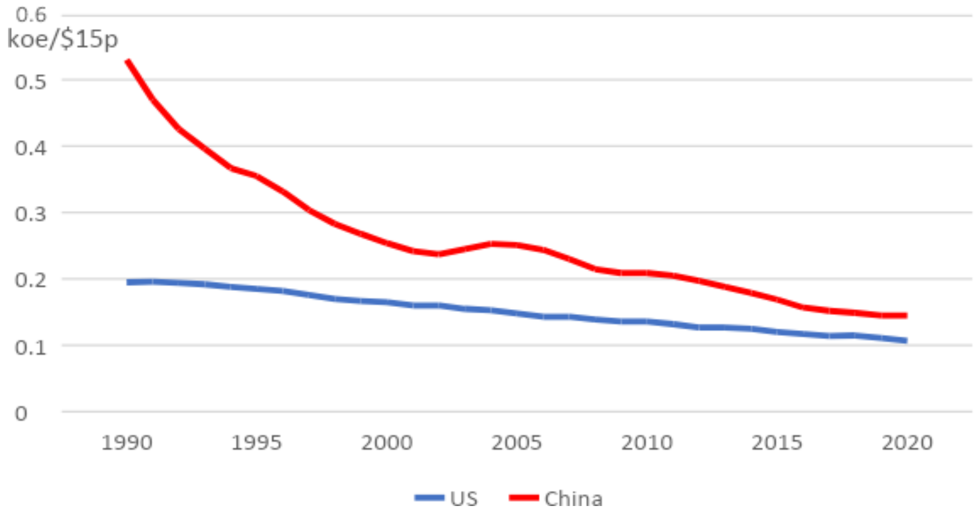
[16] "Monthly Energy Review," US Energy Information Agency, April 2020, ttps://www.eia.gov/totalenergy/data/monthly/archive/00352004.pdf

[17] Cao Hongyan, "降低 3%"彰顯綠色發展決心 ["Reducing 3%" shows the determination of green development], Economic Daily, March 10, 2021.

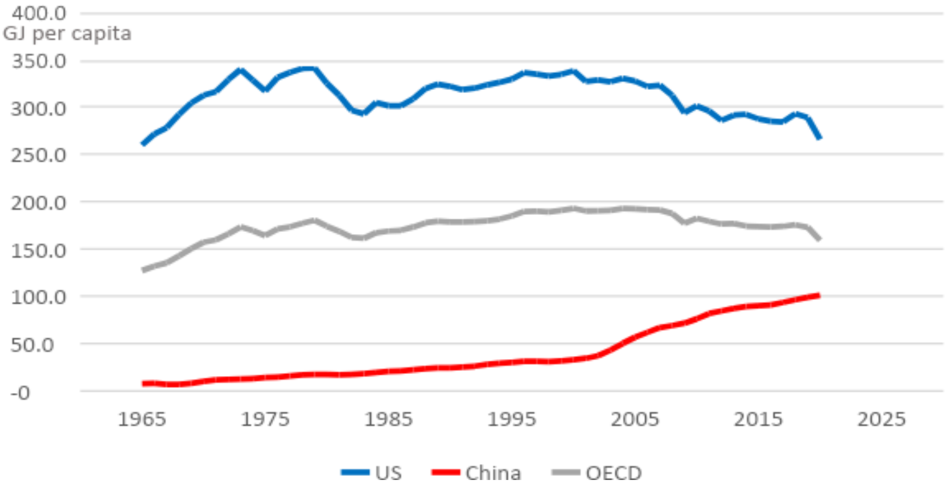
[18] Du Xiangwan, "中国能源中长期发展战略研究"报告要点 [Highlights of the report "Research on China's Medium and Long-term Energy Development Strategy"], Science and Technology Daily, March 3, 2011.

Figure 5: Energy intensity, US and China (1990-2020)[19]



As Du notes in the report, “Energy conservation, efficiency improvement and reasonable control of energy demand are at the forefront of energy strategy.” By 2012, China’s per capita energy consumption had reached the world average, but still lagged behind that of developed nations, according to the National Energy Administration.[20] It continues to lag.

Figure 6: Energy use per capita, US and China (1965-2019)[21]



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[19] “World Energy and Climate Statistics – Yearbook 2022,” Enerdata. https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html (Koe: kg of oil equivalent; $15p: dollars at constant exchange rate, price and purchasing power parities of the year 2015.

[20] 国家能源局原局长：我国人均能耗已达世界平均水平 [Former director of the National Energy Administration: my country's per capita energy consumption has reached the world average level], Xinhua News, May 27, 2012.

[21] BP Statistical Review of World Energy, 2021

New Energy Sources

Today, the possibility of an energy revolution is reshaping the nature of both US and Chinese energy policy. The emergence of new regulatory regimes, technologies, and sources of energy may shift relative US and Chinese strengths in non-trivial ways. And this complex environment may change the stakes of the competition: A new global energy industry – with new energy sources, modes of delivery, and processing requirements – is taking shape. Competition in the energy space therefore involves a new set of resources and inputs; more broadly, it also involves defining an overall industrial architecture where old rules, systems, actors, and hierarchies diminish in relevance. To compare US and Chinese strengths during the global energy transition, a new set of metrics will have to supplement traditional measurements of energy-related national power (see table).

Table 2: Relative Capacity in New Energy Domains, US and China[22]

	China	US
Deployment of select new technologies		
Wind (megawatts installed capacity)	281993	117744
of which offshore	8990	29
Solar PV (megawatts installed capacity)	254355	75572
Installed renewable energy as % of global capacity	32.0%	10.40%
Energy storage (gigawatts capacity)	0.5	0.4
Electric vehicles (thousand vehicles on the road)	4514114	1787221
Electric vehicle charging stations	807000	98981
Hydrogen fueling stations	61	64
Market share in select supply chains		
Wind turbine suppliers	37.6%	11.6%
Solar PV (cell/module production)	76%	1%
Rare earth processing	87%	0%

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[22] Sources: This table is adapted from a report by the Center for Strategic and International Studies (CSIS). (Sarah Ladislaw and Nikos Tsafos, "Race to the Top: The Case for a New U.S. International Energy Policy," CSIS, July 6, 2020.) Data on installed wind, solar, and renewable energy is from the International Renewable Energy Agency ("Renewable Capacity Statistics 2021," International Renewable Energy Agency); data on energy storage capacity is from the International Energy Agency (IEA); data on electric vehicles and EV charging stations is from the IEA ("Global EV Data Explorer," International Energy Agency); data on hydrogen fueling stations is from the IEA; data on wind turbines is from the Global Wind Energy Council (Wind turbine sizes keep growing as industry consolidation continues," Global Wind Energy Council, May 27, 2020); data on solar PV production is from Statista (Regional distribution of solar photovoltaics cell production worldwide in 2019, by country," Statista); data on rare earth and lithium processing is from the IEA ("The Role of Critical Minerals in Clean Energy Transitions," International Energy Agency, May 2021); data on NdFeB magnets is from Ping An Securities; data on lithium-ion battery production is from S&P Global Market Intelligence (Alice Yu and Mitzi Sumangil, "Top electric vehicle markets dominate lithium-ion battery capacity growth," S&P Global, February 16, 2021); data on R&D energy spending is from the IEA ("Energy Technology RD&D Budgets: Overview," International Energy Agency, October 2021).

NdFeB rare earth magnet production	87%	0%
Lithium processing	58%	0%
Lithium-ion battery production	77%	9%
Other metrics		
Energy companies in Fortune Global 500	18	8
of which top Top 10	3	0
R&D energy spending (billion USD)	8.4	8.8

The Energy Transition

China and the United States are both adjusting their approaches to energy in response to – and anticipation of – an energy revolution. But while Chinese discourse and policies suggest that Beijing sees the energy revolution as a competitive opportunity and is positioning accordingly, the United States tends to treat it more as a matter of security and a domain of international cooperation. This difference in orientation, paired with Beijing's dedicated industrial policy, already manifests in outsized Chinese capacity in new energy fields that could position it to leapfrog, or establish strategic positions of leverage over, the United States. Compounding that asymmetry, Beijing has shown itself willing to weaponize climate cooperation for competitive gain, an approach that directly targets a US vulnerability.

Xi Jinping heralded an era of "energy revolution" in 2014, elevating the issue to the "strategic height of national development and security."[23] He framed the global green and low-carbon energy wave not only as a means to secure China's energy needs, but also as an opportunity to propel China's next phase of industrial upgrading.

As the world begins to shift away from fossil fuels, China's energy mix will likely undergo technological, geopolitical, and economic disruptions, possibly altering the global energy trade's center of gravity.

China's policy response to potential disruptions across the energy landscape has been formalized in national-level policies, including the Strategic Action Plan for Energy Development (2014-2020), the 13th Five-Year Plan for Energy Development,[24] the Energy Technology Innovation Action Plan (2016-2030),[25] and the 14th Five-Year Plan (hereafter 14 FYP, for the period of 2021-2025). These reinforce the energy sector's importance in China's national security and economic development program. As the Energy Technology Innovation Action Plan notes, "The energy revolution is of great significance. Promoting the energy revolution is conducive to…supporting China's advancement into the ranks of the middle economically developed countries…enhancing China's influence in the international energy field…[it is of] great practical and far-reaching strategic significance for building a moderately prosperous society and accelerating the construction of a modern state."[26]

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[23] 习近平：积极推动我国能源生产和消费革命 [Xi Jinping: actively promote China's energy production and consumption revolution], Xinhua, June 13.

[24] 能源发展"十三五"规划 [13th Five-Year Plan for Energy Development], NEA, December 2016.

[25] 能源生产和消费革命战略 (2016-2030) [Energy Production and Consumption Revolution Strategy (2016-2030)], National Development and Reform Commission (NDRC), December 2016.

[26] Ibid.

The United States, too, frames innovation, commercialization, and deployment of renewable energy technologies to address the climate crisis as matters of national security. President Joe Biden stressed as much in a February 2021 executive order, explicitly framing climate considerations "an essential element of United States foreign policy and national security" and directing the defense and homeland security departments, as well as the Director of National Intelligence, to study the security implications of climate change.[27]

Both the US and China frame the energy revolution as a fulcrum in the competition between the two superpowers. However, the two governments frame the competition differently: The US focuses on fear of falling behind China in new energy or losing relative prestige as the global leader in the climate fight; China on the opportunity to pull ahead and chart its own course. "It's difficult to imagine the United States winning the long-term strategic competition with China if we cannot lead the renewable energy revolution. Right now, we're falling behind," US secretary of State Antony Blinken said in April 2021.[28] By contrast, Chinese policy discourse presents the energy transition as a strategic opportunity. The Strategic Action Plan for Energy Development, issued by the Chinese State Council in 2014, described the period to 2020 as a "critical period for China to build a moderately prosperous society and an important strategic opportunity period for energy development and transformation."[29] Similar language appears in a 2020 white paper published by the State Council, titled China's Energy Development in the New Era, which urged the country to "seize the opportunity of the new round of global scientific and technological revolution and industrial change, vigorously implement the innovation-driven development strategy in the energy sector."[30]

Moreover, where the United States tends to emphasize the more concrete, tactical areas of renewable energy capacity and distribution, Beijing's appears to take a broader approach to the competition, vying not only to develop capacity in the new energy space, but also to shape the emerging, global energy architecture, including everything from supply chains to rules and regulations. "The focus of the international energy competition has shifted from the traditional control of resources and strategic corridor control to pricing power, currency settlement power, and leadership in transformational change," reads China's 13th Five-Year Plan (hereafter 13FYP, for the period of 2016-2020).30 That programmatic document adds that the "global energy governance system is being reconstructed at an accelerated pace." The implication is clear: China should seize the opportunity not only to join the new global energy system, but also to shape it.

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[27] "Executive Order on Tackling the Climate Crisis at Home and Abroad," The White House, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

[28] "Tackling the Crisis and Seizing the Opportunity: America's Global Climate Leadership," Department of State, April 19, 2021.

[29] 国务院办公厅关于印发能源发展战略行动计划（2014-2020 年）的通知 [Notice of the General Office of the State Council on Issuing the Energy Development Strategic Action Plan (2014-2020)], State Council, November 29, 2014.

[30] 新时代的中国能源发展 [China's Energy Development in a New era], State Council, December 2020.

By contrast, official US discourse focuses on addressing the new energy landscape rather than shaping it. Emphasis is consistently on American leadership in the global climate and energy policy realms in order to face the climate crisis. Rather than constructing a new global energy architecture as an instrument of systemic US power, Washington appears fixated on setting ambitious emissions targets and spearheading climate diplomacy. "If America fails to lead the world on addressing the climate crisis, we won't have much of a world left," Secretary of State Blinken said in his April 2021 speech on US global climate leadership.[31] The "United States Climate Leadership in International Mitigation, Adaptation, and Technology Enhancement Act,"[32] introduced in the US Senate in April 2021, is aimed at "[restoring] United States global leadership on addressing the climate crisis" through renewed American engagement in multilateral and bilateral settings – but little attention is paid to establishing strategic American leadership in the new supply chains underpinning the emerging global energy system.

That said, there are signs that thinking among US lawmakers is shifting toward a greater focus on influencing emerging global architectures for energy, if in a limited fashion. For example, the United States Innovation and Competition Act (USICA), which was passed by the Senate in June 2021, notes the importance of the United States taking active roles in shaping the development of global critical infrastructure, including that of energy.[33]

Throughout, the US approach to today's energy revolution rests on international cooperation, including with China. John Kerry, US Special Presidential Envoy for Climate, for example, has said again and again that "we can't reach global climate goals without US-China cooperation. It's that simple."[34] But Beijing, in its more competitive approach to today's energy transition, has proven itself willing to weaponize that cooperative approach. For example, when then-Speaker of the House Nancy Pelosi visited Taiwan in August 2022, Beijing responded by halting climate dialogue with Washington.[35] This directly targets a US vulnerability, taking advantage of a US desire to cooperate in order to exact concessions while also shaping the US posture and policy on the energy transition.

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[31] Antony Blinken, "Tackling the Crisis and Seizing the Opportunity: America's Global Climate Leadership," Department of State, April 19, 2021, https://www.state.gov/secretary-antony-j-blinken-remarks-to-the-chesapeake-bay-foundation-tackling-the-crisis-and-seizing-the-opportunity-americ as-global-climate-leadership/

[32] S.1201: United States Climate Leadership in International Mitigation, Adaptation, and Technology Enhancement Act of 2021," accessed August 1, 2021, https://www.congress.gov/bill/117th-congress/senate-bill/1201/text#toc-idc6c3e0b84e5e4a72939214557fb3ccf6

[33] "S.1260: United States Innovation and Competition Act of 2021," accessed August 1, 2021, https://www.congress.gov/bill/117th-congress/senate-bill/1260/text

[34] "John Kerry: 'We can't' reach global climate goals without U.S.-China cooperation, 'it's that simple'," MSNBC, April 22, 2023, https://www.youtube.com/watch?v=7JXiPz0bI-E

[35] "China halts climate and military dialogue with the U.S. over Pelosi's Taiwan visit," NPR, August 5, 2022, https://www.npr.org/2022/08/05/1115878668/china-taiwan-pelosi-climate-military

Different Industrial Layouts

At the more tactical level of developing new energy resources and capacity, China's energy-related policy discourse, legislation, and firm-level investments have long prioritized vertical integration of energy supply chains, connecting upstream to downstream. Discussion of such integration is only just beginning to feature in Washington, and with less relative emphasis.

Xi's "energy revolution" concept prioritizes the development of a comprehensive energy industry chain. China's Energy Development in the New Era, the 2020 white paper published by the State Council, suggests that China's energy philosophy is centered on forming "an integrated innovation model with upstream and downstream linkages in energy technology innovation and collaborative technology development across the industry chain." [36]China's 14th Five Year Plan (14FYP) calls for increasing the competitiveness of industrial chains across strategic fields, including new energy: "Based on the advantages of industrial scale, supporting facilities and first-mover advantages in some fields, consolidate and enhance the competitiveness of the entire industrial chain in areas such as high-speed railways, electric power equipment, new energy, and ships, and build strategic and global industrial chains starting with complete products that are in line with the direction of future industrial change."[37]

US policy discourse on energy has historically featured none of this discussion of the energy sector as a comprehensive whole – from upstream production to midstream distribution and downstream high-tech application.[38] That is changing, however. In February 2021, just over a month after taking office, president Joe Biden ordered a review of the nation's critical supply chains, including those of the energy sector industrial base.[39] The final report following the 100-day supply chain review highlighted America's strategic weaknesses in the battery realm, in particular relative to China's integration of every step in that value chain, including processing raw inputs, product manufacturing, and recycling used batteries. The report emphasized that "securing the supply chain…requires an end-to-end coordinated supply chain strategy."[40] Meanwhile, the $1 trillion Infrastructure Investment and Jobs Act passed by the US Senate in August 2021 includes a section on clean energy technology supply chains, with major provisions for work across the value chain from upstream mapping and assessing of critical minerals, to

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[36] 新时代的中国能源发展 [China's Energy Development in a New era], State Council, December 2020。

[37] 第十四个五年规划和 2035 年远景目标纲要 [Outline of the 14th Five-Year Plan and Vision for 2035], National Development and Reform Commission, March 2021。

[38] See, for example: "Promoting Energy Infrastructure and Economic Growth," Executive Office of the President, April 10, 2019, https://www.federalregister.gov/documents/2019/04/15/2019-07656/promoting-energy-infrastructure-and-economic-growth; "Promoting energy independence and economic growth," Executive Office of the President, March 28, 2017, https://www.federalregister.gov/documents/2017/03/31/2017-06576/promoting-energy-independence-and-economic-growth; and "Summary of Legislation and Regulations Included in the Annual Energy Outlook 2022," Energy Information Administration, March 2022, https://www.eia.gov/outlooks/aeo/assumptions/pdf/summary.pdf

[39] "Executive Order on America's Supply Chains," White House, February 24, 2021.

[40] "Building Resilient Supply Chains, Revitalizing American Manufacturing, And Fostering Broad-Based Growth," White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

midstream rare earth processing, to downstream advanced battery processing.[41] There's also the Inflation Reduction Act, signed into law by president Biden in August 2022, that directs dedicates $369 billion towards energy security and climate change investments.

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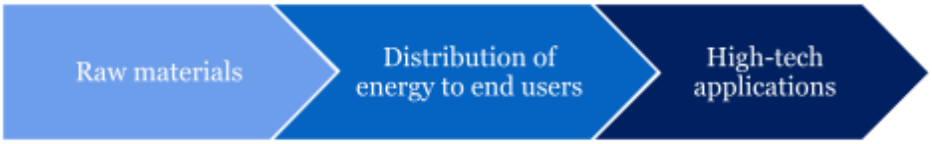
[41] "H.R.3684" Infrastructure Investment and Jobs Act," accessed August 1, 2021 https://www.congress.gov/bill/117th-congress/house-bill/3684

Benchmarking Energy Standing

The sections that follow seek to benchmark relative US and Chinese standing in energy. This analysis examines the US and China's respective energy industries through the lens of their strategic ambitions and competitive approaches. The goal is not to provide a comprehensive overview, but to select cases that reflect types of areas where strategic advantage, and asymmetry, may exist. The focus is on the relative strategic strengths and weaknesses of each country in the context of the global energy transition, where both legacy and emerging factors are at play, and where the geopolitical contest between the US and China will shape the trajectories and competitiveness of each country's energy sector.



Methodology

To reflect the centrality of the integrated supply chain in American and Chinese strategic thinking on energy, the chapter that follows is divided into three sections, roughly mapped onto the upstream, midstream, and downstream segments of the energy industry. Raw materials are considered "fundamental" inputs at the uppermost point of the supply chain. Both the US and China have, in official policy, identified advanced high-performance materials as strategic emerging fields of science and technology focus areas.[42] As such, this analysis considers the importance of high purity quartz as a strategic input in the 21st century global economy, and draw comparisons to its role as a strategic material in the 20th century. Distribution of energy to end users forms the "synthetic" section of the energy value chain. With the US being the world's largest producer of natural gas and China being the world's largest importer, the analysis takes a comparative look at the domestic and cross-border transportation capacities of gas pipelines in the two countries. Meanwhile, high-tech applications that harness and amplify the value accrued in the up- and midstream sections can spur dramatic advances in the transformation of energy systems. These are considered the "downstream" element of the energy competition.

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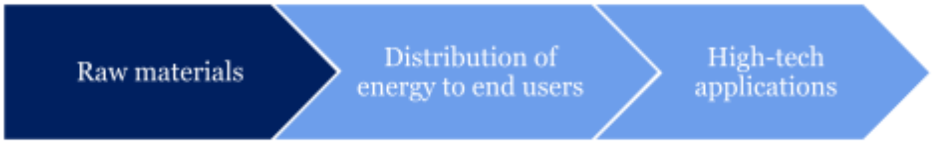
[42] "S.1260: United States Innovation and Competition Act of 2021," accessed August 1, 2021. https://www.congress.gov/bill/117th-congress/senate-bill/1260/text

Fundamentals: Strategic and Critical Minerals

This section seeks to benchmark relative capacity in energy-relevant raw materials or, put otherwise, the fundamental resource on which energy standing is based. Both the US and Chinese systems prioritize and offer clear definitions of strategic and critical minerals; accordingly, this analysis focuses on those, and relative capacity in them. The analysis begins by looking at the strategic and critical mineral landscape writ large, as defined by the two countries, before diving into high-purity quartz as a case study.



Strategic and Critical Minerals

China and the US recognize the importance of strategic and critical minerals and materials in safeguarding economic and national security. Both countries acknowledge that demand for these key minerals will likely intensify in the years ahead, driven by strategic emerging industries critical to the global energy transition. The two countries also see supply risks ahead, stemming from both resource constraints and geopolitical tensions. Strategic and critical mineral supply chains "are at serious risk of disruption," notes the White House's 100-day supply chain review report, published in June 2021.[43] "…Contrary to a common belief, this risk is more than a military vulnerability; it impacts the entire US economy and our values." For China, global geopolitical dynamics present risks to its resource security. "The international mining market has become more volatile, geopolitics has become increasingly complex, and international cooperation in the mining industry is facing new opportunities and challenges," notes China's most recent National Mineral Resources Plan, published by the Ministry of Land and Resources in 2016.[44]

China and the US have differing definitions of strategic and critical minerals. The difference is reflected in each country's identification of key minerals, which can in turn reflect differing approaches to overall mineral strategy. China has identified 24 strategic minerals, while the US has designated 35 minerals as critical. Only twelve minerals feature in both countries' lists (see table).

One of the main differences between the two definitions and approaches is the relative emphasis on supply chain dependencies. Vulnerability to supply chain disruption is a key condition of

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[43] Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100-Day Reviews under Executive Order 14017, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

[44] 全国矿产资源规划 (2016-2020) [National Mineral Resources Plan (2016-2020)], Ministry of Natural Resources, November 2016.

critical mineral under the US definition: In other words, the US only includes in its list those minerals for which supply is at risk. This not the case for China. This in turn means that China's definition of strategic minerals is more expansive than that of the US for critical minerals. For instance, where China includes energy minerals such as oil and gas in its list of strategic minerals, the US explicitly does not.

Table 3: Definitions of strategic/critical minerals, US and China

China: National Mineral Resources Plan (2016-2020)	US: A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals
A strategic mineral is one that is needed to "safeguard national economic security, national defense security and the development needs of strategic emerging industries."	A critical mineral is "a mineral identified by the Secretary of the Interior [pursuant to the Executive Order] to be: (i) a non-fuel mineral or mineral material essential to the economic and national security of the United States; (ii) the supply chain of which is vulnerable to disruption; and (iii) that serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for our economy or our national security."

This difference in definitions – as well as a larger difference of natural endowments and dependencies – is borne out in the list specific minerals identified by the two countries. The US is entirely dependent on foreign imports for 12 of its 35 critical materials, according to official 2021 figures (see table).[45] By contrast, according to available figures, chromium is the only strategic mineral for which China is essentially completely reliant on foreign imports. Moreover, China's list of strategic minerals includes a number for which China controls the supply chain (for example, China accounts for 60% and 87%, respectively, of global rare earth production and processing).[46] As researchers at the Institute of Mineral Resources under the Chinese Academy of Geological Sciences put it in a 2021 paper published in Acta Geoscientica Sinica, a journal associated with the China Geological Survey, the criteria for judging whether a mineral is strategic should include not only its economic significance and import dependence, but also whether it has "international market advantages and certain bargaining power and have important uses in strategic emerging industries."[47] This suggests that China's list of strategic minerals have offensive as well as defensive implications.

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[45] Mineral Commodity Summaries 2021, US Geological Survey, February 1, 2021, https://pubs.er.usgs.gov/publication/mcs2021

[46] "The Role of Critical Minerals in Clean Energy Transitions," International Energy Agency, May 2021

[47] 国内外战略性矿产厘定理论与方法 [Methods of Strategic Mineral Resources Determination in China and Abroad], Acta Geoscientica aSinica, 2021(2).

Table 4: Classification of strategic/critical minerals, US and China[48]

China: 24 strategic minerals		US: 35 critical minerals
Energy minerals	Oil, natural gas, shale gas, coal, coal bed methane, **uranium**	**Aluminum** (bauxite), antimony, arsenic, barite, beryllium, bismuth, cesium, **chromium**, **cobalt**, **fluorspar**, gallium, germanium, **graphite** (natural), hafnium, helium, indium, **lithium**, magnesium, manganese, niobium, platinum group metals, **potash**, the **rare earth elements** group, rhenium, rubidium, scandium, strontium, tantalum, tellurium, **tin**, titanium, **tungsten**, **uranium**, vanadium, and **zirconium**
Metallic minerals	Iron, **chromium**, copper, **aluminum**, gold, nickel, **tungsten**, **tin**, molybdenum, antimony, **cobalt**, **lithium, rare earths, zirconium**	
Non-metallic minerals	Phosphorus, **potash**, crystalline **graphite, fluorspar**	

Bolded *words are minerals that are listed as strategic or critical by both countries.*

Despite the differences between the Chinese and US approaches to classifying strategic and critical minerals, the two countries' overall minerals strategies do overlap (see table). Both countries prioritize supply chain resilience and security, scientific and technological innovation, public-private cooperation as well as international cooperation, and the development of a broader minerals industry and ecosystem.

Table 5: US critical minerals import dependence[49]

Mineral	Percent	Major import sources (2016-2019)
Arsenic, all forms	100	China, Morocco, Belgium
Cesium	100	Canada
Fluorspar	100	Mexico, Vietnam, China, South Africa
Gallium	100	China, UK, Germany
Graphite (natural)	100	China, Mexico, Canada, India
Manganese	100	Gabon, South Africa, Australia, Georgia
Niobium	100	Brazil, Canada, Germany, Russia
Rare earths	100	China, Estonia, Japan, Malaysia
Rubidium	100	Canada

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[48] Sources: National Mineral Resources Plan (2016-2020); Critical Minerals and Materials – US Department of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains.

[49] Mineral Commodity Summaries 2021, US Geological Survey, February 1, 2021.

Scandium	100	Europe, China, Japan, Russia
Strontium	100	Mexico, Germany, China
Tantalum	100	China, Germany, Australia, Indoneisa
Vanadium	96	Brazil, South Africa, Austria, Canada
Tellurium	>95	Canada, China, Germany, Philippines
Potash	90	Canada, Belarus, Russia
Cobalt	76	Norway, Canada, Japan, Finland
Rhenum	76	Chile, Germany, Canada, Kazakhstan
Bauxite	>75	Jamaica, Guyana, Australia, Brazil
Chromium	75	South Africa, Kazkhstan, Mexico, Russia
Magnesium compounds	54	China, Israel, Brazil, Netherlands
Germanium	>50	China, Belgium, Germany, Russia
Lithium	>50	Argentina, Chile, China, Russia
Titanium, sponge	>50	Japan, Kazakhstan, Ukraine
Tungsten	>50	China, Bolivia, Germany, Austria
Magnesium metal	<50	Canada, Israel, Mexico, Russia
Zirconium	<25	South Africa, Senegal, Australia, Russia

Table 6: China strategic minerals import dependence[50]

Mineral	Percent	Major import sources
Chromium	99	South Africa, Turkey, Zimbabwe
Nickel	89.2	Philippines, Indonesia, New Caledonia
Cobalt	85	Democratic Republic of Congo
Zirconium	80	Australia, South Africa
Copper	78.7	Chile, Peru, Mexico, Mongolia
Lithium	76	Chile, Argentina

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[50] 中国大宗矿产资源报告 [China Bulk Mineral Resources Report], 中国优势矿产资源报告 [China Advantageous Mineral Resources Report], and 战略新兴产业资源报告 [Strategic and Emerging Industry Resources Report], China Geological Survey.

Oil	72.5	Saudi Arabia, Russia, West Africa, South and Central America
Iron ore	70.7	Australia, Brazil
Uranium	>70	Kazakhstan, Namibia
Gold	58.2	South Africa
Aluminum	~50	Guinea, Australia, Indonesia
Gas	40.6	Turkmenistan, Australia, Qatar
Coal	7.7	Indonesia, Australia, Russia

Table 7: Priority areas in critical and strategic minerals for the US and China

China: National Mineral Resources Plan (2016-2020)	**US: Dept. of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains (2021-2031)**
Promote scientific and technological innovation to drive competitiveness of the domestic mining industry. Strengthen high-end applications for minerals in strategic emerging industries.	Foster scientific innovation and develop technologies that will ensure resilient and secure critical mineral and material supply chains independent of resources and processing from foreign adversaries.
Ensure resource security; highlight minerals for strategic emerging industries. Increase resource reserves, expand the resource base, strengthen resource protection, improve the mineral reserve system. Promote resource conservation and recycling.	Diversify supply chains, develop substitutes, improve reuse and recycling. Inter-agency coordination on critical minerals stockpiling.
Market reform and decentralization. Increase the role of the market in resource allocation. Catalyze and support private sector adoption and capacity for sustainable domestic critical mineral and material supply chains.	Catalyze and support private sector adoption and capacity for sustainable domestic critical mineral and material supply chains.
Optimize the layout and promote the coordinated development of the mining industry. Drive industrial upgrading. Implement differentiated management of mineral types and region.	Build the long-term minerals and materials innovation ecosystem—fostering new capabilities to mitigate future critical mineral and material supply chain challenges.
International cooperation in the mining industry along the Belt and Road; exploration and development of overseas mineral resources; improve the quality and level of foreign investment; participate in global mining governance	Coordinate with international partners and allies and other Federal agencies to diversify global supply chains and ensure the adoption of best practices for sustainable mining and processing.

Given the dissimilar definitions and assessments of what counts as a strategic or critical mineral, what is not listed can be as significant as what is. As the US Department of the Interior noted in its announcement of the 35 critical minerals in 2018, this list, "is not a permanent list, but will be dynamic and updated periodically to reflect current data on supply, demand, and concentration of production, as well as current policy priorities."[51] China also acknowledges that its strategic minerals list will be updated to reflect changing priorities: its outline of major thematic areas to be studied to formulate the next version of the national mineral resources plan calls for research to "forecast the degree of security of important mineral resources, study and propose a strategic mineral catalogue that is in line with China's own development strategies and interests."[52]

Among the key new materials that China is increasingly prioritizing for research and development is high purity quartz.[53]

Quartz

Quartz is the second most abundant mineral in the world, after feldspar. The hard, crystalline mineral is composed of silicon and oxygen – the second and first most abundant elements in the world, respectively – as well as other naturally occurring impurities. In other words, quartz is made up in large part of silicon dioxide ($SiO2$), a chemical compound also known as silica. Silica can take many different forms and has a wide range of industrial applications.[54]

One such application is the manufacture of metallurgical grade silicon, a key input for the production of polysilicon. Polysilicon is a high-purity form of silicon used in the semiconductor and solar industries. To make metallurgical grade silicon, quartz gravel is heated in an electric furnace, separating out much of the oxygen.[55] Silicon produced using this method typically has 2% impurities (in other words, it is about 98% pure silicon).

Further purification is necessary to produce electronic-grade polysilicon, as semiconductors and solar panels require silicon with even higher purity.[56]

Quartz can be synthetically produced. Though natural quartz crystals were used in most electronic and optical applications until 1971, they have since essentially been replaced by

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[51] "Final List of Critical Minerals 2018," Interior Department, May 18, 2018, https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018

[52] 然资源部办公厅关于开展全国矿产资源规划（2021—2025 年）重大专题研究的函 [Letter from the General Office of the Ministry of Natural Resources on the Study of Major Topics in the National Mineral Resources Plan (2021-2025)], Ministry of Natural Resources, October 8, 2019.

[53] 重点新材料首批次应用示范指导目录（2019 年版）[First Batch of Application Demonstrations of Key New Materials (2019 edition)], Ministry of Natural Resources, October 8, 2019.

[54] George H. Beall, "Industrial Applications of Silica," De Gruyter, 1994, https://www.degruyter.com/document/doi/10.1515/9781501509698-019/pdf

[55] Chalamala, Babu, "Manufacturing of Silicon Materials for Microelectronics and Solar PV," 2018, https://www.osti.gov/servlets/purl/1497235

[56] G. Fisher, M. R. Seacrist and R. W. Standley, "Silicon Crystal Growth and Wafer Technologies," in Proceedings of the IEEE, vol. 100, Special Centennial Issue, May 13, 2012, https://ieeexplore.ieee.org/document/6178756

cultured quartz crystals.[57] Known as synthetic quartz, this electronic-grade quartz crystal is used in many technological applications such as computers and communications equipment.

Natural quartz can have different levels of SiO2 content. Quartz deposits with naturally high SiO2 levels and low impurities are rare. However, to produce high purity quartz, it is important to start from high purity raw materials. High purity quartz is a crucial ingredient in the further processing of polysilicon for use in semiconductors and solar panels, as will be further explained below.

Table 8: Selection of different forms of quartz and their applications[58]

Form	Applications
Quartz sand	Manufacturing of glass and ceramics; foundry moulds in metal casting; sands for golf courses
Quartz crystal (synthetic)	Communications equipment; computers; consumer goods such as electronic games, television receivers, oscillators for watches and clocks
High purity quartz	High-tech industries including photovoltaics and semiconductors

High purity quartz

High purity quartz is typically defined as having a minimum of 99.995% SiO2 content.[59] Because high purity quartz sand is non-reactive in high temperatures and thermally stable, it is ideal for making quartz crucibles.[60] These crucibles are important ingredients in the production of semiconductors and solar panels. As was noted above, quartz gravel is heated in a powerful electric furnace to produce metallurgical grade silicon, which is further purified to polysilicon. The next step is to melt the polysilicon. But due to the stringent purity requirements, the polysilicon must be heated in a vessel with the smallest possible amount of impurity.

Otherwise, the polysilicon will react with the wrong substance, derailing the production process. The vessels that polysilicon must be melted in are high purity quartz crucibles.

The high purity quartz crucibles are filled with polysilicon. The polysilicon is then melted to form monocrystalline or multicrystalline silicon ingots. Next, the ingots are sliced into wafers, the single largest cost item in the solar panels production process.[61] Polysilicon used for

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[57] Minerals Yearbook, Silica, US Geological Survey, 2017.

[58] George H. Beall, “Industrial Applications of Silica,” De Gruyter, 1994

[59] Simon Rees, “Hot Rocks,” Benchmark Magazine, June 2016

[60] Ibid.

[61] “Cost-Effective Silicon Wafers for Solar Cells,” Arpa-E. https://arpa-e.energy.gov/technologies/projects/cost-effective-silicon-wafers-solar-cells

semiconductors need to be 99.99999999999% pure, often referred to as “11 nines.”[62] For solar panels, the polysilicon is of a slightly lesser grade: 99.999999999% pure, or “nine nines.” Using high purity quartz crystals in the production process is critical to achieving these ultra-pure standards.

The Spruce Pine region of North Carolina in the US is the world’s leading resource for high purity quartz. Spruce Pine is endowed with the world’s highest quality quartz deposits in Spruce Pine, North Carolina—a veritable “silica valley.”[63] Up to 90% of the world’s solar and semiconductor-grade high purity quartz is mined from the US town,[64] with some estimates putting it higher at 95%.[65] Two companies mine quartz at Spruce Pine: Unimin Corp., a wholly-owned subsidiary of Belgian conglomerate Sibelco; and The Quartz Corp., a joint venture between France’s Imerys and Norway’s Norsk Mineral. Unimin does not publicly disclose its output or sales figures. The Quartz Corp. reportedly has a high purity quartz production capacity of 30,000 tonnes per year.[66]

By contrast, China has low quality quartz deposits, making purification very difficult.[67] This makes China heavily reliant on imports for high purity quartz in a global market dominated by two US-based companies. In 2017, China imported $120 million worth of high purity quartz, even as it exported nearly three times as much low to medium purity quartz by volume, which was worth just $62.37 million, according to analysis by China Securities.[68] Beijing is aware of the vulnerabilities that this trade imbalance and reliance pose, and is actively working to

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[62] “Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth,” The White House June 2021. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

[63] Magnesia Features: Breaking Down Silica Valley,” Fast Markets, https://www.indmin.com/Article/3646808/Magnesia-Features/Breaking-down-Silica-Valley.html

[64] “Breaking down Silica Valley,” Fast Markets, 2016, https://www.indmin.com/Article/3646808/Breaking-down-Silica-Valley.html

[65] “High Purity Quartz Market,” UltraHPQ. https://ultrahpq.com/markets/

[66] Simon Rees, “Hot Rocks,” Benchmark Magazine, June 2016.

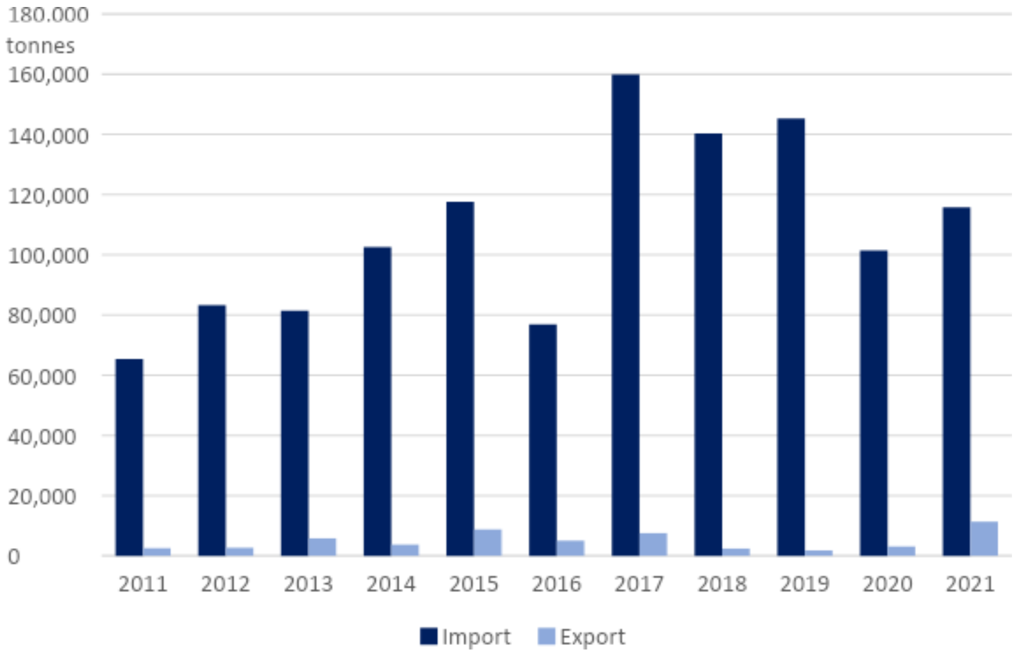
[67] Yan Lingya, 中国高纯石英资源开发利用现状及供需形势, 国土资源情报 2020 (10) [Development and Utilization Status and Supply and Demand Situation of High Purity Quartz Resources in China, Land and Resources Information 2020 (10)], 2020. http://210.42.192.44/kcms/detail/detail.aspx?filename=GTZQ202010017&dbname=CJFQLAST2020

[68] 石英产业链深度报告（一）：高端制造重要原材料，军民两用市场空间广阔 [In-depth report on the quartz industry chain (1): important raw materials for high-end manufacturing, with a broad market space for military and civilian use], China Securities, January 3, 2020.

develop its own capabilities in high purity quartz.[69] Researchers at the China Geological Survey have called for high purity quartz to be added to China's list of strategic minerals.[70]

Trade data from the UN Comtrade database paints a similar picture. Though data is unavailable for high purity quartz, Chinese researchers have used 99.99% pure silicon as a reference.[71] In 2020, China imported 33 times more silicon with silicon content of ≥ 99.99% as it exported. For the US, the reverse is true: It exported 32 times more 99.99% pure silicon than it imported.

Figure 7: China imports and exports of silicon with silicon content of ≥ 99.99%[72]



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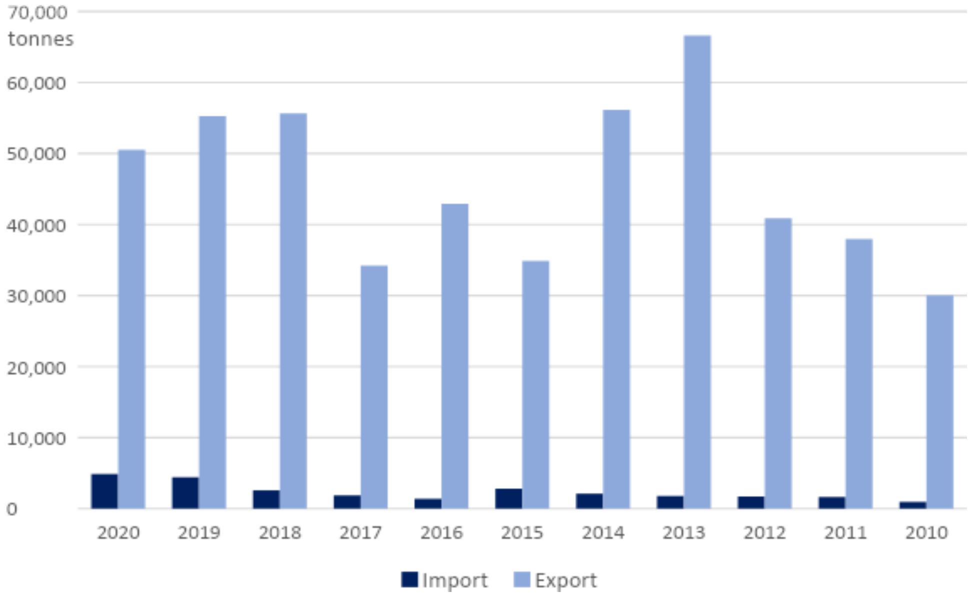
[69] For example, as early as 2011, in a policy outline for mineral exploration and prospecting, China's State Council identified high purity quartz as a mineral required for strategic emerging industries. See: 国务院办公厅关于转发国土资源部等部门找矿突破战略行动纲要（2011—2020 年）的通知 [Notice of the General Office of the State Council on Forwarding the Action Outline of the Mineral Prospecting Breakthrough Strategy (2011-2020) by the Ministry of Land and Resources and Other Departments], Ministry of Land and Resource, 2011.

[70] Zhang Wanyi, 高纯石英全球资源现状与我国发展建议 [The status quo of high-purity quartz global resources and my country's development suggestions], Conservation and Utilization of Mineral Resources, October 2019.

[71] Zhang Wanyi, 高纯石英全球资源现状与我国发展建议 [The status quo of high-purity quartz global resources and my country's development suggestions], Conservation and Utilization of Mineral Resources, October 2019.

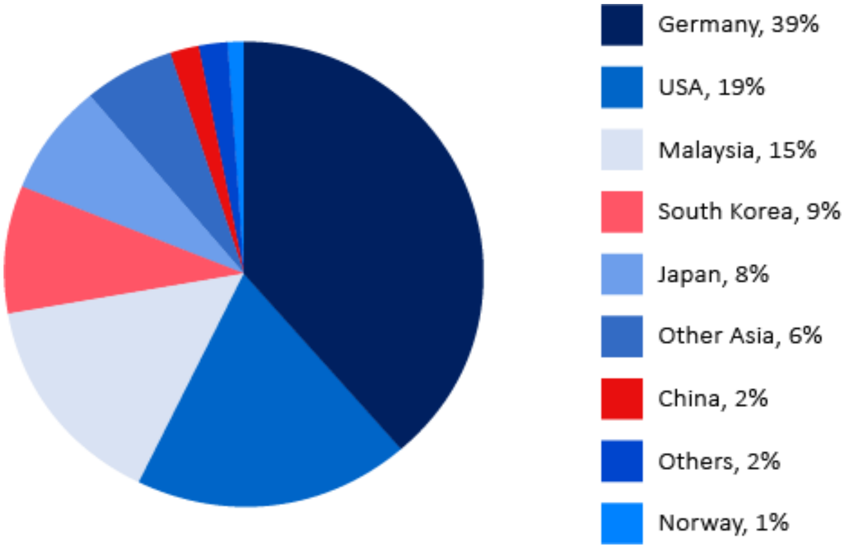
[72] UN Comtrade

Figure 8: US imports and exports of silicon with silicon content of ≥ 99.99%[73]



Germany and the US make up over half of total world exports of 99.99% pure silicon, while China accounts for only 2%. By contrast, China made up 65% of total imports of the good in 2020.

Figure 9: Exporters of silicon with silicon content ≥ 99.99%, 2020[74]



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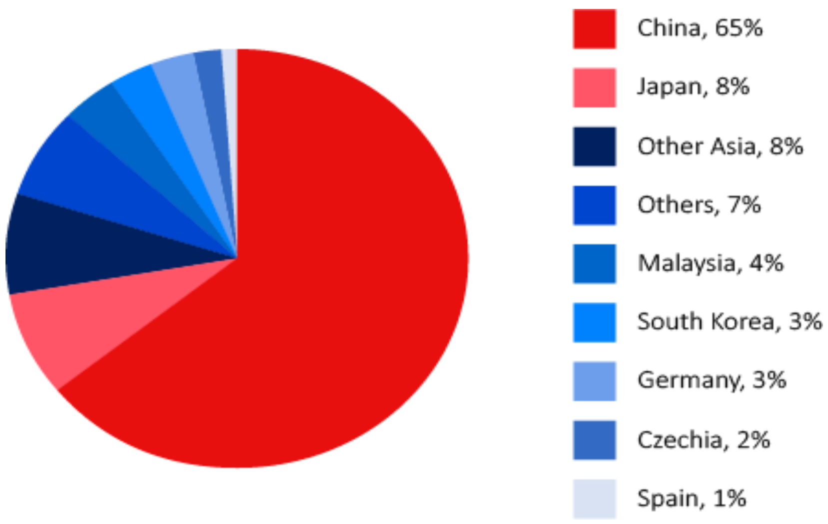
[73] UN Comtrade

[74] UN Comtrade

Figure 10: Importers of silicon with silicon content ≥ 99.99%, 2020[75]



Currently, only one Chinese company, Jiangsu Pacific Quartz Corps. (江苏太平洋石英股份有限公司), is capable of producing high-purity quartz at scale.[76] As the firm notes in its prospectus, it began mass production of high-purity quartz in 2009, “breaking the monopoly of international manufacturers on high purity quartz sand products.”[77] Jiangsu Pacific Quartz Corp. has steadily increased its production of high purity quartz over the past decade. Its capacity is also expected to increase. According to its 2020 annual report, the company is currently constructing three facilities that will have the capacity to produce 6,000 tonnes and 1,800 tonnes of electronic-grade quartz products, and 20,000 tonnes of high purity quartz sand, respectively.[78] But with Chinese demand for high purity quartz having grown at an annual rate of nearly 12% since 2014,[79] China will still be dependent on foreign sources for the foreseeable future.

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[75] UN Comtrade

[76] Yan Lingya, 中国高纯石英资源开发利用现状及供需形势, 国土资源情报 2020 (10) [Development and Utilization Status and Supply and Demand Situation of High Purity Quartz Resources in China, Land and Resources Information 2020 (10)], 2020.

[77] “首次公开发行股票招股说明书 (申报稿)”[Initial Public Offering Prospectus (Filing Draft)], 江苏太平洋石英股份有限公司, [Jiangsu Pacific Quartz Corp.], April 2012.

[78] “2020 年年度报告” [2020 annual report], 江苏太平洋石英股份有限公司, [Jiangsu Pacific Quartz Corp.], March 31, 2021.

[79] Yan Lingya, 中国高纯石英资源开发利用现状及供需形势, 国土资源情报 2020 (10) [Development and Utilization Status and Supply and Demand Situation of High Purity Quartz Resources in China, Land and Resources Information 2020 (10)], 2020.

Figure 11: China's production of quartz sand varieties[80]

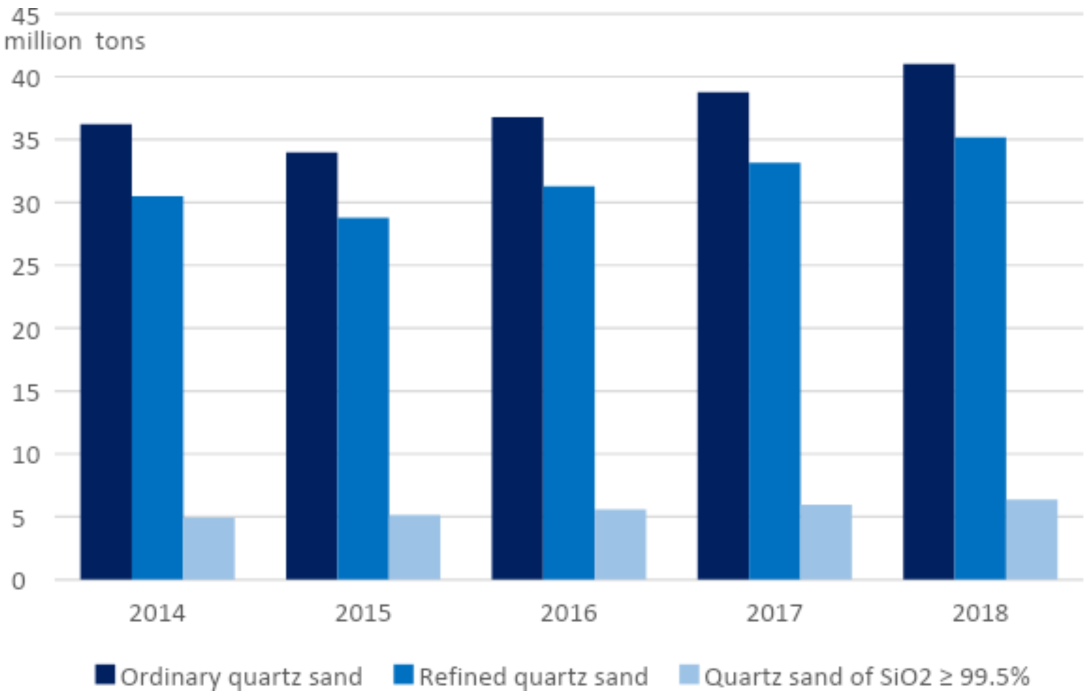
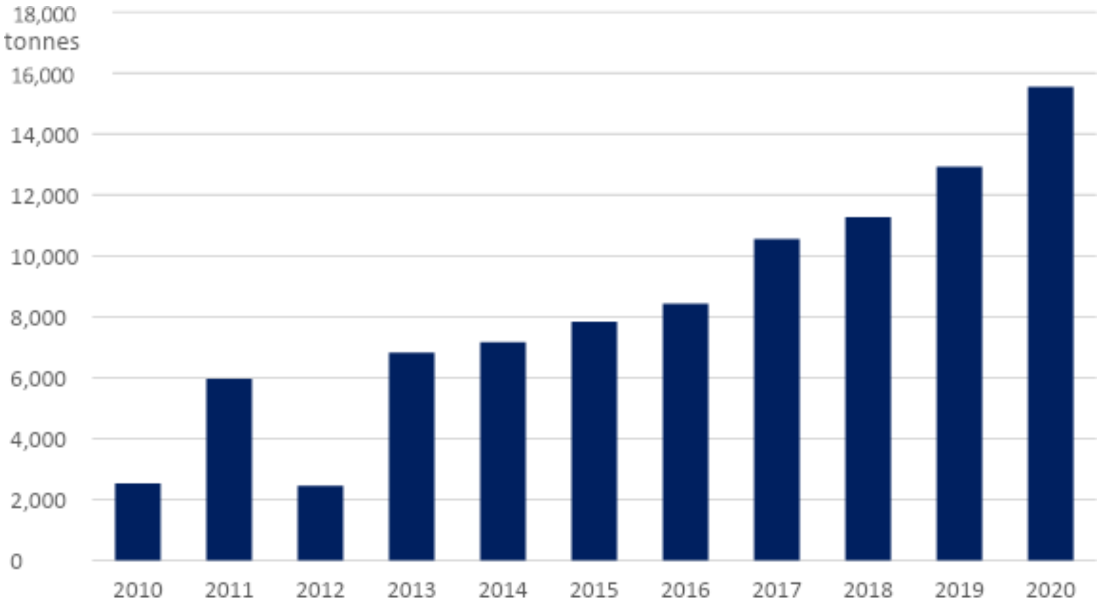


Figure 12: Jiangsu Pacific Quartz Corp. production of high purity quartz[81]



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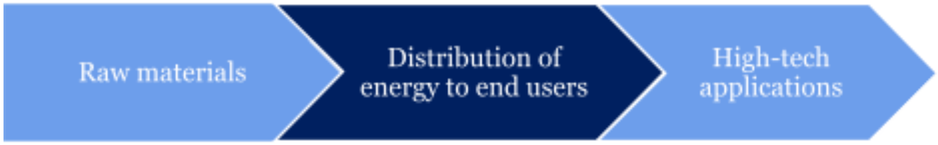
[80] Zhang Wanyi, 高纯石英全球资源现状与我国发展建议 [The status quo of high-purity quartz global resources and my country's development suggestions], Conservation and Utilization of Mineral Resources, October 2019.

[81] Jiangsu Pacific Quartz Corp. annual reports

Over the years, Jiangsu Pacific Quartz Corp. has received tens of millions of RMB of subsidies and grants from provincial, city, and county governments.[82] One of the largest is a 17 million RMB subsidy, granted by Jiangsu province in 2014, to fund the company's upgrading of its high-purity quartz production lines. Another is a 2019 grant from the provincial government to fund the company's new, 6,000-ton-a-year electronic-grade quartz production facility. Smaller subsidies are also provided on an annual.

Synthetics: Energy Infrastructures

Fundamental inputs are the fuels that drive a nation's energy sector. Those inputs require a next critical feature to be translated into economic returns and security: Energy infrastructures, which can be broadly defined as the framework that enable energy inputs to be transported, distributed, and harnessed for downstream purposes. This analysis focuses on those, and relative capacity in them, before exploring natural gas pipelines as a case study. The case study finds that China's gas energy, as with its broader conventional energy, infrastructure lags that of the United States. But Beijing does have openings for leapfrog development. Those include the pricing power that China claims as a major gas importer, and Beijing's stated aim of actively participating in "global natural gas trade and investment" and "deeply integrate into the global natural gas industry chain."[83] More broadly, this assessment of the competitive energy infrastructure balance suggests that China is overtaking, or has overtaken, the US in infrastructures for emerging energies – a reality that could neutralize the competitive advantage that the US currently enjoys based on its established lead in legacy energy fields.



Energy infrastructure is a major budget line item for the United States and China, especially as concerns infrastructures for new energy sources. Both countries' COVID-19 pandemic stimulus plans featured major spending on upgrades to roads and bridges, but also clean energy transmission and electrical grids. The White House described the US Infrastructure Investment and Jobs Act, passed by the Senate in 2021, as representing "the largest investment in clean

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[82] Ibid.

[83] The Oil and Gas Department of the National Energy Administration, the Institute for Resources and Environmental Policies at the Development Research Center of the State Council, and the Center for Oil and Gas Resource Strategies at the Ministry of Natural Resources in China, China Natural Gas Development Report [中国天然气发展报告], Beijing: Petroleum Industry Press, August 19, 2022.

energy transmission and EV infrastructure in history."[84] The Chinese government's work report, delivered by premier Li Keqiang at the National People's Congress in May 2020, made clear that "[p]riority will be given to new infrastructure"[85] including battery charging and swapping facilities for electric vehicles.

More traditional energy infrastructure, like pipelines and transmission lines, are just as crucial. As an executive order on energy infrastructure issued by the Trump administration in 2019 put it, the United States can only "fully realize [the] economic potential" of its robust energy supplies if it has:

> Infrastructure capable of safely and efficiently transporting these plentiful resources to end users. Without it, energy costs will rise and the national energy market will be stifled; job growth will be hampered; and the manufacturing and geopolitical advantages of the United States will erode.[86]

China's "Medium- to Long-term Oil and Gas Pipeline Plan," issued by the NDRC in 2017, reflected a similar sentiment. That plan described a domestically interconnected pipeline network that: "contributes to the improvement of the modern integrated transport system, improving the efficiency of factor allocation; contributes to developing new market demand and expanding the use of clean energy and natural gas, supporting the construction of modern energy system."[87]

In conventional energy, China's energy infrastructure lags behind that of the US, at least in terms of scale, if not in terms of modernity. However, China has pulled ahead in new energy (e.g., wind, solar, EV) infrastructure.

China's 13FYP on energy acknowledged this shortcoming, pointing out the Chinese energy system's "poor quality and efficiency" and "weak infrastructure."[88]

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[84] "UPDATED FACT SHEET: Bipartisan Infrastructure Investment and Jobs Act," The White House, August 2, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/02/updated-fact-sheet-bipartisan-infrastructure-investment-and-jobs-act

[85] Li Keqiang, "Report on the Work of the Government," May 22, 2020.

[86] "Promoting Energy Infrastructure and Economic Growth," Executive Office of the President, April 10, 2019.

[87] 中长期油气管规划 [Medium- and long-term oil and gas pipeline planning], NDRC, May 2017.

[88] 13th Five-Year Plan for Energy Development, National Energy Administration, December 2016.

Table 9: Comparative metrics for China and US energy infrastructure[89]

	China	US
Electricity		
Installed electricity generating capacity, MW	2,200,580	1,117,475
Electric transmission network, km	4,877,000	190,000
Rate of loss during transmission and distribution, %	5.62	4.93
Average duration of power outage, hours	13.72	4.45
Average frequency of power outage	2.99	1.649
Investment in electricity networks, (USD, 2020)	75 billion	70 billion
Gas		
Main/long distance gas transmission pipelines, km	110,000	485,975
Underground gas storage facilities	27	412
Underground gas storage capacity, bcm	10.2	136.5
Gas distribution pipelines, km	767,946	1,519,222
LNG terminals	22	19
LNG regasification capacity, Mt/year	79.9	45.8
Oil		
Oil pipelines, km	57,357.26	362,072.53
Petroleum reserves, days of import protection	Target by 2030: ≥90	1069
Renewables and new technologies		
EV chargers	807,000	98,981
EV sales share, %	5.7	2%

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[89] Sources: Data on installed electricity generating capacity is from the National Energy Administration (NEA) (and the Energy Information Administration (EIA) Data on electric transmission network is from the NEA. Data on rate of loss is from the NEA and the EIA. Data on average duration and frequency of power outage is from the NEA and the EIA. Data investment in electricity networks is from the International Energy Agency (IEA). Data on gas transmission pipelines is from the NEA and Department of Transport. Data on underground storage facilities and capacity is from Xinhua News and the EIA. Data on gas distribution pipelines is from the Ministry of Housing and Urban-Rural Development and the Department of Transport. Data on LNG terminals is from S&P Global and the Department of Transport. Data on LNG regasification capacity is from Statista. Data on oil pipelines is from CEIC and the Bureau of Transportation Statistics. Data on petroleum reserves is from Development Research Center of the State Council. Data on EV chargers, sales share, and stock is from the IEA. Data on installed wind capacity is from the Global Wind Energy Council. Data on solar PV capacity is from Statista. Data on investment in battery storage, and investment in power generation, is from the IEA.

EV stock, including plug-in hybrids and fuel cells	4,514,114	1,787,221
Wind (MW installed capacity)	281993	117744
of which offshore	8990	29
Solar PV (MW installed capacity)	254355	75572
Investment in grid-scale battery storage (USD, 2020)	958 billion	1197 billion
Investment in behind-the-meter battery storage (USD, 2020)	667 billion	329 billion
Power generation investments (USD, 2019)		
Hydro and other renewables	29 billion	3 billion
Solar PV and wind	63 billion	43 billion
Nuclear	9 billion	4 billion
Fossil fuels without carbon capture, utilisation, and storage	22 billion	11 billion

Natural gas

Natural gas offers an instructive lens through which to examine China and the US's respective energy infrastructures for several reasons. First, both countries are major figures in, and able to shape, the global gas market: China is the world's largest gas importer and one of the fastest-growing natural gas markets globally.[90] The United States is the world's largest natural gas producer and second-largest exporter. Second, gas plays an important role in both countries' energy portfolios: While gas currently comprises only 8 percent of China's energy portfolio, Beijing intends to increase that share to 12 percent by 2030.[91] For the United States, gas is and will continue to be a dominant energy source through at least 2050, accounting for around a third of total energy consumption, according to official projections.[92] Meanwhile, China is positioning gas as an important transition fuel as it attempts to shift away from coal in pursuit of its goals of cutting carbon emissions. An opinion issued by the State Council in 2018 on natural gas development, for example, described natural gas as "an important path for China to promote the revolution in energy production and consumption and build a clean, low-carbon, safe and

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[90] "Country Analysis Executive Summary: China," EIA, August 8, 2022, https://www.eia.gov/international/content/analysis/countries_long/China/china.pdf

[91] Emily Chow and Shivani Singh, "China to use more natural gas in energy mix to 2035 - CNPC," Reuters, June 24, 2021 https://www.reuters.com/business/sustainable-business/china-use-more-natural-gas-energy-mix-2035-cnpc-2021-06-24/

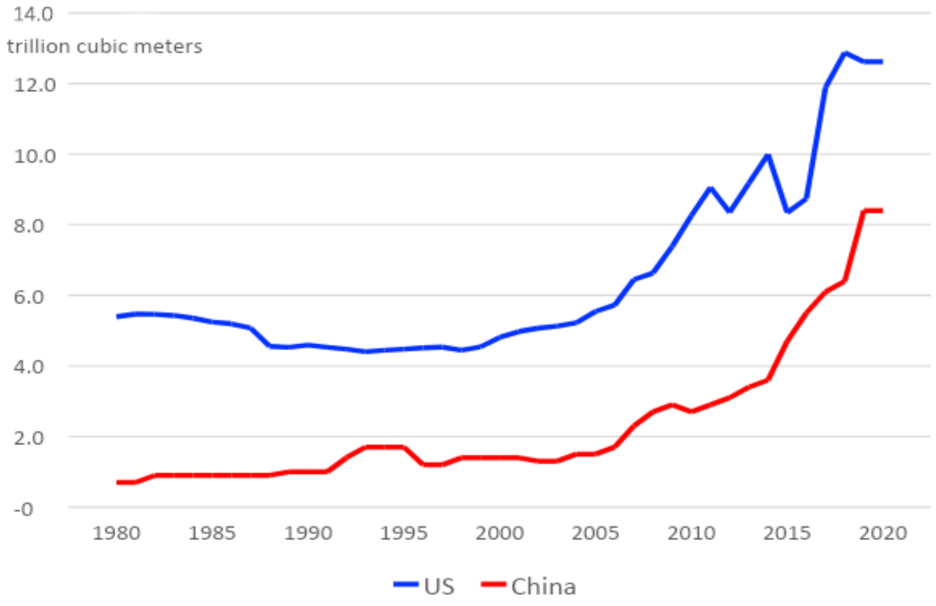
[92] Annual Energy Outlook 2021, EIA, February 3, 2021, https://www.eia.gov/outlooks/aeo/

efficient modern energy system." Fourth, official and industry sources in China frequently cite US natural gas infrastructure as a benchmark for its own.[93]

Gas reserves and import dependence

The US regards its natural gas reserves as a strategic asset in driving sustained economic growth and supporting national security. So does China. The China Natural Gas Development Report of 2021 – jointly published by the National Energy Administration, State Council, and Ministry of Natural Resources – urged the gas industry to "vigorously enhance exploration and development efforts and ensure the domestic security of natural gas supply."[94] The 14FYP also called for increased domestic production of natural gas as part of China's energy security strategy. Meanwhile, the US Department of Energy noted in a 2021 report that "abundant natural gas reserves are a strategic asset in driving sustained, long-term economic growth, achieving environmental goals, and enhancing the national security interests of the United States."[95]

Figure 13: China and US proven gas reserves[96]



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[93] See, for example: 能源蓝皮书 (2016) [China Blue Book of Energy (2016)], Social Sciences Academic Press (China); 我国将着力破解天然气产业发展深层次矛盾 [China will focus on cracking the deep-seated contradictions in the development of natural gas industry], Economic Daily, September 6, 2018,; "天然气 多探多储多为民生" [More natural gas exploration and storage for people's livelihood], People's Daily, September 6, 2018.

[94] "China natural gas development report 2021," NEA, August 21, 2021.

[95] "Economic and National Security Impacts under a Hydraulic Fracturing Ban," Department of Energy, January 14, 2021. https://www.energy.gov/sites/prod/files/2021/01/f82/economic-and-national-security-impacts-under-a-hydraulic-fracturing-ban.pdf

[96] BP Statistical Review of World Energy, 2021.

Table 10: China and US proven gas reserves[97]

	At end 2000	At end 2010	At end 2020	Share of world total	R/P ratio[98]
China	1.4	2.7	8.4	4.5%	43.3
US	4.8	8.3	12.6	6.7%	13.8

The US and China have different levels of import dependencies on gas. Where the US became a net gas exporter for the first time in decades in 2017,[99] China is importing ever more gas. China imported 42% of its total natural gas consumption in 2020,[100] an import dependence that has nearly tripled over a decade and is forecast to further increase.[101] That compares with 8.4% for the US.[102] China's import dependence is driven by challenges in developing domestic natural gas. For instance, its coalbed methane development and shale gas exploration and development both rely on foreign technology.[103] On the other hand, the US's shale boom, brought about by fracking and horizontal drilling techniques, transformed the country into a leading producer and exporter of the fuel. The US Department of Energy projects the country would revert to being a net importer of gas if fracking were banned.[104]

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[97] Source BP Statistical Review of World Energy, 2021.

[98] Reserves-to-production (R/P) ratio: If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.

[99] Naureen S. Malik, "U.S. Becomes a Net Gas Exporter for the First Time in 60 Years," Bloomberg, January 11, 2018, https://www.bloomberg.com/news/articles/2018-01-10/u-s-became-a-net-gas-exporter-for-the-first-time-in-60-years

[100] "BP Statistical Review of World Energy 2021," BP, July 8, 2021, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-repo rt.pdf

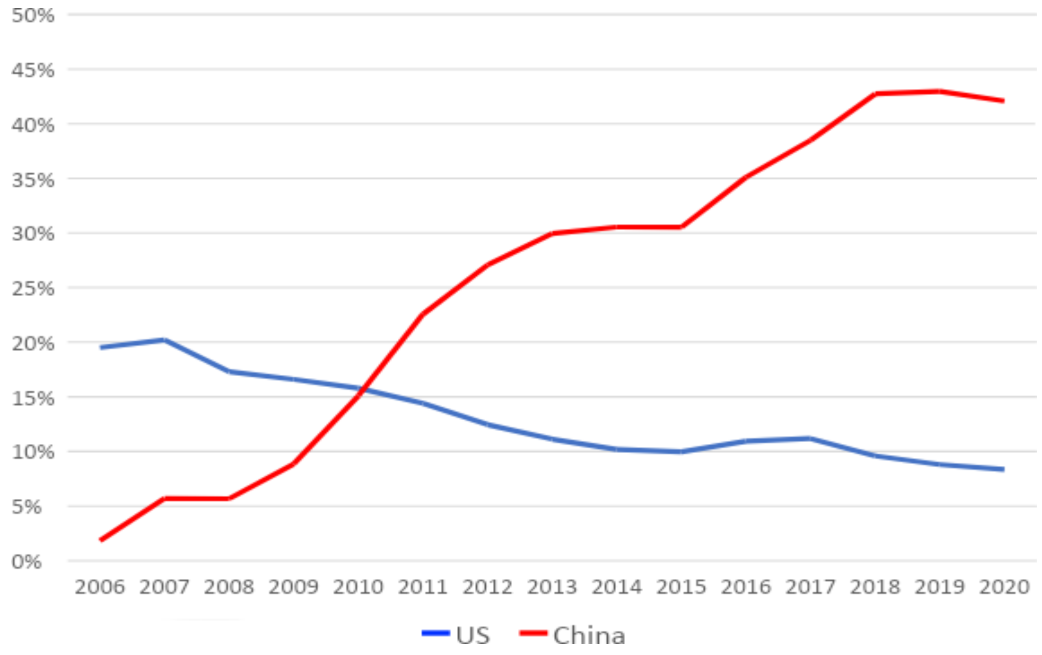
[101] 李永昌：我国天然气对外依存度的走向和上限 [Li Yongchang: The direction and upper limit of China's natural gas dependence on foreign gas], Petroleum Business News, July 3, 2020.

[102] BP Statistical Review of World Energy 2021.

[103] China Blue Book of Energy (2016).

[104] "Economic and National Security Impacts under a Hydraulic Fracturing Ban," Department of Energy.

Figure 14: China and US gas import dependence[105]



Domestic gas infrastructure

China's natural gas infrastructure has major shortcomings, including sparse pipeline network and a shortage of gas storage and peaking facilities.[106] These factors drive up transmission and distribution costs, in turn crimping consumption. China's strategic weakness in natural gas infrastructure is particularly evident when the country's gas distribution network is compared with that of the US. In 2019, China's urban gas distribution network totaled about 767,000 kilometers.[107] That year, the US boasted a network of distribution mains of over 2,122,500 kilometers.[108] On a per capita level, the US has 0.00641 kilometers of gas distribution mains per person, based on 2019 population levels. That's more than 11 times greater than the 0.00055 kilometers per capita level in China.

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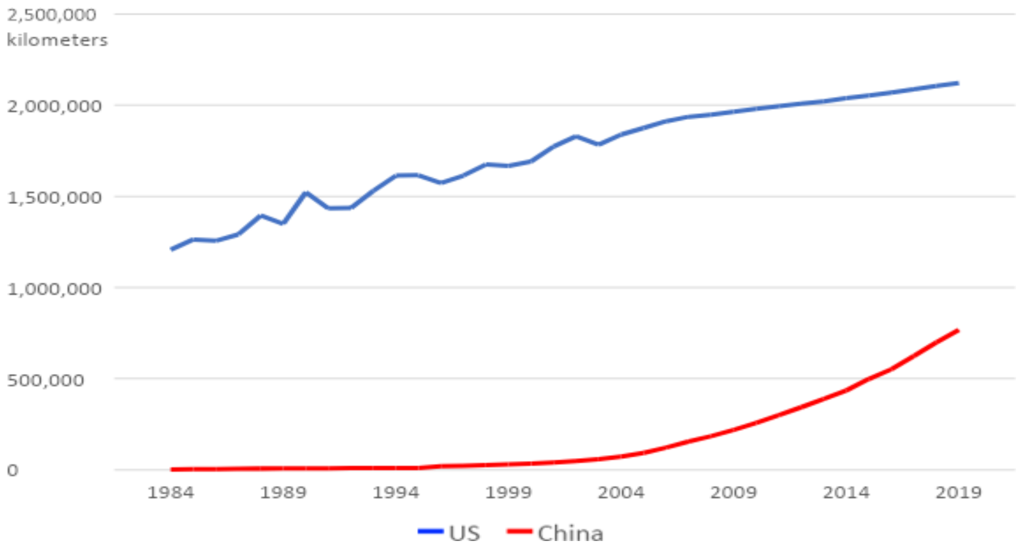
[105] BP Statistical Review of World Energy, 2021.

[106] 能源发展"十三五"规划 [13th Five-Year Plan for Energy Development].

[107] 2019 年城市建设统计年鉴 [Statistical Yearbook of Urban Construction 2019], Chinese Ministry of Housing and Urban-Rural Development.

[108] "Annual Report Mileage for Natural Gas Transmission & Gathering Systems," Department of Transportation, https://www.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-natural-gas-transmission-gathering-systems, accessed May 2023.

Figure 15: China and US domestic gas distribution network mileage[109]



China also lacks capacity in natural gas storage. In 2020, the US recorded total natural gas consumption of 832 billion cubic meters (bcm)[110] and 120 bcm of underground gas storage,[111] representing 14.4% of the total. By contrast, China's volume of working underground gas storage represents only 3% of total national consumption—a shortage that the NDRC describes as "an important bottleneck limiting the sustainable development of China's natural gas industry."[112] As the 2016 China Blue Book of Energy, the most recent edition of a series of industry annual reports published by the Social Sciences Academic Press and whose lead editors includes the deputy director of the Institute of Industrial Economics at the Chinese Academy of Social Sciences, notes, "China's storage and transportation capacity is far from adequate to meet the needs of the natural gas market, so the construction of both pipeline networks and urban gas transmission and distribution infrastructure will be a priority in future infrastructure development."[113]

The US has 412 active natural gas storage facilities, according to latest figures from 2019.[114] However, roughly 80% of wells in the US's natural gas storage fields were completed in the

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[109] Annual Report Mileage for Natural Gas Transmission & Gathering Systems, Department of Transportation; and 2019 年城市建设统计年鉴 [Statistical Yearbook of Urban Construction 2019], Chinese Ministry of Housing and Urban-Rural Development.

[110] BP Statistical Review of World Energy 2021.

[111] Underground Natural Gas Working Storage Capacity, EIA, November 2021, https://www.eia.gov/naturalgas/storagecapacity/.

[112] 关于加快储气设施建设和完善储气调峰辅助服务市场机制的意见 [Opinions on accelerating the construction of gas storage facilities and improving the market mechanism for gas storage and peaking auxiliary services], NDRC, April 2018.

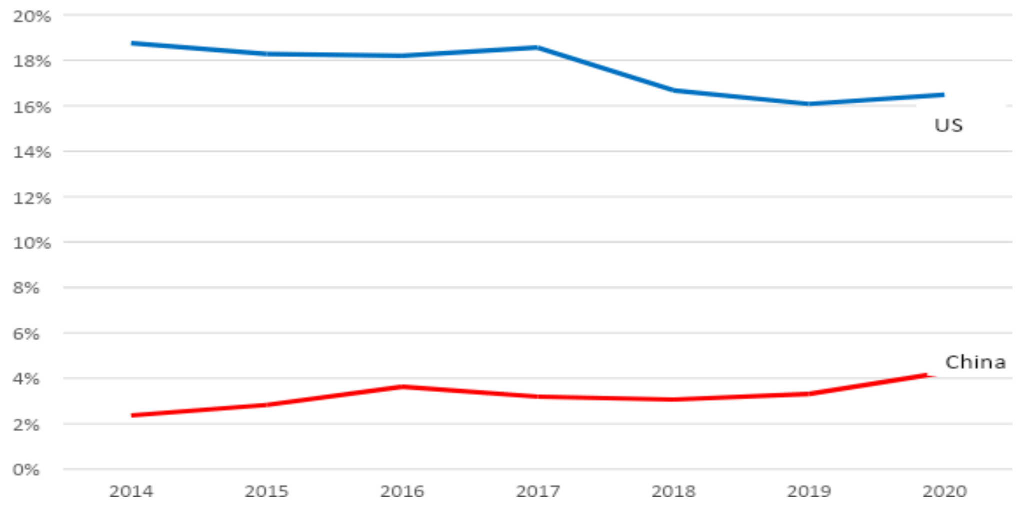
[113] China Blue Book of Energy, 2016.

[114] "Underground Natural Gas Storage Capacity," EIA, https://www.eia.gov/dnav/ng/ng_stor_cap_dcu_NUS_a.htm

1970s or earlier, meaning they have weathered decades of use and predate many current technological and material standards, according to a report by the US Department of Energy published in the wake of a historic 2015 leak from the Aliso Canyon underground gas storage facility in California.[115] By contrast, China's 27 underground gas storage facilities are much younger: the first came into operation in the 1970s, and the government only began its concerted push for such storage facilities in the early 1990s, with six coming into operation in 1999.[116]

In 2018, China's NDRC set minimum targets of gas storage capacity for gas supply companies, local governments, and urban gas enterprises.[117] Analysts cited by China Daily projected that if the targets were met, China would reach a natural gas working storage as proportion of total gas use of 16%, on par with that of the US.[118] So far, China is still far from that goal. Improving natural gas infrastructure remains an urgent task. The State Council highlighted it as a key priority in the 2020 Energy Development White Paper.[119]

Figure 16: China and US total underground natural gas storage working capacity as percentage of total natural gas consumption[120]



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[115] "Ensuring Safe and Reliable Underground Natural Gas Storage: Final Report of the Interagency Task Force on Natural Gas Storage Safety," Department of Energy, October 17, 2016, https://www.energy.gov/articles/report-ensuring-safe-and-reliable-underground-natural-gas-storage.

[116] 天然气行业专题系列报告（二）管网、LNG 接收站和储气库行业步入快速发展期 [Natural Gas Industry Special Report Series (2) Pipeline Network, LNG Receiving Stations and Storage Industry Enters Rapid Development Period], Ping An Securities, March 24, 2019.

[117] 关于加快储气设施建设和完善储气调峰辅助服务市场机制的意见 [Opinions on accelerating the construction of gas storage facilities and improving the market mechanism for gas storage and peaking auxiliary services], NDRC, April 27, 2018.

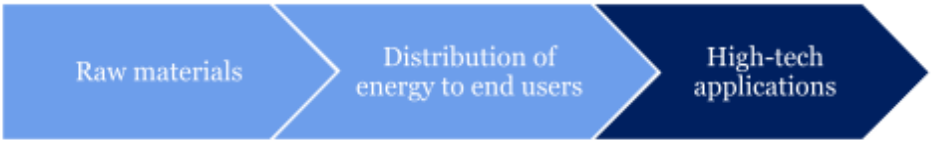
[118] Zheng Xin, "Lack of natural gas storage capacity restricting supply," China Daily, July 10, 2019.

[119] 新时代的中国能源发展 [China's Energy Development in a New era], State Council, December 2020

[120] Underground Natural Gas Working Storage Capacity, EIA; Chinese Ministry of Housing and Urban-Rural Development and other Chinese sources

Downstream: High-Tech Applications

At the upstream of the global emerging energy architecture are the materials and technology required to convert sun, wind, and other renewable resources into electricity (e.g., high purity quartz needed to manufacture solar panels). The midstream involves storing and distributing that energy. And the downstream comprises high-tech applications that harness renewable energy for complex and sophisticated uses – for example, electric vehicles, and the batteries, magnets, and motors needed to power them.



This section focuses presents a short case study one key downstream application in the energy sector: rare earth permanent magnets, which are important inputs in several strategic emerging industries, including electric vehicles and wind energy, and whose entire industry chain China exerts significant influence over. This analysis finds that while the US tries to rebuild its rare earth magnet industrial capacity, China is seeking further to reinforce its dominance in the industry by focusing on high-end, high value-add materials and applications in its downstream sector.

This section finds that while the US have works to re-establish domestic industrial capacity in each step of the rare earth magnet production process, China sees a need to redouble efforts to cement its dominance over key nodes of the entire magnet industrial chain.

Rare earth permanent magnets

Rare earth permanent magnets, as the name suggests, have permanent magnetic fields and contain rare earths that significantly increase their magnetic strength. Rare earth magnets have a wide range of critical applications, including electric vehicles, drones and planes, missiles and fighter jets, and industrial and consumer robotics. The most widely used rare earth permanent magnet today is the neodymium-iron-boron (NdFeB) magnet.[121]

China currently dominates the full global rare earths supply chain, from upstream production, to midstream processing, to downstream permanent rare earth magnet production. In 2019, China accounted for 60% of global rare earth production,[122] 87% of global rare earth processing,

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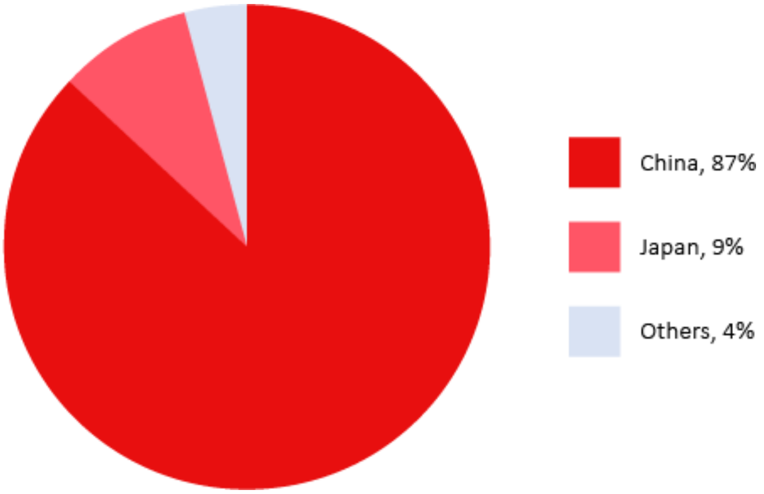
[121] “Rare Earths: Market Outlook to 2020” Roskill, 2015

[122] The Role of Critical Minerals in Clean Energy Transitions,” International Energy Agency.

and 87% of the global NdFeB magnet materials production.[123] By contrast, the US currently has no ability to produce NdFeB magnets at scale, nor produce the processed rare earth materials needed to manufacture the magnets.[124]

Figure 18: Global NdFeB magnet materials production, 2019[125]



In 2020, 70% of US imports of NdFeB magnets came from China, up slightly from 65% in 2010. The US was China's top destination for NdFeB exports, making up 13.2% of total exports (see tables). Recognizing the vulnerability posed to the US its heavy reliance on China, the US Department of Defense in 2019 took steps to stockpile a six-month supply of NdFeB magnets used in Javelin missiles and F-35 fighter jets, according to Reuters.[126]

Table 18: Top 10 sources of US NdFeB imports, 2020[127]

Country	% of US imports
China	69.8

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[123] 稀土永磁龙头，加码新能源赛道 [Rare earth permanent magnet leaders double down on new energy track], Guosen Securities, August 2021.

[124] Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100-Day Reviews under Executive Order 14017, June 2021.

[125] "Rare earth permanent magnet leaders double down on new energy track," Guosen Securities, August 2021.

[126] Ernest Scheyder, "Exclusive: Pentagon to stockpile rare earth magnets for missiles, fighter jets," Reuters, December 20, 2019, https://www.reuters.com/article/us-usa-rareearths-magnets-exclusive-idUKKBN1YO0G7

[127] Source: UN Comtrade, commodity code 850511

Japan	8.3
Germany	4.1
Philippines	3.8
Mexico	1.7
South Korea	1.4
Switzerland	1.3
Other Asia	1.2
Netherlands	1.1
Finland	1.0

Table 19: Top 10 destinations of Chinese NdFeB exports, 2020[128]

Country	% of China's exports
USA	13.2
Vietnam	10.7
India	10.3
Germany	8.8
South Korea	5.0
Japan	4.9
Thailand	4.0
Indonesia	3.2
Other Asia	2.9
Russia	2.9

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[128] Source: UN Comtrade, commodity code 850511

“Full industry chain competition”

However, it is not enough to look solely at magnet production. While discourse and analysis tend to focus just on NdFeB magnet trade, to understand the competitive balance one needs to look more broadly across the value chain. This is especially so as Chinese sources describe a new era of full industry chain competition.

NdFeB manufacturing relies on numerous preceding tiers in the rare earth supply chain to ensure the availability of raw materials and processed metals and alloys to produce the final magnet. Currently, only China has a fully integrated supply chain, beginning with mining and processing, while the US only has active operations at the very upstream node of mining (see table).

Table 20: US and China’s NdFeB supply chains[129]

	Mining	Mixed compounds	Separation, light rare earths	Separation, heavy rare earths	Oxide to metal	Magnet alloys	NdFeB sintered magnets
US	•	**	**	**	IDLE	IDLE	**
China	•	•	•	•	•	•	•

• denotes active operations
** denotes supply chain tiers in which the US government is working to re-establish industry capacity

Both the US and China recognize the importance of having at least some degree of vertical integration in their rare earth supply chain. “The neodymium-iron-boron (NdFeB) magnet supply chain is an example of a strategic and critical materials supply chain where one country is able to maintain vertical capabilities throughout the supply chain, while multiple other countries operate at only select tiers,” noted the White House’s 100-day supply chain review report.[130] “…Though only China has all essential supply chain tiers, at least some nominal capacity exists for each tier in a combination of countries outside China.”

Currently, however, the US lacks any industrial capacity in the production of NdFeB magnets. The only active rare earths mine in the US has to sell essentially all its mined materials to China for processing, as the US has no industrial capacity to do so.

Meanwhile, policy discourse in China centers not only on the existence of a vertically integrated supply chain, but also on how those vertical capabilities are distributed. The Rare Earths Industry Development Plan 2016-2020, issued by the NDRC, for example, highlighted “industrial restructuring breakthroughs” whereby capacities in upstream extraction and

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[129] Adapted from White House report on “Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth.”

[130] Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100-Day Reviews under Executive Order 14017, June 2020.

midstream processing have been successfully deployed to "accelerate the direction of high-end materials and application products."[131]

Table 21: World mine production of rare earths[132]

	2019	2020
China	132,000	140,000
US	28,000	38,000
Australia	20,000	17,000
Myanmar	25,000	30,000
Madagascar	4,000	8,000
India	2,900	3,000
Thailand	1,900	2,000
Russia	2,700	2,700
Vietnam	1,300	1,000
Brazil	710	1,000
Burundi	200	500
Others	66	100
World total (rounded)	**220,000**	**240,000**

Note: China's numbers reflect the production quota, and exclude undocumented production.

Still, Chinese researchers and officials have publicly expressed concerns over the industry's structural weaknesses, including competitive pressures posed by foreign countries such as the US as they increasingly recognize the risks of relying on China for the rare metals and seek to diversify global supply chains. Writing in the Chinese Rare Earths journal in 2020, researchers analyzed the impact of the US critical minerals strategy issued by the Department of Commerce

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[131] 稀土行业发展规划 2016-2020 [Rare earth industry development plan 2016-2020], NDRC, July 21, 2017.

[132] Mineral Commodity Summaries: Rare earths," US Geological Survey, 2021.

in 2019.[133] The paper presented the renewed focus on critical minerals from the US (and more broadly, western countries) as an important factor poised to transform the global rare earths market, compelling China to upgrade its entire rare earths industry in order to remain competitive and retain its dominant global stature. The authors write:

> In light of [US federal critical mineral strategy's] impact on the international market, China's rare earth industry will not only face downstream application technologies from Western countries, but will also face more serious challenges at the upstream raw material and functional material ends — a "two-way squeeze."[134]

As the United States and more foreign players re-establish their own rare earth supply chains, the authors continued, the international rare earth market will become more crowded and competitive, making it unsustainable for China to sell cheap raw rare earth materials while also increasing competition in midstream processing and downstream new materials development and high-tech end-use applications. "China needs to recognize that the era of full industry chain competition has arrived," they write.

A key focus for China, as it seeks to upgrade its rare earth industry to remain globally competitive amid the re-emergence of foreign players, is its downstream sector. The NDRC's 2016-2020 development plan, for example, noted that "continuous innovation capacity is not strong, the core patents are subject to [other countries], the overall strength of basic research needs to be improved…downstream high-end application products are relatively insufficient."[135]

That insufficiency is evident when comparing China's production of high-performance NdFeB materials relative to global NdFeB materials production. According to 2018 data and analysis by the Association of China Rare Earth Industry and Ping An Securities,[136] where high-performance neodymium-iron-boron magnet materials make up 26% of the global NdFeB magnet materials production, China's is only 15% of total domestic NdFeB magnet materials output (see table). Though Chinese policy documents use the term "high performance rare earth magnets," they do not offer a definition. However, JL Mag Rare Earth, a major Chinese rare earth magnet producer, defines it in its 2018 prospectus as a magnet that attains a certain specific minimum level of magnetic coercivity and maximum energy product.[137]

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[133] "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," Department of Commerce, June 4, 2019, https://www.commerce.gov/data-and-reports/reports/2019/06/federal-strategy-ensure-secure-and-reliable-supplies-critical-minerals

[134] 美国关键矿产战略对中国稀土产业的影响研究 [A study of the impact of US critical minerals strategy on China's rare earth industry], China Rare Earths, June 2020.

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Table 22: Make-up of NdFeB magnet material production, global and China[138]

	Global	China
NdFeB magnet material	26%	15%
High-performance NdFeB magnet material	74%	85%

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[138] New Materials Series In-depth Report No. 2 - Key Strategic Materials: High Performance Rare Earth Permanent Magnet Materials," Pingan Securities.

Conclusion

This report seeks to provide baseline metrics and frameworks to support assessment of relative US and Chinese energy capacity, strengths, and weaknesses across fundamental, synthetic, and downstream domains. It finds that while the US might benefit from an advantage in conventional energy domains, Beijing is positioning to compete for the energy transition – even as the US takes a relatively cooperative approach to it. Compounding that asymmetry, Beijing's competitive model is a whole of supply chain one in which supply chain dependencies promise offensive capabilities chain, a reality that could create new and under-appreciated vulnerabilities for the US. This reality factors into assessments even at the downstream, high tech elements of the energy sector. Finally, Beijing's pricing power as the world's major energy importer could provide it an opportunity to leapfrog legacy US influence over energy markets, including by building new, alternative infrastructure to shape those. Additional, future research is still needed to check conclusions – and to incorporate analyses of more granular cases or sub-areas.