SIPA

Investment Opportunities in the Greening Economy Despite an Adverse Trade Policy Landscape

Spring 2025 Capstone Workshop for Citi Global Wealth Management

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List of Acronyms

AD/CVD	Antidumping and Countervailing Duties
BESS	Battery Energy Storage System
BNEF	BloombergNEF
CAGR	Compound Annual Growth Rate
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture Utilization and Sequestration
CMA	U.S. – Japan Critical Minerals Agreement
CNC	Civil Nuclear Credit
DC	Direct Current
DOE	U.S. Department of Energy
DRC	Democratic Republic of Congo
EPA	U.S. Environmental Protection Agency
ESG	Environmental, Social, and Governance
EV	Electric Vehicle
FTA	Free Trade Agreement
GEIS	Generic Environmental Impact Statement
GW	Gigawatt
GWdc	Gigawatt Direct Current
GWh	Gigawatt-hour
HPAL	High-Pressure Acid Leech
IEA	International Energy Agency
IEEPA	International Emergency Economic Powers Act
IIJA	Infrastructure Investment and Jobs Act
IPCEI	Important Projects of Common European Interest
IRA	Inflation Reduction Act
IRS	Internal Revenue Service
ITC	Investment Tax Credit
kWh	Kilowatt-hour
LFP	Lithium-Iron-Phosphorus
LME	London Metal Exchange
LIB	Lithium-Ion Battery
MSP	Minerals Security Partnership
MW	Megawatt
MWdc	Megawatt Direct Current
MWh	Megawatt-hour
NMC	Nickel-Manganese-Cobalt
NPI	Nickel Pig Iron
NRC	Nuclear Regulatory Commission

NZE	Net Zero Emission Scenario
PTC	Production Tax Credit
PV	Photovoltaic
PWA	Prevailing Wage and Apprenticeship
REE	Rare Earth Element
SEIA	Solar Energy Industries Association
SMR	Small Modular Reactor
STEPS	Stated Policies Scenario
TCTF	Temporary Crisis and Transition Framework
TRQ	Tariff Rate Quota
USGS	U.S. Geological Survey
TWdc	Terawatt Direct Current
TWh	Terawatt-hour
USTR	United States Trade Representative
Wdc	Watt Direct Current

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Executive Summary

The request for this Capstone, defined prior to the outcome of the 2024 election, was to examine how evolving trade policy—including domestic manufacturing incentives under the Inflation Reduction Act of 2022 (IRA)—could create investment opportunities in the "greening economy" for our client Citi Global Wealth Management and its clientele of private investors.

However, by spring 2025, most sectors associated with the greening economy faced an adversely evolving policy environment. It is possible that in the coming months, the IRA will be repealed or its incentives significantly reduced by the Republican-controlled Congress as part of broader fiscal consolidation efforts. Under the second Trump Administration, trade policy has evolved rapidly with unexpectedly high tariffs threatened or imposed on a broad range of countries for a broad range of imported items. The risk of new, sustained tariffs represents a strong headwind for sectors reliant on imported components and equipment—though such measures may also serve as tailwinds for select domestic manufacturers. As of the conclusion of this Capstone project, many of these uncertainties remain unresolved.

The risk of new, sustained tariffs represents a strong headwind for sectors reliant on imported components and equipment—though such measures may also serve as tailwinds for select domestic suppliers and manufacturers. The Trump Administration's stated goal is to stimulate domestic manufacturing, but there is presently uncertainty about which tariffs will be long-term and which are subject to being changed or having exceptions created. Market participants are reported to be waiting to see where the evolving trade policies settle. Formal agreements with trading partners will likely provide more certainty than the tariffs a president can impose under authorities delegated by Congress. As of the conclusion of this Capstone project, many of these uncertainties remain unresolved.

The Capstone team has nevertheless identified investment opportunities for Citi's clientele in selected sectors that serve the greening economy despite this adversely evolving landscape. Partially offsetting the policy tailwinds are strong bipartisan policy themes which surfaced through extensive research and engagement with stakeholders. Among these are three shared priorities:

1. to secure critical mineral supply chains and reduce overdependence on China as a national security goal;

2. to meet rising energy demand—driven by AI, data centers, and electrification—a re-embrace of nuclear generation as a reliable and clean base load source; and

3. to protect and expand domestic manufacturing jobs through tariffs and domestic content incentives.

These three national priorities informed the selection of sectors most likely to withstand a less supportive policy environment towards the greening economy and a partial or full repeal of the IRA. From an initial universe of 16 clean energy sectors supported under the IRA, a screening process based on market size, policy outlook, and bipartisan national priorities yielded four priority sectors:

- Critical minerals supply;
- Nuclear power generation;
- Domestic manufacture of batteries; and
- Domestic manufacture of solar generation equipment.

Critical minerals and nuclear power energy generation occupy a central role in both the energy transition and national security discourse, with strong alignment to supply chain diversification.

Nuclear generation enjoys bipartisan support as it's carbon-free, relatively job-intensive and serves the priority to increase the capacity for firm and reliable electricity generation. Battery and solar equipment manufacturing similarly support domestic job creation and energy independence while aligning with broader policy goals.

Among these sectors, critical minerals are given particular emphasis due to their rising demand for industrial purposes generally and heightened geopolitical relevance. Five minerals—copper, cobalt, nickel, lithium, and aluminum have an essential role in clean energy systems. In the second phase of the Capstone workshop, these sub sectors were examined in detail (deep dives), including their end-uses, historical prices, global production, supply chain origins, evolving industrial policy impacts and their pools of investible players.

The resulting research confirms that investment opportunities can be found among the listed players active in these examined sectors. Among the critical minerals studied, Chinese dominance in refining especially is both a national security concern and a market supply chain issue, but more diversity of supply exists in copper, nickel and aluminum upstream. Analysts predict domestic players in these mining sectors are especially well-positioned for higher profitability if tariffs become settled on imports of these elements.

Nuclear generation seems well positioned to benefit from strong policy support and growing demand. Although the U.S. leads in existing reactors, it has come to rely too heavily on imported uranium, which has seen sustained price increases. The IRA's 45U and 45Y tax credits continue to support both existing and advanced nuclear projects. This report highlights the diverse range of nuclear-related investible players, including nuclear utilities, small modular reactors, and uranium miners.

The outlook for batteries and solar equipment manufacturing is more ambiguous. While both sectors are expected to see continued demand—batteries due to electric vehicle (EV) adoption and storage needs, and solar due to global decarbonization efforts—their dependence on IRA subsidies and foreign imports exposes them to some downside risk if the IRA incentives are amended-away. While grandfathering rules are expected to preserve IRA incentives for plants involved in battery and solar equipment manufacturing, as well as deployments that are operating or under construction, longer term projects may get deferred. Recent delays in previously announced battery plant investments underscore this uncertainty.

Simultaneously, potential tariffs on imported solar cells and their elemental inputs could negatively impact U.S. firms relying on global supply chains while potentially benefiting domestic manufacturers of batteries and solar equipment with protection for cheaper imports. The amounts and targets for tariffs in these sectors need to be more clearly settled for this calculation to be made. Despite these challenges, batteries and solar equipment manufacturing seem likely to continue receiving a sufficient level of bipartisan policy support given their contributions to domestic job creation.

For each of the four focus sectors, the report highlights recent company announcements or developments and applies a structured framework to evaluate the suitability of the publicly listed companies for wealth management clients. A two-factor sorting matrix is used: one axis reflects a firm's leadership position in the sector (as measured by market share), while the other reflects the sector's strategic importance to the company. Firms located in the matrix's lower-left quadrant—high sector leadership and high business alignment—are identified as best positioned to benefit from evolving market drivers and policy support, including tariffs and domestic content incentives. Sector-specific matrices are included in Part 2 of the report. The players in the matrices are also color-coded to distinguish those listed on US, Chinese and other international exchanges.

These findings are intended to serve as a foundation for further strategic consideration. They are not definitive investment recommendations. At the same time, private actors are key to supporting the greening economy, and this report will help direct the support of Citi and its clients to key energy transition-linked players in an otherwise adverse policy environment.

About the client

Citi Global Wealth Management aims to monitor how legislation, policy responses, and market trends shift investment opportunities and ultimately help their clients achieve their goals. Citi’s request to the Capstone Team has been to analyze how evolving trade policies, including tariffs on imports and incentives for domestic production and purchase, are influencing investment opportunities in the greening economy.

Citi Global Wealth Management combines all of Citi's resources to provide wealth management services to a wide range of clients, including family offices, the extremely wealthy, professionals, and the affluent. Within the wealth realm, the Private Bank is dedicated to serving the world’s wealthiest individuals and their families. From 52 locations across 20 countries, Citi offers its services to more than 14,000 ultra-high net worth clients from nearly 100 nations. Wealth at Work focuses on the needs of the world’s busiest professionals, ranging from lawyers to consultants to asset managers. Citigold and Citigold Private Client cater to other individuals seeking a dedicated team with complimentary financial planning, world-class investing capabilities, preferred pricing on select products and exclusive travel and lifestyle benefits. Citi Global Wealth offers customized, sophisticated, cross-border Global Wealth advising services across equities, fixed-income and multi-asset classes, to a clientele with global reach, seeking to protect and grow their wealth.

While this report does not aim to give specific investment recommendations, it aims to summarize and break down those most promising clean energy sectors by key players poised for growth throughout their respective value chains. This report will highlight Critical Minerals, Nuclear Energy, Battery Manufacturing and Solar Component Manufacturing as the sectors that Citi’s Global Wealth Management clients should have on their radar when rebalancing portfolios in light of evolving energy and trade policies. This report analyzes these targeted sectors and details the outlook for pertinent IRA tax credits, as well as wider trade policy shifts propelling unique tailwinds for key players within the sectors identified.

PART 1
Background and Context

1.1 Introduction

In the background for this report is the multi-year relationship between Columbia SIPA's Capstone Workshop program and its external client Citi Global Wealth Management. Student researchers within the Capstone program at SIPA have been regularly assisting Citi by researching a sequence of current topics where evolving government policy will have a direct effect on investment strategies for Citi's clientele of high-net-worth individuals and family offices. The topic in 2023 was to examine how the IRA was creating investment opportunities in selected sectors linked to the energy transition to a greener economy. Following up on this research, the working title for the 2025 Capstone study has been: How Trade Policy Affects Opportunities in the Greening Economy for Private Client Investors.

The term "Trade Policy" captures not only tariffs, but also government programs and incentives that promote the production and consumption of domestically manufactured goods. These include initiatives such as the IRA, the EU's Carbon Border Adjustment Mechanism (CBAM), and other programs which seek to support domestic manufacturing.

At the time of this research in the spring of 2025, most of the sectors related to a greening economy face a policy landscape with many headwinds and a few tailwinds. As explained more fully below, the headwinds include energy and fiscal policies on the part of the Trump Administration unfavorable for many of the sectors linked to the energy transition. It is possible that in the coming months the IRA will be repealed or its investment incentives substantially reduced by the Republican-controlled Congress. The threat of high and persisting new tariffs also presents strong headwinds for those sectors that rely on imported parts and equipment.

However, at least three shared priorities have emerged among the two US parties and the other Western economies that will continue to be tailwinds for some, but not all, of the sectors linked to the energy transition.

1. Securing reliable supply-chains for those parts, equipment and especially critical minerals that are vital for a range of advancing technologies. China's out-of-balance share in these markets is concerning to policymakers across the political spectrum among China's economic rivals.
2. Increasing power generation capacity to serve rising power demand in developed markets linked to AI, data centers, and other needs. Reversing a decades-long trend, electricity demand is rising among the developed economies, supporting the case for the firm, carbon-free, nuclear generation option.
3. Protecting and increasing domestic manufacturing jobs through tariffs on imports coupled with domestic purchase incentives for targeted sectors.

These three shared priorities are policy tailwinds favoring a few discrete sub sectors linked to the energy transition (this report's "examined sectors"):

- Critical minerals supply, production and procurement
- Nuclear power generation
- Domestic manufacture of batteries
- Domestic manufacture of solar generation equipment

In this sense our working title has evolved: *Investment Opportunities in the Greening Economy Despite an Adverse Trade Policy Landscape.*

As retitled, the focus of this research is heavily weighted towards the role of critical minerals in the green transition, as this industry is supported by a growing and bipartisan national security imperative with respect to these supply chains. This report also focuses to a lesser extent on sectors such as nuclear generation, battery manufacturing, and solar component manufacturing due to market demand for these energy solutions and bipartisan support for the role that these sectors play in the American manufacturing landscape. As these sectors were catalyzed by programs such as the IRA, a key consideration in the evaluation of the trajectories for these examined sectors is the likelihood of IRA tax credits at least partially surviving a likely revisit by Congress and this current administration. This process is discussed in detail below within the section below on Methodology.

Part 2 of this report provides an in-depth analysis of each examined sector and presents a framework for sorting publicly listed companies that are best positioned to endure if not benefit within this evolving trade and energy policy landscape. Finally, this analysis will draw from the insights of policy experts and market participants, revealing durable policy themes that investors should closely monitor. For example, it is expected that:

- **On-shoring and friend-shoring of supply chains for critical mineral**s will be viewed as a national security imperative and enjoy strong bipartisan support. While these minerals have wide-ranging industrial and military applications, many are also fundamental to the energy transition.
- **Nuclear energy generation** will maintain a broad bipartisan approval and is expected to remain a key pillar of the US clean energy strategy.
- **Battery manufacturing**, including for uses beyond EVs—such as grid-level storage—can be expected to continue receiving broad bipartisan support.
- **Solar equipment manufacturing** may face more partisan scrutiny but will appear to retain sufficient political backing to withstand potential IRA reforms.

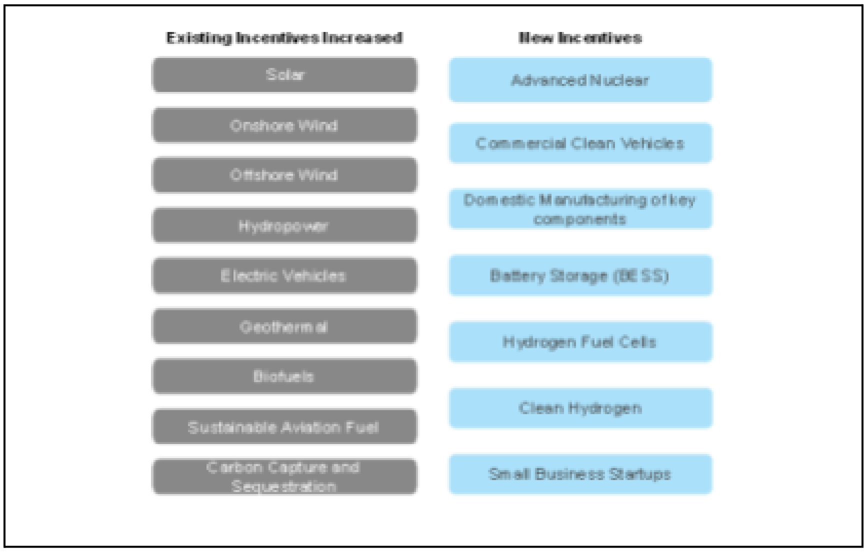
1.2 How did the Inflation Reduction Act support clean energy investments?

The IRA was signed into law on August 16, 2022. It allocated $500 billion in spending and tax breaks to boost private investment in clean energy and related sectors focused on decarbonization challenges over a period of 10 years. Approximately $265 billion of this came in the form of tax credits, a major portion of which were aimed at motivating businesses to invest in a range of at least sixteen industry sectors linked to mitigating climate change.[1] Most of these sectors like renewable energy generation, EVs and low-emission fuels had already benefited from tax credit incentives prior to the IRA. Importantly, as detailed in Figure 1 below, the IRA introduced new federal incentives for nascent industries such as nuclear generation, BESS and clean hydrogen. Our analysis therefore springs from these sixteen sectors.

…/…

[1] Kumar, A., O'Rourke, S., Mehta, N., Badlam, J., Silvis, J., & Cox, J. (2022, October 24). *The Inflation Reduction Act: Here's what's in it.* McKinsey & Company. https://www.mckinsey.com/industries/public-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it.

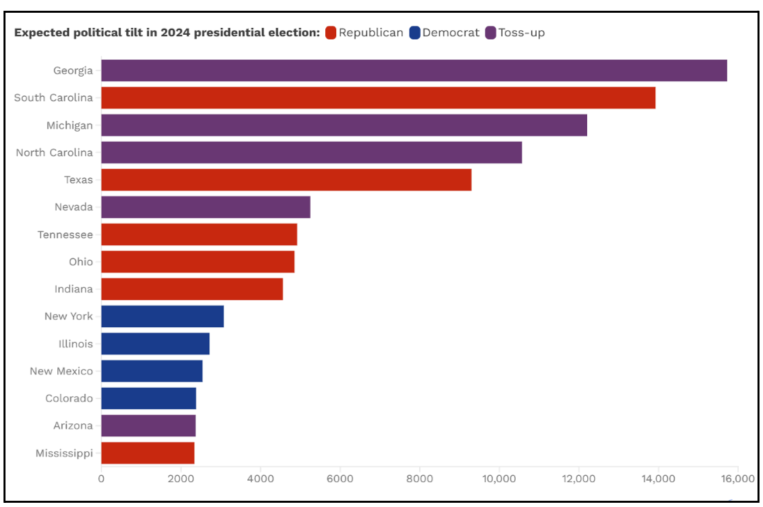
Figure 1. Pre and Post IRA-Supported Sectors



Source: The White House (2023)

A major component of the IRA that provided it with a strong political foundation was its focus on Domestic Job Creation. New and enhanced tax credits that especially rewarded investment in U.S. manufacturing, products with U.S. content, the payment of prevailing wages to workers, and siting investments in targeted areas (lower income, native reservations, energy communities) were among the Act's innovations targeting job-creation. This worked by defining base tax credits for the various sectors which are increased if the eligible investment involves defined labor standards for workers mirroring what union contracts normally include. The tax credits can be increased further in some cases if the investment involved a defined amount of U.S. content, or if the investment is sited in a targeted community. In fact, the amount of job creation and renewed manufacturing activity the IRA spurred in Republican states helped create a strong political incentive against the full repeal of the IRA.[2]

Figure 2. Top 15 States for Jobs from New Clean Energy Project Since the 2022 IRA



Source: Cipher (2024)[3]

[2] Fujii-Rajani, R., & Patnaik, S. (2025, January 6). *What will happen to the Inflation Reduction Act under a Republican trifecta?* Brookings. https://www.brookings.edu/articles/what-will-happen-to-the-inflation-reduction-act-under-a-republican-trifecta

[3] Clifford, C. (2024, September 4). *Majority of top states for jobs from new clean projects are GOP, battleground*. Cipher

1.2.1 Incentives targeting Energy Communities

The provisions in the IRA regarding energy communities were viewed as a significant tool for incentivizing renewable energy investment in communities that historically relied on fossil fuel-related industries. These are locations that fall into three categories: brownfield, statistical area or coal closure category. For example, if the project is located in a low-income community or on Tribal land, a renewable energy project would be eligible for a 10 percent adder to the Investment Tax Credit (ITC). If a Production Tax Credit (PTC) were elected, the project would be entitled to a bonus credit of up to 10 percent (i.e., the PTC would be multiplied by 110 percent) if located in one of these favored sites.

1.2.2 Incentives targeting stronger Labor Standards

By creating incentives for paying prevailing wages and utilizing qualified apprentices from registered apprenticeship programs in clean energy projects, the IRA aimed to help expand well-paying union jobs and support proven pathways into the industry that allow workers to earn while they learn.

To receive increased credit under the Act, applicants would need to:

- Pay workers the local prevailing wage, defined in accordance with the U.S. Department of Labor standards, for work on facility construction, as well as for alterations and repairs in a five-to-twelve-year period, depending on the credit, after a facility is placed in service;[4] and
- Hire a sufficient proportion of workers from registered apprenticeship programs, including hiring these qualified apprentices for at least 10 percent of the labor hours spent on facility construction, alteration, or repair work (rising to 12.5 percent for facilities where construction begins in 2023 and 15 percent in 2024 and later years).[5]

1.2.3 Incentives targeting supply chain security

Incentives in the IRA reflect the concern that the U.S. has become too dependent on imported equipment, and the critical minerals to producing such equipment, particularly from China. As explained further below, these provisions seem likely to survive amendment by the new Congress given the bipartisan nature of these national security concerns.[6] Notably, there are several overlapping tax credits in the Act aimed at promoting the purchase and production of batteries and their critical minerals in the U.S. with incentives based on capital investment amount (investment tax credits - ITC) or on units-of-production (production tax credits – PTC). However, this report will primarily focus on PTC-type incentives under section 45X of the IRA when discussing critical minerals and advanced manufacturing of batteries and solar components. Further details can be found within the section below on our methodology.

1.2.4 IRA Reforms and Outlook

News. https://www.ciphernews.com/articles/majority-of-top-states-for-jobs-from-new-clean-energy-projects-are-gop-battleground/

[4] U.S. Department of the Treasury. (2023, October 20). *FACT SHEET: How the Inflation Reduction Act's Tax Incentives Are Ensuring All Americans Benefit from the Growth of the Clean Energy Economy.* U.S. Department of the Treasury. https://home.treasury.gov/news/press-releases/jy1830

[5] Ibid

[6] Baskaran, G. (2024, November 14). *Seven Recommendations for the New Administration and Congress: Building U.S. Critical Minerals Security*. Center for Strategic and International Studies. https://www.csis.org/analysis/seven-recommendations-new-administration-and-congress-building-us-critical-minerals

When evaluating the future of the IRA, it is essential to quantify and contextualize the extent to which its subsidies have already been disbursed or allocated. Doing so provides a clearer understanding of how much funding remains at risk of repeal or modification, as well as the mechanisms available to the new administration should it pursue such a course.

Prior to the new administration taking office in January 2025, approximately 80% of IRA funds had been allocated to clean energy projects, leaving only one-fifth potentially vulnerable to rollback under President Trump.[7] However, while 80% of the funds were allocated, not all had been fully disbursed. This distinction was leveraged by the administration in January, when it ordered a funding freeze on pending IRA allocations to review their alignment with its policy priorities.[8] Although courts across the country challenged this action as an overreach of presidential authority, the resulting bureaucratic delays undermined investor confidence and heightened uncertainty regarding the timely disbursement of essential funding for climate-related projects.[9]

Self-funding Tax Credits: It is important to note that while the IRA increased the capacity of federal agencies to make loans or grants or direct payment subsidies to support the targeted climate-related projects and sectors, most of the financial incentives under IRA are in the form of tax credits earned by owners of the targeted activities. These tax credits are self-funding insofar as the owners may use them to offset their own tax liabilities or can assign them to third parties for value, either by (1) inducing a favorable "tax equity" investment from a corporate partner to co-own their activity or (2) selling the credits outright – this latter option is an IRA innovation.

In sum these tax credits are routinely monetized through their sale or exchange to corporations seeking to use the credit against their tax liabilities. These transactions do not require disbursements from federal agencies. The tax credits turn into funds provided by the assignee corporations, so the freezing of disbursements by federal agencies under policies of the new administration does not yet disturb the payment of most IRA incentives in the activities studied by this report.

While President Trump has expressed a desire to repeal the IRA, any repeal or amendment would require new legislation passed by Congress. An outright repeal would be difficult to achieve given the number of Republican constituencies benefiting from the Act's job-creating provisions. Nevertheless, there is a strong incentive for Republicans to partially repeal or amend elements of the IRA in order to offset the cost of extending the 2017 Trump-era tax cuts.[10]

A partial repeal of IRA provisions could take several forms according to recent interviews with Washington-based observers and consultants. One likely avenue is the modification of tax credit eligibility, particularly through the removal of certain "adder" incentives—such as those tied to labor standards—which may instead become baseline requirements to qualify for the core credit. Market participants also expect that any repeal or reduction on the IRA incentives would include "safe harbors" preserving incentives at original levels for operating businesses and those under construction. This view is based on the grandfathering provisions included in previous legislation

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[7] Milman, O., & Uteuova, A. (2025, January 14). *Biden Trump-proofs $74bn in climate funding but $20bn remains vulnerable*. The Guardian. https://www.theguardian.com/us-news/2025/jan/14/biden-trump-climate-change-funds

[8] Vij, N. (2025, February 24). *Trump's Funding Freeze and The Debate over Climate Dollars* . ClearBlue Markets. https://www.clearbluemarkets.com/knowledge-base/trumps-funding-freeze-and-the-debate-over-climate-dollars

[9] Phillis, M. (2025, April 2). *Federal judge questions whether EPA move to rapidly cancel 'green bank' grants was legal*. AP News. https://apnews.com/article/epa-federal-green-bank-grants-7b158181bbf1053686bab67b02fa0e35

[10] Luna, N. (2024, June 14). *US elections: the Inflation Reduction Act and the risk of repeal.* Columbia Threadneedle Investments.
https://www.columbiathreadneedle.com/en/insights/us-elections-the-inflation-reduction-act-and-the-risk-of-repeal/

by prior Republican-controlled congresses that have reduced or sun-setted tax credits for various purposes. Additionally, partial rollbacks could materialize through funding cutoffs or the rescission of regulations administered by agencies such as the Environmental Protection Agency (EPA).[11]

As noted earlier, the current administration has centered its agenda on bolstering domestic manufacturing, addressing national security concerns related to critical mineral supply chains, and driving job creation. These shared priorities are bipartisan themes. As developed in greater detail below, the present context supports an assessment that IRA provisions tax credits under 45X (Advanced Manufacturing) and 45U (Nuclear Production) enjoy the broadest bipartisan backing among clean energy incentives within the IRA. This is the foundation of how the "examined sectors" have been selected: they are positioned to benefit from continued policy support, even amidst an evolving and uncertain legislative landscape.

1.2.5 Advanced Manufacturing and Nuclear Generation Tax Credits

This is to explain how IRA provisions improve the economics of projects and support the growth of the examined sectors.

Advanced Manufacturing (45X): To strengthen domestic clean energy supply chains, the IRA introduced the 45X Advanced Manufacturing Production Credit, which offers per-unit tax credits for U.S.-produced components such as solar cells, wind turbine parts, inverters, battery cells/modules, and critical minerals. The credit incentivizes onshore manufacturing by providing fixed amounts (e.g., $35 per kWh for battery cells and $10 per kWh for battery modules) and gradually phases down after 2029. Unlike investment credits, 45X rewards output rather than capital expenditure. It plays a key role in reducing reliance on foreign supply chains and revitalizing U.S. clean energy manufacturing through performance-based incentives.

Advanced Nuclear Production Credit (45U): The IRA introduced the 45U Advanced Nuclear Production Tax Credit to support the continued operation and competitiveness of existing nuclear facilities. This technology-neutral credit provides up to $15 per megawatt-hour (MWh) of electricity produced by qualifying nuclear power plants, adjusted for inflation and reduced on a sliding basis after gross receipts from electricity sales are taken into account. The credit applies to facilities that were in service before January 1, 2023, and is available for electricity produced and sold after December 31, 2023, through 2032. By offsetting operating costs and enhancing financial viability, 45U aims to prevent premature retirements of nuclear plants—thereby preserving zero-emissions baseload power and supporting U.S. decarbonization goals.

Together, these credits serve as key financial drivers for projects across our selected sectors, laying the foundation for a more detailed analysis below of their policy outlooks in the current environment.

…/…

[11] Ibid.

1.3 The U.S. Tariff Landscape of 2025

The Trump Administration's renewed use of tariffs is a core tool of its industrial policy. During the recent campaign and since taking office, President Trump has attributed various objectives for the tariffs: to raise revenues, to compel foreign cooperation on US border security against fentanyl and migration, to compel fair trade practices with counterparts, to promote security of US supplies for critical goods and raw materials, to protect and promote US manufacture of tariffed products. The latter two objectives seem most durable and are bipartisan, shared priorities.

Global investors are grappling with uncertainty around these various objectives and the dynamic applications and pauses of tariffs in this second Trump presidency. The seeming wave of abrupt and expansive tariff measures has created a volatile investment climate, leaving investors scrambling to reassess supply chain vulnerabilities.[12] In response, many are deferring or withholding long-term capital commitments in the U.S., adopting a cautious, "wait-and-see" stance as they evaluate the evolving trade environment. For example, at his inauguration President Trump announced his intent to impose sweeping tariffs on foreign imports, warning of a 25% tariff on Canadian goods beginning February 1.[13] On February 1, the administration invoked the International Emergency Economic Powers Act (IEEPA) to address the flow of illicit drugs into the US and issued an executive order imposing the promised tariffs on imports from Mexico and Canada, along with a 10% tariff on all goods from China. However, just two days later, the administration agreed to a 30-day postponement of the Mexican and Canadian tariffs, which was extended again one month later.

The sequence of tariffs continued in February, as the administration revived 25% duties on all steel and aluminum imports from his first term by eliminating broad country and product-specific exceptions. In March, the administration imposed 25% tariffs on auto imports, and on April 2nd, "Liberation Day" displayed the expansive list of reciprocal tariffs on most trading partners. These latter tariffs were paused after triggering a dramatic selloff in financial markets, erasing over $6 trillion in U.S. stock market value within two trading sessions and prompting a retaliatory 34% tariff on U.S. exports by China, which escalated into a tit-for-tat hike to above 100% between both the U.S. and China, a course of events that is on-going.[14]

To understand key differences among tariffs threatened or implemented during Trump's second presidency, the legal authorities underlying announced and threatened tariffs are explored in Table 1 below, which highlights that the president is limited to legal frameworks established by Congress and which are often subject to procedural review.

…/…

[12] Hilferty, K. M., Weaver, C., Renner, C., Gonzalez, H. P., & Guo, B. (2025, March 31). *Global Implications of the US Administration's Tariff Strategy.* Morgan Lewis. https://www.morganlewis.com/pubs/2025/03/global-implications-of-the-us-administrations-tariff-strategy

[13] Grantham-Philips, W. (2025, April 10). *A timeline of Trump's tariff actions so far*. PBS NewsHour. https://www.pbs.org/newshour/economy/a-timeline-of-trumps-tariff-actions-so-far

[14] Wu, H., Kurtenbach, E., & TANG, D. (2025, April 4). *China slaps a 34% tax on all US imports in retaliation for Trump's tariffs.* AP News. https://apnews.com/article/china-tariff-trade-trump-earths-02cd23e913649f32985f075058e787c4

Table 1. Presidential Authorities to Implement Tariffs

Act	Conditions	Application & Key Decision Makers	Duration & Oversight
Trade Act of 1974, Section 604 **("Section 604")**	Provides legal authority to the President to proclaim and modify tariffs, trade actions, trade agreements and obligations.	Mechanism for implementing decisions from investigations (e.g., Section 301, 201, or AD/CVD actions).	No independent review; procedural only
Trade Act of 1974, Section 301 **("Section 301")**	Must address **unfair foreign trade practices**	The U.S. Trade Representative (USTR) conducts an investigation	USTR must review effectiveness every 4 years (§307(c))
Trade Expansion Act of 1962, Section 232 **("Section 232")**	To **safeguard national security** by limiting imports that threaten domestic industries vital to defense.	The Department of Commerce ("Commerce") conducts a national security investigation.	No automatic sunset review; presidents can modify, extend, or remove at their discretion
Tariff Act of 1930, Section 705 **("Section 705")**	Must address whether **countervailable subsidies** from a foreign government are harming a U.S. industry.	(1) U.S. Department of Commerce makes the subsidy determination. (2) U.S. International Trade Commission (USITC) assesses material injury.	Mandatory 5-year sunset review (§751(c))
Tariff Act of 1930, Section 735 **("Section 735")**	Covers the final phase of an **antidumping** investigation—whether goods are sold in the U.S. at less than fair value (dumping).	(1) Following a petition from the public, Commerce investigates pricing behavior and makes the AD determination. (2) USITC again evaluates injury to U.S. industry.	Mandatory 5-year sunset review (§751(c))
Trade Act of 1974, Section 103(a) International Emergency Economic Powers Act **(IEEPA)**	Must address **foreign threats to U.S. national security or economy.**	(1) The President declares a national emergency under the National Emergencies Act (2) Congress must be notified within 48 hrs of issuing the executive order	Must be renewed every year, otherwise, all actions automatically terminate

Source: Capstone analysis

Upon closer examination, some trends among President Trump's tariffs are observable. Recurring themes of national security, protection of domestic industries and manufacturing, as well as reducing reliance on foreign sources of strategic materials, particularly from China, appear among the sequence of tariffs in the below chart.

Table 2 below provides a more comprehensive timeline of Trump's sweeping tariff policy upon taking office in January, 2025 and highlights the differing rationale between IEEPA tariffs and those advanced under Sections 232, 301, or 705.

…/…

Table 2. Tariff Landscape 2025

2025 Evolving Tariff Landscape

DATE ANNOUNCED	TARGETED RATIONALE	PRODUCT TYPES	TARIFF %	LEGAL AUTHORITY	STATUS
1/31/2025	Aimed at bolstering domestic semiconductor manufacturing and addressing national security concerns	Integrated Circuits	TBD	Section 232	Investigation phase begun
2/1/2025	To address the flow of illicit drugs across from the Canadian & Mexican border	All goods that are USMCA non-compliant	25% (10% for energy)	IEEPA	Implemented after initial 30-day pause for negotiation
2/10/2025	Revives 2018 tariffs on steel and aluminum imports, hikes aluminum rate to 25%, and removes any country-specific exemptions	Steel & Aluminum	25%	Section 232	Implemented
2/25/2025	Aimed at bolstering domestic production of essential materials and reduce reliance on foreign sources	Copper	TBD	Section 232	Investigation phase begun
3/1/2025	Aimed at bolstering domestic production of essential materials and reduce reliance on foreign sources	Timber & Lumber	TBD	Section 232	Investigation phase begun
3/26/2025	To encourage domestic manufacturing, reduce reliance on foreign suppliers, and protect U.S. automotive sector	Automobile & Automobile parts	25%	Sections 232, 301, 604	Implemented (auto parts on 5/3/2025)
4/2/2025	Liberation Day Baseline and Reciprocal tariffs to address unfair trade practices	All products	Baseline 10% + Reciprocal	IEEPA	Implemented - Reciprocal tariffs suspended for 90 days
4/9/2025	To address reliance on equipment produced by Chinese manufacturers	Maritime cargo handling equipment	20-100%	Section 301	Investigation phase begun
4/10/2025	Ongoing: China (initiated on 2/1/2025 to address synthetic opioid supply chains)	All products	145%	IEEPA	Implemented
4/14/2025	Aimed at bolstering domestic production of essential medicines & materials and reduce reliance on foreign sources	Pharmaceuticals & Semiconductors	TBD	Section 232	Investigation phase begun
4/15/2025	Aimed at bolstering domestic production of essential materials and reduce reliance on foreign sources	Critical Minerals	TBD	Section 232	Investigation phase begun
4/22/2025	Extension of the original 2012 China solar tariffs but now applicable Southeast Asian countries if they are found source Chinese parts components	Solar Cells	Up to 3,521%	Section 705, 735	Investigation phase begun

Source: Capstone analysis

…/…

Upon examination, tariffs advanced via Sections 232, 301, and 735 may have investigations or implementations spanning prior administrations due to bipartisan objectives and national security concerns. In contrast, tariffs advanced via the IEEPA during this administration do not necessarily share such historical bipartisan connection. For example, Section 232 tariffs implemented by Trump in 2018 on imports of Chinese EVs, batteries and solar technologies, were expanded under the Biden administration and thus reflected a bipartisan foreign policy shift on trade relations with China.[15]

IEEPA tariffs, on the other hand, whether targeting Canada, Mexico, China, or a host of countries during "Liberation Day" serve as negotiating levers, designed to extract concessions from trade partners, and are likely less durable. For instance, within just a few days of the "Liberation Day" tariffs on April 2nd, over 50 countries reached out to initiate negotiations,[16] while negotiations with China stall.[17] Notably, critical minerals were among the sectors exempted from these IEEPA tariffs—but were nevertheless threatened separately under the initiation of a Section 232 on April 15th.[18] Additionally, while Section 301 tariffs on China may be subject to the outcome of negotiations, it is important to note the broader shifting U.S.-China policy landscape, which will mean that these particular tariffs may persist alongside evolving geopolitical considerations. As such, key to understanding the longevity of tariffs is this connection to bipartisan foreign policy objectives.

Figure 3 below showcases this shifting U.S. policy landscape with respect to China. It begins with 2010 as its point of reference, as it highlights that national security concerns, particularly around critical minerals and rare earths, were observable since the Obama administration.[19]

…/…

[15] Magill, K. (2024, September 16). *Biden finalizes China tariff hikes, including for EVs, batteries and solar panels*. Utility Dive. https://www.utilitydive.com/news/joe-biden-china-tariff-hikes-ev-battery-semiconductor-final/727014/

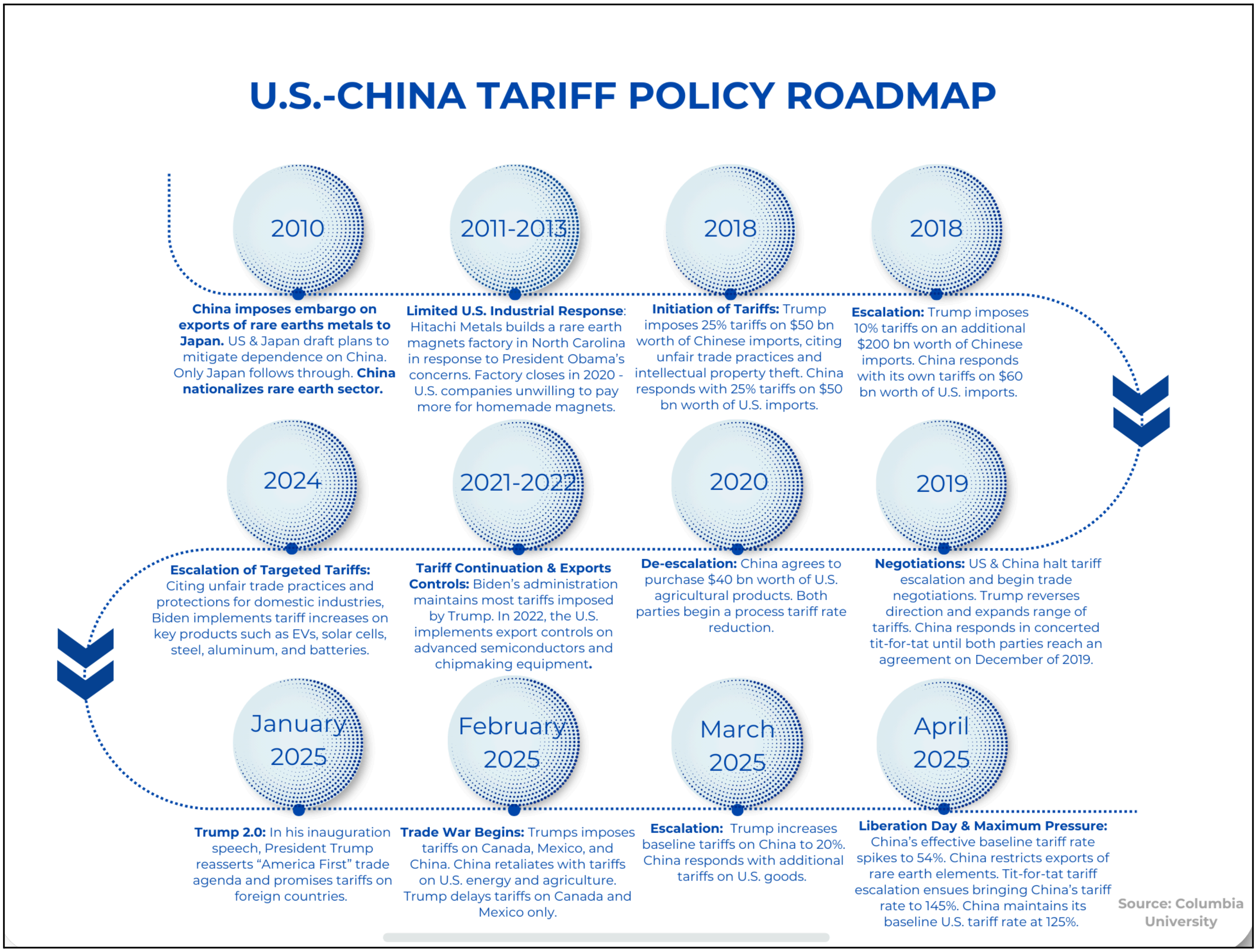
[16] Hilferty, K. M., Weaver, C., Renner, C., Gonzalez, H. P., & Guo, B. (2025, March 31). *Global Implications of the US Administration's Tariff Strategy.* Morgan Lewis. https://www.morganlewis.com/pubs/2025/03/global-implications-of-the-us-administrations-tariff-strategy

[17] Mangan, D., Breuninger, K., Wilkie, C., Cassella, M., Pound, J., & Iordache, R. (2025, April 28). *Trump tariffs on China now total 145%, White House clarifies: Live updates*. CNBC. https://www.cnbc.com/2025/04/28/trump-xi-tariffs-china-bessent.html

[18] Scheyder, E., & Pitas, C. (2025, April 16). *Trump orders tariff probe on all US critical mineral imports.* Reuters. https://www.reuters.com/markets/commodities/trump-signs-order-launching-probe-into-reliance-imported-critical-minerals-2025-04-15/

[19] Bradsher, K. (2025, April 16). *How China took over the world's rare earths industry*. The New York Times. https://www.nytimes.com/2025/04/16/business/china-rare-earths-us.html

Figure 3. U.S, - China Tariff Policy Roadmap



Source: Capstone analysis

During the course of this research, conversations with policy experts and market participants revealed a consensus aligned with the aforementioned views and which is elaborated in Part 2. It can be summarized as follows:

- Existing tariffs targeting selected products and minerals from China will endure;
- Exceptions will be made for critical minerals when tariffs are imposed on friends and allies for the sake of advancing trade negotiation objectives; and
- The current trajectory of tariffs on all imports from China will likely endure in some form for the near term.

Market participants say the Trump Administration's goal of stimulating domestic manufacturing is undermined by the present uncertainty about which tariffs are durable, long term and not easily changed or given to exceptions being created. Market participants are waiting to see where matters settle. Formal agreements with trading partners like the USMCA, which replaced NAFTA during the first Trump term, are viewed with more certainty than the tariffs a president imposes under authorities that Congress delegates. In the latter class the tariffs imposed when the president declares an emergency seem less durable to *the Market* than the ones which follow an investigation such as with the section 232 process.

Tariff Landscape and the Examined Sectors in this report: Explained further below is the rationale for the deeper examination in Part 2 of this report of eight sectors: five critical minerals (copper, aluminum, nickel, lithium cobalt) along with nuclear generation and batteries and solar equipment manufacturing.

The status of import tariffs on the five minerals studied in Part 2 is evolving dynamically like so much of the Administration's trade policy. The White House excluded from its April 2 Reciprocal tariffs most minerals including the five minerals reviewed in Part 2 along with uranium, the key fuel for nuclear generation. However, the import of aluminum has already been subject to tariffs since 2017 under separate initiatives and the rest of the minerals are at risk of becoming tariffed.

Aluminum has been separately subject to a 10% section 232 tariff under the Trade Expansion Act of 1962 since 2017; this tariff was essentially reactivated in February 2025 when the new administration removed broad exemptions previously-granted and raised the aluminum tariff to 25%. As noted, there is a pending investigation launched under section 232 in February 2025 of copper imports that is likely to result in 25% tariffs for that mineral. More recently on April 15 the Administration launched 232 investigations to assess risks to supply chains of processed metals and minerals including uranium, aluminum, nickel, cobalt, lithium, graphite and 17 rare earths on government lists of critical minerals. The evolving tariffs on Canadian and Mexican imports may become another source of tariffs on imports of these minerals depending on how those matters settle.

As for the other sectors studied, a tariff on imported solar equipment from China has been in place since the first Trump Administration but that may be supplanted by higher tariff levels covering a broader range of importers, and imported batteries will likely be included in the pending tariff initiatives under the second Administration. Possible tariffs on uranium and imports of other equipment inputs could affect nuclear generation costs.

1.4 Incentives in the European Union

In the general context of the European Union, the European Commission has stated clearly in the regulation of competition and State aid that aid granted by EU countries is supervised if it "threatens to distort competition by favoring certain undertakings or the production of certain goods,"[20] and that "aid may be permitted if justified by objectives of general interest"[21] such as R&D and environment protection. In this case, possible incentives granted to our examined sectors would be under policies affecting certain social and economic areas rather than under those boosting only select industries.

While Europe does not have a direct equivalent to the U.S. Inflation Reduction Act, the Temporary Crisis and Transition Framework (TCTF) is the most important framework in this regard. On January 31, 2023, the European Commission announced the release of a draft proposal "to transform the State aid Temporary Crisis Framework into a Temporary Crisis and Transition Framework to facilitate and accelerate Europe's green transition."[22] The framework is said to be "part of the Green Deal Industrial Plan," "contributing to its second pillar aiming at ensuring faster access to funding for companies

[20] Publication Office of the European Union. (2017, March 24). *Competition.* European Union. https://eur-lex.europa.eu/EN/legal-content/glossary/competition.html

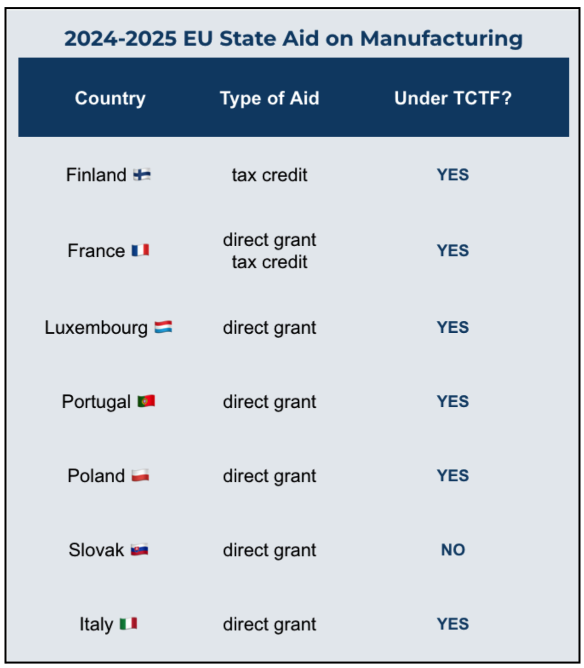
[21] Publication Office of the European Union. (2017, March 24). *State aid.* European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:state_aid

[22] European Commission. (2023, January 31). *State aid: Commission consults Member States on proposal for a Temporary Crisis and Transition Framework.* European Commission. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_513

operating in the EU", and aiming to support decarbonisation and net-zero transition by boosting investments for renewable energies, which will be in place until 31 December 2025. Specifically, TCTF allows EU countries to "grant aid for less mature technologies, such as renewable hydrogen;" "incentivise investments leading to a significant reduction of emissions by including higher aid ceilings and simplified aid calculations;" and "allows support from Member States for the production of batteries, solar panels, wind turbines, heat-pumps, electrolysers and carbon capture usage and storage as well as the related critical raw materials necessary for the production of such equipment."

The State aid from January 2024 to the end of February 2025 granted by European Union countries has been reviewed for this report. According to our statistics, 45 State aids were approved by the European Commission during this period in support of the renewable energy industries, 35 of which support investments in deployment and only 12 of which support investments in either R&D or production of equipment and raw materials, all taking the form of either direct grants or tax credits. Among the 12 State aids, 7 are approved under TCTF, 2 are cross-Europe aids, including 1 Important Projects of Common European Interest (IPCEI), and others under Green Deal Industrial Plan or other policy frameworks.

Figure 4. 2024 - 2025 EU State Aid on Manufacturing


2024-2025 EU State Aid on Manufacturing

Country	Type of Aid	Under TCTF?
Finland	tax credit	YES
France	direct grant tax credit	YES
Luxembourg	direct grant	YES
Portugal	direct grant	YES
Poland	direct grant	YES
Slovak	direct grant	NO
Italy	direct grant	YES

Source: European Commission[23], Capstone analysis

Looking forward, while TCTF provisions are going to expire after 2025, the 2025-2029 College of Commissioners presented a new deal on February 25, 2025, named the Clean Industrial Deal, which "will accelerate decarbonisation, while securing the future of manufacturing in Europe."[24] The communication also announced that a new State aid framework will be released in Q2 2025 and that the new Competitiveness Fund is planned to accelerate EU funding and will govern the proposed Industrial Decarbonisation Bank.[25] Furthermore, IPCEI is also mentioned in the document. IPCEI

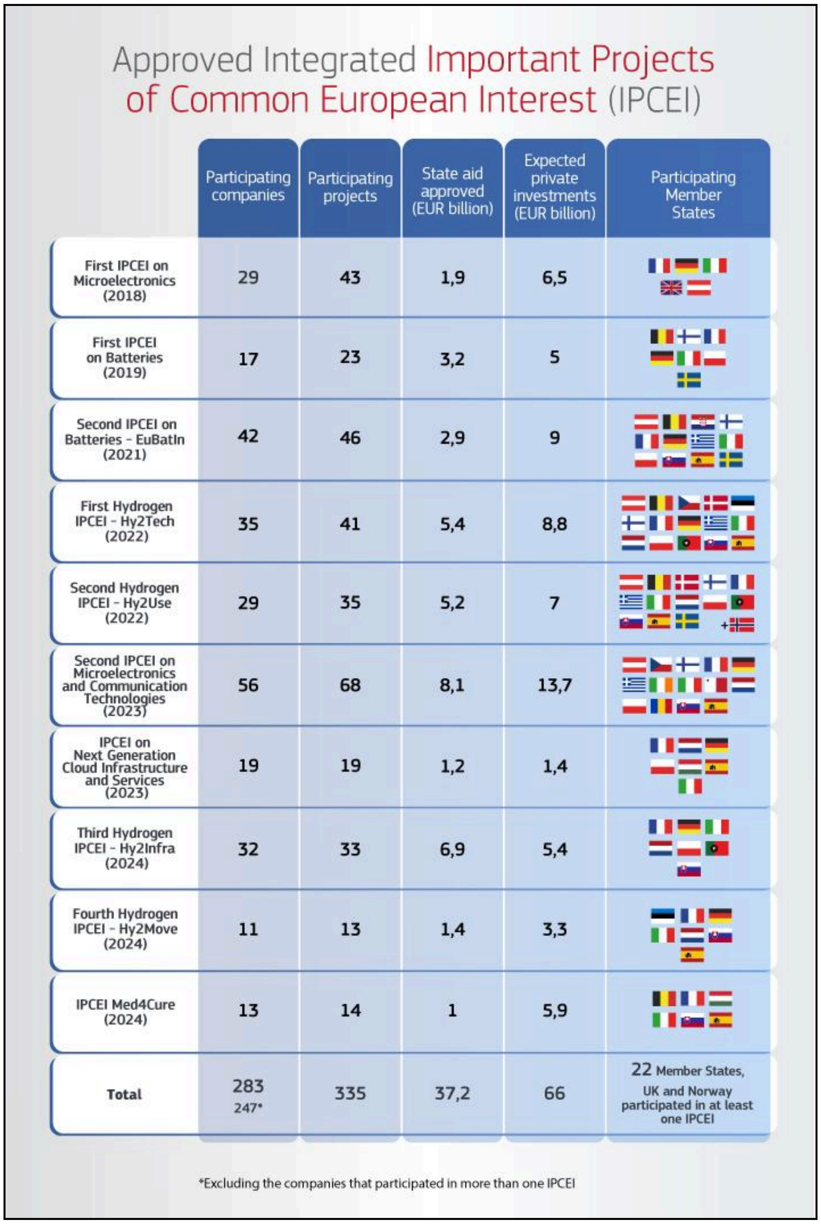
[23] European Commission. https://commission.europa.eu/index_en

[24] European Commission. (2025, February 25). *A Clean Industrial Deal for competitiveness and decarbonisation in the EU.* European Commission. https://ec.europa.eu/commission/presscorner/detail/en/ip_25_550

[25] European Commission. (2025, February 26). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation.* European

refers to Important Projects of Common European Interest. Besides the Fourth Hydrogen IPCEI (Hy2Move) approved in 2024, which is counted among the 12 State aids supporting renewable energies manufacturing, there are three other IPCEIs in the past supporting the R&D across the value chains of batteries and hydrogen, including First IPCEI on Batteries approved in 2019, Second IPCEI on Batteries (EuBatIn) approved in 2021, and First Hydrogen IPCEI (Hy2Tech) approved in 2022.

Figure 5. Approved IPCEI



Approved Integrated Important Projects of Common European Interest (IPCEI)

	Participating companies	Participating projects	State aid approved (EUR billion)	Expected private investments (EUR billion)	Participating Member States
First IPCEI on Microelectronics (2018)	29	43	1,9	6,5	
First IPCEI on Batteries (2019)	17	23	3,2	5	
Second IPCEI on Batteries - EuBatIn (2021)	42	46	2,9	9	
First Hydrogen IPCEI - Hy2Tech (2022)	35	41	5,4	8,8	
Second Hydrogen IPCEI - Hy2Use (2022)	29	35	5,2	7	+
Second IPCEI on Microelectronics and Communication Technologies (2023)	56	68	8,1	13,7	
IPCEI on Next Generation Cloud Infrastructure and Services (2023)	19	19	1,2	1,4	
Third Hydrogen IPCEI - Hy2Infra (2024)	32	33	6,9	5,4	
Fourth Hydrogen IPCEI - Hy2Move (2024)	11	13	1,4	3,3	
IPCEI Med4Cure (2024)	13	14	1	5,9	
Total	283 247*	335	37,2	66	22 Member States, UK and Norway participated in at least one IPCEI

*Excluding the companies that participated in more than one IPCEI

Source: European Commission[26]

1.5 Capstone Report Methodology

To narrow the focus of this report to the four sectors examined, a three-step screening process was employed. First, recognizing that Citi's clients require liquid investment opportunities, all sectors

Commission. https://commission.europa.eu/document/download/9db1c5c8-9e82-467b-ab6a-905feeb4b6b0_en

[26] European Commission. *Approved integrated Important Projects of Common European Interest (IPCEI)*. European Commission. https://competition-policy.ec.europa.eu/state-aid/ipcei/approved-ipceis_en

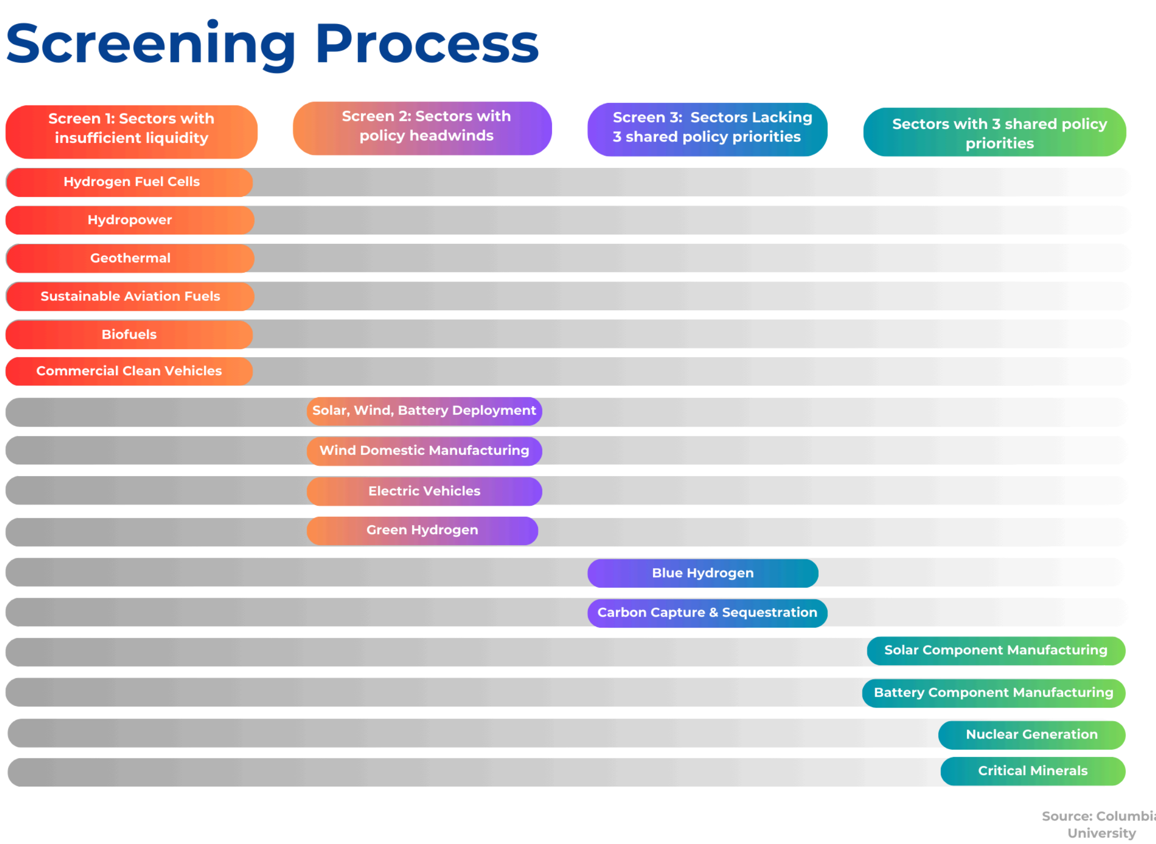
with an insufficient number of publicly listed companies, particularly within U.S. stock exchanges, were excluded and are stacked under the first column of Figure 6 below.

For sectors that passed this initial screen, their respective policy outlooks were then evaluated. Specifically assessed were the stability and outlook of key IRA tax credits relevant to each sector, as well as the potential impact of proposed or existing tariffs. An exclusionary screen for sectors facing strong policy headwinds under Trump 2.0. was then added and sectors excluded at this stage are stacked under the second column. In addition to conducting independent research, the project team interviewed legal and political consultants who are close to policy-makers along with experts from academia to better understand the likely resilience of each sector's core IRA tax credit. This analysis considered (1) the administration's current policy objectives, (2) the degree of bipartisan support for individual tax credits and their respective sectors, (3) structural legal protections that pose challenges to repealing IRA provisions, and (4) the adverse effects of legal and administrative uncertainty on inward investment—particularly in scenarios involving the dismantling or restructuring of federal agencies responsible for issuing tax credits, grants, and reimbursements.

Next, after considering the largely unfavorable evolution of tariffs and regulatory shifts, the remaining sectors were sifted through a third screen that evaluated whether sectors were supported by the three previously defined bipartisan and broadly-shared priorities. The sectors that did not meet this requirement were the final exclusions and are stacked under column three below.

Figure 6 illustrates the process used to screen out sectors from the final analysis. The sectors remaining in column four advanced through the prior three screens and met all three aforementioned shared policy priorities.

Figure 6. Sector Screening Process



Therefore, in the initial assessment of investable opportunities, the team identified eight sectors with a sufficient number of publicly listed companies suitable for Citi's investors: (1) Solar, (2) Wind, (3) Battery Energy Storage Systems (BESS), (4) Electric Vehicles (EVs), (5) Critical Minerals, (6) Nuclear Generation, (7) Carbon Capture Utilization and Sequestration (CCUS), and (8) Clean Hydrogen. These sectors are outlined in the second column of Figure 5. However, upon closer examination of their respective policy outlooks, it became clear that different segments within each sector's value chain are subject to varying levels of political support.

For instance, in the cases of Solar, Wind, and BESS, deployment activities have faced unfavorable policy headwinds under the current administration. This was evident from executive actions taken immediately after President Trump assumed office in January 2025, including the suspension of new leasing for renewable energy projects on federal lands.[27] Conversely, domestic manufacturing and production remain central to the administration's policy agenda. This is reflected in recent measures such as proposed reductions in the corporate tax rate for U.S. manufacturers and executive orders aimed at reducing regulatory burdens—particularly for sectors tied to critical minerals.[28] As a result, the deployment side of these clean energy technologies has been excluded from the analysis in Part 2, while retaining their manufacturing components as viable investment opportunities.

A similar distinction emerged within the clean hydrogen sector. "Blue" hydrogen, produced from natural gas with CO_2 emissions captured via CCUS, is likely to receive stronger support from the administration, due to its alignment with its broader agenda to expand oil and gas production in the U.S.[29] In contrast, "green" hydrogen, produced using electricity from nearby solar and wind installations, faces a more uncertain outlook. As a nascent industry, green hydrogen is heavily reliant on subsidies for growth, such as those provided under the IRA and the Infrastructure Investment and Jobs Act (IIJA). Recent indications that the administration may suspend funding for green hydrogen hubs have significantly increased the policy headwinds for this segment of the market.[30]

…/…

[27] Johnson, L. (2025, January 29). *Trump pauses renewable projects leasing on federal lands, waters*. ESG Dive. https://www.esgdive.com/news/trump-pauses-renewable-projects-leasing-on-federal-lands-waters-interior-executive-order/738647/

[28] National Association of Manufacturers. (2025, March 21). *President's Executive Order Strengthens U.S. Manufacturing by Accelerating Permitting and Unlocking Critical Resources*. National Association of Manufacturers. https://nam.org/presidents-executive-order-strengthens-u-s-manufacturing-by-accelerating-permitting-and-unlocking-critical-resources-33546/

[29] Daly, M. (2025, February 14). *Trump creates council for 'energy dominance,' boosts natural gas exports and offshore drilling*. AP News.. https://apnews.com/article/f0e0d3b2dfb0f6a3e81cadd2dcd56696

[30] FCW Team. (2025, March 27). *Trump White House Considers Axing Green Hydrogen Hub Funds in Democratic States, Preserving Red-State Projects*. FuelCellsWorks. https://fuelcellsworks.com/2025/03/27/clean-energy/trump-white-house-considers-axing-green-hydrogen-hub-funds-in-democratic-states-preserving-red-state-projects

Table 3 below details our assessment of these policy considerations for sub sectors that made it past our first screen.

Table 3. IRA Outlook

2025 IRA Outlook: Amendments and Implementation Pauses Expected

Industry	Pertinent IRA Provision	Description of benefits conferred	Amended Outlook
Critical Minerals Production	Advanced Manufacturing Production Credit (45X)	Offers tax credits for the production of critical minerals used in various clean energy technologies.	• **Favorable** – Strong bipartisan support with special interest from the new administration.
Nuclear Generation	Nuclear Power Production Tax Credit (45U)	Provides a tax credit for existing nuclear power plants to support their continued operation.	• **Favorable** – Strong bipartisan support with special interest from the new administration. .
Component Manufacturing (Wind, Solar, Batteries)	Advanced Manufacturing Production Credit (45X)	Offers production tax credits for domestic manufacturing of components for solar and wind energy, including inverters and related equipment. Also covers domestic manufacturing of battery components.	• **Wind** – **Unfavorable** – Industry faces strong policy headwinds • **Solar** – **Uncertain** – May benefit indirectly from bipartisan manufacturing support • **Batteries** – **Uncertain** – Bipartisan support
Carbon Capture & Sequestration	CCUS Tax Credit (45Q)	Enhances tax credits for carbon capture, utilization, and storage (CCUS) projects, increasing the credit amount per ton of CO_2 captured.	• **Uncertain** – Bipartisan support without special interest from the new administration.
Clean Hydrogen	Clean Hydrogen Production Tax Credit (45V)	Establishes a tax credit for the production of clean hydrogen, with the credit amount varying based on the carbon intensity of the hydrogen produced.	• **Green Hydrogen** – **Unfavorable** – Dependent on Wind and Solar deployment • **Blue Hydrogen** – **Uncertain** – Bipartisan support without special interest from the new administration.
Electric Vehicles	Clean Vehicle Credit	Provides up to $7,500 tax credit for purchasers of new clean vehicles, with specific requirements for critical minerals and battery components.	• **Unfavorable** – Stricter eligibility criteria or reduced funding likely

Source: Capstone analysis

As a result of these considerations, critical minerals and nuclear generation have been identified as the sectors most likely to benefit from clear policy tailwinds during President Trump's second term. As previously noted, critical minerals enjoy strong bipartisan support due to the national imperative to secure and strengthen domestic supply chains.[31] In Part 2 below, five types of specific minerals have been identified for inclusion in this analysis, focusing on those deemed essential to the energy transition. For each of the examined five, a detailed sector breakdown is provided, examining the value chain, market structure, and underlying project economics—enabling investors to pinpoint where the most compelling opportunities lie within a sector poised to play a pivotal role in the energy transition and U.S. foreign policy over the next decade. For these reasons, critical minerals are designated as *the priority sector* for clean energy investors to monitor closely in the years ahead.

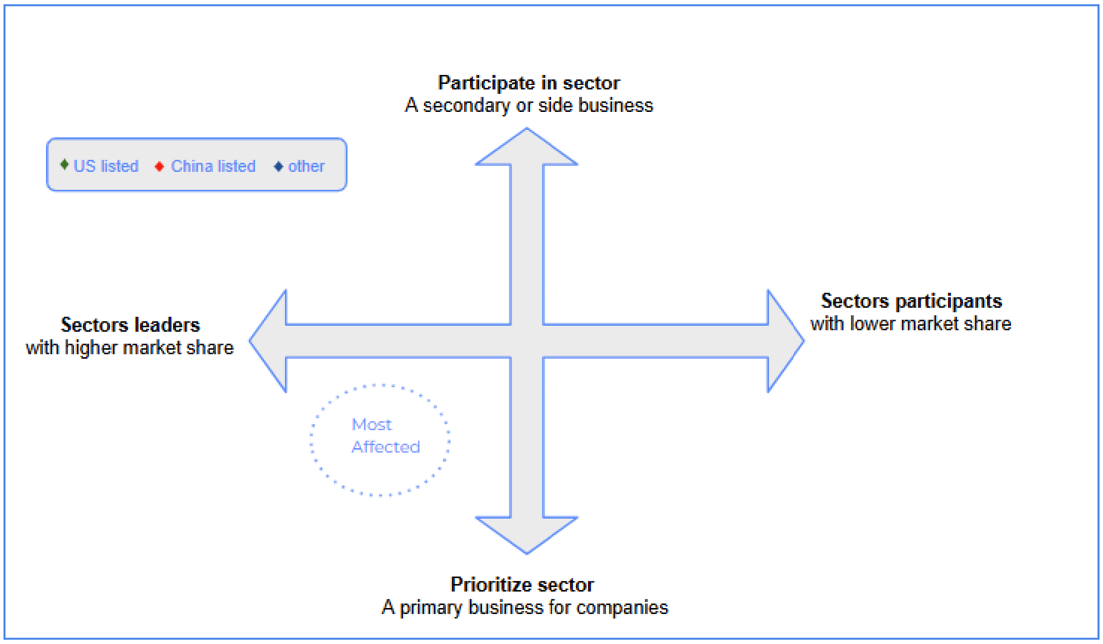
Nuclear generation, batteries, and solar component manufacturing have also been designated for closer examination in Part 2 of this report. For nuclear generation, bipartisan momentum and rising energy demand are playing a key role in revitalizing this industry. The deep dive in Part 2 for batteries and solar component manufacturing builds on earlier observations regarding the

[31] The White House. (2024, September 20). *FACT SHEET: Biden-Harris Administration Takes Further Action to Strengthen and Secure Critical Mineral Supply Chains*. The White House. https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2024/09/20/fact-sheet-biden-harris-administration-takes-further-action-to-strengthen-and-secure-critical-mineral-supply-chains/

administration's emphasis on reshoring and expanding domestic manufacturing capabilities.

For each sector in our analysis, we provide a sorting matrix of selected companies, ranked according to their attractiveness as investment opportunities. As shown in Figure 7 the matrix positions these companies along two axes: one reflecting their relative market leadership and the other representing the strategic priority of the relevant sector for the company in question.

Figure 7. Likelihood - Scope (L-S) Matrix



Source: Capstone analysis

Finally, sectors such as EVs, CCUS, and blue hydrogen were excluded from the scope of the deep dive analysis in light of their uncertain policy outlooks under the current administration. In the case of EVs, upon taking office, President Trump immediately revoked the Biden-era targets aimed at achieving 50% EV sales in the U.S. by 2030, signaling a retreat from federal support for the sector.[32] While CCUS and blue hydrogen may continue to benefit from IRA provisions—provided these are not repealed or curtailed—they lack sufficiently compelling investment narratives linked to national security imperatives or rising market demand. As such, these three sectors were not pursued further in the Part 2 analysis.

The analysis in Part 2 offers a comprehensive deep dive into each of the examined sectors below with the goal of constructing a mosaic of actionable investment opportunities for Citi's clients—grounded in sector fundamentals and resilience in the face of today's increasingly volatile trade and policy environment.

1. Critical Minerals
2. Nuclear Generation
3. Battery Manufacturing
4. Solar Component Manufacturing

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[32] Fitzgerald, J. (2025, January 21). *President Trump Signs Executive Order Revoking Biden-Era EV Targets*. Car and Driver. https://www.caranddriver.com/news/a63495060/president-trump-revokes-biden-ev-mandates/

PART 2
Sector Analysis

2.1 Critical Minerals

Critical Minerals: Strategic Imperatives Support Investment

As noted already, the policies of the Trump Administration are generally unfavorable for the sectors linked to the greening economy. However, three policy priorities that are fully shared by both US political parties and the other Western governments will favor players involved with the supply and production of those *critical minerals* linked to the energy transition, as well as to military applications and other 21st-century industries. Those three policy priorities are:

1. Security of strategic supply chains, especially where China's share is viewed as out-of-balance.
2. Increasing power generation capacity to serve the rising electricity demand.
3. Protecting and increasing domestic manufacturing jobs.

Critical minerals or metals have broadly come to refer to those basic elements of equipment and products tied to defense, energy, and the advancing digital economy. The term has been specifically defined to include discrete element lists under specific legislation and programs. The Inflation Reduction Act, with its section 45X tax credits equal to 10% of production costs for the supply or production of "critical minerals," cross-referenced the U.S. Geological Survey's (USGS) critical minerals designations. Under the Energy Act of 2020, "critical materials" are defined as any non-fuel substance identified by the Secretary of Energy as both highly susceptible to supply disruption and essential to the performance of key energy-related technologies, including energy production, transmission, storage, and conservation.[33] These are alternatively called "energy transition minerals" as they play a critical role in modern technologies, defense systems, and especially clean energy solutions.[34] A pending House bill, the *Critical Minerals Consistency Act of 2024*, would amend the *Energy Act of 2020* to ensure that all critical materials designated by the Department of Energy (DOE) are included in the USGS critical minerals list. This would add copper among other elements not currently on the USGS list.

The global critical minerals market is expanding rapidly, valued at approximately $320 billion as of 2022, with a projected compound annual growth rate (CAGR) of 5.69% over the next ten years.[35] A recent study by the International Energy Agency (IEA) illustrated the intersection between the minerals that play a critical role in modern technologies, defense systems, and those especially central to the greening economy: the "transition minerals."[36]

…/…

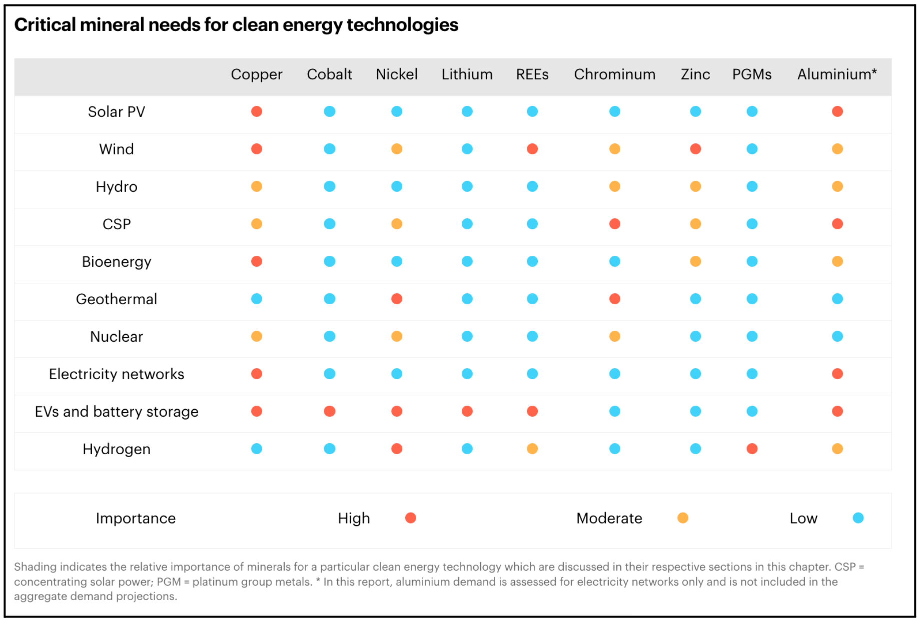
[33] U.S. Department of Energy. *What Are Critical Materials and Critical Minerals?* U.S. DOE. https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals

[34] United Nations Department of Economic and Social Affairs. (2025, January). *World economic situation and prospects 2025: Harnessing the potential of critical minerals for sustainable development.* UN. https://desapublications.un.org/sites/default/files/publications/2025-01/WESP%202025_Harnessing%20the%20Potential%20of%20Critical%20Minerals%20for%20Sustainable%20Development_WEB.pdf

[35] International Energy Agency. (2023, July). *Critical minerals market review 2023: Key market trends.* IEA. https://www.iea.org/reports/critical-minerals-market-review-2023/key-market-trends

[36] United Nations Department of Economic and Social Affairs. (2025, January). *World economic situation and prospects 2025: Harnessing the potential of critical minerals for sustainable development.* UN. https://desapublications.un.org/sites/default/files/publications/2025-01/WESP%202025_Harnessing%20the%20Potential%20of%20Critical%20Minerals%20for%20Sustainable%20Development_WEB.pdf

Figure 8. Critical Mineral Needs for Clean Energy Technologies



Source: IEA (2023)[37]

This Capstone report focused its research on five of the most vital of these *transition minerals*: copper, aluminum, nickel, cobalt, and lithium. Copper and aluminum are critical to the broadest range of industrial sectors and have the highest value growth potential in absolute terms. Cobalt, nickel, and lithium were selected based on their critical roles in batteries and other clean energy technologies, along with projected demand growth and strategic relevance to national security and global trade. Each of these minerals is examined in more detail in the following sections.

China's dominance in Mineral Processing Raises Concerns Among Competitors

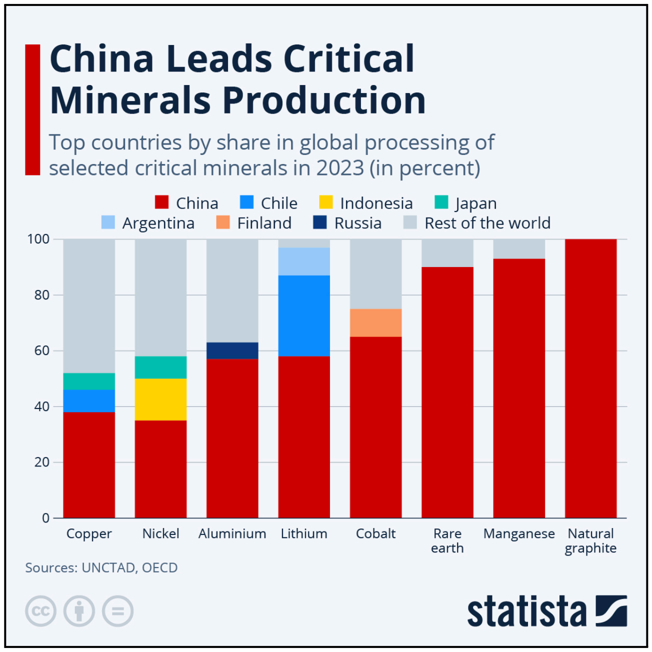
In recent years, governments and competitors have grown increasingly alarmed by China's dominance across critical mineral supply chains, which include extraction, processing, and refining. As illustrated in Figure 9 below, China currently controls a substantial share of global production capacity for several key transition minerals, including rare earth elements (REEs), graphite, and tungsten.[38] It also holds a dominant position in the midstream processing of lithium, cobalt, and nickel.

…/…

[37] International Energy Agency. *Critical minerals*. IEA. https://www.iea.org/topics/critical-minerals

[38] Fleck, A. (2024, July 31). *China leads critical minerals production.* Statista. https://www.statista.com/chart/32748/top-countries-processing-critical-minerals/

Figure 9. China Leads Critical Minerals Production



Sources: Statista (2024)[39]

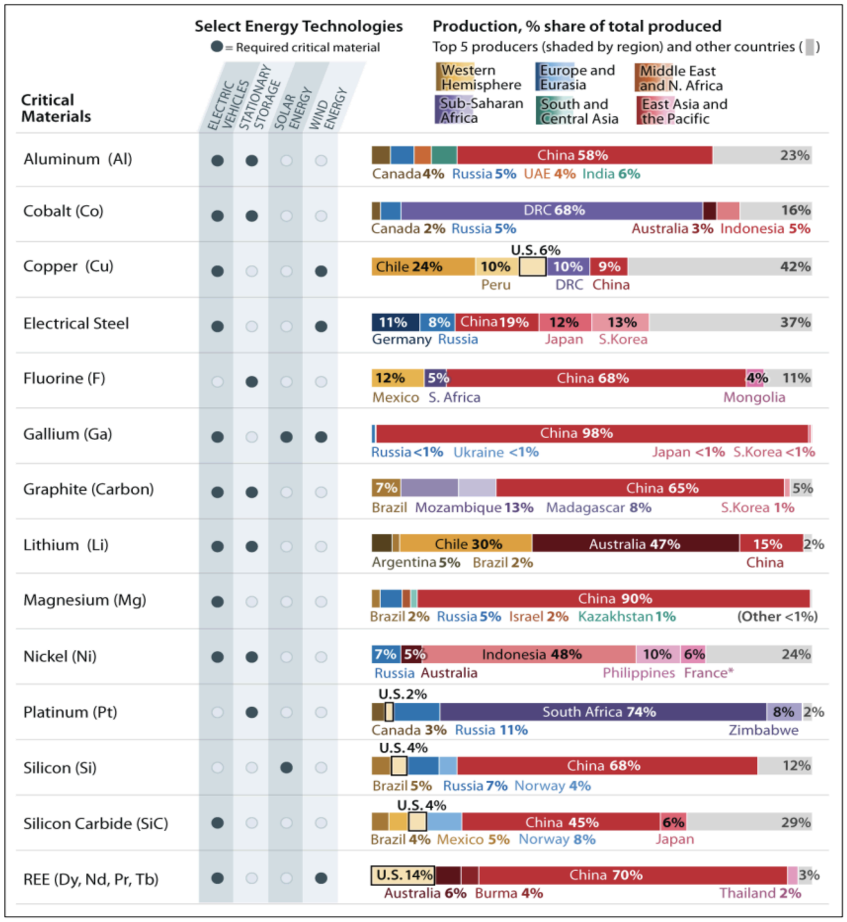
Disruptions caused by the COVID-19 pandemic and Russia's invasion of Ukraine exposed the fragility of existing supply chains to importing countries and underscored the urgency to diversify sources and reduce strategic dependencies. In response, importing nations have begun implementing proactive policies to reconfigure value chains. These efforts include expanding domestic production, investing in refining and recycling infrastructure, and forming new partnerships through "friend-shoring," which involves sourcing materials from politically aligned and stable nations.[40] Figure 10 below displays both China's general dominance along with the other countries where critical minerals sourcing is feasible and increasingly significant.

…/…

[39] Ibid.

[40] Benson, E., & Kapstein, E. B. (2023, February 1). *The Limits of "Friend-Shoring."* Center for Strategic and International Studies. https://www.csis.org/analysis/limits-friend-shoring

Figure 10. Critical Minerals Production by Country



Source: Congressional Research Service Reports (2023)[41]

China's dominance in the supply of REEs has become alarming to importers, as many of these elements are indispensable for advanced military systems including missile guidance, radar, and aircraft components. With over 90% of global processing capacity located in China, any disruption would directly impact defense readiness.[42] Lithium, cobalt, and nickel present midstream vulnerabilities: although mined in diverse locations, China refines over 50-70% of lithium and cobalt, and nearly 35% of nickel, giving it leverage over battery production and clean energy development.[43] These dependencies leave critical sectors vulnerable to coercion or disruption during geopolitical tensions.

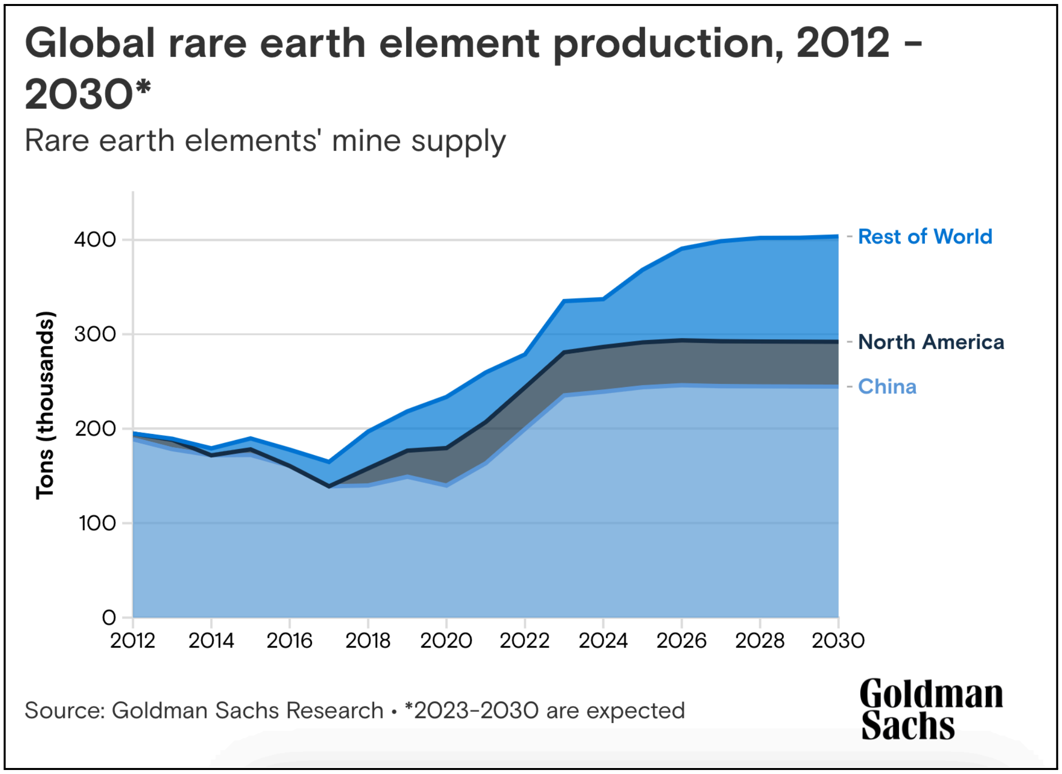
…/…

[41] Kaboli, E. (2025, March 5). *Critical minerals and materials for selected energy technologies*. U.S. Congress. https://www.congress.gov/crs-product/R48149

[42] Andrews-Speed, P., & Hove, A. (2023, June). China's rare earths dominance and policy responses. The Oxford Institute for Energy Studies. https://www.oxfordenergy.org/publications/chinas-rare-earths-dominance-and-policy-responses/

[43] International Energy Agency. (2021, May). *The role of critical minerals in clean energy transitions: Executive summary.* IEA. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

Figure 11. Rare Earth Supply by Country



Source: Goldman Sachs (2023)[44]

In 2023, China previously demonstrated a willingness to use export controls strategically, imposing restrictions on gallium and germanium, materials essential to semiconductors and military optics, and later tightening graphite exports by requiring special export permits.[45] In April 2025, China escalated its trade dispute with the United States by halting exports of seven heavy REEs, such as dysprosium, terbium, and yttrium, and related magnets, which are critical for technologies including electric vehicles, smartphones, aircraft, and defense systems. Although officially framed as export licensing requirements, the restrictions have effectively stopped exports, with shipments grinding to a halt as exporters await government licenses—a process that can take months.[46] Given these precedents, there is growing concern that Beijing could further limit access to REEs, lithium compounds, or other high-leverage materials, amplifying the urgency for Western countries to establish resilient, independent supply chains.[47]

…/…

[44] Cohen, J., Shirley, W. &. Svensson, K. (2023, September 13). *Resource Realism: The geopolitics of critical minerals supply chain.* Goldman Sachs. https://www.goldmansachs.com/insights/articles/resource-realism-the-geopolitics-of-critical-mineral-supply-chains

[45] Baskaran, G., & Schwartz, M. (2024, December 4). *China Imposes Its Most Stringent Critical Minerals Export Restrictions Yet Amidst Escalating U.S.-China Tech War.* Center for Strategic and International Studies. https://www.csis.org/analysis/china-imposes-its-most-stringent-critical-minerals-export-restrictions-yet-amidst

[46] Bradsher, K. (2025, April 13). *China tightens grip on rare earths, alarming global manufacturers.* The New York Times. https://www.nytimes.com/2025/04/13/business/china-rare-earths-exports.html

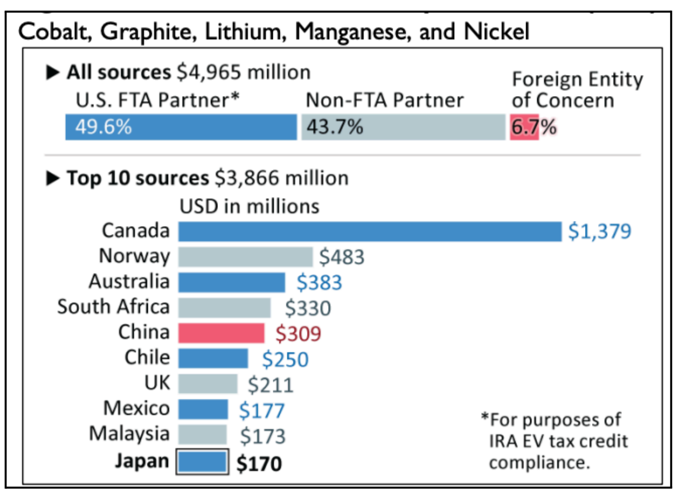
[47] Jackson, L., Lv, A., Onstad, E., & Scheyder, E. (2025, April 4). *China hits back at US tariffs with rare earth export controls on key rare earths.* Reuters. https://www.reuters.com/world/china-hits-back-us-tariffs-with-rare-earth-export-controls-2025-04-04/

Initiatives to Diversify Supply Chains

Domestically, the United States has also launched several initiatives to support American production capacity. Key examples include the CHIPS and Science Act, the Infrastructure Investment and Jobs Act, and the invocation of the Defense Production Act. The IRA may be the most impactful domestic sourcing initiative. The IRA's Section 45X Advanced Manufacturing Production Credit provides a 10% tax credit on production costs for companies that both mine and process critical minerals within the United States. Initially, the 45X credit excluded mining activities, focusing solely on processing.[48] However, following industry feedback, the Treasury Department revised the rules in October 2024 to include certain material and extraction costs, provided the mining and processing occur domestically.[49] Additionally, the credit is transferable, enabling companies with limited tax liabilities to sell the credit for immediate cash benefits, which is especially beneficial for startups and smaller firms in the mining and refining sectors.[50]

Other major initiatives such as the 2023 U.S.-Japan Critical Minerals Agreement (CMA) and the Minerals Security Partnership (MSP) reflect this growing momentum in the Western economies toward building secure, transparent, and sustainable supply chains. Each of these aims to reduce reliance on foreign suppliers and strengthen the resilience of critical mineral supply chains. Figure 12 below illustrates the breakdown of U.S. critical mineral imports in 2023, highlighting the reliance on both Free Trade Agreement (FTA) and non-FTA partners, with a notable 6.7% still sourced from foreign entities of concern, chiefly China. Canada, Australia, and Japan feature among the top FTA partners, underscoring the strategic importance of deepening cooperation with allied nations through frameworks like the CMA and MSP.

Figure 12. U.S. Critical Minerals Import Sources, 2023



Source: Congressional Research Service Reports (2024)[51]

[48] Baskaran, G., & Schwartz, M. (2024, November 6). *U.S. Department of Treasury Releases Final Ruling on Section 45X.* Center for Strategic and International Studies. https://www.csis.org/analysis/us-department-treasury-releases-final-ruling-section-45x

[49] U.S. Department of the Treasury. (2024, October 24). *U.S. Department of the Treasury Releases Final Rules to Onshore Clean Energy Technologies, Strengthen Critical Minerals Supply Chains, and Expand U.S. Manufacturing Base as Part of Investing in America Agenda.* U.S. Department of the Treasury. https://home.treasury.gov/news/press-releases/jy2671

[50] Ward, J. (2024, July 1). *Recapture considerations for Inflation Reduction Act credits* (C. M. Turgeon, Ed.). The Tax Adviser. https://www.thetaxadviser.com/issues/2024/jul/recapture-considerations-for-inflation-reduction-act-credits.html

[51] Kitamura, Kyla H. (2023, May 10). *Mining industry and sustainable development: Overview and issues for Congress*. U.S. Congress. https://www.congress.gov/crs-product/IF12517

The CMA, signed in March 2023, aims to secure supplies of key minerals such as lithium, nickel, and cobalt for EV battery production by enhancing cooperation between the two nations.[52] Although Japan is not a major miner, its strong processing and manufacturing capabilities make it a strategic partner. The CMA also enables Japanese EV manufacturers to qualify for U.S. tax credits under the IRA, despite the absence of a full U.S.- Japan free trade agreement.

Additionally, the MSP is a multilateral initiative aimed at strengthening and diversifying global critical mineral supply chains, with a focus on clean energy and advanced technologies. The United States co-founded the MSP in 2022 and has played a leading role in shaping its vision, driven by the strategic need to reduce dependency on adversarial suppliers like China and to secure the mineral resources critical for America's economic growth, clean energy transition, and national security. Since assuming the MSP chair in July 2024, South Korea has prioritized expanding recycling projects, strengthening ties with Southeast Asia, and elevating economic security, especially in light of its near-total import dependence and leadership in semiconductor manufacturing. The MSP now supports over 30 global projects and serves as a key platform to counterbalance supply risks posed by China's dominance in critical minerals, with participation from 15 partner governments, including the United States, Australia, Canada, Japan, South Korea, the United Kingdom, and the European Union, who bring together a wide array of technical, diplomatic, and financial expertise. These partners collaborate across mining, processing, refining, and recycling stages of the value chain, while also engaging with resource-rich countries such as Argentina, the Democratic Republic of the Congo (DRC), Namibia, the Philippines, and Zambia through the MSP Forum, to promote local value addition and build more resilient and diversified global supply networks.

ESG and Human Rights Considerations in Critical Mineral Supply Chains

Despite their positive role in enabling clean energy technologies, the extraction and processing practices for critical minerals have drawn criticism over environmental, social, and governance (ESG) concerns. According to the IEA, mining for minerals such as cobalt, lithium, and nickel often occurs in regions with limited environmental protections and weak labor regulations.[53] For instance, over 70% of global cobalt is sourced from the DRC, where numerous investigations, including those by Amnesty International and the United Nations, have documented cases of child labor and unsafe working conditions.[54] Similarly, large-scale lithium extraction in South America’s “Lithium Triangle” (Argentina, Bolivia, and Chile) has sparked criticism over excessive water use and adverse impacts on Indigenous lands.[55] Environmental degradation, including deforestation, toxic waste discharge, and carbon-intensive refining processes, also presents growing challenges, particularly in jurisdictions lacking strong oversight.

These issues are noted as many private investors are inclined to look beyond traditional financial metrics and consider ESG performance, particularly environmental impact, labor practices, and human rights records. Private investors seeking to align their capital with both long-term value

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[52] Kitamura, Kyla H. (2025, January 8). *U.S.-Japan Critical Minerals Agreement.* U.S. Congress. https://www.congress.gov/crs-product/IF12517

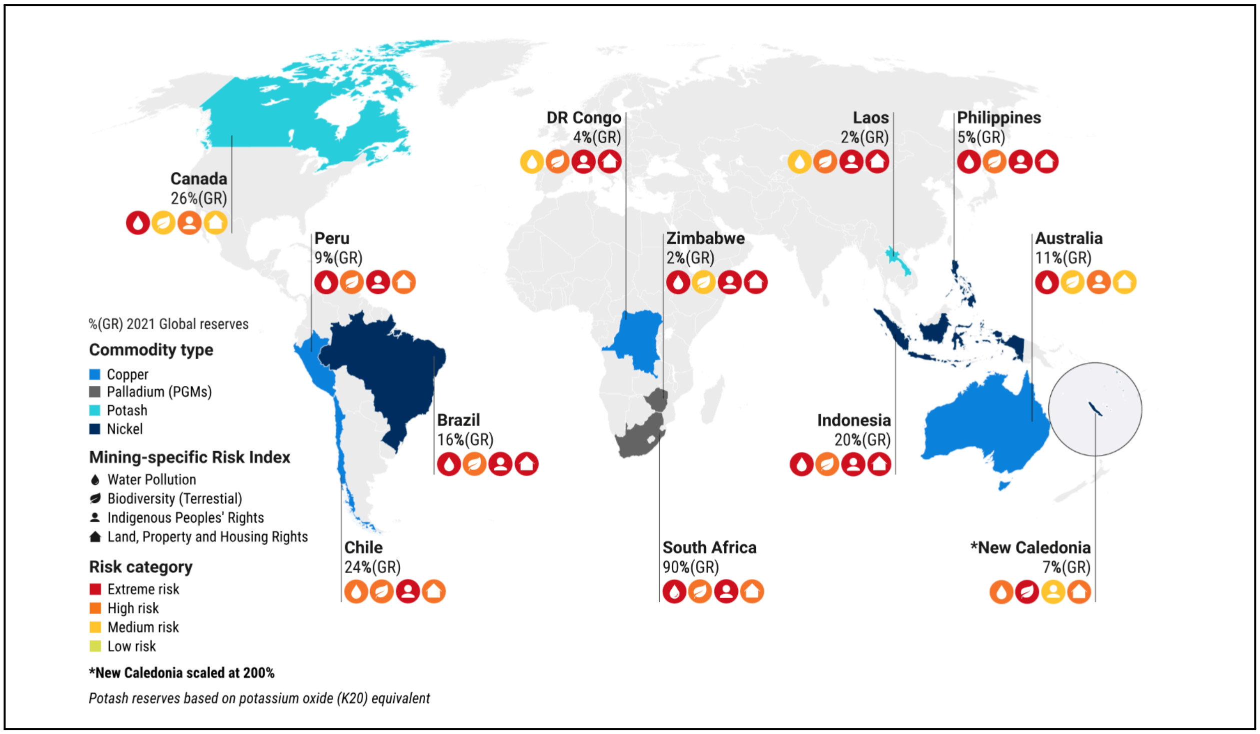
[53] International Energy Agency. (2021, May). *The role of critical minerals in clean energy transitions: Reliable supply of minerals.* IEA. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/reliable-supply-of-minerals

[54] Amnesty International. (2023, September 12). *DRC: Cobalt and copper mining for batteries leading to human rights abuses.* Amnesty International. https://www.amnesty.org/en/latest/news/2023/09/drc-cobalt-and-copper-mining-for-batteries-leading-to-human-rights-abuses/

[55] Ahmad, S. (2020, January 15). *The Lithium Triangle: Where Chile, Argentina, and Bolivia Meet.* Harvard International Review. https://hir.harvard.edu/lithium-triangle/

creation and meaningful global impact will carefully assess supply chains, and support companies that prioritize ethical sourcing and community engagement, while avoiding exposure to reputational and regulatory risks associated with exploitative operations. As governments and corporations work to secure reliable access to these essential materials, there is likely to be a growing emphasis on traceability, sustainability certifications, and transparent sourcing practices to ensure that the clean energy transition does not come at the expense of human dignity or environmental protection.

Figure 13. Geographic Distribution of Key Global Mineral Reserves and Associated Mining-Specific Risks



Source: Verisk Maplecroft (2022)[56]

[56] Verisk Maplecroft. *Metals & mining: Above-ground risk and sustainability solutions*. Verisk Maplecroft. https://www.maplecroft.com/industries/metals-and-mining/

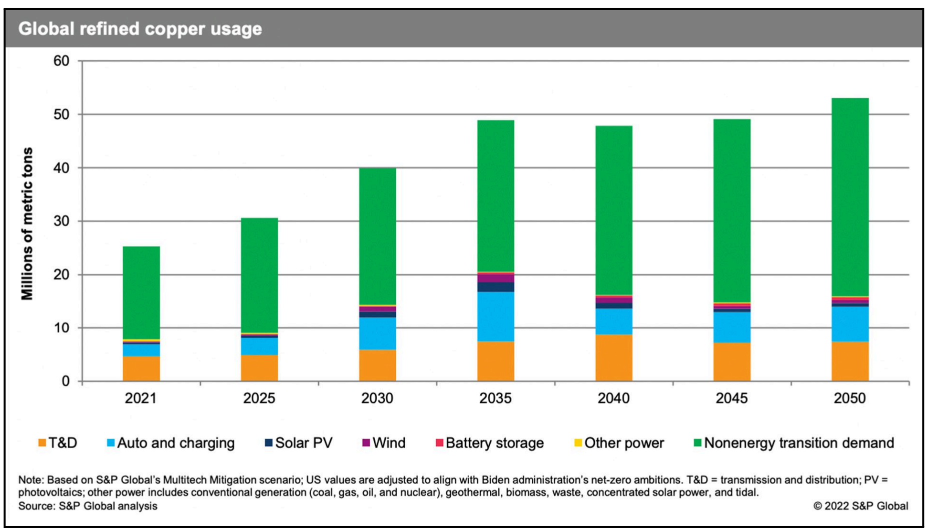
2.1.1 Copper

1. Main Uses, Historical Prices, and Production Levels

Long considered a foundational material in industrial development, copper has also become a critical enabler of the global energy transition. Its unique conductive and thermal properties make it indispensable across various applications from traditional infrastructure and manufacturing to cutting-edge technologies in renewable energy, EVs, and grid modernization.[57]

Copper is widely used in wind turbines, solar panels, hydropower stations, EV motors and batteries, smart grids, and energy storage systems. It also plays a central role in the production of consumer electronics, HVAC (Heating, Ventilation, and Air Conditioning) systems, and building materials. The metal's relevance is projected to grow, with projections showing global refined copper demand set to rise sharply through 2035, driven by clean energy deployment and other sources of non-energy transition demand.[58]

Figure 14. Global Refined Copper Usage



Source: S&P Global (2022)[59]

The global copper market has witnessed significant price volatility over the past decade, reflecting shifting macroeconomic conditions, geopolitical risks, and evolving supply-demand dynamics.[60] Between 2015 and 2016, prices dropped below USD 5,000 per metric ton ($5/lb) due to oversupply

[57] International Copper Association. (2022). *The role of copper in the transition to a clean energy economy.* International Copper Association. https://internationalcopper.org/

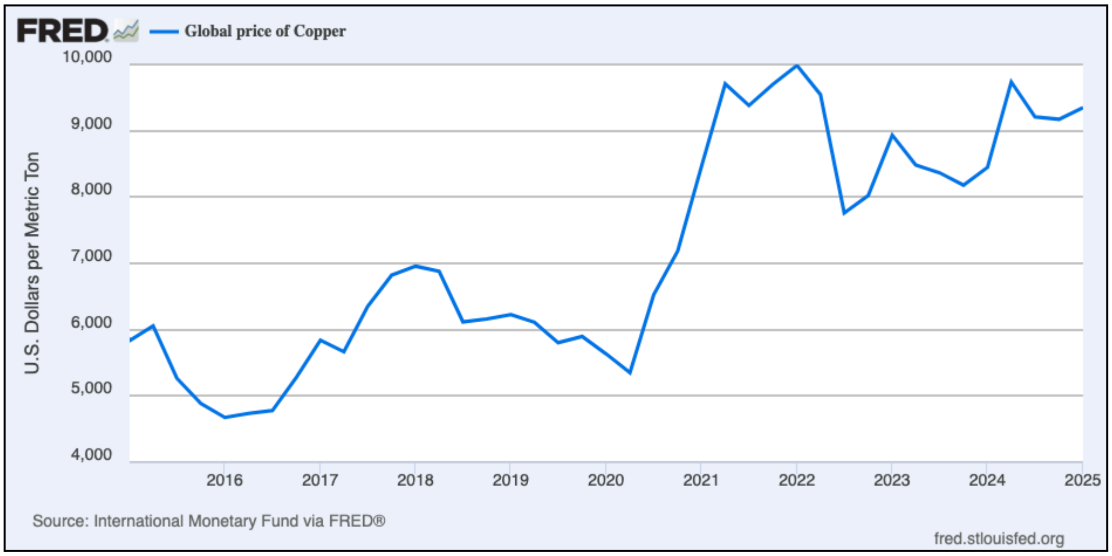
[58] S&P Global. (2022, July 14). *The future of copper: Will the looming supply gap short-circuit the energy transition?* S&P Global. https://cdn.ihsmarkit.com/www/pdf/0722/The-Future-of-Copper_Full-Report_14July2022.pdf

[59] Ibid.

[60] International Monetary Fund. (2025, April 10). *Global price of copper, US dollars per metric ton (PCOPPUSDM).* Federal Reserve Bank of St. Louis. https://fred.stlouisfed.org/series/PCOPPUSDM

and soft Chinese demand.[61] Recovery began in 2017–2018 amid renewed industrial investment, pushing prices back to around USD 7,000 per ton.

Figure 15. Global Price of Copper



Source: FRED (2025)[62]

The COVID-19 pandemic initially disrupted demand, with prices stabilizing between USD 5,500 and 6,200 per ton in 2019–2020. However, a dramatic shift occurred in 2021–2022 when post-pandemic stimulus, infrastructure investment, and a surge in green energy spending pushed prices above USD 10,000 per ton.[63] Supply issues in major producers like Chile and Peru further tightened the market.[64]

Since 2023, prices have remained volatile, ranging between USD 7,500 and 9,000 per ton, due to labor strikes, geopolitical tensions, and uneven demand across sectors. As of early 2025, copper prices are holding steady between USD 8,500 and 9,500 per ton, a range that supports increased production, supported by strong EV and semiconductor demand, lingering supply constraints, and delays in new mine development.[65]

On the supply side, global copper mine production has steadily increased from around 16 million metric tons in 2010 to over 22 million tons in 2024.[66] Yet, this growth has not kept pace with the accelerating demand from clean energy sectors. Unlike other minerals, copper benefits from a mature and transparent global spot market traded on platforms like the London Metal Exchange (LME) and

[61] Shanghai Metals Market. (2014, December 28). *What are major factors to affect copper prices in 2015? SMM Interviews.* Shanghai Metals Market. https://news.metal.com/newscontent/100068163/What-Are-Major-Factors-to-Affect-Copper-Prices-in-2015-SMM-Interviews

[62] International Monetary Fund. (2025, April 10). *Global price of copper, US dollars per metric ton (PCOPPUSDM).* Federal Reserve Bank of St. Louis. https://fred.stlouisfed.org/series/PCOPPUSDM

[63] World Bank Group. (2022, October). *Commodity markets outlook: The impact of the energy transition on metals demand.* World Bank Group. https://openknowledge.worldbank.org/handle/10986/38160

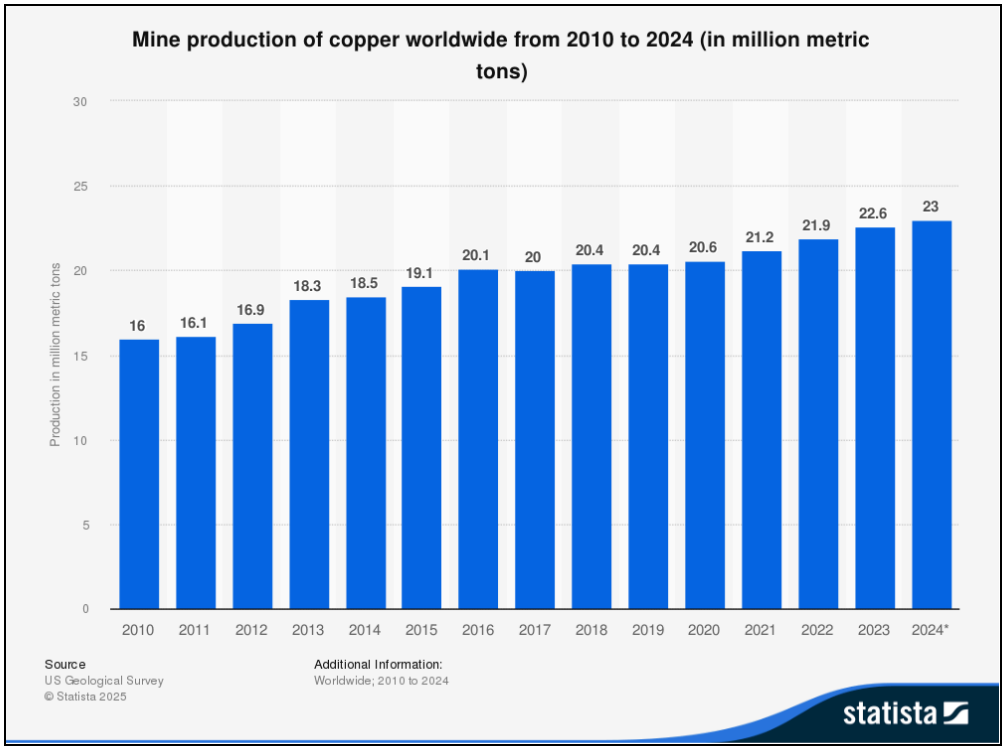
[64] Bare Syndicate. (2024, December 19). *The global copper supply chain in 2025: Challenges and opportunities.* Bare Syndicate. https://baresyndicate.com/global-copper-supply-chain-2025/

[65] Blake, O. (2025, April 22). *Copper's Volatile Dance: How Geopolitics and Green Energy Keep Prices Hot.* AInvest. https://www.ainvest.com/news/copper-volatile-dance-geopolitics-green-energy-prices-hot-2504/

[66] US Geological Survey. (February 3, 2025). *Mine production of copper worldwide from 2010 to 2024 (in million metric tons) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/254839/copper-production-by-country/

the Commodity Exchange (COMEX), which provides benchmarks for pricing and tools for hedging. Nevertheless, the market remains exposed to volatility from macroeconomic shocks, regulatory changes, and supply chain disruptions.

Figure 16. Worldwide Copper Production by Volume, 2010 - 2024



Source: US Geological Survey (2025)[67]

With limited new mine supply and mounting clean tech demand, copper's strategic importance is only expected to deepen. While prices may remain susceptible to short-term swings, the long-term fundamentals point to sustained value in the energy transition era.

2. Value Chain Breakdown and Concentrated Players

The copper value chain is globally integrated but still shaped by key geographic concentrations and structural bottlenecks. Upstream copper mining is dominated by Chile, Peru, and China, which together accounted for over 46.6% of global mine output in 2024. Chile leads globally, producing around 27% of the world's copper, followed by Peru with approximately 10% and China at about 8%.[68] These countries host some of the world's largest open-pit operations and have long-standing mining infrastructure. Emerging producers such as the DRC, Zambia, and Indonesia are becoming more prominent but continue to face challenges related to political instability, infrastructure, and environmental regulation. The United States remains a moderate producer but has seen renewed interest in boosting domestic output.[69]

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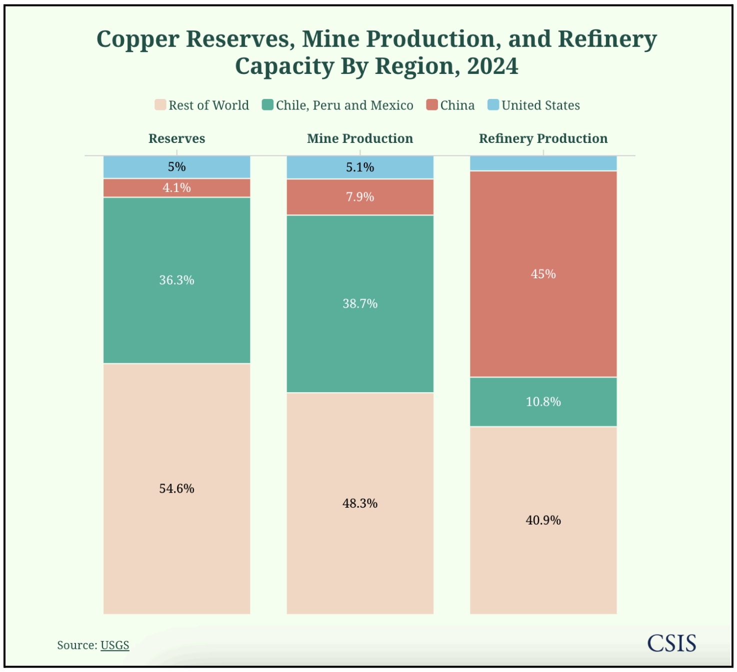
[67] US Geological Survey. (February 3, 2025). *Mine production of copper worldwide from 2010 to 2024 (in million metric tons) [Graph]*. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/254839/copper-production-by-country/

[68] Baskaran, G., Hernandez-Roy, C., Ziemer, H., & Murgia, F. (2024, November 13). *Latin America: The World's Copper Stronghold.* Center for Strategic and International Studies. https://features.csis.org/copper-in-latin-america/

[69] Ibid.

Figure 17. Copper Reserve, Production, and Refinery by Region, 2024



Source: Center for Strategic and International Studies (2024)

e midstream segment, encompassing smelting and refining, presents its own concentration challenges. China is by far the dominant player, accounting for approximately 45% of global copper refining capacity in 2024. It is home to seven of the ten largest copper refineries, including the massive Guixi facility, which alone has a capacity of 1.1 million metric tons.[70] While Chile and Peru contribute roughly 10–11% of refining output, much of their mined copper is exported for processing. Other countries like India, Russia, and the U.S. maintain smaller but strategically significant refining facilities. China's role as the world's primary copper processor gives it substantial influence over the midstream value chain– an increasingly sensitive issue as copper demand surges and trade tensions rise.[71]

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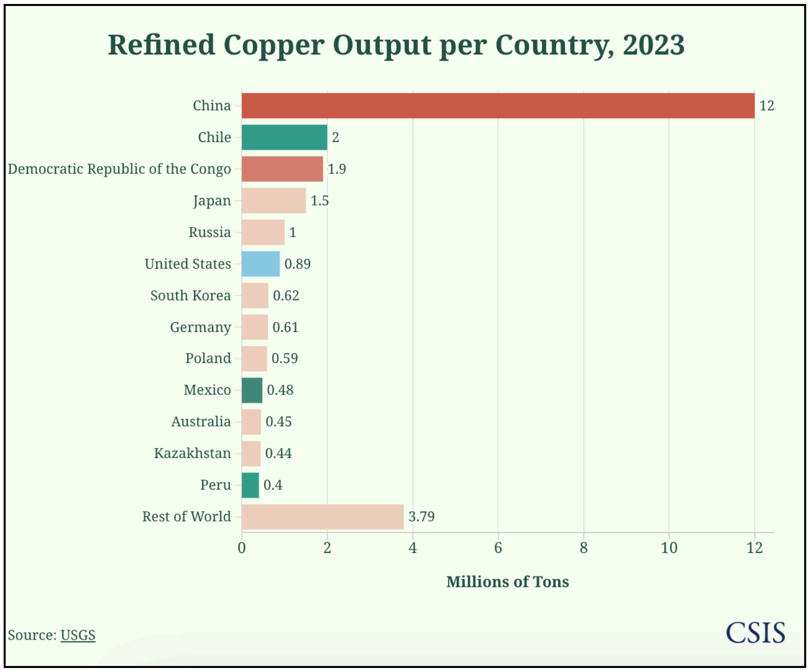
[70] ICSG. (September 11, 2024). *Leading copper refineries worldwide in 2024, based on capacity (in 1,000 metric tons) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/1180215/global-leading-copper-refineries-by-capacity/

[71] Tang, L., & Han, L. (2025, January 6). *COMMODITIES 2025: China to turn up heat in copper processing even as global output lags.* S&P Global. https://www.spglobal.com/commodity-insights/en/news-research/latest-news/metals/010625-commodities-2025-china-to-turn-up-heat-in-copper-processing-even-as-global-output-lags

Figure 18. Refined Copper Output by Country, 2023



Source: Center for Strategic and International Studies (2024)

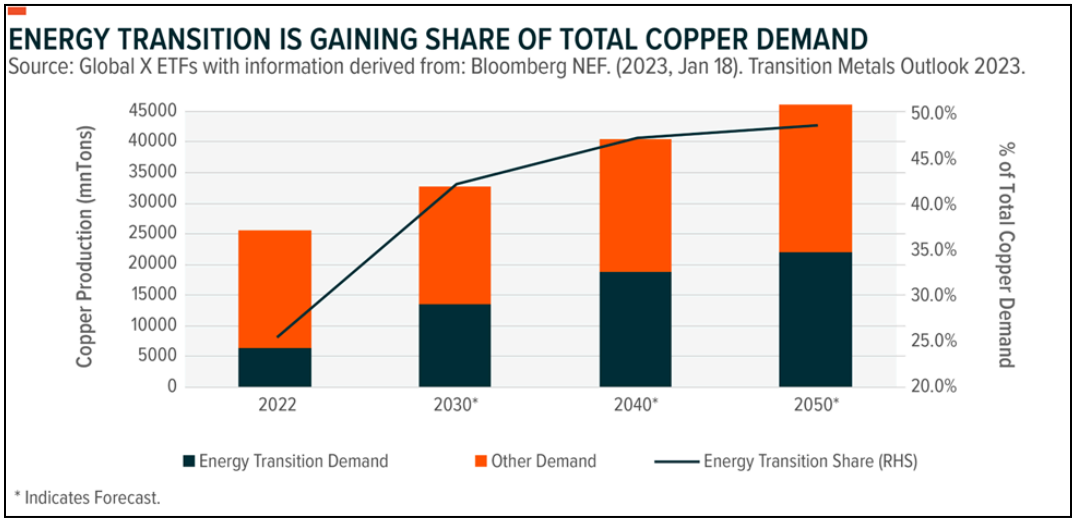
Projects in states like Arizona, Montana, and Texas, primarily mining projects, with some incorporating refining operations, have attracted increased investment and policy attention as part of U.S. efforts to rebuild domestic copper production capacity.[72] However, many of these initiatives remain in early development and continue to face significant hurdles, including complex permitting procedures, local community resistance, and environmental review processes that can stretch over decades. Internationally, countries such as Indonesia and Zambia, and the DRC are emerging as prospective contributors to future copper supply, backed by sizable reserves and growing foreign investment. As a result, despite active efforts to diversify supply chains, the global copper market remains vulnerable to disruption, especially given the long lead times and capital intensity associated with bringing new mining and refining capacity online.[73]

3. Demand and Production Outlook; Recent Developments

Global copper demand is projected to grow steadily through 2050, driven by surging needs in clean energy technologies and electrification infrastructure. Between 2022 and 2050, total copper demand is expected to nearly double, with the share attributable to energy transition applications, including electric vehicles, renewable power, and grid modernization, rising from under 25% today to nearly 50% by mid-century.[74] The shift underscores copper's central role as a foundational material in the transition to low-carbon systems.

[72] Nolan, R. (2024, October 17). *Copper: Powering America's Future and Securing Our Supply Chains.* National Mining Association. https://nma.org/2024/10/17/copper-powering-america/
[73] International Copper Study Group. (2020). *The world copper factbook 2020.* International Copper Study Group. https://internationalcopper.org/wp-content/uploads/2021/01/2020_10_13_ICSG_Factbook_2020.pdf
[74] Mohamed, S. E. P., & Marican, M. (2023, September 20). *The role of copper in the energy transition.* Det Norske Veritas. https://www.dnv.com/article/the-role-of-copper-in-the-energy-transition-247342/

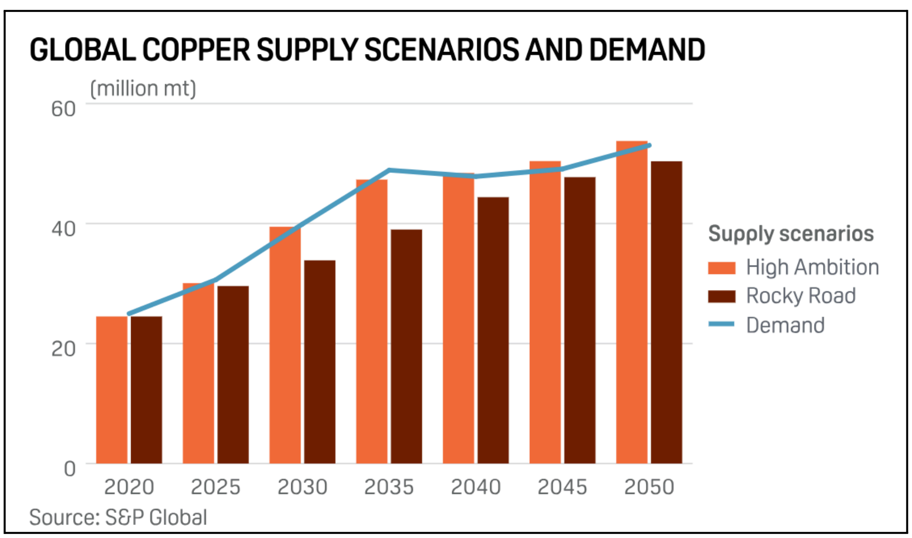
Figure 19. Energy Transition Demand Outlook



Source: Global X ETFs (2023)

Supply forecasts suggest moderate expansion, but risks remain. According to S&P Global, global copper production must rise from roughly 25 million metric tons in 2022 to at least 50 million metric tons by 2050 to meet demand under high-ambition climate pathways.[75] However, under less optimistic “rocky road” scenarios, supply growth may fall short of projected demand by more than 5 million metric tons annually. This mismatch highlights the urgency of accelerating investment in new mining projects, expanding refining capacity, and integrating recycled copper into the supply chain at scale.

Figure 20. Global Copper Supply and Demand Scenarios



Source: S&P Global (2022)

[75] S&P Global. (2022, July 14). *The future of copper: Will the looming supply gap short-circuit the energy transition?* S&P Global. https://cdn.ihsmarkit.com/www/pdf/0722/The-Future-of-Copper_Full-Report_14July2022.pdf

Recent Policy Shifts and Market Disruptions

Recent developments have introduced new headwinds for copper supply chains. As noted already, the new Trump Administration has initiated several section 232 investigations under the Trade Expansion Act of 1962 to determine whether the importation of targeted articles threatens national security, with the objective of meeting conditions under the Act for the President to impose import tariffs.[76] Copper is one of the articles being investigated. Chile has publicly opposed proposed U.S. tariffs on copper, arguing that such measures would disrupt global trade and harm American manufacturers.[77] Meanwhile, the U.S. has been advancing domestic capacity through project expansions by major players like Freeport-McMoRan and Rio Tinto, supported by the federal critical minerals incentives under the IRA.

As noted already as well, the likelihood for the IRA to be amended by the new Congress, in a manner that reduces incentives for domestic production of critical minerals, is low in light of national security of supply considerations. Copper is presently not included among the elements defined as "critical minerals" for purposes of the 45X incentives under the IRA, but there is some bipartisan support to include it.

At the same time, U.S. tariffs on imported copper, which are currently under consideration through the Trump Administration's ongoing Section 232 investigation, would, if sustained, increase the commodity price in the United States and benefit any player involved in domestic mining. The Section 232 investigation frames copper imports as a potential national security risk and could lead to significant duties on imported refined and semi-finished copper products. Analysts project that sustained tariffs could reduce copper import volumes by as much as 25% by late 2025, triggering upward pressure on domestic copper prices. Beneficiaries would likely include U.S.-based producers such as Freeport-McMoran and Rio Tinto's U.S. operations, who would enjoy improved margins and stronger competitive positioning against foreign suppliers. However, tariff-driven volatility could also tighten supply chains and temporarily elevate costs for U.S. manufacturers reliant on copper inputs.

Mining sector analysts interviewed for this report point out that even if tariffs on elements like copper are perceived in the market as durable, they may not necessarily stimulate companies with US sales and production to expand production. Expanding mines is so capital intensive, and returns so delayed, that these players may just elect to enjoy the higher domestic prices that result from higher tariffs on imports. This is especially likely if the mining companies are not confident that the tariffs are durable.

Globally, policy shifts in Asia are also reshaping the landscape. Indonesia has announced new export restrictions on copper concentrates by 2026, aimed at boosting domestic smelting capacity. These measures could tighten global supply and increase processing costs for downstream buyers. Similarly, political instability and environmental protests in Panama and Peru have sparked disruptions at major sites, including Cobre Panama, raising concerns over reliability in key production hubs.[78]

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[76] The White House. (2025, April 15). *Fact sheet: President Donald J. Trump ensures national security and economic resilience through Section 232 actions on processed critical minerals and derivative products.* The White House. https://www.whitehouse.gov/fact-sheets/2025/04/fact-sheet-president-donald-j-trump-ensures-national-security-and-economic-resilience-through-section-232-actions-on-processed-critical-minerals-and-derivative-products/

[77] Solomon, D. B. (2025, April 15). *Chile pushes back against Trump copper tariff probe.* Reuters. https://www.reuters.com/markets/commodities/chile-pushes-back-against-trump-copper-tariff-probe-2025-04-15/

[78] Baskaran, G., & Reynal, P. (2025, May 8). *Reviving Cobre Panamá Could Be Strategic to U.S. Minerals Security.* Center for Strategic and International Studies. https://www.csis.org/analysis/reviving-cobre-panama-could-be-strategic-us-minerals-security

At the same time, tariff-driven market volatility is expected to influence pricing dynamics in the near term. Analysts forecast that U.S. copper tariffs could reduce import volumes by up to 25% by Q4 2025, potentially triggering short-term supply shocks and contributing to upward price pressure.[79]

4. Key Players and Sorting Matrix

The copper market remains less consolidated than a few other critical minerals but is still dominated by a group of major publicly traded companies that hold significant control over both mining and refining activities. Many of these firms are vertically integrated, enabling them to manage upstream extraction and midstream processing within a single corporate structure. This integration provides strategic advantages, hedging against supply disruptions, managing costs, and ensuring long-term access to critical material.

As of 2025, leading publicly listed copper producers include Freeport-McMoRan (U.S.), BHP Group (Australia), Glencore (Switzerland), First Quantum Minerals (Canada), and Anglo American (UK). The original analysis also included Codelco (Chile); however, it has been removed from the final selection below as it is a state-owned entity, not publicly traded, making it distinct from the other firms evaluated. These companies are positioned in the upper tier of the market, with substantial sector exposure, strong vertical integration, and large market capitalizations.

Others, such as Southern Copper (Mexico), Hudbay Minerals (Canada), and KGHM Polska Miedź (Poland), maintain strong operational footprints but do so at smaller scales or with more limited vertical integration. Chinese firms, including Jiangxi Copper, Zijin Mining, and Tongling Nonferrous, continue to play leading roles in copper refining but often lack upstream diversification and face mounting pressure from Western trade and investment restrictions.

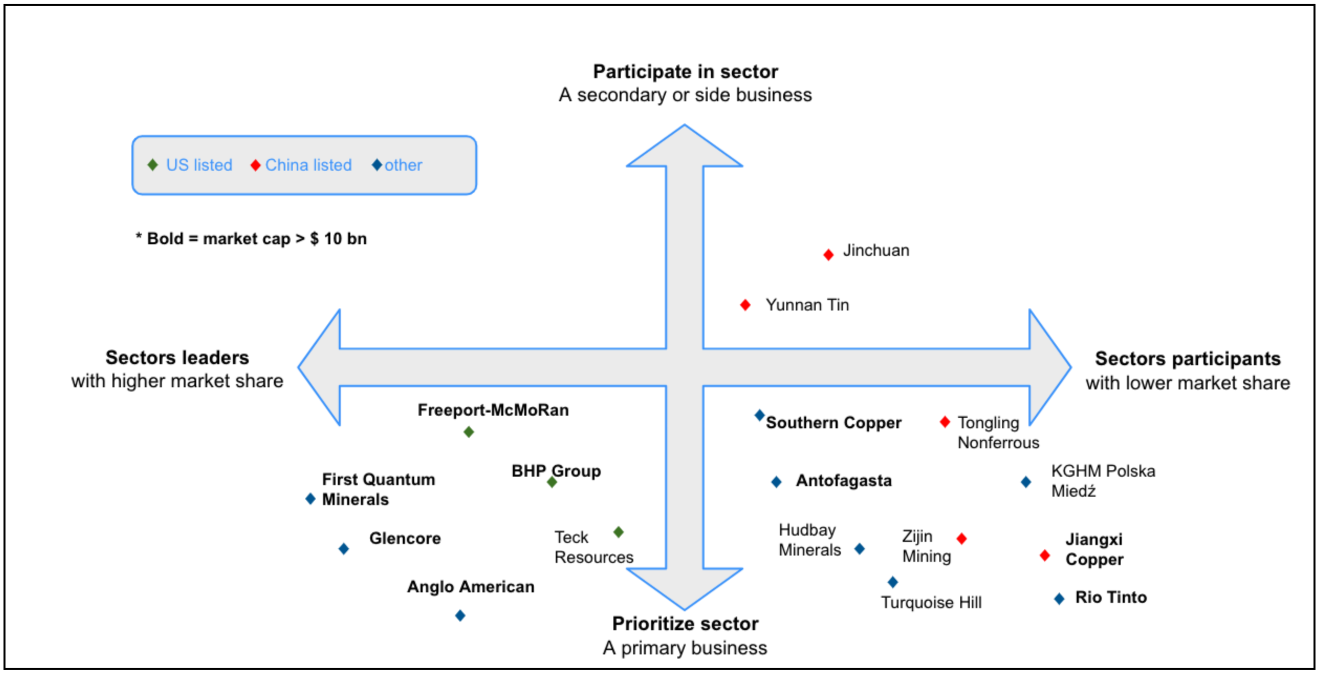
A sorting matrix developed for this study categorizes these companies by their exposure to both upstream (mining) and midstream (refining) segments, as well as their market capitalization and exchange listing. The analysis finds that firms listed on Western exchanges with high sector exposure and strong vertical integration, such as Freeport-McMoRan, BHP Group, Glencore, and First Quantum Minerals, are best positioned to capture value from long-term structural demand growth driven by clean energy technologies and electrification.

These players are also more likely to meet evolving expectations around ESG performance, permitting transparency and supply chain traceability, factors that are increasingly prioritized by investors and policymakers alike.

…/…

79 Reuters. (2025, April 15). *Citi sees copper prices falling slower as U.S. tariffs ease.* Reuters. https://www.reuters.com/markets/commodities/citi-sees-copper-prices-falling-slower-us-tariffs-ease-2025-04-15/

Figure 21. Matrix of Key Copper Mining and Refining Players Globally

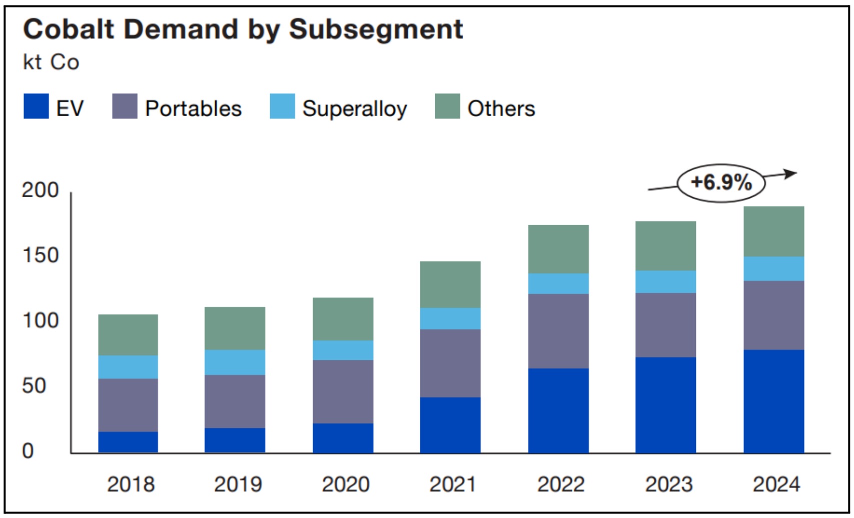


2.1.2 Cobalt

1. Main Uses, Historical Prices and Production Levels

Cobalt plays a central role in a diverse array of commercial, industrial, and military applications. Historically valued for its use in superalloys, hard metals and catalysts, cobalt's strategic significance has surged due to its importance in chargeable battery chemistries, especially those used in EVs and consumer electronics. Today, the largest share of global cobalt demand originates from the batteries sector, where cobalt-based cathodes support energy density and performance in lithium-ion batteries. Other major applications include gas turbine engine parts, airbags, catalysts for petroleum and chemical refining, and specialty metal alloys.[80]

Figure 22. Cobalt Demand by Subsegment, 2018 - 2024



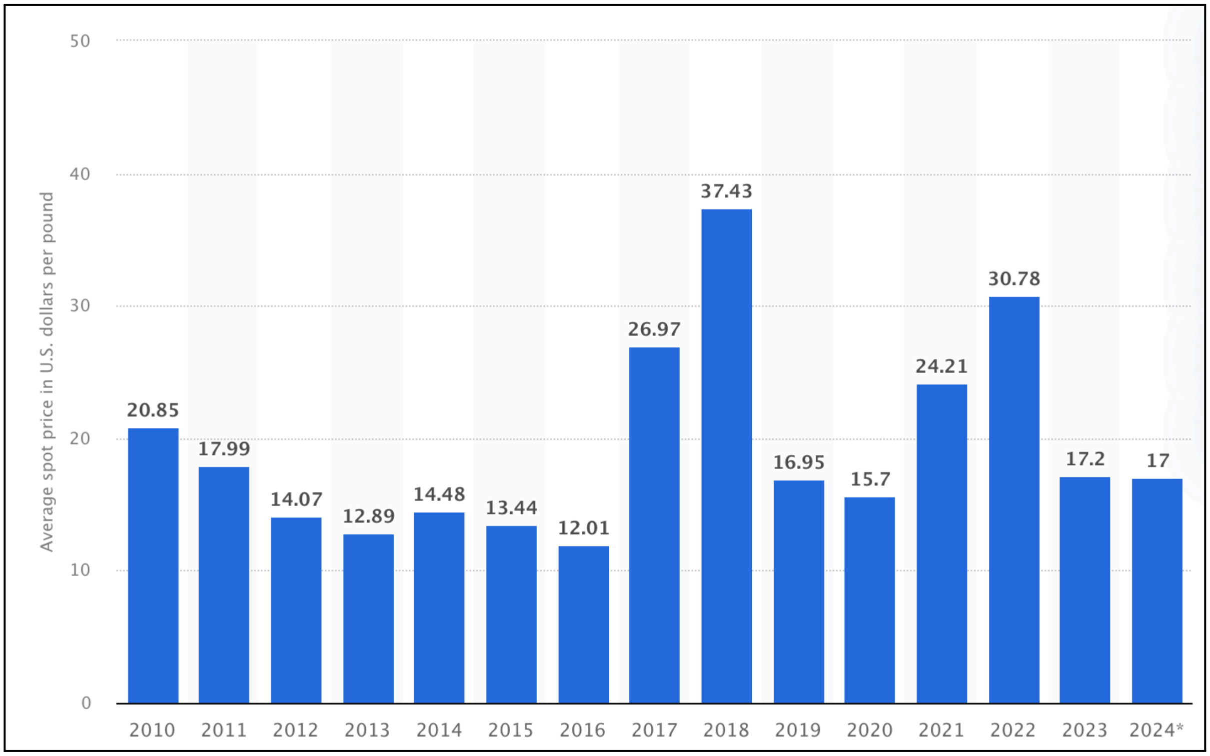
Source: Cobalt Institute (2024)

Between 2023 and 2024, the global demand for cobalt increased by 7% year-on-year, driven largely by continued expansion in EVs and portable electronics.[81] Demand from other sectors such as aerospace and industrial alloys is expected to grow at a more moderate pace of approximately 5% in 2025.

Cobalt's market trajectory is shaped by both technological shifts and commodity cycles. A price rally in 2017-2018 was fueled by expectations of surging EV demand and tight supply, but was followed by a sharp correction in 2019 as oversupply conditions emerged. It peaked again at $82,000 per tonne in March 2022 but declined amid weakening fundamentals. Much of this oversupply was the result of increased copper output, since cobalt is primarily recovered as a byproduct of copper and nickel mining. Prices have remained depressed through the early 2020s, reflecting both persistent market surpluses and a structural shift in battery chemistry that has reduced cobalt intensity per unit of storage. The prevailing price range would not support increased production capacity unless the evolving supply to demand ratio contracted and prices cycled upwards.

[80] Cobalt Institute. (2024). *Quarterly Cobalt Market Update Overview 2024 Q4.* Cobalt Institute. https://www.cobaltinstitute.org/wp-content/uploads/2025/01/Cobalt-Institute_Q4-2024-cobalt-market-report.pdf
[81] Ibid.

Figure 23. Average cobalt spot price in U.S. (USD per pound), 2010 - 2024



Sources: US Geological Survey (2025)[82]

In February 2025, the DRC - the world's largest cobalt producer - implemented a four-month export ban in an attempt to address low cobalt prices.[83] The DRC has also initiated discussions with Indonesia on potential collaboration to manage pricing and supply, suggesting that key producers may seek a more deliberate approach to market stabilization.[84]

The pricing structure of cobalt has also evolved. Market participants have increasingly moved away from traditional metal-based pricing contracts towards contract references based on cobalt hydroxide or sulfate. This shift reflects growing demand for intermediate chemical products in battery manufacturing, especially among Chinese buyers where domestic sulfate pricing gained traction in late 2022. In 2023, a sharp drop in sulfate-linked contract prices led to significant losses, prompting many producers to revert to hydroxide-based benchmark by 2024. Contract negotiations are often a mix of reference prices, such as equal split between sulfate and hydroxide, to spread risk. The focus on hydroxide pricing will likely grow, as hydroxide production is expected to increase significantly.[85]

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[82] US Geological Survey. (February 3, 2025). *Average cobalt spot price in the United States from 2010 to 2024 (in U.S. dollars per pound) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/339743/average-spot-price-of-cobalt-in-the-us/

[83] Kasongo, A. A., & Rolley, S. (2025, February 24). *Congo bans cobalt exports for four months to curb oversupply.* Reuters. https://www.reuters.com/markets/commodities/congo-suspends-cobalt-exports-four-months-counter-oversupply-bloomberg-news-2025-02-24/

[84] Reuters. (2025, March 20). *Congo plans cobalt export quotas, partnership with Indonesia to tackle glut.* Reuters. https://www.reuters.com/markets/commodities/congo-plans-cobalt-export-quotas-partnership-with-indonesia-tackle-glut-2025-03-19/

[85] Cook, A. (2024, January 30). *Cobalt oversupply brings change to long-term contracts.* Fastmarkets. https://www.fastmarkets.com/insights/cobalt-oversupply-brings-change-to-long-term-contracts/

On the production side, cobalt reserves are highly concentrated. The DRC, Australia and Indonesia collectively hold more than three-quarters of currently known reserves globally.[86] The DRC alone accounts for over 75% of global mine production. Indonesia has emerged as a key producer through its nickel industry, with cobalt production rising from 2,700 tonnes in 2021 to 28,000 in 2024. It benefited from its 2024 nickel ore export ban, which catalyzed the growth of domestic refining. Chinese-backed investments have developed large-scale high-pressure acid leech (HPAL) facilities, including the Zhejiang Huayou's Huafei plant which is the world's largest HPAL facility.

Australia remains a marginal player despite holding 15% of global cobalt reserves. As of September 2024, nine projects were in the pre-feasibility phase.[87] Companies such as Glencore, Cobalt Blue and Ardea Resources are among the key actors operating or advancing projects in Australia. China maintains a dominant position through majority control of cobalt mining operations in the DRC and Indonesia, underscoring its critical role in the cobalt value chain.[88] While the DRC is seeking to diversify its investment base, China remains the key player, and Indonesia is planning a tenfold increase in output by 2030.

Figure 24. Breakdown of Chinese and Non-Chinese Owned Cobalt Production Globally

Cobalt production (tonnes)	Non-Chinese Owned Production	Chinese Owned Production	2030F (Total)	2030F (Share)
DRC	94,989	109,159	204,148	67.9%
Indonesia	23,288	25,591	48,879	16.3%
Australia	7,070	0	7,070	2.4%
Philippines	5,270	0	5,270	1.8%
Russia	4,838	0	4,838	1.6%
Canada	4,510	0	4,510	1.5%
Cuba	4,496	0	4,496	1.5%
Papua New Guinea	541	3,067	3,608	1.2%
Turkey	2,835	0	2,835	0.9%
New Caledonia	2,799	0	2,799	0.9%
ROW	10,336	1,901	12,237	4.1%
Total	**160,974**	**139,718**	**300,692**	**100.0%**

Source: Visual Capitalist (2024)

2. Value Chain Breakdown and Concentrated Players

[86] Ewing, S. M. (2025, January). *Mineral Commodity Summaries 2025 Cobalt.* U.S. Geological Survey. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-cobalt.pdf

[87] Australian Trade and Investment Commission. (2025, April). *Australian Critical Minerals Prospectus.* Australian Government. https://international.austrade.gov.au/en/do-business-with-australia/sectors/energy-and-resources/critical-minerals/prospectus

[88] Venditti, B. (2024, October 14). *Visualizing China's Cobalt Supply Dominance by 2030.* Elements by Visual Capitalist. https://elements.visualcapitalist.com/visualizing-chinas-cobalt-supply-dominance-by-2030/

The cobalt value chain is highly consolidated, spanning a vertically integrated set of actors that dominate mining, refining and processing. However, overproduction and price volatility have created structural headwinds for market participants.

China leads the midstream segment by a wide margin, with approximately 78% of global cobalt refining capacity under its control.[89] Chinese firms such as Zhejiang Huayou Cobalt operate large-scale refining operations and have spearheaded the development of HPAL facilities which enhance cobalt production capacity, especially in Indonesia.[90] These technological and financial investments have enhanced refining throughput and strengthened China's position in the value chain.

Table 4. Share of Global Refined Cobalt Production by Country (%)

Country	Share of global refined production	
	2022	2023
China	76.1%	78.5%
Finland	9.9%	8.8%
Canada	4.0%	3.1%
Japan	0.2%	1.9%
Norway	1.9%	1.7%
Australia	2.0%	1.7%
Madagascar	1.9%	1.7%
Morocco	1.1%	1.0%
ROW	2.9%	1.6%

Source: Cobalt Institute (2024)

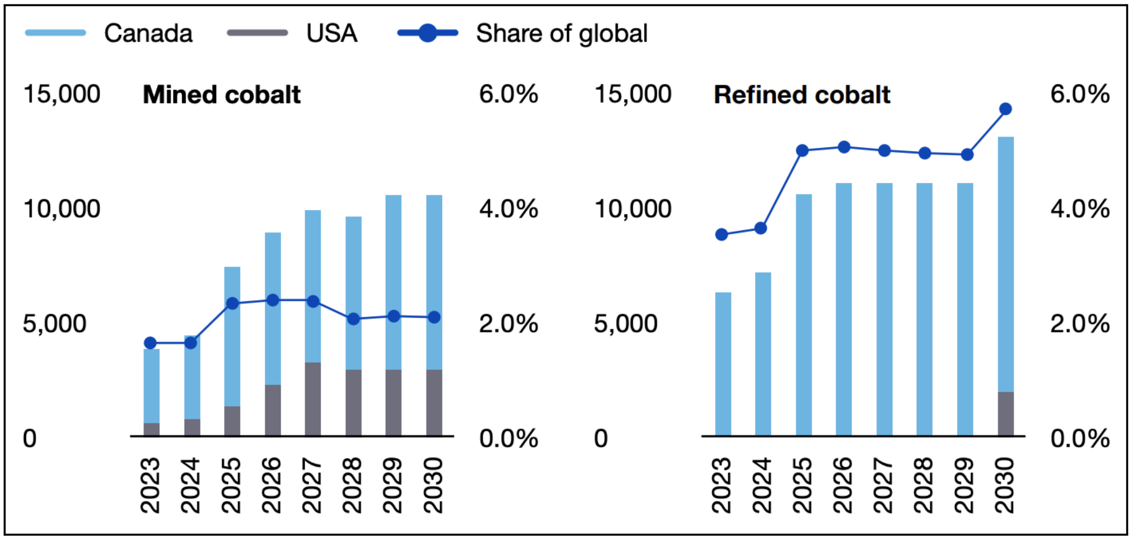
This degree of consolidation has strategic implications. Just two companies - CMOC Group and Glencore - produce more than 40% of global mine output, while Huayou Cobalt and CMOC dominate refining capacity. Smaller producers, including a long tail of artisanal and byproduct operations, supply the remainder of the market but lack the scale or influence of the largest players. This results in a value chain in which upstream concentration and downstream integration reinforce the market dominance of a few well-capitalized firms.

The U.S. has limited cobalt reserves and minimal domestic production capacity. In 2023, construction at the country's only primary cobalt mine, Idaho Cobalt Operations, was halted due to low cobalt prices. Only two other known mining operations exist: Lundin Mining Corporation's Eagle Mine, which produces nickel and copper concentrates that are processed abroad, and Vale's

[89] Cobalt Institute. (2024, May). *Cobalt Market Report 2023.* Cobalt Institute. https://www.cobaltinstitute.org/wp-content/uploads/2024/05/Cobalt-Market-Report-2023_FINAL.pdf
[90] Mine. (2025, March 14). *The global cobalt market: outlook to 2030.* Mine. https://mine.nridigital.com/mine_mar25/cobalt-market-outlook-2030

Thompson Mine, which also produces nickel and copper. Currently, approximately five companies in the U.S. produce cobalt chemicals.

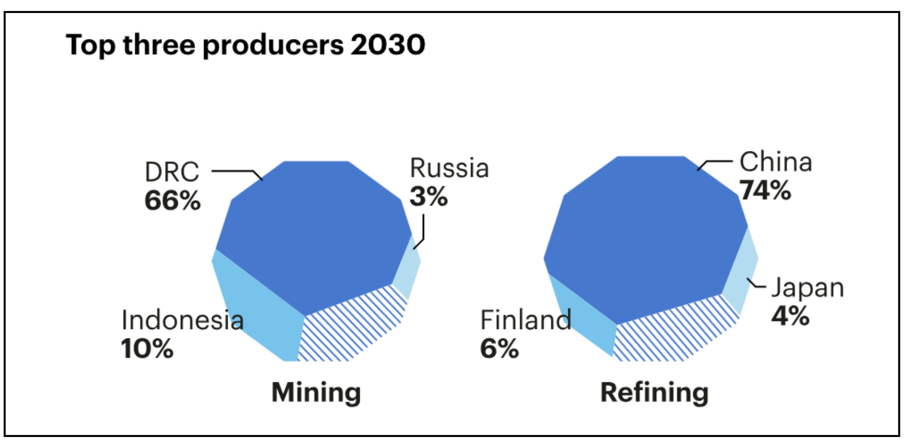
Figure 25. Potential Mined and Refined Cobalt Supply in U.S. and Canada (kt cobalt)



Source: Cobalt Institute (2024)

Efforts to diversify supply and increase refining capacity outside of China remains in early stages. While projects in countries such as Australia and Canada are progressing, they have yet to materially shift the global balance. In the near-term, Chinese-backed investments in Indonesia and DRC will continue to shape the midstream and upstream landscape. According to the IEA, China is expected to have a 74% share of global cobalt refining by 2030, illustrating its enduring centrality in the value chain.

Figure 26. Forecasted Key Cobalt Mining and Refining Players, 2023



Source: IEA (2024)[91]

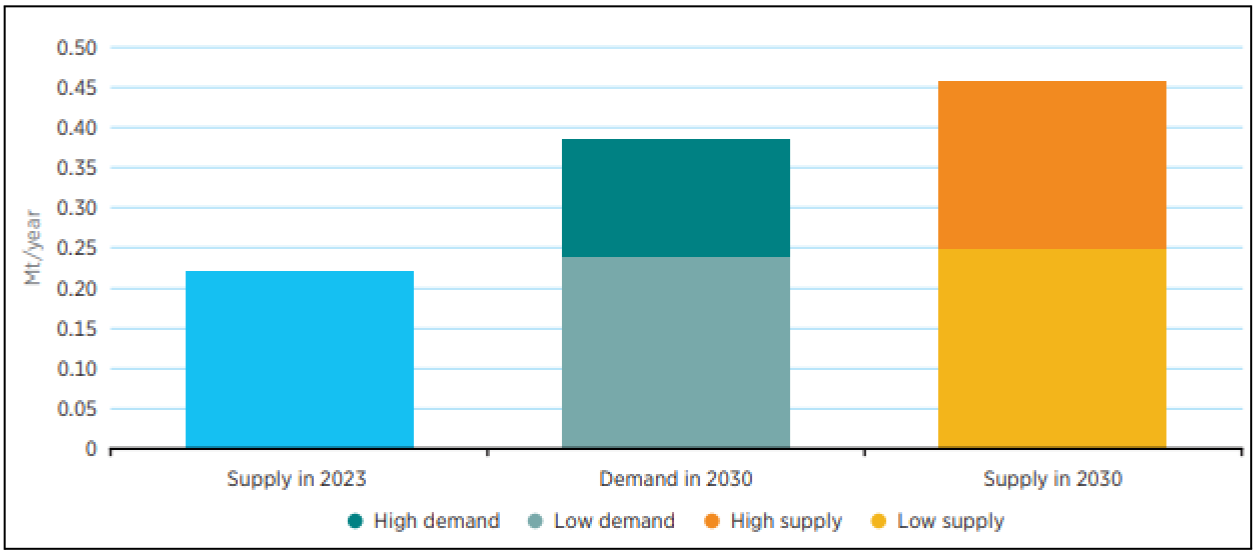
[91] International Energy Agency. (2024, May). *Cobalt: Outlook for key energy transition minerals.* IEA. https://www.iea.org/reports/cobalt

…/…

3. Demand and Production Outlook; Recent Developments

Cobalt demand is increasingly characterized by structural uncertainty. While the battery-grade cobalt has historically benefited from growth in EVs and portable electronics, evolving battery chemistries are beginning to erode this demand base. Notably, lithium-iron-phosphate (LFP) batteries, which do not require any cobalt, have surged and are forecasted to dominate over nickel-manganese-cobalt (NMC) chemistries. In China, LFP now accounts for approximately 75% of new installations, compared to just 25% of NMC. Although Western automakers still rely heavily on NMC chemistries, competitive pressures around cost and safety is prompting a gradual transition to LFP.

Figure 27: Cobalt Supply and Demand, 2023 and 2030



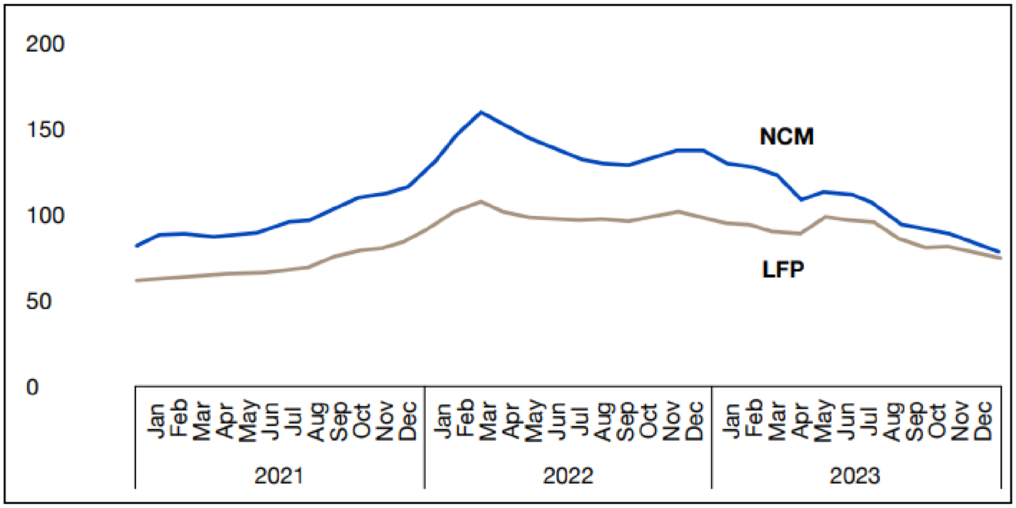
Source: IRENA (2024)

According to International Renewable Energy Agency (IRENA) 's battery-chemistry scenarios, global cobalt demand could range from 0.24 Mt to 0.39 Mt per year by 2030, with only ~10% growth under a high-LFP "innovation" scenario versus nearly 60% growth if NMC remains prevalent.[92] Technology mix is the decisive factor for cobalt's trajectory. The fall of cobalt and nickel prices have improved the cost competitiveness of NMC cells compared to LFP, which could potentially slow the shift away from NMC batteries. The decline in raw materials price could slow the decline in average cobalt intensity in batteries.

…/…

[92] IRENA. (2024). *Batteries for Electric Vehicles.* IRENA. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Sep/IRENA_Critical_materials_Batteries_for_EVs_2024.pdf

Figure 28: Weighted Average Global Cell Prices ($/kWh)



Source: Cobalt Institute (2024)

Consequently, cobalt demand from the EV sector is unlikely to grow at previously expected rates. Continued or growing demand from aerospace and consumer electronics may offer partial offsets, but whether this is sufficient to counterbalance the expected decline from the EV sector remains unclear.

Against this backdrop, cobalt production remains high, largely due to strong copper prices that support continued cobalt byproduct output. Surplus conditions are expected to persist through the medium term. Forecasts project that cobalt supply will remain in excess of demand until at least 2028, with the market surplus peaking in 2024 and gradually falling to approximately 3,000 metric tons by the end of the decade.[93]

In the evolving cobalt market, companies are adjusting their strategies in response to shifting demands, price volatility, and geopolitical factors. Despite market challenges, several companies are expanding their involvement in the cobalt industry. CMOC Group increased its cobalt production by 20.7% in the first quarter of 2025, demonstrating resilience amid export restrictions from the DRC.[94] Sumitomo Metal Mining invested A$4.6 million (approximately US$2.9 million) in Ardea Resources, enhancing its stake in cobalt-nickel projects. Lygend Resources & Technologies capitalized on tariff exemptions from its cobalt production in Indonesia. Electra Battery Materials secured funding to advance its cobalt sulfate refinery in Ontario, aiming to supply battery grade materials for over 1 million electric vehicles annually.

Conversely, some companies are scaling back their cobalt operations due to market pressures. Glencore engaged in preliminary discussions to divest their copper-cobalt mines in the DRC due to operational challenges and low cobalt prices. First Quantum Minerals halted their nickel-cobalt operations in Western Australia, citing unprofitable conditions amid weak metal prices.[95]

These strategic shifts reflect the dynamic nature of the cobalt industry, influenced by technological advancements, market demands and geopolitical considerations.

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[93] Home, A. (2025, February 6). *Another cobalt bust but this time it's different.* Reuters. https://www.reuters.com/markets/commodities/another-cobalt-bust-this-time-its-different-andy-home-2025-02-06/

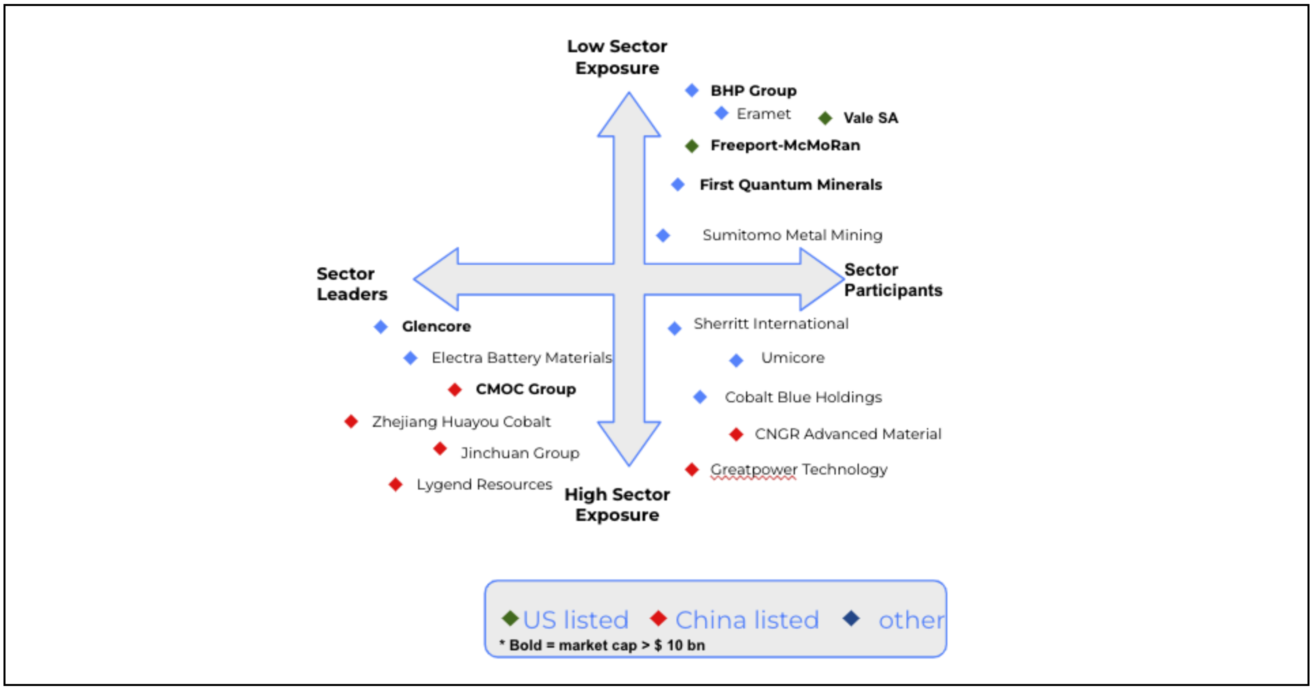
[94] Reuters. (2025, April 8). *China's CMOC boosts cobalt output at Congo mines despite export ban.* Reuters. https://www.reuters.com/markets/commodities/chinas-cmoc-boosts-cobalt-output-congo-mines-despite-export-ban-2025-04-08/

[95] Lorinc, J. (2024, January 15). *First Quantum Halts Australian Nickel Mine on Weak Metal Prices.* Bloomberg. https://www.bloomberg.com/news/articles/2024-01-15/first-quantum-halts-australian-nickel-mine-on-weak-metal-prices

4. Key Players and Sorting Matrix

The global cobalt market is highly consolidated, with a small number of publicly traded firms controlling a disproportionate share of upstream and midstream activities. Key publicly listed companies include CMOC Group, Glencore, BHP Group, Vale SA, Freeport-McMoRan, First Quantum Minerals. CMOC and Glencore dominate over 40% of cobalt mine output, while Huayou Cobalt leads in refining capacity. While smaller firms contribute to the overall cobalt supply, they lack the scale or integration to meaningfully influence dynamics in the industry.

Figure 29. Matrix of Key Cobalt Mining and Refining Players Globally



Source: Capstone analysis

A sectoral sorting matrix produced for this study classifies these firms by upstream and midstream exposure as well as market capitalization. Companies with diversified operations are better positioned to weather the current market conditions as they could better offset cobalt price volatility with revenues from other metals. Conversely, pure-play cobalt companies with limited diversification face heightened risk when oversupply and narrow margins prevail.

Evolving industrial policies are poised to benefit U.S. cobalt producers—particularly through subsidies under the IRA and potential import tariffs that would raise domestic prices. However, headwinds remain: resource availability is limited, there is no existing refining capacity, permitting timelines are protracted, and constrained capital for new projects. In this context, sustained IRA incentives and import tariffs could spur the private sector to invest into new cobalt mines and refineries, but realizing that upside will require complementary regulatory reforms, such as streamlined permitting, developing the workforce while balancing environmental and social considerations—to ensure that domestic production and processing actually materializes in the coming decade.

Looking beyond the US, companies with operations in geopolitically stable regions that maintain favorable trade relations with major markets like the US stand to gain a competitive edge. Firms that have or can establish refining and processing facilities in regions with favorable trade conditions would also be less susceptible to geopolitical conditions.

In conclusion, companies that produce cobalt with broader metal portfolios and operate in secure, low-risk regions are best equipped to navigate today's oversupplied and low-margin market. In the US, the IRA and prospects of import tariffs offer a strong pull for onshoring cobalt production, so long as other constraints are also tackled. Elsewhere, producers that tap into stable jurisdictions will be able to better cement their advantage.

2.1.3 Nickel

1. Main Uses, Historical Prices, and Production Levels

Nickel has long served as a cornerstone of industrial development, historically driven by its critical role in stainless steel production. In recent years, however, nickel's strategic importance has expanded, propelled by its indispensable properties — including high energy density and corrosion resistance — that make it essential for clean energy technologies. Today, nickel is a key component in battery cathodes for EVs, grid-scale energy storage systems, and other emerging applications critical to the global energy transition.

As of 2024, the global nickel market is valued at approximately USD 46.39 billion.[96] Nickel's importance is increasingly defined by its dual role: while continuing to support traditional industries such as construction and manufacturing through stainless steel production, it is rapidly becoming a critical material for the clean energy economy.

The United States remains heavily reliant on imports to meet its nickel needs. In 2024, the U.S. imported roughly USD 2.9 billion worth of nickel, equivalent to about 140 million tons. Canada leads U.S. import sources for primary nickel, accounting for 46% between 2020 and 2023, followed by Norway for 11%, Australia for 8%, and Brazil for 6%. For nickel-containing scrap, Canada again dominated at 41%, with Mexico following at 27%, the United Kingdom at 9%, and Russia trailing behind at 4%.[97]

Despite these established supply relationships, the U.S. remains significantly vulnerable to external supply shocks due to its limited domestic mining and refining capacity for Class I battery-grade nickel. This supply chain risk is amplified by increasing global competition for high-grade nickel driven by EV adoption and energy storage demand, underscoring the need for strategic investment in domestic production and recycling capabilities.

1.1 Use Case Application

Nickel's exceptional physical and mechanical properties have made it a critical material across a wide range of industries, supporting both traditional and emerging sectors. The "first use" of nickel refers to its initial conversion into intermediate products, which then undergo further processing to create final goods. Today, stainless steel production continues to dominate nickel's first-use demand, accounting for approximately 65% of total consumption. This is followed by batteries at 15%, a segment that has seen rapid growth driven by the rise of EVs and energy storage technologies. Nickel-based alloys represent 8% of usage, particularly in high-performance industries such as aerospace and chemical processing. Other applications include electroplating at 6%, used for corrosion resistance and aesthetic finishes, and special steels at 5%, enhancing mechanical properties in industrial machinery and construction.

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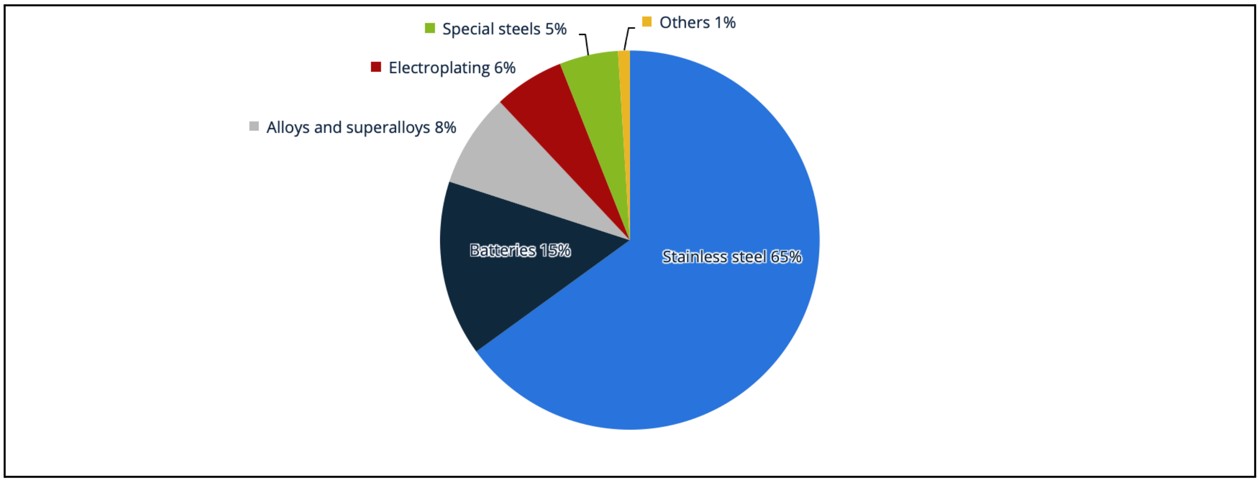
[96] Straits Research. (2025, February 18). *Nickel Market Size to Surpass USD 82.59 Billion by 2033.* GlobeNewswire; Straits Research. https://www.globenewswire.com/news-release/2025/02/18/3027931/0/en/Nickel-Market-Size-to-Surpass-USD-82-59-Billion-by-2033-Straits-Research.html

[97] Stewart, A. A. (2025, January). *Mineral Commodity Summaries 2025 Nickel.* U.S. Geological Survey. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nickel.pdf

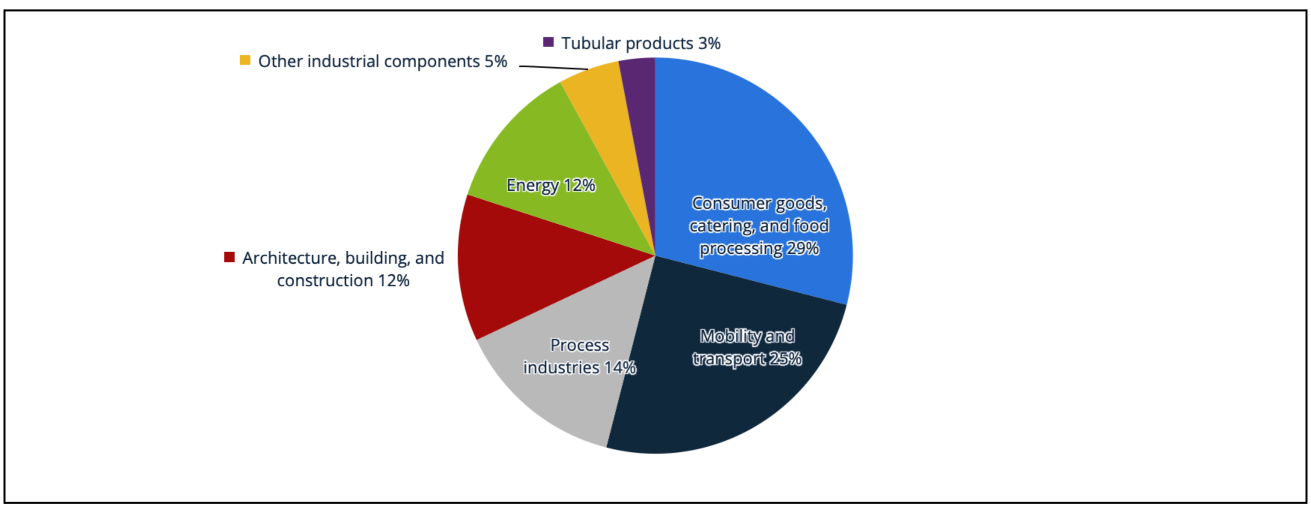
Figure 30. Nickel First Use Case



Source: Norilsk Nickel (2025)[98]

When viewed through the lens of end-use markets, consumer goods account for the largest share at 29%, spanning appliances, electronics, and household products. Transportation, including both traditional automotive sectors and the fast-growing EV segment, represents 25% of nickel consumption. Process industries, such as chemical production, food processing, and pharmaceuticals, contribute 14%, while construction uses about 12% of global nickel output, primarily for corrosion-resistant structures. The energy sector accounts for 12%, reflecting nickel's expanding role in battery energy storage, renewable energy infrastructure, and oil and gas applications. Other minor uses make up the remainder.

Figure 31. Nickel End Use Case



Source: Nickel Institute (2024)[99]

[98] Norilsk Nickel. (May 24, 2024). *Distribution of primary nickel consumption worldwide in 2023, by industry [Graph]*. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/545041/distribution-of-nickel-consumption-worldwide-by-industry/

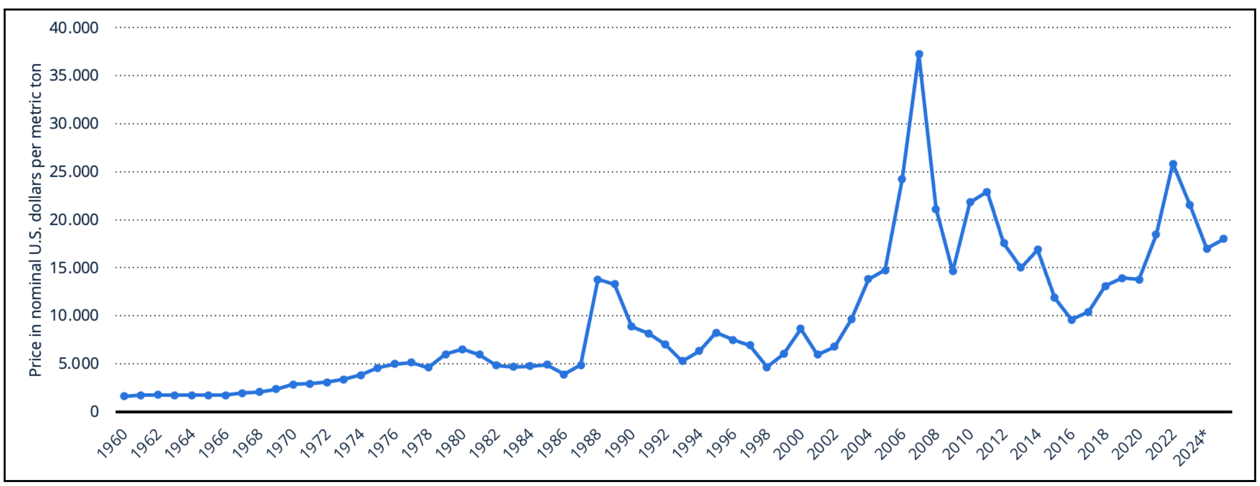
[99] Nickel Institute. (August 6, 2024). *Distribution of nickel end use worldwide in 2023, by type [Graph]*. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/571963/distribution-of-nickel-end-use-worldwide/

This evolving demand landscape highlights a fundamental shift: while nickel remains critical to conventional industries, clean energy and transportation applications are emerging as the dominant forces shaping its future. The accelerating adoption of EVs and the expansion of renewable energy systems are expected to significantly boost nickel consumption over the next decade, further solidifying its strategic position in the global materials economy.

1.2 Pricing Trends and Investment Dynamics

Nickel's price trajectory has historically been characterized by significant volatility, shaped by both broader industrial cycles and sector-specific supply disruptions. Prices peaked above USD 35,000 per metric ton in 2007, during a global commodities boom driven by surging Chinese demand and global supply constraints. This was followed by a sharp collapse to below USD 10,000 per ton during the 2008–2009 financial crisis, highlighting nickel's sensitivity to macroeconomic downturns. Throughout much of the 2010s, prices fluctuated within a range of USD 10,000 to USD 18,000 per ton, reflecting relatively balanced market fundamentals and moderate demand growth. In 2022, nickel prices surged again, peaking at approximately USD 31,275 per ton, triggered by supply disruptions related to the Russia-Ukraine conflict and a significant short squeeze event on the LME. As of early 2025, prices have corrected and stabilized at around USD 15,745 per ton, driven by expanded Indonesian supply and the emergence of temporary oversupply conditions.

Figure 32. Average Prices for Nickel Worldwide, 1960 - 2025



Source: World Bank (2024)[100]

Current market forecasts from World Bank Commodity Market Outlook project that nickel prices will stabilize within a range of USD 15,800 to USD 16,000 per ton (equivalent to USD 7.17–7.26 per pound) in 2025 and 2026, reflecting expanded Indonesian supply and temporary surplus conditions.[101][102] While this range is expected to support ongoing production, a higher price level between USD 18,000 and USD 22,000 per ton (approximately USD 8.15–10 per pound) is generally considered necessary to incentivize new investment in battery-grade Class I nickel production, particularly for capital-intensive projects such as HPAL facilities. Maintaining sustainable pricing is

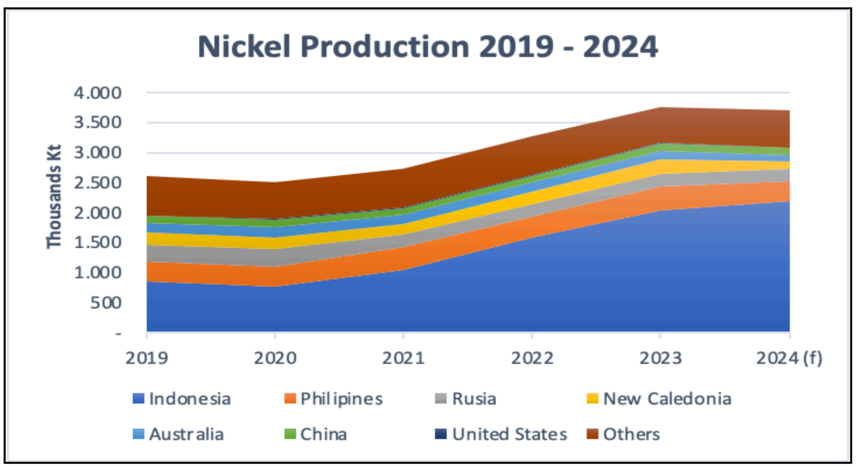
[100] O'Neill, A. (2024, November 19). *Average prices for nickel worldwide from 1960 to 2025.* Statista. https://www.statista.com/statistics/675880/average-prices-nickel-worldwide/
[101] L, J. (2025, March 28). *Nickel's Wild Ride: What's Driving Prices and Future Demand?* Carbon Credits. https://carboncredits.com/nickel-wild-ride-what-driving-prices-and-future-demand/
[102] World Bank. (2025, April). *Commodity Market Outlook 2025*. World Bank. https://openknowledge.worldbank.org/server/api/core/bitstreams/fbc3b73a-916d-4309-ab09-6324b3feef0f/content

critical for ensuring sufficient project economics while avoiding unsustainable overcapacity expansions that could destabilize the market.

1.3 Production History and Reserve Landscape

Global nickel mine production has experienced significant growth, reaching approximately 3.7 million metric tons in 2024. This expansion has been largely driven by Indonesia, which now produces around 2.2 million metric tons, accounting for over 50% of global output. As shown in Figure 33 Nickel Primary Production, Indonesian production has surged over the past five years, reshaping the traditional structure of global nickel supply. Other major producers include the Philippines with approximately 330,000 metric tons (~12% share), Russia with 240,000 metric tons (~7%), New Caledonia with 190,000 metric tons (~6%), and Australia with 160,000 metric tons (~5%). The remaining production is distributed among China, the United States, and other countries. This concentration of supply increases market exposure to geopolitical, regulatory, and operational risks, particularly as demand for battery-grade nickel intensifies.

Figure 33. Nickel Primary Production, 2019 - 2024

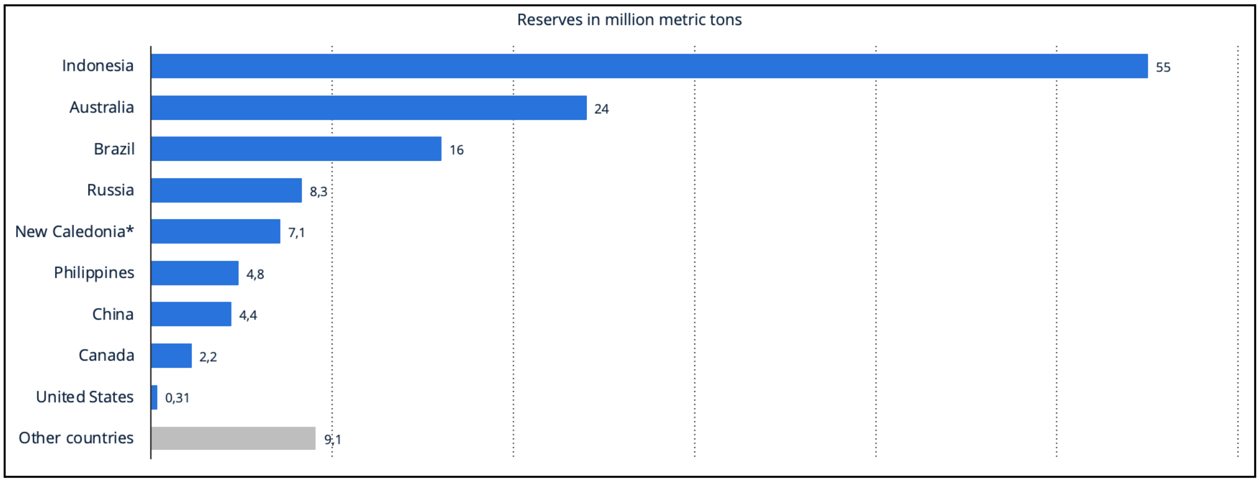


Source: USGS (2025)[103]

In terms of reserves, Indonesia also holds the dominant position globally. As illustrated in Figure 34 Nickel Reserve by Country, Indonesia controls approximately 55 million metric tons, representing around 39% of total known reserves worldwide. Australia follows with 24 million metric tons (~17% share), Russia with 8.3 million metric tons (~6%), New Caledonia with 7.1 million metric tons (~5%), and the Philippines with 4.8 million metric tons (~3%). Other countries collectively hold about 30.8 million metric tons (~22%). This reserve distribution highlights Indonesia's critical role not only in current production but also in shaping the long-term supply outlook. The heavy concentration of both reserves and production in a single geography raises strategic considerations for supply chain diversification, investment in alternative sources, and recycling initiatives.

[103] Stewart, A. A. (2025, January). *Mineral Commodity Summaries 2025 Nickel.* U.S. Geological Survey. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nickel.pdf

Figure 34. Nickel Reserves by Country, 2024



Source: USGS (2025)

2. Value Chain Breakdown and Concentrated Players

The global nickel value chain is highly concentrated, with Indonesia and China playing dominant roles across upstream mining and midstream processing activities. In the upstream segment, Indonesia now accounts for over 50% of global nickel mine production, followed by the Philippines, Russia, and New Caledonia. Upstream production is divided into two main types: Class I nickel, which is battery-grade material essential for EVs, and Class II nickel, primarily used for stainless steel applications such as ferronickel and nickel pig iron (NPI). Major upstream players include Vale, Tsingshan, Norilsk Nickel, and BHP.

In Indonesia, the upstream nickel sector is led by a combination of private firms and joint-venture companies, notably Tsingshan Holding Group (China), Vale Indonesia (partially owned by Indonesia's state-owned mining holding, MIND ID),[104][105] and domestic conglomerates such as Harita Group.[106] Foreign players typically operate under mandatory divestment requirements and pay royalties to the Indonesian government, with MIND ID increasingly acquiring strategic ownership stakes in major projects, consistent with Indonesia's national policy to strengthen domestic control over critical minerals such as nickel — a policy formalized as of April 26, 2025 to increase the percentage for royalty amidst current pressing nickel price.[107] Supply stability faces growing risks, driven by rising resource nationalism and the tightening of ESG standards. In particular, evolving profit repatriation rules introduce financial risks for multinational companies operating in Indonesia:

- **Double Taxation Risk**: After paying corporate income taxes, royalties, and export duties, companies repatriating profits are subject to an additional 20% withholding tax (PPh 26), unless reduced through applicable tax treaties. This situation has raised concerns over an effective double taxation burden.

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[104] MIND ID. https://mind.id/en

[105] VOI. (2025, April 22). *MIND ID Has An Investment Project Of 14.3 Billion US Dollars To Be Offered To Danantara.* VOI - Waktunya Merevolusi Pemberitaan. https://voi.id/en/economy/477321

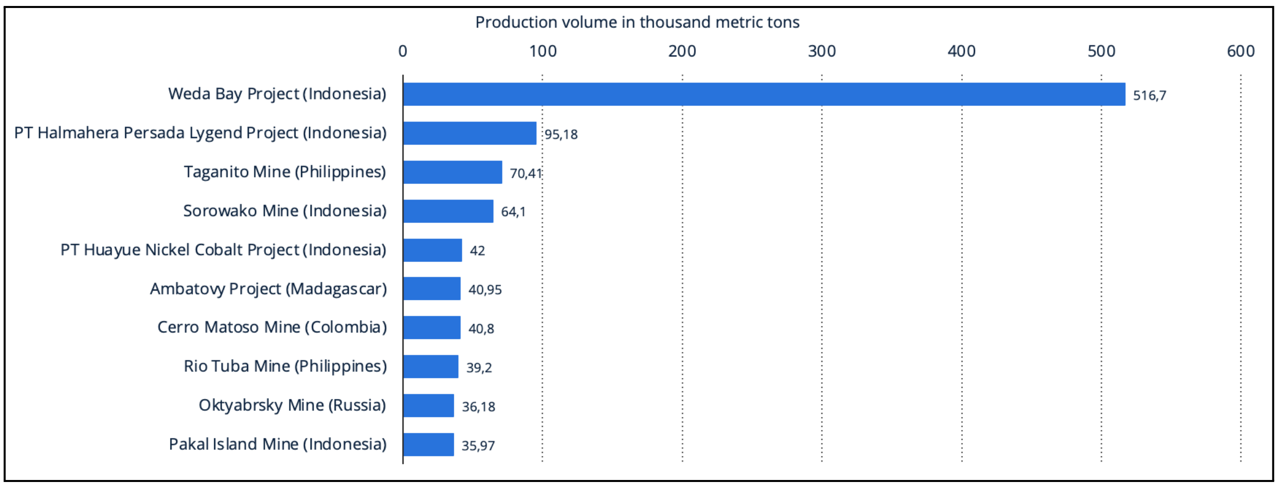
[106] Harita Nickel. *Overview of Harita Nickel.* Harita Nickel. https://careers.haritanickel.com/public/assets/Company%20Profile%20Harita%20Nickel.pdf

[107] Muliawati, F. D. (2025, April 16). *Tarif Royalti Nikel Cs Resmi Naik, Ini Reaksi Pengusaha.* CNBC Indonesia. https://www.cnbcindonesia.com/news/20250416180239-4-626578/tarif-royalti-nikel-cs-resmi-naik-ini-reaksi-pengusaha

- **Profit Repatriation Restrictions**: Under regulations introduced following the 2021 Omnibus Law, companies must reinvest dividends domestically to qualify for tax relief; otherwise, the full withholding tax rate applies, limiting flexibility for overseas capital returns.

These regulatory developments increase financial uncertainty and could influence Indonesia's long-term investment attractiveness. Nonetheless, Indonesia's tax treaties with both the United States and China offer similar benefits, with withholding taxes on dividends reduced to 10% for shareholders holding at least 25% ownership (15% otherwise), and 10% for interest and royalties. While both U.S. and Chinese investors benefit from these terms, Chinese companies have expanded more rapidly in Indonesia's mining and industrial sectors, supported by downstreaming policies promoting local value addition, access to special economic zones, and broader bilateral cooperation frameworks such as the Belt and Road Initiative. Meanwhile, U.S. investors often adopt alternative structuring strategies, including routing investments through regional hubs like Singapore, to optimize tax and operational efficiencies within Indonesia's regulatory landscape.

Figure 35. Leading Nickel Mines Worldwide by Production Volume, 2023



Source: Mining Technology (2024)[108]

In the midstream segment, Indonesia and China lead global nickel processing and refining, accounting for over 75% of total refining capacity.[109] China's dominance is particularly strong in refining Class II products (NPI) and in HPAL facilities required for Class I nickel production. Industrial collaborations between Indonesia and China have enabled the development of large-scale low-cost nickel industrial parks, boosting production efficiency. However, refining capacity for Class I battery-grade nickel remains constrained, creating a structural bottleneck that could limit supply growth for EV battery materials. Key midstream players include Tsingshan, Jinchuan, Huayou Cobalt, and Sumitomo.

In the downstream segment, demand is increasingly driven by the battery manufacturing industry. Class I nickel is essential for producing nickel-rich cathode materials used in EV batteries, while Class II nickel continues to serve the stainless steel sector. Battery-related demand is projected to

[108] Mining Technology. (June 18, 2024). *Leading nickel mines worldwide in 2023, by production volume (in 1,000 metric tons) [Graph]*. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/1356185/worldwide-largest-nickel-mines-by-production-volume/

[109] Reuters. (2025, February 5). *Chinese firms control around 75% of Indonesian nickel capacity, report finds.* Reuters. https://www.reuters.com/markets/commodities/chinese-firms-control-around-75-indonesian-nickel-capacity-report-finds-2025-02-05/

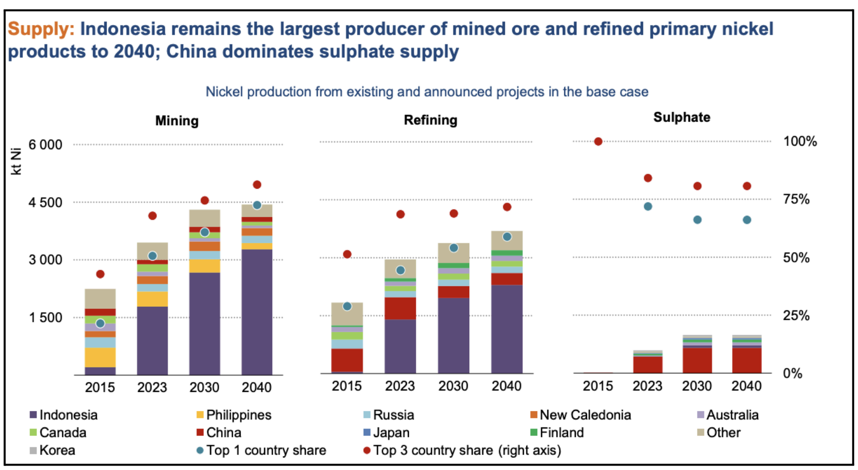
account for approximately 60% of Class I nickel usage by 2040 under net-zero aligned scenarios. Major consumers include leading battery manufacturers and EV makers such as CATL, Tesla, LG Chem, and SK Innovation.

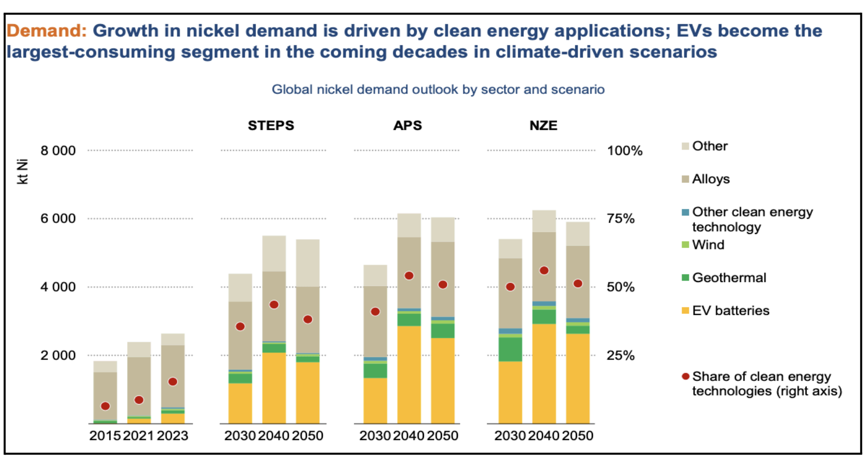
The current market structure highlights several critical dynamics. The nickel supply chain remains highly concentrated in both mining and refining stages, exposing it to geopolitical and ESG compliance risks. Long-term demand for high-purity Class I nickel is expected to outpace supply growth, despite a temporary surplus in Class II products. The persistent lack of ESG-compliant nickel supply and refining capacity further compounds structural constraints. Although recycling initiatives are expanding, recycled nickel remains a limited portion of overall supply, suggesting that primary production will continue to dominate the market in the medium term.

3. Demand and Production Outlook; Recent Developments

Global nickel demand is forecast to grow steadily through 2040 and beyond, fueled primarily by surging requirements from the EV and energy storage sectors. According to the IEA, demand for battery-grade nickel could increase more than sixfold by 2040, underscoring nickel's critical role in global decarbonization pathways. Stainless steel applications, meanwhile, are expected to maintain a stable baseline of demand growth, particularly in emerging economies such as India and Southeast Asia, offering additional support to long-term market fundamentals.

Figure 36. Supply and Demand Projections of Nickel





Source: IEA (2024)[110]

[110] International Energy Agency (2024, May). *Global Critical Minerals Outlook 2024*. IEA.

On the supply side, structural challenges persist. Indonesia's expanding dominance raises concerns regarding ESG performance, particularly due to high carbon emissions from coal-powered smelting operations and regulatory uncertainties surrounding local content and export policies. HPAL projects, aimed at producing battery-grade Class I nickel, continue to face delays, high capital costs, and technical hurdles, further constraining medium term future supply growth.

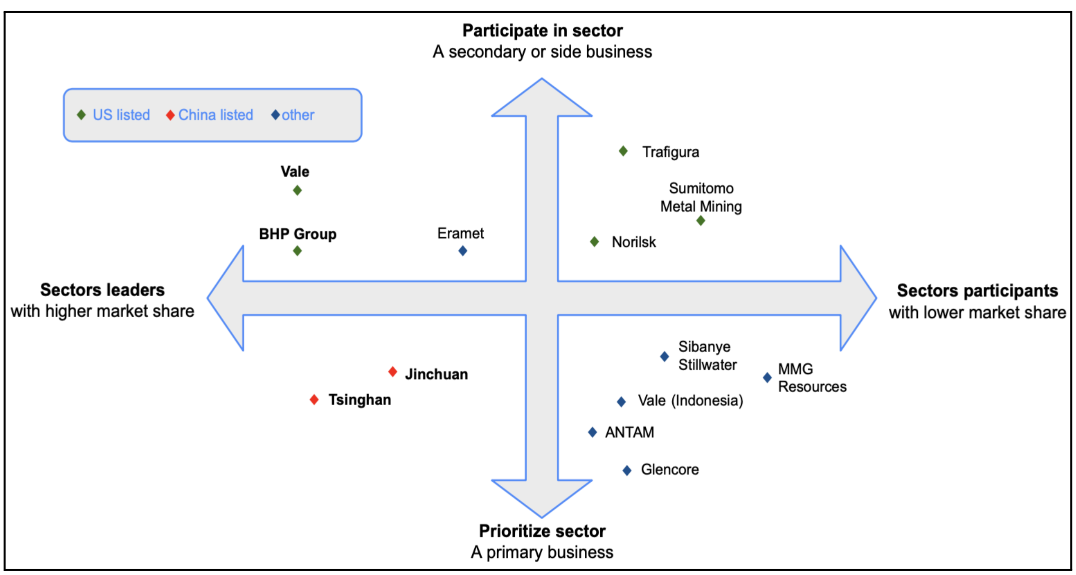
Policy responses in key consumer markets are reshaping investment dynamics. In the United States, the IRA offers incentives such as Section 45X Advanced Manufacturing Production Credits, providing a 10% tax credit for domestically processed Class I nickel used in battery components. Additionally, EV tax credit eligibility rules embedded in the IRA emphasize supply chain localization, heightening the importance of secure and ESG-compliant nickel supply sources. However, despite these policy measures, U.S. domestic nickel production capacity remains limited, and timelines for expansion are long, ensuring that heavy reliance on imports will continue in the near to medium term. This exposes U.S. supply chains to geopolitical risks and underscores the strategic need for diversification away from concentrated suppliers.

Furthermore, while recycling contributes approximately 30% of global nickel supply, only a small fraction - around 1% - meets battery-grade quality standards. This highlights a major constraint in scaling secondary supply to meet the demands of the clean energy transition, reinforcing the need for investment across both primary and secondary nickel supply chains.

4. Key Players and Sorting Matrix

Tsingshan Holding Group, a Chinese conglomerate with major operations in Indonesia, is the world's largest nickel producer, historically focused on low-cost NPI production. However, Tsingshan is also expanding its investments into battery-grade nickel projects to tap into future growth areas.

Figure 37. Matrix of Key Nickel Mining and Refining Players Globally



Source: Capstone Analysis

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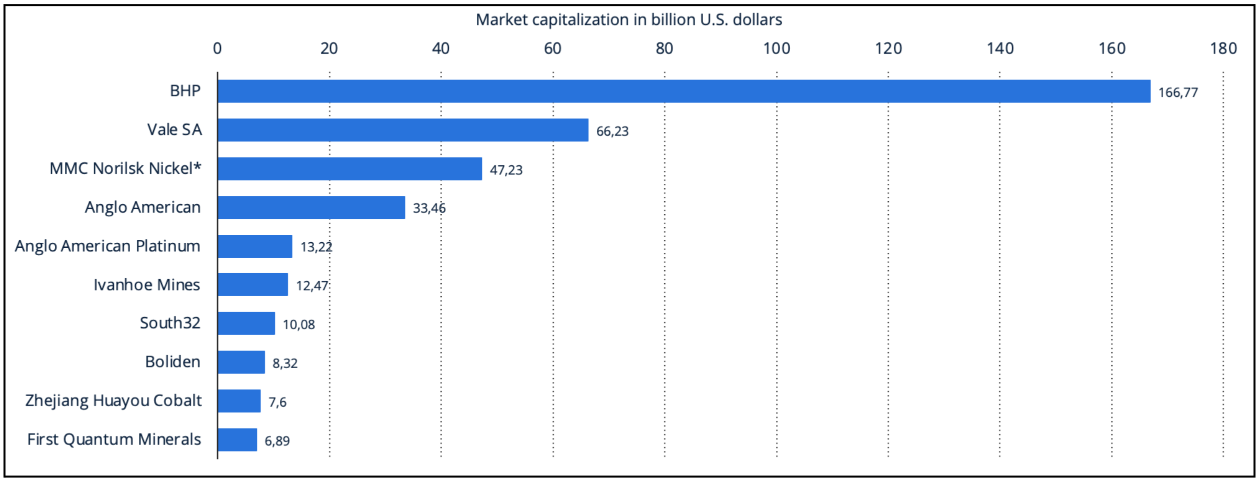
https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeeac9de99a/GlobalCriticalMineralsOutlook2024.pdf

Figure 38. Leading Nickel Mining Companies Worldwide Based on Market Capitalization (in billion U.S. dollars), January 2024



Source: Value Today (2024)[111]

Beyond these major players, other companies such as First Quantum Minerals (Canada), Eramet (France), and Sumitomo Metal Mining (Japan) are actively pursuing strategies to scale their battery-grade nickel production. These companies aim to integrate more deeply into the battery and EV supply chains through downstream investments and strategic partnerships.

In an increasingly competitive market, the companies best positioned for long-term success share several key characteristics: a high proportion of exposure to Class I nickel production, vertical integration across mining, refining, and manufacturing partnerships, and robust ESG credentials that align with tightening regulatory standards and investor expectations. As battery demand continues to reshape the global nickel market, control over ESG-compliant, high-purity nickel supply chains will become a critical determinant of competitive advantage.

The global nickel market remains relatively fragmented, with several major mining and metals companies holding diversified exposure across a range of commodities. However, a select group of players is increasingly positioning themselves to dominate the high-purity, battery-grade Class I nickel segment, which is critical to meeting accelerating demand from EV and energy storage sectors.

Vale S.A. of Brazil stands out as a leading global supplier of Class I nickel, operating major assets in Canada (notably the Voisey's Bay mine) and Indonesia. The company has made strategic investments to expand its battery-grade nickel production capabilities, aligning with the surge in EV demand. Similarly, BHP Group of Australia operates the Nickel West project in Western Australia, a fully integrated operation supplying high-purity nickel products directly to battery manufacturers, supported by a focus on sustainable and traceable production practices. Glencore, headquartered in Switzerland, maintains significant nickel operations through its Integrated Nickel Operations (INO) in Canada and other regions, and is increasingly emphasizing ESG-compliant nickel production to meet growing regulatory and investor scrutiny.

[111] Value.Today. (January 5, 2024). *Leading nickel mining companies worldwide in January 2024, based on market capitalization (in billion U.S. dollars) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/1350719/worldwide-largest-nickel-miners-by-market-cap/

2.1.4 Aluminum

1. Main Uses, Historical Prices, and Production Levels

Aluminum has long been recognized as a foundational material in global industrial development, valued for its unique combination of strength, light weight, corrosion resistance, and conductivity. Traditionally essential to the transportation, construction, and consumer goods sectors, aluminum's role is expanding rapidly as a critical material in the global energy transition notwithstanding that a. aluminum production is a significant source of carbon emissions. The production process, particularly smelting, is energy-intensive and reliant on electricity, leading to high emissions in grids reliant on fossil fuels. Its climate-linked applications now extend across EVs, renewable energy infrastructure, energy storage systems, and modern power grids.

As of 2024, the global aluminum market is valued at approximately USD 178.84 billion.[112] Aluminum's growing importance is increasingly defined by its dual role: while continuing to support traditional industrial bases such as construction and manufacturing, it is now pivotal to enabling decarbonization across transportation and power sectors.

In the United States, aluminum supply chains remain highly import-dependent: approximately 4.26 million tons of aluminum were imported in 2024, valued at around USD 18.6 billion, with Canada supplying 56% of total U.S. imports. While recycling provides an important source of domestic aluminum (approximately 80% of U.S. aluminum production is from recycled material), the country remains vulnerable to disruptions in primary aluminum supply and global market volatility.[113][114]

1.1 Use Case Application

As a critical enabler of energy transition and infrastructure modernization, aluminum serves a broad range of end-use sectors. Transportation, including electric vehicles, accounts for approximately 35% of total consumption, followed by construction and infrastructure at 28%, consumer goods at 20%, electrical applications such as power grids and wiring at 10%, and other applications at 7%. Growing demand increasingly favors aluminum's role in decarbonization strategies, leveraging its lightweight properties to enhance vehicle fuel efficiency and its conductivity and durability to support renewable energy deployment and grid expansion. Positioned at the intersection of industrial resilience and sustainability, aluminum produced from greener electricity sources is expected to be foundational to the global shift toward a low-carbon economy.

1.2 Pricing Trends and Investment Dynamics

Aluminum's price trajectory has historically been characterized by cyclical fluctuations, shaped by broader industrial demand cycles, energy costs, and supply chain disruptions. Prices peaked near USD 3,200 per metric ton in 2008, driven by a global commodities boom fueled by rapid Chinese industrialization. This was followed by a steep decline to around USD 1,200 per ton during the 2008–2009 financial crisis, underscoring aluminum's sensitivity to macroeconomic downturns. Throughout the 2010s, prices largely fluctuated within a range of USD 1,600 to USD 2,400 per ton,

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[112] Statista. (May 25, 2021). *Size of the global aluminum market between 2020 and 2027 (in billion U.S. dollars) [Graph]*. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/1113683/global-aluminum-market-size/

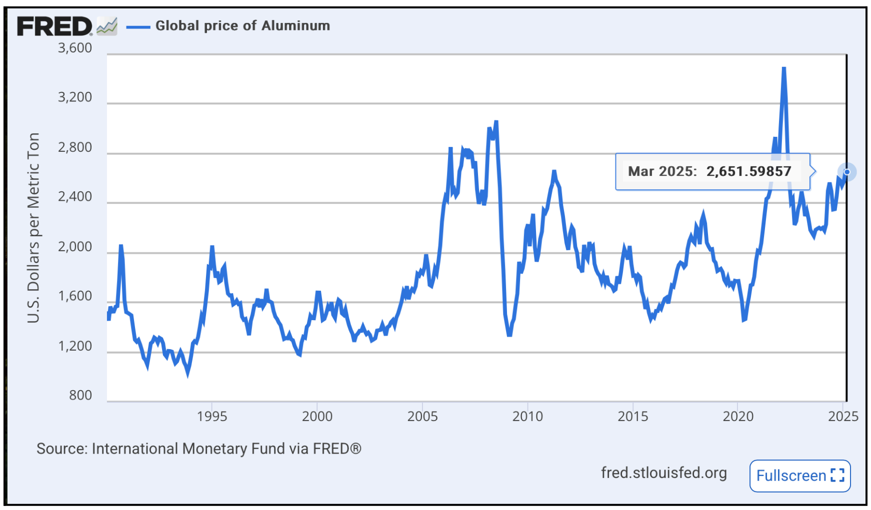
[113] Merrill, A. M. (2025, January). *Mineral Commodity Summaries 2025 Aluminum.* U.S. Geological Survey. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-aluminum.pdf

[114] The Aluminum Association. *Infinitely Recyclable.* The Aluminum Association. https://www.aluminum.org/Recycling

reflecting relatively balanced supply-demand dynamics and improving energy efficiency in production.

In 2022, aluminum prices surged again, reaching a peak above USD 3,400 per ton, driven by the European energy crisis, COVID-linked supply constraints, EV boom, and infrastructure stimulus demand. As of early 2025, prices have moderated and stabilized at approximately USD 2,650 per ton, supported by steady demand growth in energy transition sectors (such as electric vehicles and renewables infrastructure) and constrained supply from major producers. In China, which accounts for more than half of global primary aluminum production, the government has implemented a cap of approximately 45 million tons of annual capacity. This cap reflects strategic considerations: Chinese authorities determined that aggressive capacity expansion offers diminishing economic returns relative to the substantial environmental costs, particularly given aluminum's high energy intensity and carbon emissions profile.[115]

Figure 39. Global Aluminum Price, 1990 - 2025



Source: International Monetary Fund via FRED (2025)

Current market forecasts from World Bank Commodity Market Outlook project that aluminum prices will remain within the range of USD 2,100 to USD 2,175 per ton (equivalent to $0.95–0.99/lb) in 2025 and 2026.[116] This pricing band is generally sufficient to sustain ongoing production and recycling investments. However, a higher, sustained price closer to USD 2,800–3,000 per ton would be necessary to incentivize significant new low-carbon primary aluminum projects, especially outside China where energy costs and ESG pressures are higher. Maintaining balanced pricing is critical to support the transition toward greener production in those locations where major electricity volumes can be generated from nuclear, hydro and renewables, without triggering oversupply risks that could destabilize the market.

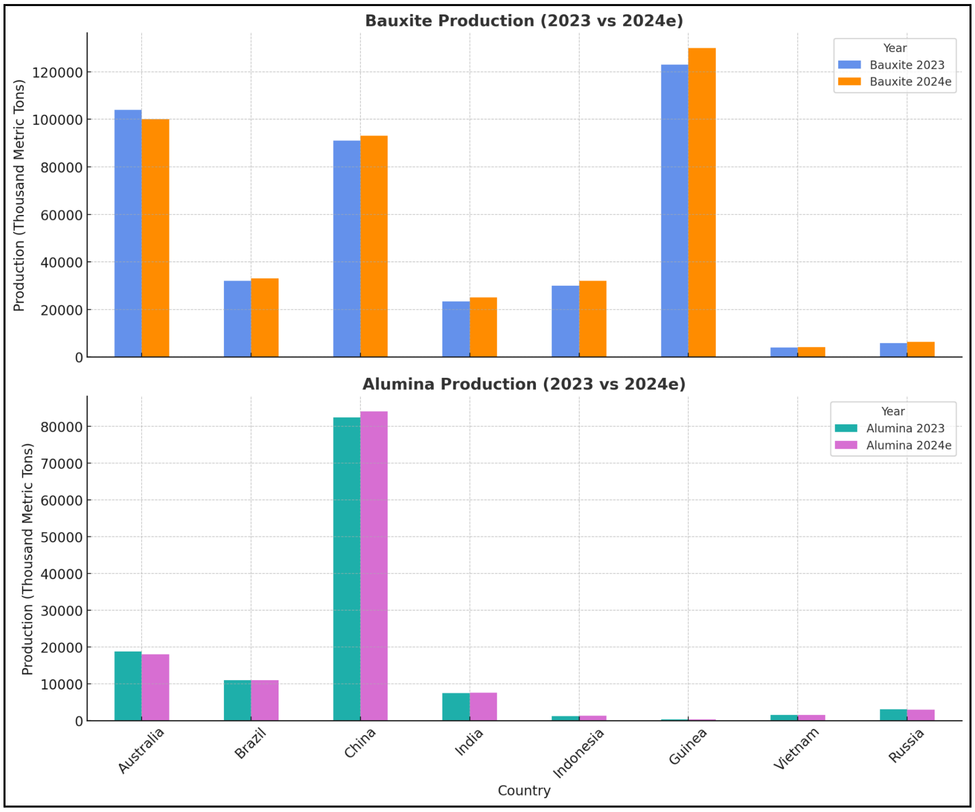
[115] Offshore Engineer Energy News. (2025, April 24). *What next as China approaches peak aluminum production? Andy Home*. Energy News. https://energynews.oedigital.com/mining/2025/04/24/what-next-as-china-approaches-peak-aluminum-production-andy-home

[116] World Bank. (2025, April). *Commodity Market Outlook 2025*. World Bank. https://openknowledge.worldbank.org/server/api/core/bitstreams/fbc3b73a-916d-4309-ab09-6324b3feef0f/content

2. Value Chain Breakdown and Concentrated Players

Bauxite serves as the primary ore for aluminum production. Through the refining process, bauxite is converted into alumina (aluminum oxide), which is then further processed into primary aluminum via electrolysis. As such, the security and availability of bauxite reserves are critical to sustaining the global aluminum supply chain, making bauxite and alumina production key strategic indicators for market stability and investment planning.

Figure 40. Bauxite and Alumina Production by Country, 2023 and 2024 Estimate

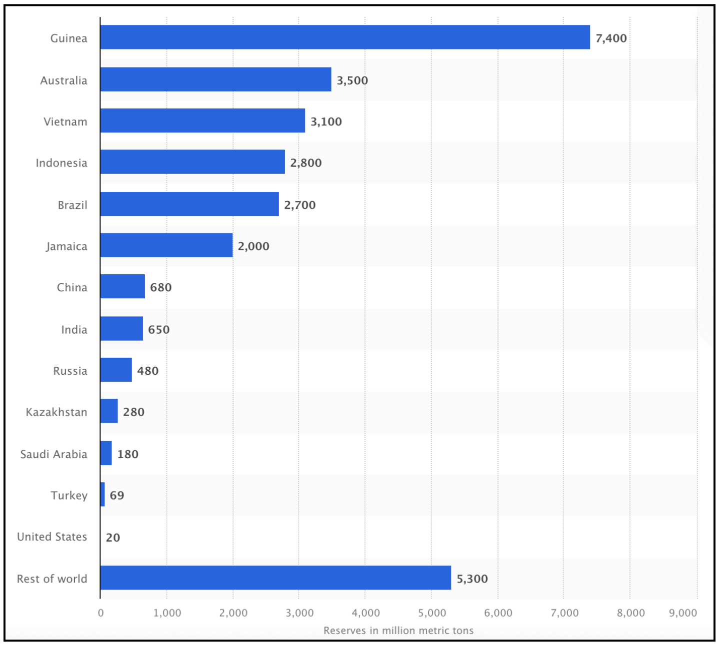


Source: USGS (2025),[117] Capstone Analysis

…/…

[117] Merrill, A. M. (2025, January). *Mineral Commodity Summaries 2025 Aluminum.* U.S. Geological Survey. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-aluminum.pdf

Figure 41. Bauxite Reserve Estimate by Country (Million Metric Tons), 2024



Source: USGS (2025)[118]

Global bauxite production in 2024 is projected to reach approximately 417 million metric tons, with output highly concentrated among a few key producers. Guinea leads with an estimated 122 million metric tons, accounting for around 29% of global supply, followed by Australia at 102 million metric tons (24%) and Indonesia at 90 million metric tons (21%). Other notable producers include Brazil (8%), India (6%), Vietnam (2%), and Russia (1%), with the remainder distributed across smaller producers.

On the refining side, global alumina production in 2024 is forecasted at approximately 155 million metric tons. China remains the dominant force, producing roughly 84 million metric tons and representing 54% of global output. Australia follows with 12% market share, Brazil with 8%, and India with 5%. Smaller contributions come from Russia, Vietnam, Guinea, and Indonesia, each accounting for between 1% and 4% of global alumina production.

This production concentration underscores China's outsized influence over the midstream aluminum value chain and reinforces the strategic importance of diversified sourcing strategies. Political instability in bauxite-rich Guinea, environmental vulnerabilities in hydro-powered refining hubs, and rising trade tensions introduce material risks to aluminum supply chains. At the same time, these dynamics create investment opportunities in secondary aluminum production, geographic diversification of refining capacity, and sustainable supply chain initiatives.

The aluminum supply chain is globally integrated but structurally imbalanced, characterized by fragmentation in the upstream segment and high concentration in the midstream. Understanding these dynamics is critical for assessing supply risks, investment opportunities, and structural challenges across the value chain.

[118] Ibid.

Upstream (Mining & Extraction)

Primary aluminum production begins with the extraction of bauxite ore, predominantly sourced from a few key countries — Australia, China, Guinea, and Brazil. Although global bauxite reserves are relatively abundant, production remains geographically skewed, exposing the sector to moderate supply risks arising from political instability, export restrictions, or trade disputes. Leading companies operating in the upstream segment include Rio Tinto, Alcoa, Rusal, and South32, all of which hold significant positions in bauxite mining and raw material sourcing.

Midstream (Processing & Refining)

The midstream segment involves the conversion of bauxite into alumina and subsequently into primary aluminum through energy-intensive smelting processes. China dominates this phase, accounting for more than 60% of global aluminum smelting capacity. The sector is highly sensitive to electricity costs, with smelters relying on hydroelectric power (notably in Canada, Norway, and parts of South America) enjoying notable cost advantages. However, climate-related risks, such as water scarcity impacting hydropower generation, are emerging as significant vulnerabilities for midstream operations globally.

Downstream (Fabrication & End Use)

The downstream segment involves the transformation of primary aluminum into fabricated products — including sheets, extrusions, and castings — that are essential for key industries such as automotive, aerospace, packaging, construction, and electrical infrastructure. Major players in the downstream market include Novelis, Constellium, and Arconic. Unlike the midstream, the downstream aluminum market remains more regionally diversified, with major consumption centers across North America, Europe, and Asia.

Market Structure and Supply Risks

The aluminum industry's structure — fragmented upstream and concentrated midstream — creates unique vulnerabilities. China's dominance in smelting amplifies exposure to geopolitical and trade risks, while upstream supply remains sensitive to country-specific political and environmental factors. Additionally, growing pressure to decarbonize aluminum production is reshaping industry dynamics, with renewable energy adoption increasingly influencing smelting competitiveness. Trade exposure remains high, with tariffs, quotas, and carbon border adjustment mechanisms (CBAM) poised to significantly impact global aluminum flows. While efforts to diversify smelting capacity outside China, particularly in the Middle East and North America, are progressing, these initiatives face headwinds related to capital intensity, permitting timelines, and access to low-carbon energy sources.

…/…

3. Demand and Production Outlook; Recent Developments

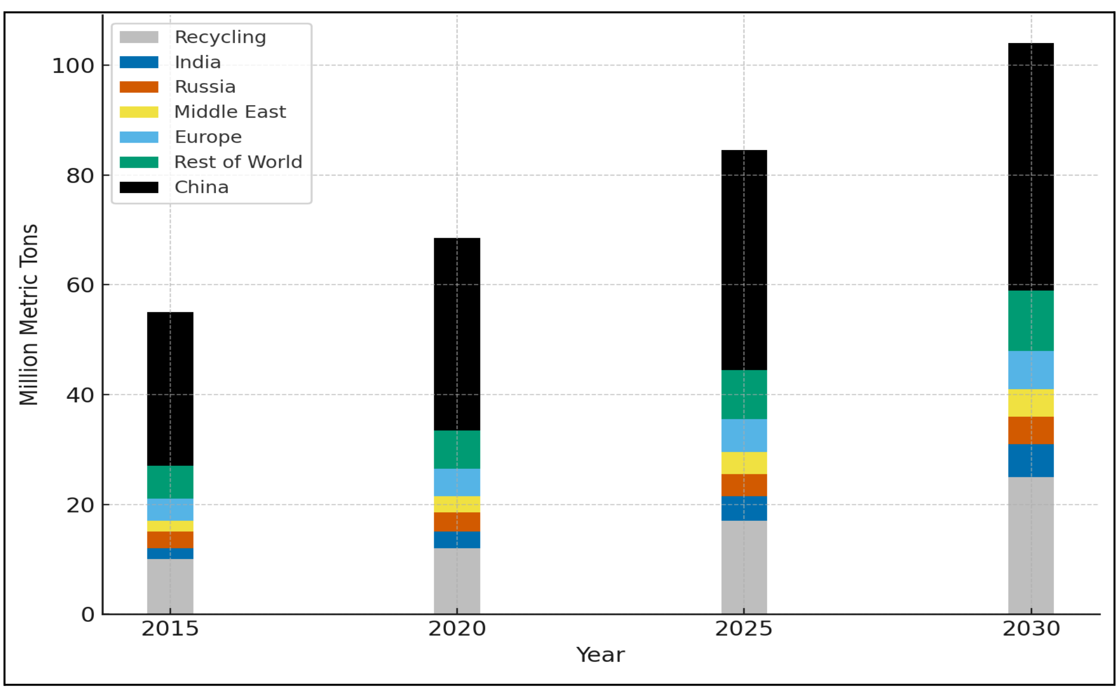
Aluminum is positioned for multi-decade growth, anchored by two enduring structural trends: the electrification of transportation and the global shift toward low-carbon infrastructure. These demand drivers—underpinned by regulatory momentum, decarbonization mandates, and clean energy deployment—are reshaping aluminum's strategic importance across industries. However, cautious optimism is warranted as geopolitical risks, environmental pressures, and trade barriers continue to influence the supply-demand balance.

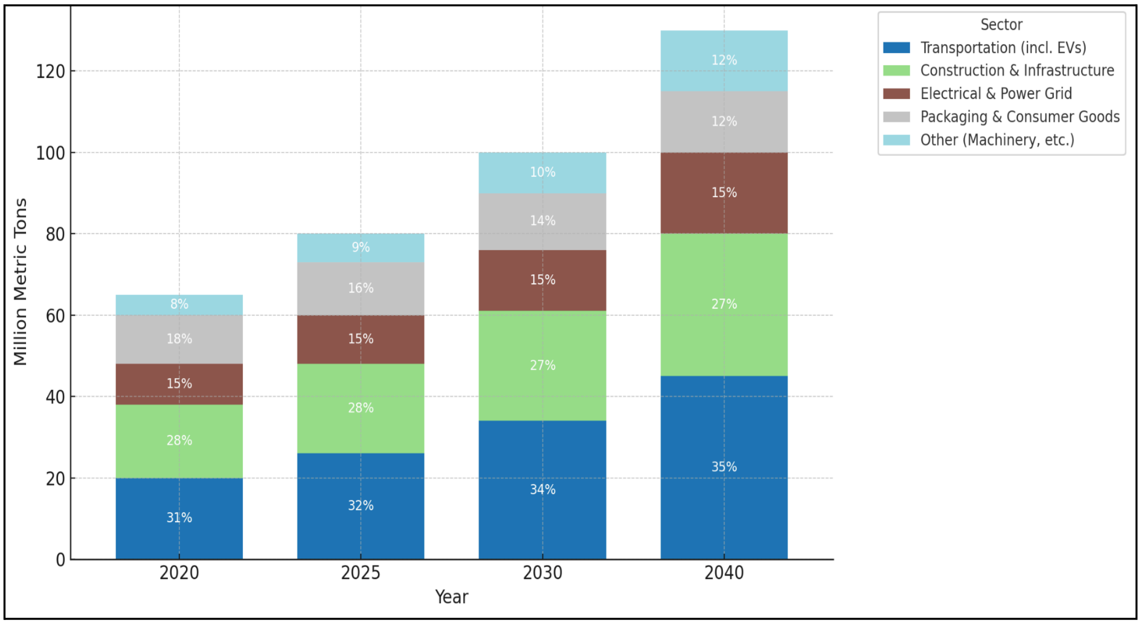
In transportation, aluminum's lightweight and high-strength characteristics are critical to improving energy efficiency and extending EV battery range. As automakers accelerate electrification, aluminum demand in the sector is projected to expand significantly, with its share of total consumption reaching approximately 36% by 2040, as shown in Figure 42. Applications such as EV frames and battery enclosure will continue to serve as key growth pillars in the decarbonization of mobility.

Parallel growth is unfolding in the infrastructure and energy sectors. The rollout of solar, wind, and grid modernization projects is intensifying demand for durable, conductive materials. Aluminum's structural performance and conductivity make it indispensable for transmission lines, renewable energy components, and large-scale construction. These segments are expected to remain stable and resilient sources of demand through 2040, reinforcing aluminum's long-term role in enabling the global energy transition.

Total aluminum consumption is forecast to exceed 120 million metric tons annually by 2040—nearly doubling from 2020 levels—underscoring the material's critical positioning in clean energy value chains and its long-term investment appeal.

Figure 42. Aluminum Supply and Demand Forecast





Source: World Economic Forum (2023),[119] IEA (2024),[120][121] Capstone Analysis

Supply Dynamics: Opportunities and Risks

While the demand outlook is highly favorable, aluminum supply growth faces key structural challenges and emerging opportunities:

- **Production Caps in China:** China, which dominates global primary aluminum production, continues to limit new smelting capacity to 45 Million Ton to mitigate environmental and energy consumption concerns. These production caps, while constraining near-term supply growth, support a healthier long-term pricing environment.[122]
- **Trade Policy Shifts:** Expansion Revival and increase of the Section 232 tariffs in the United States in 2025 — raising duties to 25% and removing key exemptions — has intensified efforts to secure domestic supply chains, favoring North American producers.[123] As noted already, the US imports most of the aluminum it uses with Canada providing about half of the these aluminum imports. In April Canada responded to tariffs on aluminum and other of its exports to the US with tariffs of its own on selected US products.
- **Industrial Policy Support:** The DOE's $6 billion commitment to industrial decarbonization includes initiatives to revitalize domestic primary aluminum production for the first time in

[119] Aleksić, J., & Vargas, D. B. (2023, November 28). *Aluminium demand will rise 40% by 2030. Here's how to make it sustainable.* World Economic Forum. https://www.weforum.org/stories/2023/11/aluminium-demand-how-to-make-it-sustainable/
[120] International Energy Agency. (2024, May). *Global Critical Minerals Outlook 2024: Outlook for key minerals.* IEA. https://www.iea.org/reports/global-critical-minerals-outlook-2024/outlook-for-key-minerals
[121] International Energy Agency (2024, May). *Global Critical Minerals Outlook 2024.* IEA. https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeeac9de99a/GlobalCriticalMineralsOutlook2024.pdf
[122] Home, A. (2025b, April 25). *As China nears peak aluminium production, what next?* Reuters. https://www.reuters.com/markets/commodities/china-nears-peak-aluminium-production-what-next-andy-home-2025-04-24/
[123] The White House. (2025, February 11). *Fact Sheet: President Donald J. Trump Restores Section 232 Tariffs.* The White House. https://www.whitehouse.gov/fact-sheets/2025/02/fact-sheet-president-donald-j-trump-restores-section-232-tariffs/

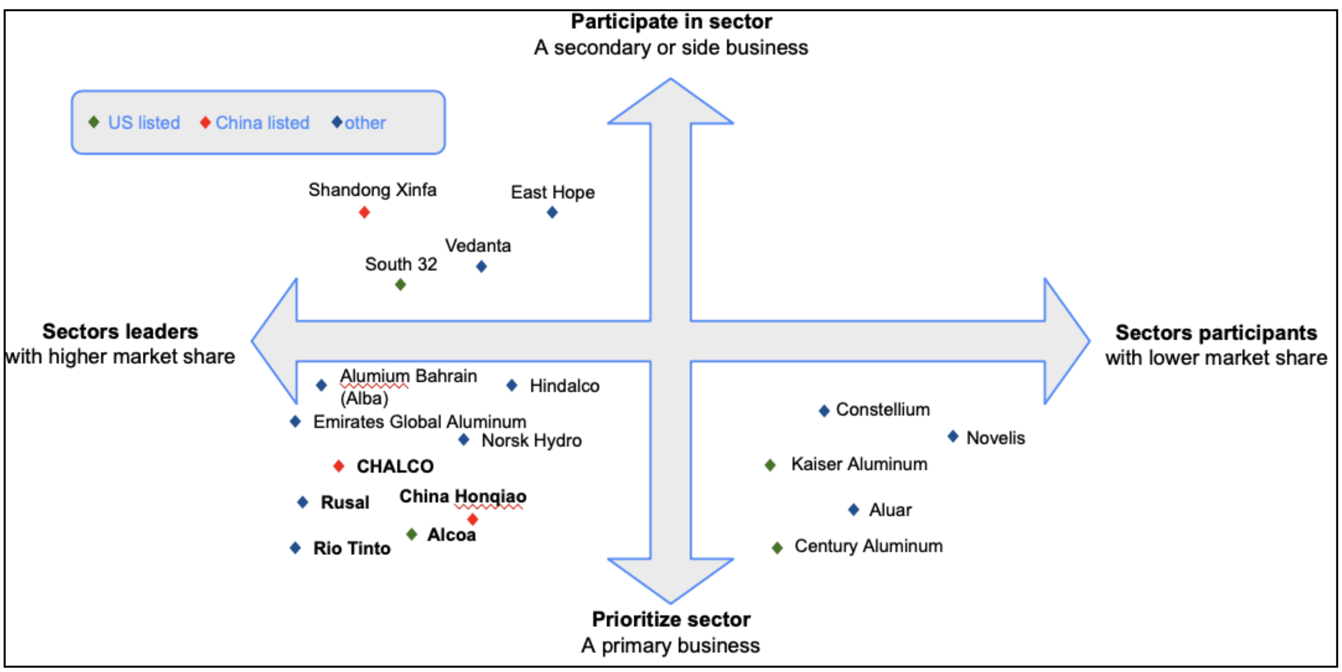
over four decades. Companies like Century Aluminum are strategically positioned to capitalize on this reshoring momentum.[124]

- **Section 45X Production Tax Credit (IRA Incentive):** Aluminum purified to 99.9% or processed to at least 99% purity now qualifies as an eligible critical mineral for the 10% Advanced Manufacturing Production Tax Credit (45X).[125] This incentive is particularly impactful for aluminum substantially transformed into solar manufacturing components, such as frames and mounting systems, strengthening demand for high-purity aluminum and supporting further downstream investment.
- **Industry Consolidation:** M&A activity is increasing as major players move to secure upstream resources and strengthen integration. Alcoa's $2.2 billion acquisition of Alumina Ltd. in 2025 underscores the strategic premium being placed on securing bauxite and alumina supply in a tightening global market.

4. Key Players and Sorting Matrix

The aluminum industry is shaped by a combination of state-owned enterprises, diversified mining conglomerates, and publicly listed multinationals, each occupying different strategic positions across the value chain. Leadership within the sector is no longer determined purely by production volume; vertical integration, geographic diversification, and strong commitments to low-carbon aluminum production are becoming decisive factors in maintaining competitive advantage and securing future growth.

Figure 43. Matrix of Key Aluminum Mining and Refining Players Globally

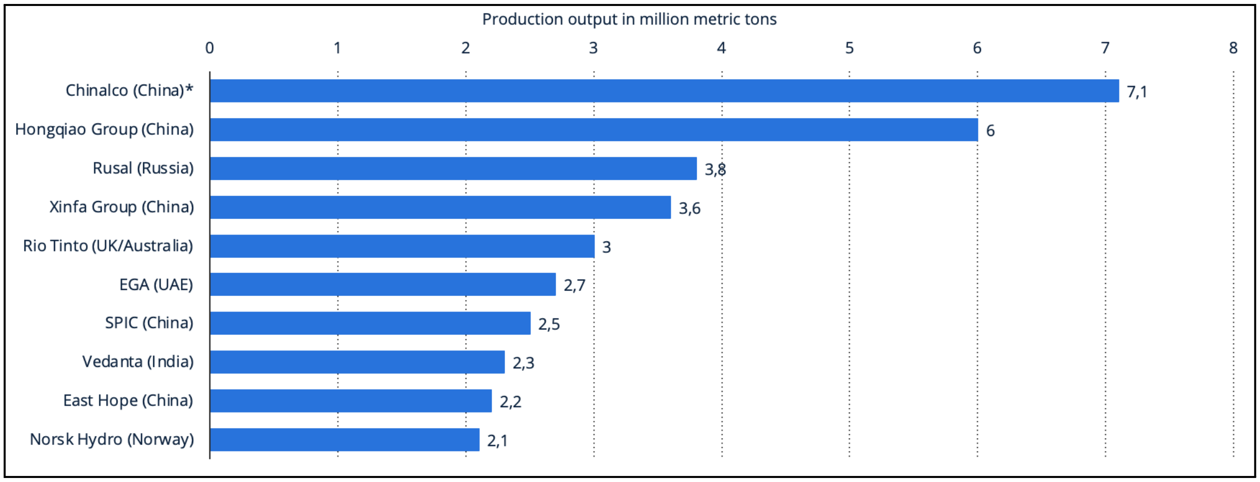


Source: Capstone analysis

[124] SAFE. (2025, January 15). *STATEMENT: Century Aluminum Advances U.S. Manufacturing Goals with Phase One Contract under DOE Grant.* SAFE. https://secureenergy.org/statement-century-aluminum-advances-u-s-manufacturing-goals-with-phase-one-contract-under-doe-grant/

[125] Internal Revenue Service (IRS), Treasury. (2024, October 28). *Advanced Manufacturing Production Credit.* Federal Register. https://www.federalregister.gov/documents/2024/10/28/2024-24840/advanced-manufacturing-production-credit

Figure 44. Leading Primary Aluminum Producing Companies Based on Production Output, 2022



Source: RUSAL[126]

At the upstream and midstream levels, leading integrated players include Rio Tinto (Australia/UK), Rusal (Russia), Chalco (China), and Alcoa (United States). These companies have established end-to-end control across mining, refining, and smelting, giving them strategic leverage over raw material supply chains and production costs. Rio Tinto, in particular, is expanding its leadership through investment in low-carbon aluminum initiatives such as the ELYSIS joint venture,[127] while Alcoa is accelerating decarbonization efforts across its global smelting operations. Rusal and Chalco, despite operating in more politically sensitive markets, maintain strong positions in global supply chains due to their scale and upstream resource ownership.

Major smelters and fabricators operating at scale include China Hongqiao Group, Emirates Global Aluminium (EGA)in the UAE, Norsk Hydro (Norway), and South32 (Australia). Hongqiao remains the largest private-sector aluminum producer globally, aggressively expanding into energy transition metals. EGA leverages low-cost Gulf energy to maintain competitive export operations, while Norsk Hydro stands out as a global leader in renewable-powered aluminum production, benefiting from hydropower assets that position it favorably in a decarbonizing economy. South32 continues to grow its alumina and aluminum operations with a strong focus on sustainable production practices.

On the downstream side, specialized fabricators such as Novelis (U.S./India), Constellium (Europe), and Kaiser Aluminum (U.S.) dominate. These companies are less exposed to primary commodity price cycles and instead derive value through the production of high-margin aluminum products tailored for automotive, aerospace, and industrial applications. Novelis is particularly prominent, being the world's largest recycler of aluminum and a critical supplier to global automotive OEMs, while Constellium's expertise in aerospace-grade aluminum alloys gives it an advantage in premium markets.

[126] RUSAL. (April 28, 2023). *Leading primary aluminum producing companies in 2022, based on production output (in million metric tons) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/280920/largest-aluminum-companies-worldwide/

[127] Rio Tinto. (2024, June 28). *Rio Tinto to install carbon free aluminium smelting cells using first ELYSIS technology licence.* Rio Tinto. https://www.riotinto.com/en/news/releases/2024/rio-tinto-to-install-carbon-free-aluminium-smelting-cells-using-first-elysistm-technology-licence

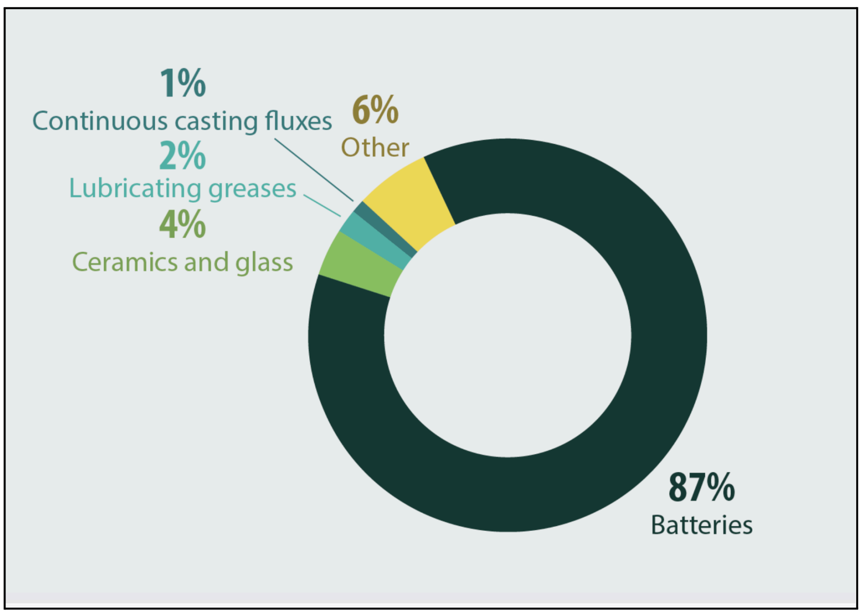
The strategic sorting matrix of major aluminum companies highlights a clear divide between vertically integrated sector leaders and secondary participants. Companies that combine scale, geographic diversity outside of high-risk regions, and leadership in low-carbon production are increasingly favored by investors and policymakers. As sustainability, security of supply, and decarbonization reshape industry priorities, integrated producers with innovation capabilities and ESG leadership are positioned to outperform over the coming decade.

2.1.5 Lithium

1. Main Uses, Historical Prices and Production Levels

Known as the "white gold"[128] of the energy transition, lithium plays a crucial role in the global shift toward a "greening" economy. Traditionally, lithium is used in producing glass and ceramics, lubricants, pharmaceuticals, polymers, and air treatment products. Today, it's central to the production of rechargeable lithium-ion batteries (LIBs) which are the technological foundation for EVs, grid-scale renewable energy storage, and a broad range of consumer electronics, including smartphones and laptops. In 2023 and 2024, batteries accounted for approximately 87%[129] of total lithium demand.[130] Lithium's dominant role in powering energy transition technologies has elevated it from a niche industrial material to a strategic asset. The U.S. and its allies have increasingly prioritized this "transition mineral" with incentives for domestic investments, recognizing its role in achieving clean energy goals and securing national industrial competitiveness.

Figure 45. Lithium Use Case, 2023



Source: Natural Resources Canada (2025)

The global lithium market has experienced dramatic price volatility over the past 15 years, shaped by demand surges, supply gaps, and shifting investor sentiment. Between 2010 and 2015, prices remained relatively stable, with battery-grade lithium trading at approximately USD 6,000 per ton. The landscape began to change in 2015, when early signals of mass EV adoption and battery gigafactory development spurred investor enthusiasm that culminated in a sharp price rally through 2017 and 2018. Prices exceeded USD 20,000 per ton primarily driven by the rapid expansion of the Chinese EV market. Growing lithium mining and production investments combined oversupply with

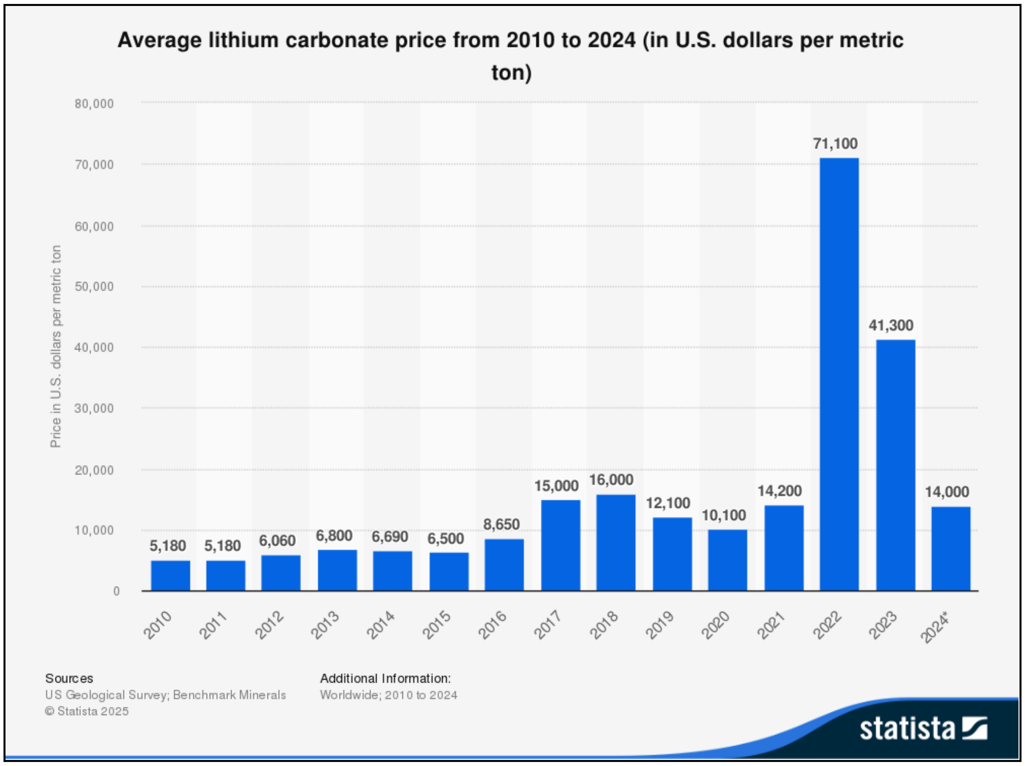
[128] World Economic Forum. (2024, April 29). *This metal is known as the "white gold" of the energy transition.* World Economic Forum. https://www.weforum.org/videos/lithium-energy-transition/

[129] Jaskula, B. W. (2025, January). *Mineral Commodity Summaries 2025 Lithium.* U.S. Geological Survey. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-lithium.pdf

[130] Government of Canada. (2025, March 12). *Lithium facts.* Government of Canada. https://natural-resources.canada.ca/minerals-mining/mining-data-statistics-analysis/minerals-metals-facts/lithium-facts

slower-than-expected EV rollout resulting in a price correction between 2019 and 2020.[131] As with so many commodities, the market underwent a second and more extreme rally in 2022, due to a large supply deficit during COVID-19 and a sharp rebound in Chinese demand. Prices surged to an all-time high of approximately USD 79,637 per ton in December 2022.[132]

Figure 46. Average Lithium Carbonate Pricing, 2010 - 2024



Source: USGS (2025)[133]

Since 2023, the lithium market has undergone another major correction. As supply from new projects in Australia, Argentina, and Chile began to fill the market, accompanied by technological improvements, prices fell to around USD 14,000 per ton.[134] These fluctuations reflect both the immaturity of the lithium spot market and the difficulties in aligning long-cycle mining investment with rapid shifts in downstream demand. While the lithium spot market is fairly young, top market players have been making concerted efforts to nurture a spot market that can deviate from the traditional long-term offtake agreements model, and increasing activity in the spot market has been observed. On the supply side, global mine production has expanded significantly, rising from just 28,100 metric tons of lithium content in 2010 to approximately 240,000 metric tons by 2024[135] - an

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[131] L, J. (2024, May 29). *Understanding Lithium Prices: Past, Present, and Future.* Carbon Credits. https://carboncredits.com/understanding-lithium-prices-past-present-and-future/

[132] Saptakee S. (2024, September 16). *The Lithium Paradox: Price Plummet, Supply Surge, and Demand Dip – What's Happening Now?* Carbon Credits. https://carboncredits.com/the-lithium-paradox-price-plummet-supply-surge-and-demand-dip-whats-happening-now/

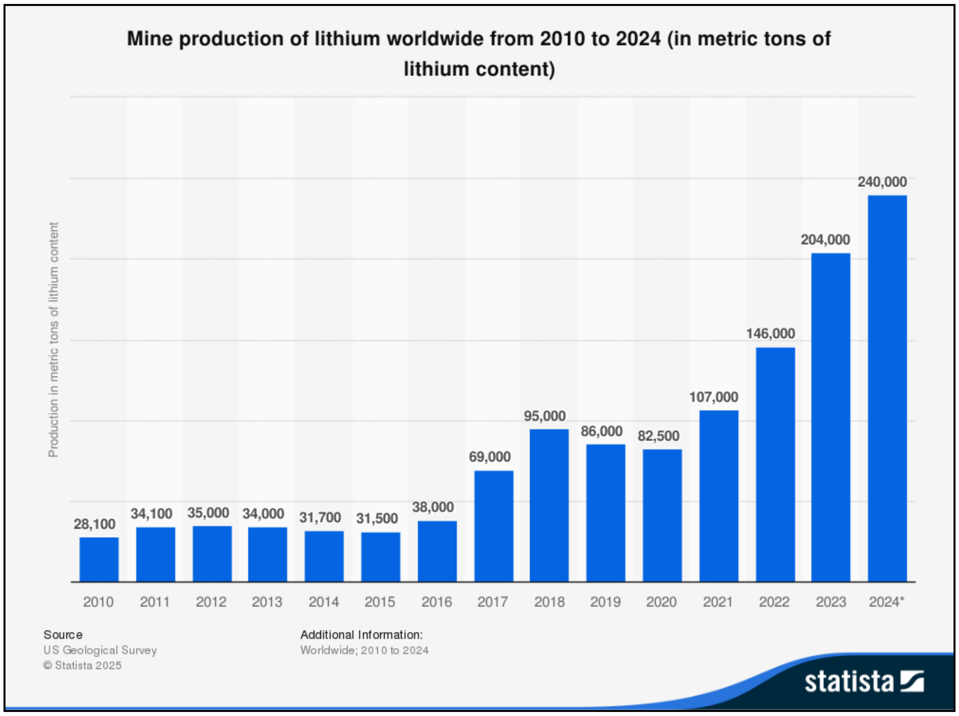
[133] US Geological Survey. (February 3, 2025). *Average lithium carbonate price from 2010 to 2024 (in U.S. dollars per metric ton) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/606350/battery-grade-lithium-carbonate-price/

[134] Ibid.

[135] US Geological Survey. (February 3, 2025). *Mine production of lithium worldwide from 2010 to 2024 (in metric tons of lithium content) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/606684/world-production-of-lithium/

almost nine-fold increase in under 15 years. However, persistent supply surplus in 2023 and 2024 and weaker-than-projected demand, especially from the EV sector as the subsidies expire, have been rattling the market. In the first quarter of 2025, some price segments of the global lithium market plummeted to their lowest point since 2021- the lithium carbonate CIF North Asia price fell below US$9,550 per ton in February.[136] The prevailing price level has hindered production, with more project delays and production curtailments among major producers. The prices will have to rise in the long term to sustain production. For the foreseeable future, lithium prices will likely remain volatile, but changes are in progress to help stabilize the market as it matures and develops.

Figure 47. Mine Production of Lithium Worldwide, 2010 - 2024



Source: USGS (2025)[137]

2. Value Chain Breakdown and Concentrated Players

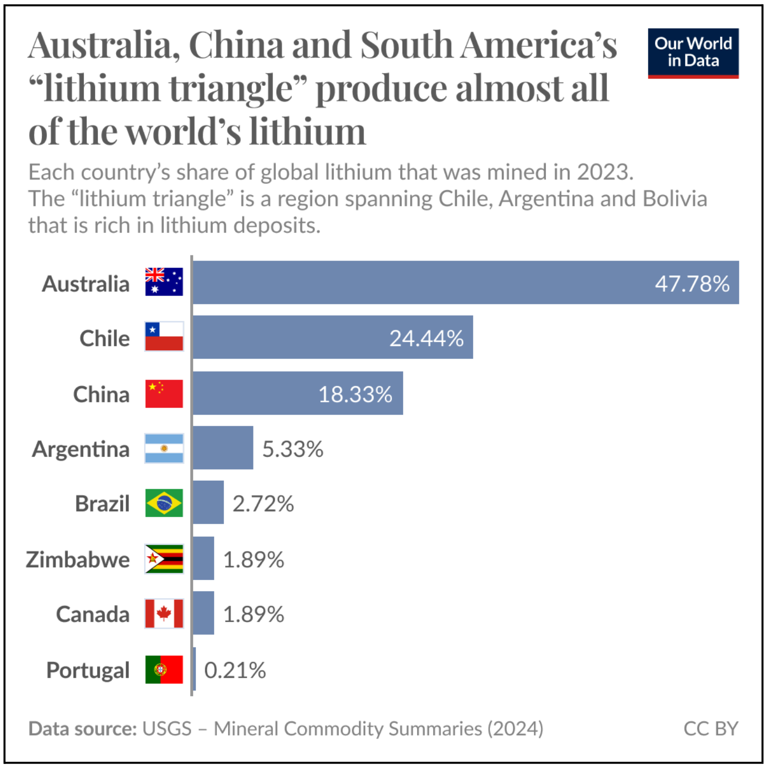
The lithium value chain is geographically concentrated and marked by significant strategic vulnerabilities. Upstream global lithium mining and extraction is dominated by a handful of countries - notably Australia, Chile and China as the top three producers. In 2023, Australia leads with roughly 48% of global output, primarily derived from hard rock spodumene mining. Chile and Argentina - home to vast salt flats in the so-called Lithium Triangle (Chile, Argentina, Bolivia) in South America - account for around 24% and 5%,[138] respectively, using brine-based extraction techniques. China, with both hard rock and brine resources, contributed approximately 18% of global output in 2023. Emerging producers, including Brazil, Zimbabwe, Canada, and Portugal, remain marginal but are drawing increasing investor attention.

[136] Williams, G. (2025, April 7). *Lithium Market Update: Q1 2025 in Review.* Nasdaq. https://www.nasdaq.com/articles/lithium-market-update-q1-2025-review

[137] US Geological Survey. (February 3, 2025). *Mine production of lithium worldwide from 2010 to 2024 (in metric tons of lithium content) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/606684/world-production-of-lithium/

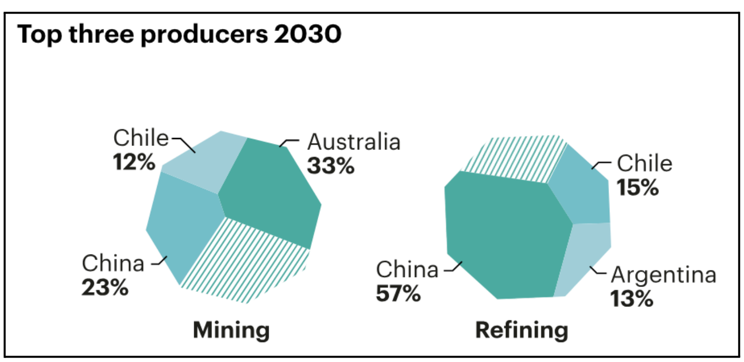
[138] Ritchie, H., & Rosado, P. (2025, February 2). *The world's lithium is mined in just a handful of countries.* Our World in Data. https://ourworldindata.org/data-insights/the-worlds-lithium-is-mined-in-just-a-handful-of-countries

Figure 48. Lithium Production Globally, 2023



The midstream presents the most acute supply chain concentration. China controls between 60% and 70%[139] of global lithium refining capacity, processing both domestic and imported raw materials into battery-grade compounds such as lithium carbonate and lithium hydroxide. According to the IEA,[140] China is expected to retain a 57% share of global lithium refining and 23% of mining by 2030, illustrating its enduring centrality in the value chain. This degree of concentration has prompted alarm in Western capitals, particularly in light of recent export restrictions imposed by Beijing[141] on other high-leverage materials such as graphite and rare earth elements.

Figure 49. Lithium Producer Forecast 2030



Source: IEA (2023)

[139] International Energy Agency. (2023, January). *Clean energy supply chains vulnerabilities.* IEA. https://www.iea.org/reports/energy-technology-perspectives-2023/clean-energy-supply-chains-vulnerabilities
[140] International Energy Agency. (2024, May 17). *Lithium*. IEA. https://www.iea.org/reports/lithium
[141] Baskaran, G., & Schwartz, M. (2024, December 4). *China Imposes Its Most Stringent Critical Minerals Export Restrictions Yet Amidst Escalating U.S.-China Tech War.* Center for Strategic & International Studies. https://www.csis.org/analysis/china-imposes-its-most-stringent-critical-minerals-export-restrictions-yet-amidst

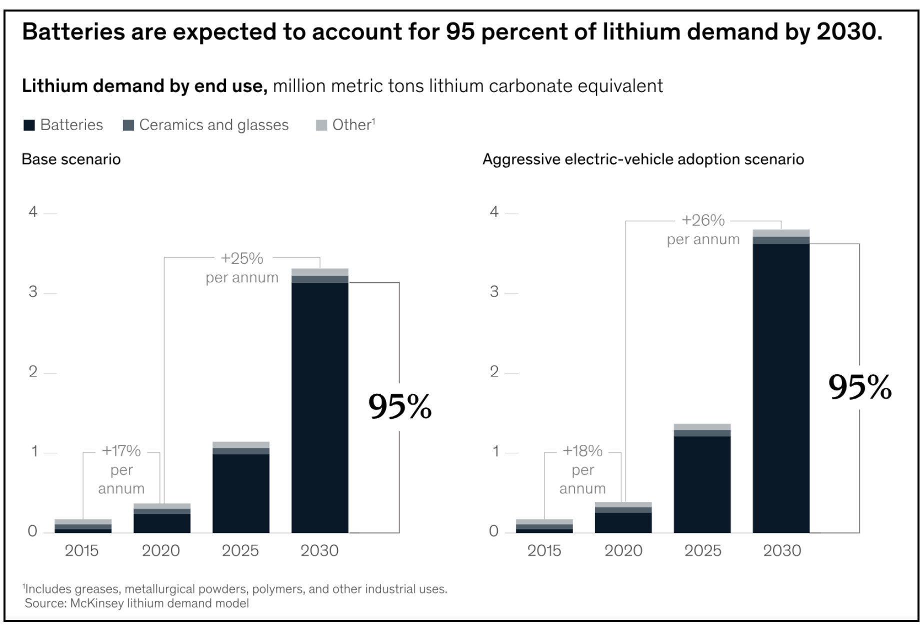
Efforts to diversify supply chains are underway. The U.S., Canada, and the European Union have all launched initiatives to build domestic refining infrastructure and strengthen commercial partnerships with resource-rich allies. In the U.S., the IRA Section 45X Advanced Manufacturing Production Tax Credit offers a 10% tax credit on the production costs of eligible critical minerals, including lithium, when both mining and refining occur domestically.[142] However, refineries under development in places like Texas, Québec, and Western Australia are only in their early stages, and not yet operating at a sufficient scale to shift market fundamentals. Countries such as Argentina, Zimbabwe, and Brazil are seen as promising alternatives for future supply, but challenges related to permitting, infrastructure, and environmental governance can hinder the process.[143]

3. Demand & Production Outlook; Recent Developments

Global lithium demand is forecast to grow at a compound annual rate of 25% over the remainder of this decade. By 2030, demand is expected to reach between 3 and 4 million tons of lithium carbonate equivalent, a near quadrupling from 2023 levels. Batteries will remain the dominant use - projected to rise to 95% of lithium demand by 2030, with EVs and grid storage accounting for nearly all incremental demand growth.[144]

Lithium production is projected to grow in tandem, with a forecast anticipating a 20 % annual expansion in global supply capacity through 2030. However, current project pipelines may not be sufficient to meet the most aggressive decarbonization scenarios, particularly those modeled under the IEA's Net Zero Emissions pathway. Recycling is expected to play an increasingly important role in balancing the market, but presently accounts for less than 3% of global lithium supply.[145]

Figure 50. Lithium Supply and Demand Forecast

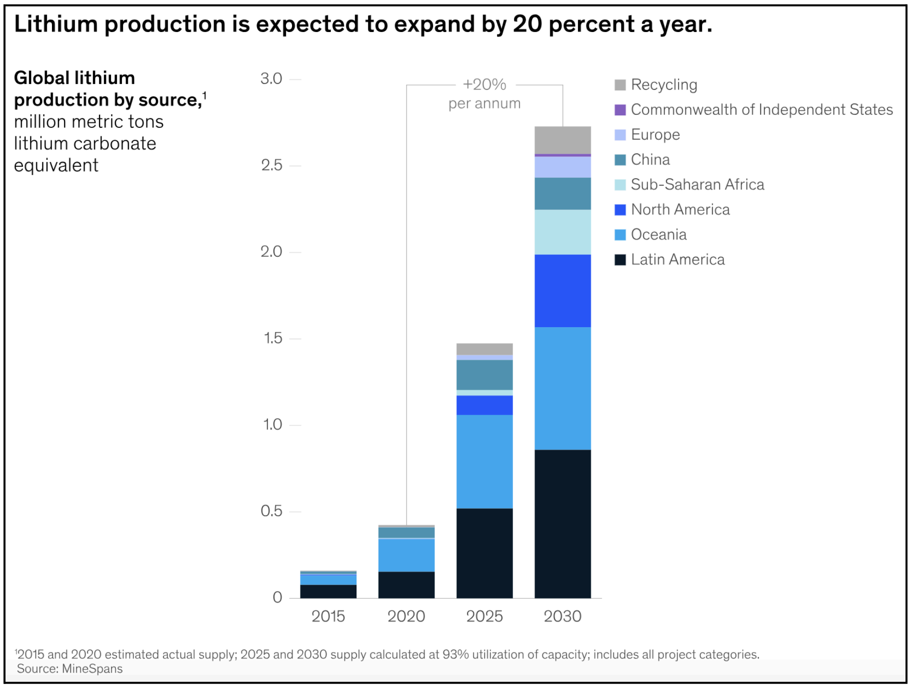


[142] Baskaran, G., & Schwartz, M. (2024, November 6). U.S. *Department of Treasury Releases Final Ruling on Section 45X.* Center for Strategic & International Studies. https://www.csis.org/analysis/us-department-treasury-releases-final-ruling-section-45x

[143] L, J. (2024, June 27). *The Ultimate Guide to Lithium and Lithium Prices.* Carbon Credits. https://carboncredits.com/ultimate-guide-to-lithium-and-lithium-market-prices/

[144] Azevedo, M., Baczynska, M., Hoffman, K., & Krauze, A. (2022, April 12). *Lithium mining: How new production technologies could fuel the global EV revolution.* McKinsey & Company. https://www.mckinsey.com/industries/metals-and-mining/our-insights/lithium-mining-how-new-production-technologies-could-fuel-the-global-ev-revolution

[145] International Energy Agency. (2024, November). *Recycling of Critical Minerals: Executive summary.* IEA. https://www.iea.org/reports/recycling-of-critical-minerals/executive-summary



Source: McKinsey (2022)

On the policy front, trade tensions between the U.S. and China have introduced new risks and uncertainties. In April 2025, the Trump Administration updated tariffs on Chinese LIBs, setting duties that will rise to a maximum of 173 %.[146] In addition, a Section 232 investigation initiated on April 15[147] raises the possibility of future tariffs on imported lithium compounds and other critical minerals. These developments have added prominent disruptions and risks to market dynamics, including prices, supply chain shifts and production. In the meantime, it also demonstrates an urgency for Western efforts to onshore or "friend-shore" lithium supply chains. Accompanied by the headwinds, there exist the tailwinds for U.S. domestic lithium production. As industry participants view that the IRA 45X tax credit is less likely to face reduction under the current administration, the combination of IRA-driven incentives and heightened tariff risks can potentially bolster U.S. domestic supply chains and gradually reduce reliance on imports. However, short-term market disruption and higher input costs for U.S. manufacturers can dim the outlook, particularly when the current lithium prices have been massively discouraging investments and project implementations.[148]

Over the past months, the global lithium market has experienced a series of major developments, underscoring the market's dynamism and volatility. In March 2025, Rio Tinto[149] completed its $6.7 billion acquisition of Arcadium Lithium, consolidating its position in Argentina's Rincon brine project and furthering its ambitions in battery-grade lithium production. The deal reflects a broader shift among Western mining majors to gain direct exposure to transition mineral assets.

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[146] Chang, A., Gamio, L., & Robles, P. (2025, April 12). *How Much Are Tariffs on Chinese Goods? It's Trickier Than You Think.* The New York Times. https://www.nytimes.com/interactive/2025/04/12/business/economy/china-tariff-product-costs.html

[147] Ross, D. J., Mandell, L., Shenai, N., Schmidtlein, R. K., & Kim, M. (2025, April 17). *President Trump Announces Three New Section 232 Investigations After Suspending Reciprocal Tariffs, Excluding Certain Electronics, and Increasing Tariffs on China.* Wilmerhale. https://www.wilmerhale.com/en/insights/client-alerts/20250417-president-trump-announces-then-suspends-reciprocal-tariffs-defers-tariffs-on-certain-electronics-and-increases-tariffs-on-china

[148] Williams, G. (2025, April 7). *Lithium Market Update: Q1 2025 in Review.* Nasdaq. https://www.nasdaq.com/articles/lithium-market-update-q1-2025-review

[149] Rio Tinto. (2025, March 6). *Rio Tinto completes acquisition of Arcadium Lithium.* Rio Tinto. https://www.riotinto.com/en/news/releases/2025/rio-tinto-completes-acquisition-of-arcadium-lithium

Meanwhile, the near-term price outlook has caused Albemarle - the world's largest lithium producer - to suspend several projects outside of China and Chile. In August 2024, Australia-based Pilbara Minerals reported an 89% year-on-year drop in annual net income. Further, the company postponed plans to build the world's largest lithium mine. Both Albemarle and Pilbara Minerals decided to cut their capital expenditures.[150] This retrenchment reflects rising capital costs and declining margins in a market adjusting from a phase of exuberant growth to more disciplined investment.

In a significant U.S. domestic development, the Trump Administration designated Smackover Lithium's South West Arkansas (SWA) Project[151] as a Priority Transparency Critical Mineral Project under Executive Order 14241. Smackover Lithium is a joint venture formed in 2024 between Standard Lithium and the Norwegian energy leader Equinor. This designation, announced on April 21, 2025, places the project on the Federal Permitting Dashboard, streamlining regulatory reviews and positioning it as a strategic initiative to reduce U.S. reliance on foreign lithium, particularly from China. Reinforcing the project's federal backing, the DOE awarded a $225 million grant[152] in January this year to this partnership between Standard Lithium and Equinor. The funding is allocated for the development of Phase 1 construction, and the project has become the first Direct Lithium Extraction (DLE) initiative to receive support under the DOE's Transparency Program. Although the earliest commencement of the phase 1 construction will not be sooner than 2028, these moves signal high-level federal endorsement for both unconventional extraction methods and the localization of lithium supply chains.

4. Key Players and Sorting Matrix

The lithium market remains highly consolidated,[153] with a small number of publicly listed firms controlling a disproportionate share of global mining and refining capacity. These companies increasingly pursue vertical integration strategies, linking upstream extraction with midstream processing and downstream battery production in order to hedge against supply chain risk and compress costs.

As of March 2025,[154] leading publicly traded companies include Sociedad Química y Minera de Chile (SQM), Ganfeng Lithium, Albemarle, Tianqi Lithium, Arcadium Lithium (now a subsidiary of Rio Tinto), Pilbara Minerals, Lithium Americas, and Standard Lithium. Market capitalizations vary significantly, with SQM topping $10.5 billion and smaller firms like Standard Lithium valued below $250 million. Chinese firms such as Ganfeng and Tianqi maintain dominant positions in global refining but are increasingly constrained by Western investment and trade barriers.

…/…

[150] Williams, G. (2025, April 7). *Lithium Market Update: Q1 2025 in Review.* Nasdaq. https://www.nasdaq.com/articles/lithium-market-update-q1-2025-review

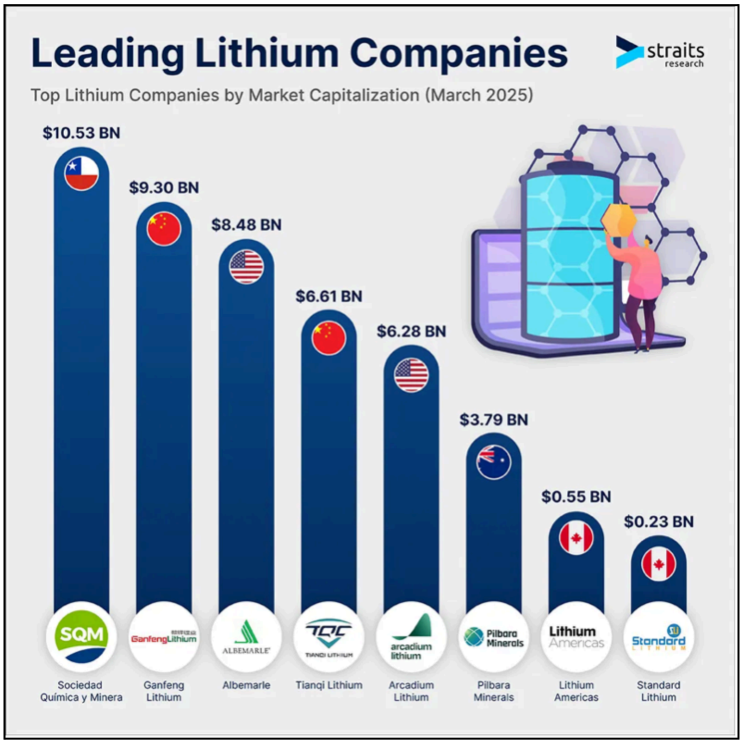
[151] Standard Lithium. (2025, April 21). *Smackover Lithium's South West Arkansas Project Receives Special Designation as a Priority Transparency Critical Mineral Project From the Trump Administration.* Standard Lithium. https://www.standardlithium.com/investors/news-events/press-releases/detail/190/smackover-lithiums-south-west-arkansas-project-receives

[152] Standard Lithium. (2025, January 16). *Standard Lithium and Equinor Finalize $225 Million Grant from the U.S. Department of Energy for the South West Arkansas Project.* Standard Lithium. https://www.standardlithium.com/investors/news-events/press-releases/detail/183/standard-lithium-and-equinor-finalize-225-million-grant

[153] Mordor Intelligence. *Lithium Market Size & Share Analysis - Growth Trends & Forecasts (2025 - 2030).* Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/lithium-market

[154] Straits Research. (2025, March 6). *Top 8 Lithium Producers Ranked by Market Cap (March 2025).* Straits Research. https://straitsresearch.com/statistic/largest-lithium-companies

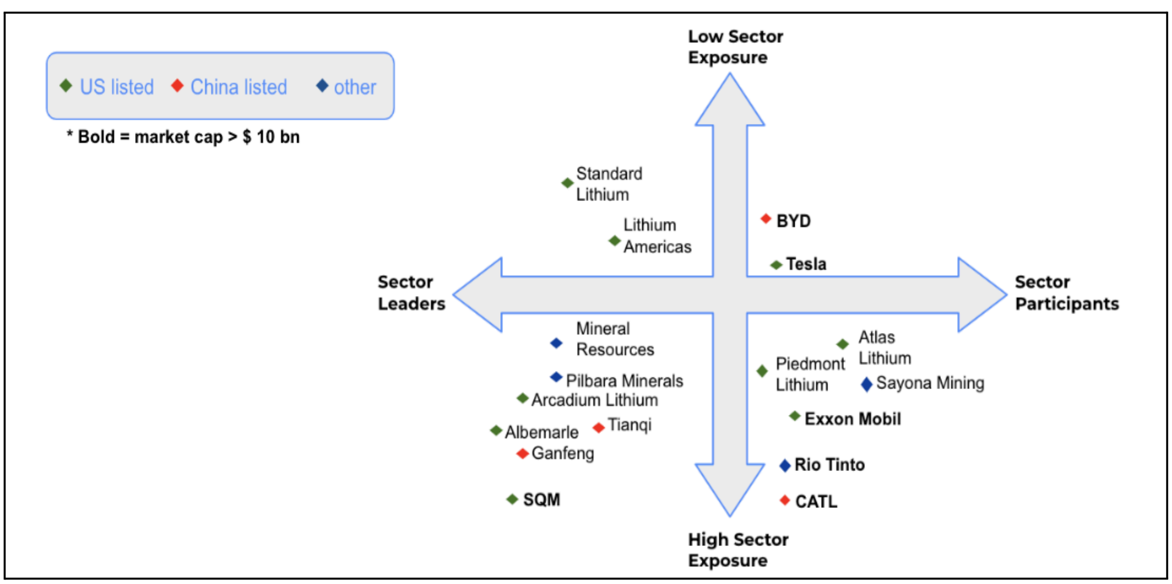
Figure 51. Leading Lithium Companies by Market Capitalization, 2025



Source: Straits Research (2025)

A sectoral sorting matrix produced for this study classifies these firms by upstream and midstream exposure as well as market capitalization. The analysis finds that leading companies listed on Western exchanges with high exposure to the lithium value chain - particularly SQM, Albemarle and Pilbara Minerals - are best positioned to benefit from long-term demand growth and policy-driven realignment of supply chains. These firms are also more likely to meet investor expectations related to ESG performance, permitting transparency, and supply chain traceability. In the meantime, factoring in the impact from the Trump Administration's latest tariff measures and the demonstrated determination to boost U.S. domestic supply chains, smaller market participants such as Standard Lithium and Lithium Americas in North America may stand in a more advantageous position to grow in the future.

Figure 52. Matrix of Key Lithium Mining and Refining Players Globally



Source: Capstone analysis

Looking ahead, despite the near-term challenges of oversupply, weaker demand, falling prices, and policy uncertainties, the future of the lithium market remains optimistic. The anticipated global expansion in EVs and renewable energy storage systems will drive lithium demand in the long run[155] as the market rebalances to a higher price level.

[155] Williams, G. (2025, April 7). *Lithium Market Update: Q1 2025 in Review.* Nasdaq. https://www.nasdaq.com/articles/lithium-market-update-q1-2025-review

2.2 Nuclear Generation

1. Global Overview

As noted already, nuclear generation may be the only power generation source with bipartisan support in the present policy environment. Nuclear energy is a proven, effective, mature technology which has the capability to provide continuous base load power at a time when electricity demand is reversing course and rising in developed economies. Nuclear energy can also play a role in decarbonization, and its benefits are considered to outweigh the risks posed by mitigation measures required for waste disposal and cost complexities. Nuclear energy is both carbon-free and firm, without the intermittency constraints of renewables.

Categorization of Investment Avenues and Nuclear Players:

In order to better understand investible players in the nuclear industry, the major players are categorized as follows:

- Nuclear Generation: Utilities and competitive generation companies that own and run nuclear power plants producing electricity for residential, commercial, and industrial customers fall under this category. Nuclear generation is now positioned as a crucial part of the energy transition due to its unique feature as a firm and carbon-free energy source. In an effort to diversify their energy portfolios, generation companies with nuclear sources are investing in prolonging the lifespan of their current reactors as well as investigating the integration of Small Modular Reactors (SMRs). Additionally, collaborations with tech companies to power energy-intensive data centers have emerged as a new avenue for growth.
- Nuclear Industrials: This category encompasses companies that design, manufacture, and supply components, systems, and services essential for the construction and operation of nuclear reactors. The push for advanced nuclear technologies, including SMRs, has spurred innovation among industrial firms.[156] There is a concerted effort to modernize existing infrastructure and develop next-generation reactors that promise enhanced safety and efficiency.
- Small Modular Reactors (SMRs): SMRs are sophisticated nuclear reactors that can produce up to 300 megawatts per unit, about one-third of what conventional reactors can produce.[157] They are designed for modular construction, offering flexibility in deployment and potential cost reductions. SMRs have drawn a lot of interest as a practical way to meet rising energy demands, especially when it comes to powering remote areas and data centers. Companies like TerraPower and X-energy are at the forefront of the surge in venture capital investments. Notwithstanding the fervor, obstacles still exist with regard to supply chain development, regulatory approvals, and demonstrating the SMRs' economic viability.
- Uranium Miners: Uranium miners are companies engaged in the exploration, extraction, and processing of uranium ore, which serves as the primary fuel for nuclear reactors.[158] Geopolitical tensions and a resurgence of interest in nuclear energy as a clean power

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[156] Holland, E. I., Verbelen, Y., Connor, D. T., Martin, T., Higginson, M., & Scott, T. B. (2023). *An Introduction to Nuclear Industrial Archaeology.* Sustainability, 15(7), 6178. https://doi.org/10.3390/su15076178

[157] Baker Hughes. *Energizing the future: Exploring the promise of small modular reactor technologies.* Baker Hughes. https://www.bakerhughes.com/reuter-stokes/smr-reactors

[158] Utility Power Alliance (UPA). https://www.theupa.org/

source around the world has had a major impact on the uranium market. When uranium spot prices jumped above $100 per pound in 2024, mining activity increased, particularly in the United States. Businesses are concentrating on increasing output to satisfy the rising demand while juggling environmental concerns and regulatory obstacles.

Table 5. Nuclear Generation Includes a Range of Investable Players

Category	Company Name	Market Cap (In $ Billion)	Revenue from Nuclear Industry (%)
Nuclear Generation	Constellation Energy Corporation (CEG)	11.0	~95%
	Public Service Enterprise Group (PEG)	64.6	~25%
	Duke Energy Corp. (DUK)	91.02	~25%
	Dominion Energy Inc. (D)	48.24	~35%
	PG&E Corp (PCG)	16.0	~30%
	Vistra Corp (VST)	43.08	~30%
Nuclear Industrials	BWX Technologies (BWXT)	9.3	~90%
	Fluor Corporation (FLR)	$5.21	~90%
	Westinghouse Electric Company	$7.875	>90%
Small Modular Reactors (SMRs)	NuScale Power Corp. (SMR)	$1.61	Potentially 100%
	TerraPower	Private	Potentially 100%
	X-energy	Private	Potentially 100%
	Oklo Inc. (OKLO)	$2.75	Potentially 100%
Uranium Miners	Cameco Corporation (CCJ)	$16.63	Potentially 100%
	Uranium Energy Corp (UEC)	$1.81	Potentially 100%
	Energy Fuels Inc. (UUUU)	$0.72	Potentially 100%
	Denison Mines Corp (DNN)	$1.08	Potentially 100%
	NexGen Energy (NXE)	$2.39	Potentially 100%

Source: Capstone analysis

2. Production and Cost Trends

The total U.S. energy generation[159] increased modestly between 2000 and 2024 from 3,800 TWh to 4,200 TWh. At the same time, nuclear energy consistently produced 750–800 TWh yearly. Share of nuclear energy to total energy production has remained consistent at approximately 20% with a slight decline in 2023 to 18.5% as global production rose.

However, the nuclear energy landscape in the United States is changing rapidly as demand for power rises. Assisted by the Bipartisan Infrastructure Law and the IRA, the domestic nuclear industry is leveraging federal funding, loan authority, and new tax incentives to extend reactor operations, increase capacity, and restart retired reactors. United States will now need at least 700 to 900 gigawatts (GW)[160] of additional firm power to keep pace with updated load growth projections to reach net-zero emissions. While the Trump Administration does not favor wind and solar energy, nuclear generation meets other Administration priorities around energy security and expanding electricity supply.

US Nuclear Supply:

As of August 1, 2023, the United States had 93 operating commercial nuclear reactors at 54 nuclear power plants in 28 states.[161] The average age of these nuclear reactors is about 42 years. The oldest operating reactor, Nine Mile Point Unit 1 in New York, began commercial operation in December 1969. The newest reactor to enter commercial service is Unit 3 at the Alvin W. Vogtle Electric Generating Plant in Georgia, which began commercial operation on July 31, 2023, and is the first reactor to come online since Watts Bar 2 was commissioned in 2016.

The number of operating reactors declined to 104 in 1998 and remained there through 2013. The number declined to 92 operating reactors in 2022. Total U.S. nuclear net summer electricity generation capacity peaked in 2012 at about 102,000 megawatts (MW) and declined to 94,765 MW in 2022. Although the number of reactors has declined since 2012, power plant uprates—modifications to increase capacity—at individual nuclear power plants have made it possible for the entire operating nuclear reactor fleet to maintain high capacity-utilization rates (or capacity factors). These relatively high-capacity factors helped nuclear power to provide 19%–20% of total annual U.S. electricity generation[162] from 1990 through 2021. Some reactors also increased annual electricity generation by shortening the length of time reactors are offline for refueling.

Nuclear reactors are decommissioned after they are retired from commercial service. According to the U.S. Nuclear Regulatory Commission, 22 commercial nuclear power reactors at 18 sites are in various stages of decommissioning.[163]

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[159] World Nuclear Association. (2024, August 27). *Nuclear Power in the USA*. World Nuclear Association. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power

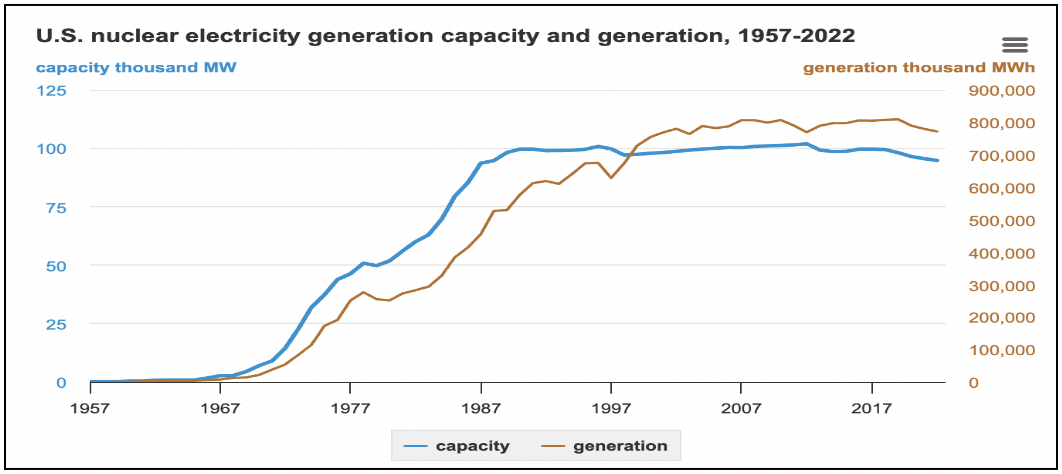
[160] Office of Nuclear Energy. (2024, September 30). *5 Ways the U.S. Nuclear Energy Industry Is Evolving in 2024*. U.S. DOE. https://www.energy.gov/ne/articles/5-ways-us-nuclear-energy-industry-evolving-2024

[161] U.S. Energy Information Administration. (2023, August 24). *Nuclear explained: U.S. Nuclear Industry.* U.S. EIA. https://www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php

[162] World Nuclear Association. (2024b, August 27). *Nuclear Power in the USA*. World Nuclear Association. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power

[163] Brown, P., & Holt, M. (2022, February 7). *U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns.* U.S. Congress. https://www.congress.gov/crs-product/R4682

Figure 53. U.S. Nuclear Electricity Generation Capacity and Generation, 1957 - 2022

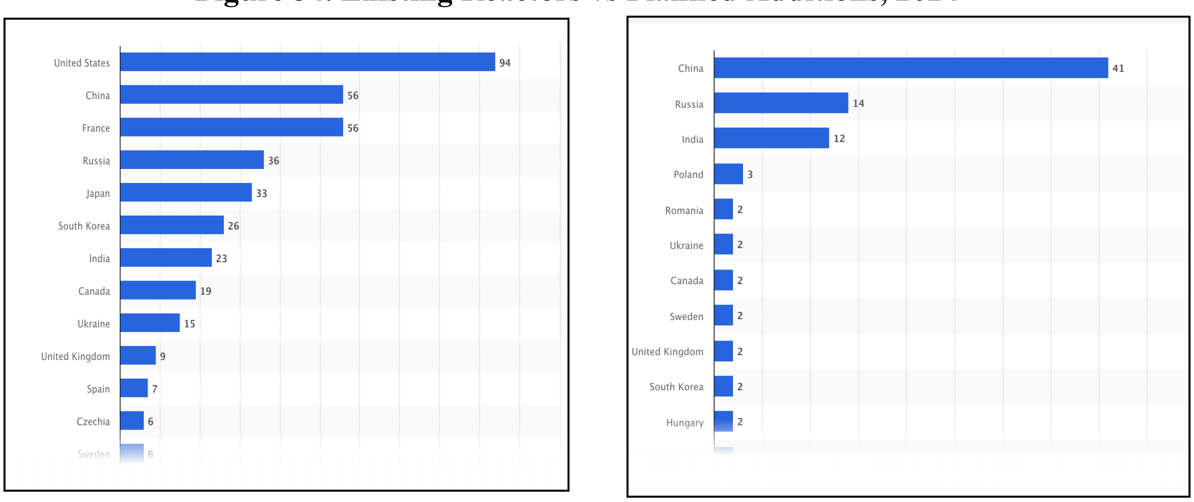


Source: U.S. Energy Information Administration (2023)

Capacity Additions outside the US:

In 2023, five new nuclear reactors with a combined capacity of 5.5 GW[164] began operations in Belarus, China, Korea, Slovak Republic and the United States. Combined with the 1.6 GW of existing reactors that were restarted after suspended operations, this more than offset the 6.3 GW of nuclear capacity retirements in 2023, resulting in a net increase of operational nuclear capacity. Through the first nine months of 2024, 4.5 GW of new nuclear capacity has been connected to the grid from new nuclear reactors in China, India, United Arab Emirates and the United States. Over the same period, construction started on seven other reactors: five in China, and one each in Egypt and Russia. As of October 2024, there were 62 reactors with around 75 GW of capacity under construction, which would increase worldwide nuclear capacity by nearly 20% when connected to electricity systems.

Figure 54. Existing Reactors vs Planned Additions, 2024



Source: World Nuclear Association[165]

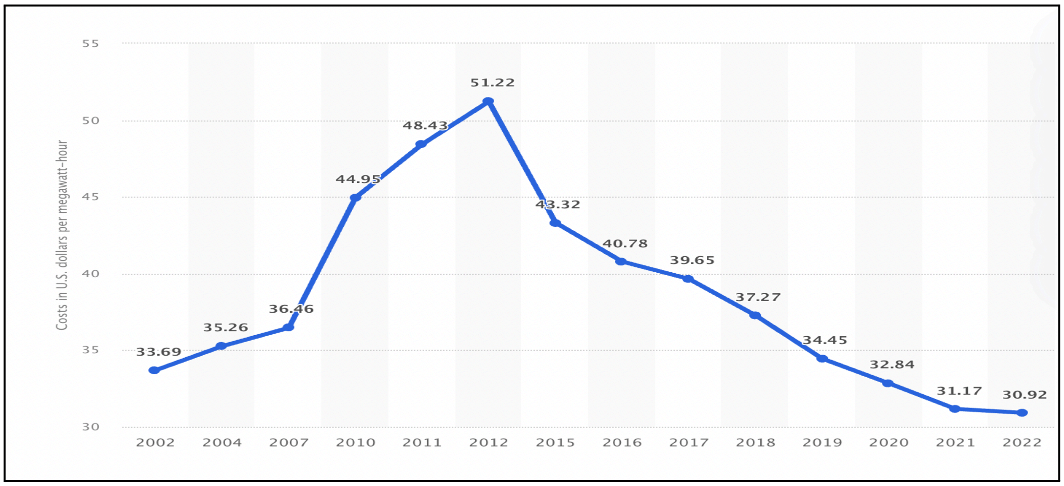
[164] Nuclear Engineering International. (2024, October 17). *Modest growth in nuclear capacity forecast by 2050.* Nuclear Engineering International. https://www.neimagazine.com/news/iea-forecasts-modest-growth-in-nuclear-capacity-by-2050/

[165] World Nuclear Association. (May 7, 2024). *Number of planned nuclear power reactors worldwide as of May 2024,*

Historical Cost Trends for Existing Reactors[166]

Average nuclear generation costs have come down from $51.22/MWh in 2012 to $30.92/MWh in 2022. While $31/MWh compares favorably with average power prices in many wholesale power markets, there is a wide range of average operating cost among the nuclear generation fleet and many periods where power market pricing is below $30/MWh. This 40% reduction in nuclear generating costs since 2012 has been driven by: a 41% decrease in fuel costs; a 51% decrease in capital expenditures; and a 33% decrease in operating costs. These are the total costs of generation including capital costs, fuel costs and operating and maintenance (O&M costs).

Figure 55. Historical Cost for Reactors, 2002 - 2022



Source: NEI[167]

Cost Components and Synergies: (Existing Reactors)

Approximately 80 percent of the electricity generated from nuclear power in the U.S. comes from plants with multiple reactors. The economies of scale allow plant operators to spread costs over more generation, resulting in a lower average generating cost. As depicted in the chart below, the average total generating cost at multiple-unit plants was $29.53 per MWh compared to $41.62 per MWh[168] for single-unit plants.

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by country [Graph]. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/268154/number-of-planned-nuclear-reactors-in-various-countries/

166 World Nuclear Association. (2024, August 27). *Nuclear Power in the USA.* World Nuclear Association. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power

167 NEI. (December 31, 2023). *Electricity production costs for nuclear power plants in the United States from 2002 to 2022 (in U.S. dollars per megawatt-hour) [Graph].* In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/184754/cost-of-nuclear-electricity-production-in-the-us-since-2000/

168 Nuclear Energy Institute. (2025, February). *Nuclear Costs In Context.* NEI. https://nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/2024-Costs-in-Context_final.pdf

Table 6. Cost Summary ($/MWh), 2023

2023 Cost Summary ($/MWh)

Category	Plants / Sites	Fuel	Capital	Operating	Total Generating
All U.S.	54	$5.32	$7.06	$19.38	**$31.76**
Plant Size[2]					
Single-Unit	18	$5.50	$10.72	$25.40	**$41.62**
Multiple-Unit	36	$5.27	$6.23	$18.03	**$29.53**
Operator					
One Plant	11	$5.57	$5.92	$20.73	**$32.22**
Multiple Plants	43	$5.24	$7.39	$18.99	**$31.63**

Source: EUCG

Source: Nuclear Energy Institute (2025)

Small Modular Reactors: SMRs offer distinct advantages that alter the traditional nuclear business model, streamline delivery, and expand nuclear energy's potential applications.[169] Rather than relying on economies of scale, SMRs use modular, standardized components that can be fabricated in factories. This "market modularity" allows for aggregation of reactor units built in series or parallel to establish larger nuclear plants. This can remove redundancies in regulatory approvals and construction while taking advantage of more durable demand signals. Repeat builds using standardized components, can drive down costs, making SMRs a bankable, cost-competitive solution. Congress has supported SMR technology demonstrations through several actions. Apart from PTC's and ITCs as detailed in the previous section, there are significant policy incentives to drive SMR production and uptake. The Advanced Reactor Demonstration Program (ARDP), which was authorized in the Energy Act of 2020 and funded in the IIJA and IRA, has dedicated $5.6 billion to move 10 SMR designs of varying maturity toward demonstration. Most notably, DOE awarded a combined $3.2 billion to demonstrate TerraPower's Natrium ($1.97 billion) and X-Energy's Xe-1000 ($1.23 billion) by 2028. Between 2025 and 2030, several other SMR projects are planned for development such as the Long Mott Generating Station (USA).[170] Interest in SMR is widespread, as evidenced by the fact that nations other than the US such as South Korea, Japan, France, Canada, and the United Kingdom are investigating its deployment. However, there are still obstacles in spite of the excitement. The most significant obstacle is that the current domestic production of HALEU, which is necessary for SMRs, is not enough to meet the anticipated demand. To prevent deployment delays, SMR developers are working hard to create a trustworthy HALEU supply chain.

…/…

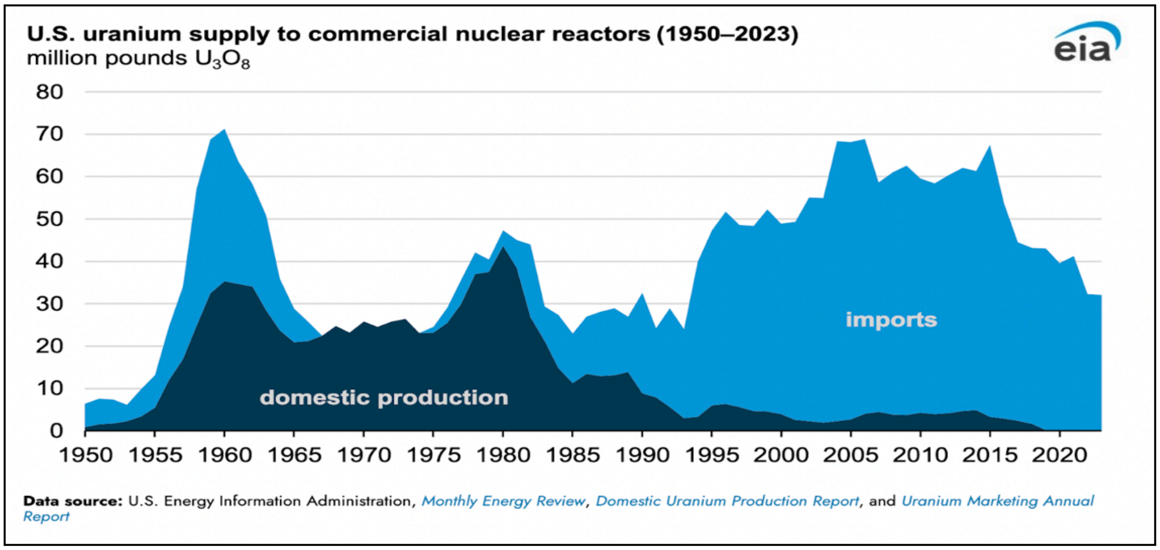
[169] Energy Futures Initiative Foundation. (2024, November). *Making Small Modular Reactors Bankable Investments*. EFI Foundation. https://efifoundation.org/wp-content/uploads/sites/3/2024/11/Making-Small-Modular-Reactors-Bankable-Investments.pdf

[170] U.S. Nuclear Regulatory Commission. (2025a, April 4). *Long Mott Energy, LLC – Long Mott Generating Station Xe-100 Power Reactor Application.* U.S. NRC. https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/applicant-projects/long-mott.html

3. Supply Chains

During the Cold War the US produced most of its uranium fuels, but since the early 1990s, imports have met most of the US domestic demand. Currently, 80–90% of the uranium used in the United States is imported, with Canada, Kazakhstan, and Australia being the main suppliers.

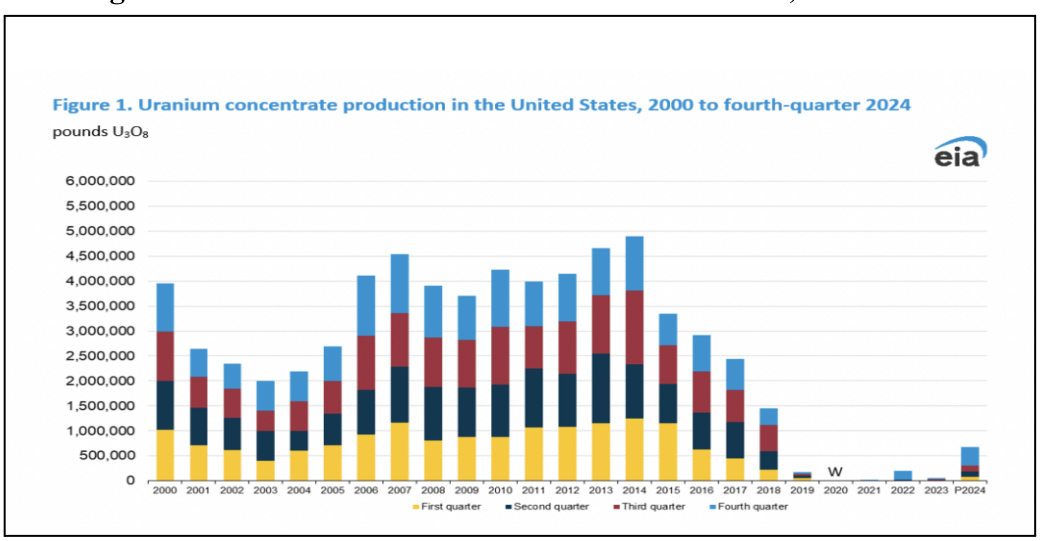
Figure 56. U.S. Uranium Supply to Commercial Nuclear Reactors, 1950 - 2023



Source: U.S. Energy Information Administration (2025)[171]

Global prices for uranium were driven down by abundant capacities outside the US through 2005. For the first fifteen years of the new century, US domestic production was fairly stable, but US production costs were not covered by declining global uranium prices, so the US has experienced a material decline in domestic uranium production over the past ten years.

Figure 57. Uranium Concentrate Production in U.S., 2000 - 2024



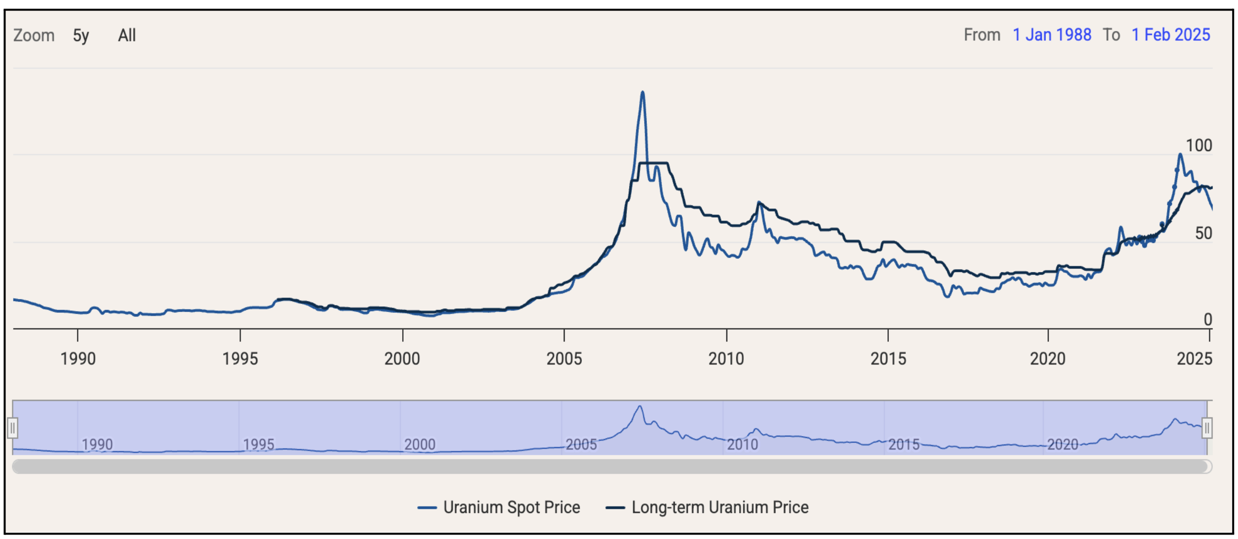
Source: U.S. Energy Information Administration (2025)

[171] U.S. Energy Information Administration (2025, January 30). *U.S. nuclear generators import nearly all the uranium concentrate they use*. U.S. EIA. https://www.eia.gov/todayinenergy/detail.php?id=64444

Due to increased demand for energy security and a decrease in reliance on Russian imports, uranium spot prices soared past $100/lb in early 2024.[172] To guard against price shocks, nuclear utilities in the United States rely on long-term contracts, which historically average $40–60/lb.[173] Due to the widening gap between spot and contract prices, stakeholders have had to update their procurement plans. In order to secure favorable prices and guarantee a steady supply, utilities are speeding up fuel purchases through 2030. This has also led to a revival of domestic production, with more money going toward uranium mining in Texas, Wyoming, and Idaho.

The urgency surrounding U.S.-based sourcing has increased due to federal strategic initiatives such as DOE's $3.4 billion uranium reserve[174] and possible import restrictions on Russian fuel. Uranium prices are now seen by stakeholders, such as fuel processors, SMR developers, and plant operators, as a crucial early warning indicator for the feasibility of investments, possible cost increases, and the capacity to fulfill carbon reduction requirements. Compared to previous decades, uranium pricing is now a more significant strategic planning variable due to its volatility and upward trend. The current trajectory suggests uranium prices will remain elevated through 2028, with spot levels potentially exceeding $120/lb[175] as supply struggles to catch up with surging demand. Long-term contracts are also trending higher, locking in structurally higher costs for utilities and SMR developers alike.

Figure 58. Uranium Price, 1990 - Feb 2025



Source: Cameco Corporation[176]

[172] American Nuclear Society. (2025, April 2). *Uncertainty contributes to lowest uranium spot prices in 18 months.* Nuclear Newswire; American Nuclear Society. https://www.ans.org/news/article-6909/uncertainty-contributes-to-lowest-uranium-futures-in-18-months/

[173] World Nuclear Association. (2024c, November 20). *US Nuclear Fuel Cycle.* World Nuclear Association. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-fuel-cycle

[174] American Nuclear Society. (2024, June 28). *With $3.4 billion to spend, the DOE opens RFP for low-enriched uranium.* Nuclear Newswire; American Nuclear Society. https://www.ans.org/news/article-6167/with-34-billion-to-spend-the-doe-opens-rfp-for-lowenriched-uranium/

[175] American Nuclear Society. (2025, April 2). *Uncertainty contributes to lowest uranium spot prices in 18 months.* Nuclear Newswire; American Nuclear Society. https://www.ans.org/news/article-6909/uncertainty-contributes-to-lowest-uranium-futures-in-18-months/

[176] Cameco Corporation. (2024). *Uranium price*. https://www.cameco.com/invest/markets/uranium-price

Uranium Import Ban: The United States banned uranium imports from Russia in May 2024, with the option for businesses to request waivers until January 1, 2028.[177] The ban went into effect in August 2024. The uranium market is now more volatile because of this change. U.S. utilities have cut their uranium purchases in half over the past several months citing concerns about rising costs and possible supply shortages.[178] Uranium has so far been among the minerals exempted from the Trump Administration's imposed or threatened tariffs, but there is uncertainty. This hesitancy highlights the need for a stable domestic supply chain and the market's sensitivity to changes in policy.

Enrichment and Conversion Costs: Once a reliable aspect of purchasing nuclear fuel, enrichment and conversion costs are now important pricing factors for U.S. stakeholders. Geopolitical upheavals have caused a strong reaction from the market, particularly the continued move away from Russian enrichment services.[179] Since 2021, enrichment prices have more than doubled and conversion prices have tripled.[180] The DOE is providing funding for new facilities in the United States, such as Centrus Energy's HALEU[181] pilot project, in order to make up the difference. While fuel suppliers are vying to increase domestic capabilities, utilities are securing long-term contracts at premium prices to guarantee supply security. Due to limited Western capacity and decreased access to Russian services, enrichment and conversion service prices are predicted to remain high or increase even more. U.S. stakeholders predict a competitive market through 2030 with premium pricing emerging as the new norm.

4. Impact of Trade Related Policies

IRA:

The IRA encourages investment in nuclear energy by offering sizable tax credits to support nuclear power generation in the US for both new and existing reactors.

- The IRA includes the 45U Clean Electricity Production Tax Credit (PTC), which provides a tax credit of up to $15/MWh[182] for electricity generated by nuclear power plants that are already in operation. This credit is available until 2032 but it is phased out if the wholesale electricity prices obtained by the generator rises above $25/MWh. After that, the credit will be reduced on a sliding basis. This PTC aims to subsidize older nuclear plants to limit early shutdowns brought on by the economic pressures of low market power prices.
- The 45Y Clean Electricity PTC and the 48E Clean Electricity Investment Tax Credit[183] (ITC) are two important tax credits that are applicable to new reactors. Electricity produced by recently constructed new nuclear reactors is eligible for a $30/MWh credit

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[177] U.S. Department of Energy. (2024). *Russian Uranium Ban Waiver Guidance.* U.S. DOE. https://www.energy.gov/ne/russian-uranium-ban-waiver-guidance

[178] Zadeh, J. (2025, March 31). *Uranium Market Freezes as Tariff Threats Rattle Would-be Buyers.* Discovery Alert. https://discoveryalert.com.au/news/uranium-market-tariff-impact-2025-turmoil/

[179] U.S. Energy Information Administration. (2024, June 6). *Uranium Marketing Annual Report*. U.S. EIA. https://www.eia.gov/uranium/marketing/

[180] Kazmin, A., & Sanderson, H. (2024, March 12). *US ramps up uranium efforts as nuclear industry breaks from Russia*. *Financial Times*. https://www.ft.com/content/8182ae01-c512-451d-b9a6-64023cac7467

[181] Centrus Energy. (2023, November 7). *Centrus Makes First HALEU Delivery to U.S. Department of Energy*. Centrus Energy. https://www.centrusenergy.com/news/centrus-makes-first-haleu-delivery-to-u-s-department-of-energy/

[182] Nuclear Energy Institute. (2022). *Nuclear Energy in the Inflation Reduction Act.* NEI. https://lp.nei.org/rs/766-WBL-877/images/Inflation%20Reduction%20Act%20Summary%20of%20Nuclear%20Provisions.pdf

[183] King, B., Larsen, J., Kolus, H., & Brummen, A. van. (2024, May 23). *Tech-Neutral Tax Credits: The Foundation of US Electric Power Decarbonization.* Rhodium Group. https://rhg.com/research/tech-neutral-tax-credits-electric-power/

under the 45Y PTC. The incentive also aims to promote the development of small modular reactors and advanced reactors. The 48E ITC, which provides an investment tax credit of up to 30% of the project's capital costs, is an alternative for developers. If projects fulfill additional requirements, such as using materials sourced domestically, being situated in energy communities, or offering robust labor and apprenticeship programs, this ITC can be raised by 50%.

By subsidizing revenues through PTCs or supporting capital structures through ITCs, these IRA tax credits greatly increase the economic feasibility[184]of nuclear energy projects. These tax credits support policy objectives to accelerate the deployment of next-generation nuclear technology while preserving current nuclear generation. They serve a Biden-era policy objective to preserve nuclear power as a vital part of the U.S. clean energy transition along with a Trump priority for expanding electricity sources by stabilizing the financial outlook for aging reactors and encouraging the growth of new nuclear projects.

Examples of IRA Impact:

- Diablo Canyon Power Plant (California): Tax credits have facilitated this plant to remain functional beyond its planned closure, contributing approximately 16 billion kilowatt-hour (kWh) of power annually.[185]
- Palo Verde Generating Station (Arizona): This plant continues to operate at a high capacity due to federal tax credits, generating over 30 billion kWh of power annually.[186]
- Monticello Nuclear Plant (Minnesota): As a result of tax credits supporting license renewal applications, Monticello has been able to maintain its annual output of 6 billion kWh of power. [187]

The risk of IRA repeal or reform creates uncertainty and leads to an investment climate that is now riskier.[188] As noted already, nuclear generation is supported by the shared bipartisan policy priorities to increase firm power supplies and preserve jobs, so the risk of material reductions to IRA's incentives for nuclear investment is considered to be low – but the matter has not yet been clarified. Nuclear investments typically require five to ten years of lead-time and necessitate long-term visibility on policy and regulation. Developers and utilities may postpone or cancel projects if tax credits such as Section 45U are removed or revised, or if cost-raising tariffs are

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[184] Chupka, M., Greenwald, J., Ibarra Jr., V., & Brown, J. D. (2023, December). *Implications of Inflation Reduction Act Tax Credits for Advanced Nuclear Energy.* Nuclear Innovation Alliance. https://nuclearinnovationalliance.org/sites/default/files/2023-12/Final%20Report%20V1%20-%20Implications%20of%20Inflation%20Reduction%20Act%20Tax%20Credits%20-%20December%202023.pdf

[185] Grid Deployment Office. (2024, January 17). *Biden-Harris Administration Finalizes Award of $1.1 Billion in Credits to Pacific Gas and Electric's Diablo Canyon Power Plant.* U.S. DOE. https://www.energy.gov/gdo/articles/biden-harris-administration-finalizes-award-11-billion-credits-pacific-gas-and

[186] Environment+Energy Leader. (2024, January 19). *DOE Finalizes $1.1 Billion Funding for California's Diablo Canyon Power Plant.* Environment+Energy Leader. https://www.environmentenergyleader.com/stories/doe-finalizes-11-billion-funding-for-californias-diablo-canyon-power-plant,701

[187] Xcel Energy. (2025, January 2). *Xcel Energy's Monticello nuclear plant receives federal approval to extend operations*. Xcel Energy. https://corporate.my.xcelenergy.com/s/about/newsroom/press-release/xcel-energy-s-monticello-nuclear-plant-receives-federal-approval-to-extend-opera-MCJUO44CSYL5EC7GVEIXYC3NJRVQ#:~:text=The%20federal%20approval%20allows%20the,100%25%20carbon%2Dfree%20electricity.

[188] Ho, J. (2025, March 25). *Tariffs and uncertainty are prompting foreign investors to re-think U.S. investment.* Marketplace. https://www.marketplace.org/story/2025/03/25/tariffs-and-uncertainty-are-prompting-foreign-investors-to-re-think-u-s-investment

imposed. In policy-volatile environments, financial institutions are also less inclined to underwrite multibillion-dollar nuclear assets.

Other regulatory tailwinds

Under the Biden Administration:

- In September 2023, the Biden Administration unveiled the Nuclear Energy Strategy Framework,[189] emphasizing the role of nuclear power in achieving the nation's climate and energy security goals. This framework includes increased investment in nuclear fuel supply chains, efforts to commercialize advanced reactor designs, and policies to enhance the economic viability of existing nuclear plants. A key component of this strategy is the establishment of domestic high-assay low-enriched uranium (HALEU) supply chains, which are critical for fueling advanced reactors and reducing dependence on foreign nuclear fuel sources.
- The ADVANCE Act, signed into law in July 2024, establishes key regulatory reforms designed to accelerate the development and deployment of advanced nuclear reactors.[190] A central component is the establishment of specific review deadlines for certain types of nuclear licensing applications, such as Section 207.[191] The Act mandates a 25-month review deadline for reactors being built on already-operating nuclear sites, ensuring a more predictable and efficient regulatory process.
- In early 2024, the Nuclear Regulatory Commission (NRC) approved a rulemaking process to establish a risk-informed, performance-based regulatory framework for advanced reactors. The NRC has also worked on finalizing regulations that would enable the deployment of microreactors in remote areas, supporting energy security and grid resilience in underserved regions.[192]
- In October 2024, the NRC proposed a rule codifying a Generic Environmental Impact Statement (GEIS)[193] to be used in the licensing process for advanced nuclear reactors. GEIS is intended to simplify and shorten the environmental review timeline, reducing regulatory burdens while maintaining stringent safety and environmental protection standards. The NRC estimates that the GEIS could reduce the costs of environmental reviews for new advanced reactors by between 20 percent and 45 percent, depending on the project's scope and location.
- In March 2023, the DOE announced the launch of the "Pathways to Commercial Liftoff: Advanced Nuclear" initiative, outlining the steps necessary to scale up advanced nuclear reactor deployment.[194] This initiative provides a roadmap for achieving cost reductions,

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[189] Wyoming Energy Authority. (2023, June 5). *Nuclear Energy - Industrial Development Strategic Framework and Roadmap*. Wyoming Energy Authority. https://wyoenergy.org/wp-content/uploads/2023/07/08_31_23-Nuclear-Energy-strategic-framework-1.pdf

[190] U.S. Nuclear Regulatory Commission. (2024). *ADVANCE Act (Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2024)*. U.S. NRC. https://www.nrc.gov/about-nrc/governing-laws/advance-act.html

[191] Lee, S., Hayes, M., & Lauron, C. (2025, March 4). *Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2024 (ADVANCE Act of 2024) Section 207 - Combined License Review Procedure*. U.S. NRC. https://www.nrc.gov/docs/ML2504/ML25041A145.pdf

[192] U.S. Nuclear Regulatory Commission. (2025, April 10). *Microreactors.* U.S. NRC. https://www.nrc.gov/reactors/new-reactors/advanced/modernizing/microreactors.html

[193] Federal Register. (2024, October 4). *Generic Environmental Impact Statement for Licensing of New Nuclear Reactors*. Federal Register. https://www.federalregister.gov/documents/2024/10/04/2024-22385/generic-environmental-impact-statement-for-licensing-of-new-nuclear-reactors

[194] Kozeracki, J., Vlahoplus, C., Erwin, K., Propp, A., Razdan, S., Auguste, R., Stuhldreher, T., Walrond, C., Bates, M., Bickford, E., Foss, A., Gaston, D., Herman, C., Stanley, R., Valderrama, B., Scott, K., Granzier-Nakajima, T.,

improving supply chain resilience, and fostering public-private partnerships in the nuclear sector. Additionally, the DOE's Loan Programs Office has expanded financial support for new nuclear projects, offering loan guarantees to help facilitate the construction of small modular reactors and next-generation nuclear facilities.

Under the Trump Administration:

President Trump signed several executive orders in his first week in office with the goal of bolstering American leadership in artificial intelligence and energy. These included Executive Orders on Unleashing American Energy,[195] declaring a National Energy Emergency and Removing Obstacles to American Leadership in Artificial Intelligence. He followed up on February 14th by issuing another executive order, Establishing the National Energy Dominance Council, acknowledging the vital role that energy plays in maintaining America's technological advantage.[196]

President Trump also revealed a significant investment program under this initiative headed by a joint venture of Open AI, Oracle, MGX, and SoftBank. Over the next four years, the venture intends to spend $500 billion in AI infrastructure—which consists of data centers ideally co-located or coupled with electric generating plants.[197] Among the biggest and fastest-growing consumers of electricity, data centers are expected to foster increased energy demand. Data centers now account for almost 2 percent of world electricity consumption; by 2030, the U.S. "algorithm economy" alone is expected to rise to more than 9 percent of national power demand, or "load."[198]

As noted already, Trump's energy policy is aimed at reviving domestic energy production, especially when it comes to national security and job creation. The executive order "Unleashing American Energy," calls for actions to speed up the permitting process for significant energy and infrastructure projects, including nuclear. By increasing domestic production capacity, these actions could partially counteract the negative effects of IRA reform or burdensome import tariffs, if Congress agrees to provide incentives or low-cost loans to companies that make nuclear components.

The 2024 bipartisan ADVANCE Act, which facilitates advanced reactor licensing, funds early-stage SMRs and supports workforce training, is viewed as having support from the Trump Administration. If combined with selective IRA components with bipartisan support, nuclear projects situated in key areas will likely continue to receive some degree of federal assistance.

Existing Reactors: In terms of policy, it is anticipated that the DOE will keep up its support through programs such as the Civil Nuclear Credit (CNC) program, which offers financial aid to

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Donohoo-Vallett, P., Fanning, T., & Dixon, B. (2024). *Pathways to Commercial Liftoff: Advanced Nuclear. U.S.* DOE. https://liftoff.energy.gov/wp-content/uploads/2024/10/LIFTOFF_DOE_Advanced-Nuclear_Updated-2.5.25.pdf

[195] The White House. (2025, January 20). *Unleashing American Energy*. The White House. https://www.whitehouse.gov/presidential-actions/2025/01/unleashing-american-energy/

[196] The White House. (2025, February 14). *Establishing the National Energy Dominance Council*. The White House. https://www.whitehouse.gov/presidential-actions/2025/02/establishing-the-national-energy-dominance-council/

[197] Duffy, C. (2025, January 21). *Trump announces a $500 billion AI infrastructure investment in the US.* CNN Business. https://www.cnn.com/2025/01/21/tech/openai-oracle-softbank-trump-ai-investment/index.html

[198] Perlis, M., Dorrough, E., & Hein, J. (2025, February 18). *Will the Trump Administration Clear a Path through the Nuclear Regulatory Thicket for the Co-Location of Data Centers with Nuclear Generation? (Part 1 of 2).* Inside Energy & Environment. https://www.insideenergyandenvironment.com/2025/02/will-the-trump-administration-clear-a-path-through-the-nuclear-regulatory-thicket-for-the-co-location-of-data-centers-with-nuclear-generation-part-1-of-2/

stop nuclear plants from early closures.[199] The long-term role of nuclear power in the domestic energy mix could be strengthened by the selection of additional reactors for CNC based on economic need and emissions impact. To increase reactor performance and safety, operators will likely spend money on cybersecurity, digital upgrades, and component replacements. Overall, existing reactors are anticipated to receive policy and federal support to act as a foundation for clean energy transitions, especially in markets where SMRs and new large reactors will not be operational until the early 2030s.

Tariffs: As already mentioned, the imposed and threatened tariffs by the Trump Administration could result in higher costs for uranium inputs. These tariffs could also raise the capital expenditures for new nuclear facilities as a result of tariffs on steel, aluminum, and other materials needed to build nuclear reactors.

Even a slight increase in input prices could defeat the purpose of the production credit in an industry with lengthy fuel procurement cycles and strictly controlled costs. Additionally, industry analysts from ClearView Energy Partners[200] and the World Nuclear Association caution that in the short term, tariffs could destabilize plant economics and discourage reinvestment, despite supporters' claims that tariffs are meant to preserve and revitalize the United States' currently small uranium enrichment capacity. Furthermore, the efficacy of the IRA's technology-neutral credits would be diminished if tariffs were applied to imported components used in SMRs, which would raise the cost of building new reactors even more.

While tariffs on uranium imports would increase fuel costs for nuclear generators, they would benefit domestic uranium suppliers. The United States is reviving its uranium enrichment capabilities in response. To increase domestic uranium mining, production, enrichment, and conversion capacity, the House of Representatives' Energy and Commerce Subcommittee on Energy, Climate, and Grid Security approved the Nuclear Fuel Security Act in October 2023.[201] The act aims to create and expand vital U.S. nuclear fuel programs. We expect to see more focus on increasing uranium supply.

5. Recent Announcements and Players Matrix

In the last 24 months, there have been significant private-sector developments in the intersection of new nuclear energy and artificial intelligence:

- Google has entered into an agreement[202] to purchase power from SMRs developed by Kairos Power. This deal will contribute up to 500 MW of carbon-free electricity to the U.S. power grid, reinforcing the role of SMRs in the clean energy transition.
- Microsoft has signed a 20-year power purchase agreement with Constellation Energy[203] to receive electricity from the revived Three Mile Island Unit 1 nuclear reactor in

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[199] Grid Deployment Office. (2023). *Civil Nuclear Credit Program.* U.S. DOE. https://www.energy.gov/sites/default/files/2023-02/Civil%20Nuclear%20Credit%20Program%20Fact%20Sheet%20%28February%202023%29.pdf

[200] Johnson, K. (2025, April 7). *Trump's Tariffs Are Killing His Plans for Energy Dominance.* Foreign Policy. https://foreignpolicy.com/2025/04/07/trump-tariffs-energy-dominance-trade-war/

[201] Hurley, C. (2023, October 24). *Latta's Bipartisan Bill to Bolster U.S. Nuclear Energy Production Approved by E&C Energy Subcommittee.* Bob Latta. https://latta.house.gov/news/documentsingle.aspx?DocumentID=404095

[202] Terrell, M. (2024, October 14). *New nuclear clean energy agreement with Kairos Power.* Google Blog. https://blog.google/outreach-initiatives/sustainability/google-kairos-power-nuclear-energy-agreement/

[203] Constellation. (2024, September 20). *Constellation to Launch Crane Clean Energy Center, Restoring Jobs and Carbon-Free Power to The Grid.* Constellation. https://www.constellationenergy.com/newsroom/2024/Constellation-to-Launch-Crane-Clean-Energy-Center-Restoring-Jobs-and-Carbon-Free-Power-to-The-Grid.html

Pennsylvania. The reactor will provide Microsoft with 835 MW of zero-carbon power, ensuring reliable and sustainable energy for its data centers to support artificial intelligence applications and cloud computing.

- Oklo Inc., an advanced nuclear technology company,[204] has partnered with Switch, a leading AI infrastructure provider, to deploy 12 GW of Oklo Aurora powerhouse projects by 2044. This non-binding Master Power Agreement represents one of the largest corporate clean power agreements to date, underscoring the growing interest in nuclear energy for AI-driven power demands.
- Siemens has collaborated with NVIDIA[205] to integrate artificial intelligence into its digital twin technology for nuclear power plants. This partnership is focused on improving predictive maintenance and operational efficiency by enabling real-time monitoring and optimization of plant operations, ultimately enhancing the safety and reliability of nuclear energy production.
- GE Hitachi Nuclear Energy has teamed up with Microsoft[206] to leverage AI and cloud computing in the development of next-generation SMRs. By incorporating advanced computing and automation, the partnership seeks to accelerate the deployment of advanced nuclear technologies.
- IBM has joined forces with TerraPower, a nuclear innovation company co-founded by Bill Gates, to apply artificial intelligence and machine learning to the design and optimization of advanced nuclear reactors. This collaboration focuses on enhancing reactor safety and efficiency, particularly for TerraPower's Natrium reactor[207], which features a molten salt energy storage system designed to enhance grid stability and flexibility.

These strategic partnerships highlight the increasing convergence between AI and nuclear energy, as sustainability-minded technology companies seek to secure reliable, zero-carbon power sources to sustain the rapid growth of data centers and computational infrastructure.

…/…

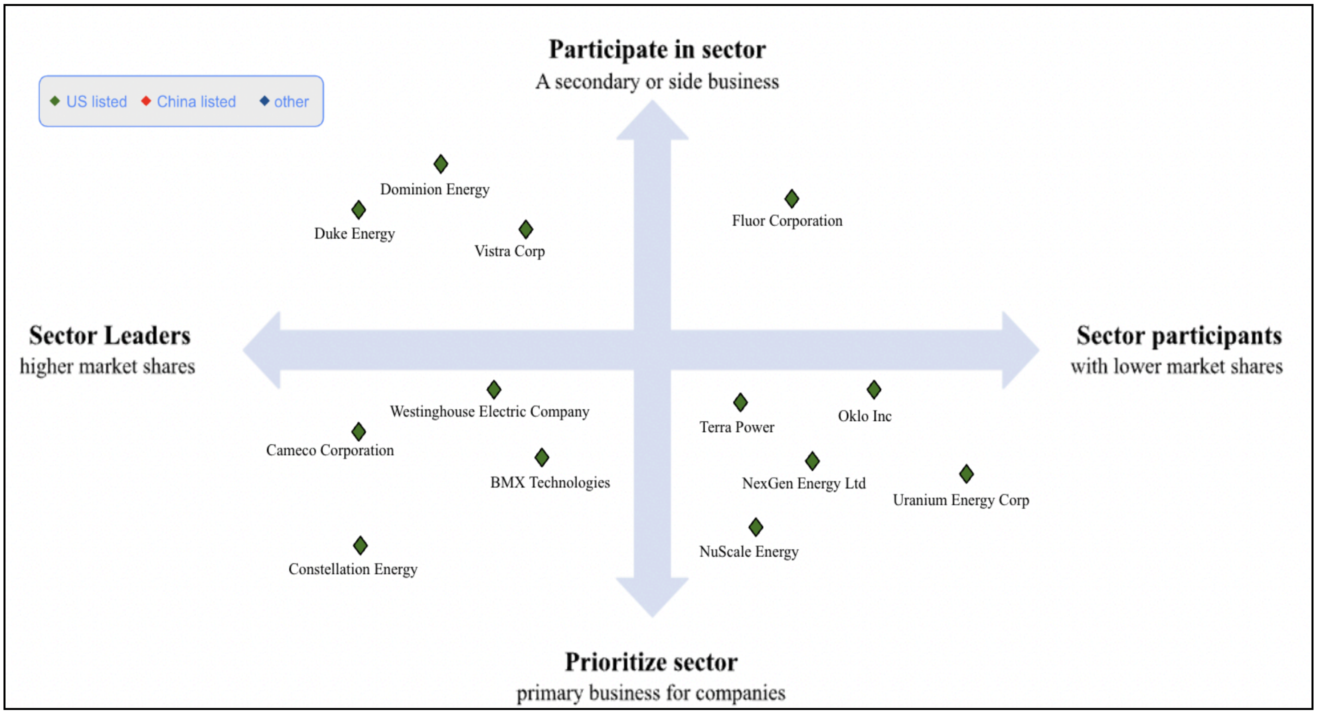
[204] Oklo. (2024, December 18). *Oklo and Switch Form Landmark Strategic Relationship to Deploy 12 Gigawatts of Advanced Nuclear Power, One of the Largest Corporate Clean Power Agreements Ever Signed*. Oklo. https://oklo.com/newsroom/news-details/2024/Oklo-and-Switch-Form-Landmark-Strategic-Relationship-to-Deploy-12-Gigawatts-of-Advanced-Nuclear-Power-One-of-the-Largest-Corporate-Clean-Power-Agreements-Ever-Signed/default.aspx

[205] Kerris, R. (2021, November 15). *Siemens Energy Taps NVIDIA to Develop Industrial Digital Twin of Power Plant in Omniverse.* NVIDIA Blog. https://blogs.nvidia.com/blog/siemens-energy-nvidia-industrial-digital-twin-power-plant-omniverse/

[206] Microsoft. (2024, June 3). *Hitachi and Microsoft enter milestone agreement to accelerate business and social innovation with generative AI*. Microsoft. https://news.microsoft.com/2024/06/03/hitachi-and-microsoft-enter-milestone-agreement-to-accelerate-business-and-social-innovation-with-generative-ai/

[207] TerraPower. *The Plant*. TerraPower. https://www.terrapower.com/natrium/

Figure 59. Matrix of Key Nuclear Players Globally



Source: Capstone analysis

Constellation Energy Corporation (CEG): Constellation Energy Corporation (CEG) is the biggest carbon-free energy generator in the United States, emphasizing nuclear power most of all.[208] The corporation stated annual revenues of around $23.57 billion and a market capitalization of almost $65.25 billion as of 2025. With ten reactors spread over several states, Constellation's nuclear fleet accounts for about 62% of its energy generation. Strategic activities of the corporation, such the proposed reopening of the Three Mile Island Unit 1 reactor to satisfy the rising energy needs of AI data centers, show even more the company's strong entrenchment in the nuclear sector.

Duke Energy Corporation (DUK): Duke Energy Corporation (DUK) is among the biggest electric power holding businesses in the United States.[209] Duke Energy stated yearly revenues of around $30.36 billion and a market capitalization of almost $92.35 billion as of 2025. With many reactors spread around the Carolinas, the company's nuclear fleet accounts for almost 25% of its overall energy production. Reflecting its strong entrenchment in nuclear energy and commitment to long-term, carbon-free electricity generation, the business recently obtained clearance from the U.S. Nuclear Regulatory Commission to extend the operating licenses of its Oconee Nuclear Station by 20 years. Additionally, Constant investments in nuclear plant operations and maintenance help Duke Energy to maintain the dependability and efficiency of its nuclear assets, therefore strengthening its established position in the nuclear field.

[208] Tatananni, M. (2025, April 9). *Constellation Energy Stock Is a Buy. There Are 'Select Opportunities' for Nuclear.* Barron's. https://www.barrons.com/articles/constellation-energy-stock-nuclear-buy-6d4c584f

[209] Benzinga. (2025, February 13). *Duke Energy Powers Up: Q4 EPS Rises, Revenue Beats And 2025 Outlook Holds Firm.* Tiger Trade. https://www.itiger.com/news/2511252811

Dominion Energy Inc. (D): Dominion Energy Inc., based in Virginia, is a leading energy company with a strong presence in nuclear power generation.[210] In 2025, Dominion declared annual sales of $17.17 billion and a market value of roughly $48.24 billion. Dominion owns the North Anna and Surry power plants, and the company's nuclear activities account for about 35% of its overall energy production. Constant expenditures in facility modernization and license renewals show Dominion's dedication to nuclear energy, therefore guaranteeing long-term survival of its nuclear fleet for instance, The company continues to invest in modernizing its nuclear facilities and has reaffirmed its long-term operating earnings growth guidance of 5% to 7% through 2029.

Vistra Corp. (VST): Vistra Corp., headquartered in Irving, Texas, is one of the largest competitive power producers in the United States with a growing emphasis on nuclear energy. In 2025, Vistra Corp reported annual revenues of $17.22 billion[211] and had a market capitalization of around $43.08 billion.[212] Vistra Corp significantly expanded its nuclear portfolio in 2024 with its acquisition of Energy Harbor,[213] additionally adding 4,000 MW of nuclear generation capacity to its existing fleet. Prior to that, Vistra had also strengthened its market presence by acquiring Dynegy Inc. in 2018 and Crius Energy in 2019, enhancing its position in both generation and retail energy sectors. Nuclear energy now accounts for roughly 25–30% of Vistra Corp's total electricity generation. Vistra's ongoing investments in modernizing facilities, upgrading operations, and extending licenses, clearly demonstrates its commitment to expanding and strengthening its nuclear assets and strategically emerging as a key player in the U.S. nuclear energy landscape.

BWX Technologies (BWXT): Leading supplier of nuclear components and fuels to the United States government including Navy nuclear propulsion systems, BWX Technologies (BWXT) has a market cap of over $9.45 billion and had revenues of $2.7 billion in 2024.[214] Given that nuclear-related operations account for almost 90% of BWXT's income, it is clearly highly ingrained in the nuclear industry. The company has enlarged its commercial activities by means of acquisitions like Kinectrics, Inc., thereby improving its capabilities in the nuclear power and medical industries. It is also engaged in the development of new nuclear technologies, like microreactors.

Fluor Corporation (FLR): Fluor Corporation works on significant infrastructure and energy projects all across the United States.[215] The company's market capitalization is $5.59 billion and its revenues in 2024 are approximately $16.3 billion. Though nuclear is a lesser portion of its total business approximating at about 10%, Fluor plays a significant role in the nuclear sector through its majority ownership (51%), of NuScale Power, a SMR pioneer. Fluor's importance in the nuclear industry value chain is further shown by the nuclear engineering, procurement, and decommissioning contracts it has received in the United States

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[210] Dominion Energy. (2025, February 12). *Dominion Energy announces 2024 financial results*. Dominion Energy. https://news.dominionenergy.com/press-releases/press-releases/2025/Dominion-Energy-announces-2024-financial-results/default.aspx

[211] Nasdaq. (2025, April 27). *Vistra Corp. Common Stock (VST)*. Nasdaq. https://www.nasdaq.com/market-activity/stocks/vst

[212] Companies Market Cap. (2025, April 27). *Market capitalization of Vistra (VST)*. Companies Market Cap. https://companiesmarketcap.com/vistra/marketcap/

[213] Vistra Corp. (2024, March 1). *Vistra Completes Energy Harbor Acquisition*. PR Newswire. https://www.prnewswire.com/news-releases/vistra-completes-energy-harbor-acquisition-302077375.html

[214] LevelFields. (2025, February 12). *Leading Nuclear Stocks for 2025: Fluor's Rise and NuScale's Innovation*. LevelFields. https://www.levelfields.ai/news/leading-nuclear-stocks-for-2025-fluors-rise-and-nuscales-innovation

[215] Fluor Corporation. (2025, February 18). *Fluor Reports Fourth Quarter and Full Year 2024 Results*. Fluor Corporation. https://newsroom.fluor.com/news-releases/news-details/2025/Fluor-Reports-Fourth-Quarter-and-Full-Year-2024-Results/default.aspx

Westinghouse Electric Company: Originally used in the nuclear sector, Westinghouse is a historic name well-known for providing nuclear fuel, technologies, plant design, equipment for nuclear power plants all throughout the globe.[216] Among the most sophisticated in the market is the AP1000 reactor design developed by the business. Westinghouse's thorough participation in the nuclear fuel cycle and reactor technology emphasizes its close absorption into the nuclear industry. Cameco Corporation bought a 49% share in Westinghouse in 2023.

TerraPower: Founded by Bill Gates, TerraPower is creating cutting-edge nuclear reactor designs including the Natrium reactor, which blends a molten salt energy storage technology with a sodium fast reactor.[217,218] The company's projected yearly income is $298.8 million. TerraPower has raised approximately $1 billion to date, although particular market capitalization numbers are not publicly available because of its privately held status. Deeply ingrained in the nuclear industry, the company specializes on fuel cycles and next-generation reactor designs. By means of its creative approach, TerraPower seeks to improve the safety, efficiency, and sustainability of nuclear power.

Oklo Inc. (OKLO): Oklo is an advanced nuclear technology company developing compact fast reactors to provide clean, reliable energy solutions.[219] To meet the rising energy needs of AI-driven technologies, Oklo inked a 20-year contract in December 2024 to provide Switch Inc., a significant data center operator, up to 12 gigawatts of nuclear power. Oklo's market value as of April 2025 is approximately $3.13 billion. Reflecting present concentration on research and development phases, the corporation reported no income for 2024. Oklo's nuclear concentration is 100% since the company is focused solely on nuclear energy.

NuScale Power Corp: NuScale Power reported annual revenue of approximately $37 million in 2024, marking a 62.4% increase from the previous year.[220,221] The company's market valuation as of April 2025 is approximately $1.99 billion. NuScale, which provides scalable and adaptable nuclear power solutions, is focused on the construction of SMRs. With possible uses in power generation, desalination, and industry operations, the company's SMR technology is meant to offer safe, dependable, and reasonably priced nuclear energy.

Cameco Corporation (CCJ): With a portfolio focused on high-grade mines in Canada's Athabasca Basin, including Cigar Lake and McArthur River, Cameco is the second-largest uranium producer worldwide.[222,223] Cameco's market-cap stands at $17.75 billion and the compared declared $2.26 billion in income in FY2024. Cameco has positioned itself as a premium uranium provider with long-term commitments. Its 2022 co-acquisition of Westinghouse Electric expanded its value chain reach from mining to fuel cycle services. For energy-transition investors looking for scale, liquidity, and geopolitical relevance in the uranium industry, its exposure to physical uranium inventories, strong balance sheet, and rising institutional interest makes it a core holding.

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216 TerraPower. *The Plant*. TerraPower. https://www.terrapower.com/natrium/
217 Ibid.
218 Growjo. (2025). *TerraPower company profile*. Growjo. https://growjo.com/company/TerraPower
219 Morningstar. (2025). *Oklo Inc Class A Shares*. Morningstar. https://www.morningstar.com/stocks/xnys/oklo/quote
220 Yahoo Finance. (2025). *NuScale Power Corporation (SMR)*. Yahoo Finance. https://finance.yahoo.com/quote/SMR/
221 Business Wire. (2025, March 3). *NuScale Power Reports Fourth Quarter and Full Year 2024 Results*. Yahoo Finance. https://finance.yahoo.com/news/nuscale-power-reports-fourth-quarter-211500828.html
222 Yahoo Finance. (2025). *Cameco Corporation (CCJ)*. Yahoo Finance. https://finance.yahoo.com/quote/CCJ/
223 Cameco Corporation. (2025). *Financial and Investor Reports*. Cameco Corporation. https://www.cameco.com/invest/financial-information

Uranium Energy Corp (UEC): Crucially supporting America's drive for nuclear energy independence, Uranium Energy Corp is a U.S.-based ISR uranium producer and strategic reserve holder.[224] The company has a $2 billion market capitalization and declared 66.83 million in trailing 12-month income. UEC holds entirely licensed assets in Texas and Wyoming and manages one of the biggest unencumbered physical uranium stockpiles in the United States. UEC's strategic value lies in its alignment with federal clean energy goals and energy security priorities especially as the U.S. seeks alternatives to Russian fuel. UEC provides leveraged exposure to pricing and policy tailwinds as domestic uranium demand increases through government procurement, DOE programs, and utility contracting.

NexGen Energy Ltd. (NXE): NexGen is a high-potential development-stage company promising significant upside as governments re-embrace nuclear and global demand for clean energy grows. NexGen Energy is developing the Arrow deposit, one of the world's largest undeveloped high-grade uranium resources, located in the Athabasca Basin. NexGen has a market cap of $2.40 billion, which reflects investor confidence in its future production potential even though it is pre-revenue. Based on cost per pound, the Rook I project, now under permitting, is expected to be among the most efficient uranium mines worldwide. Attracting strategic funding and offtake interest, the company positions itself as a next-generation supplier for utilities moving away from geopolitical risk and toward ESG-compliant suppliers. [225]

[224] Yahoo Finance. (2025). *Uranium Energy Corp. (UEC)*. Yahoo Finance. https://finance.yahoo.com/quote/UEC/
[225] NexGen Energy. (2025). *Reports and Filings*. NexGen Energy. https://www.nexgenenergy.ca/investor-center/default.aspx#financial-reports

2.3 Battery Manufacturing

1. Global Overview

Over the past decade, batteries have transitioned from niche applications to becoming foundational components of decarbonized energy and transport systems. Since 2010, battery costs have declined by approximately 90%, accompanied by notable gains in energy density and durability. These advances have reinforced batteries' position as a core technology in the shift toward low-emission infrastructure.

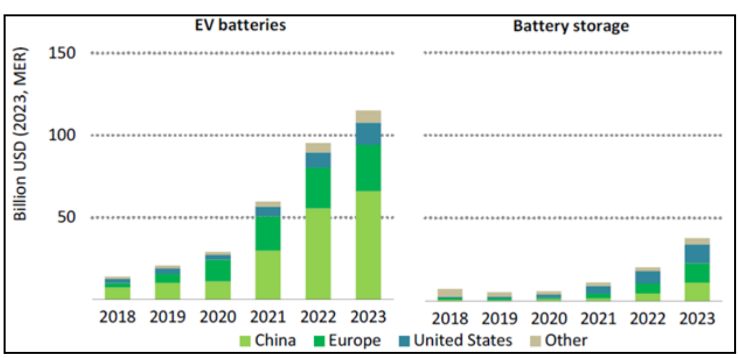
In the power sector, batteries increasingly support grid flexibility, a function historically provided by natural gas and reservoir-based hydropower. As renewable energy penetrates electricity markets, battery storage is emerging as a scalable and economically viable means of balancing supply and demand—particularly when deployed alongside solar photovoltaic (PV) or wind systems.

In transportation, the widespread adoption of EVs has catalyzed structural changes across the automotive value chain. Unlike internal combustion engine vehicles, EVs rely heavily on battery systems, prompting collaboration between automakers, battery producers, and raw material suppliers. Utilities, too, are engaging with automotive and storage firms to develop integrated mobility and energy platforms.

Beyond energy and mobility, batteries are also proving essential to the digital economy. In data centers, battery systems ensure power continuity while supporting peak shaving and operational efficiency. As data intensity grows—driven by artificial intelligence, cloud computing, and digital services—batteries are becoming integral to resilient and sustainable IT infrastructure.

Global investment in battery technologies reached $150 billion in 2023, reflecting an eightfold increase in EV battery deployment and a fivefold surge in stationary storage since 2018.[226] Of this, $115 billion targeted EV batteries and $40 billion was directed toward energy storage. Investment remains concentrated in China, the United States, and Europe, which together account for over 90% of global flows. EV investment disparities largely mirror adoption rates, while battery storage growth has been enabled by regulatory reform, increased renewable generation, and diversified business models - including energy arbitrage and demand management. Utility-scale installations dominate capacity growth, though Europe leads in small-scale applications linked to distributed solar generation.

Figure 60. Global Investment in Storage and EVs Batteries, 2018 - 2023



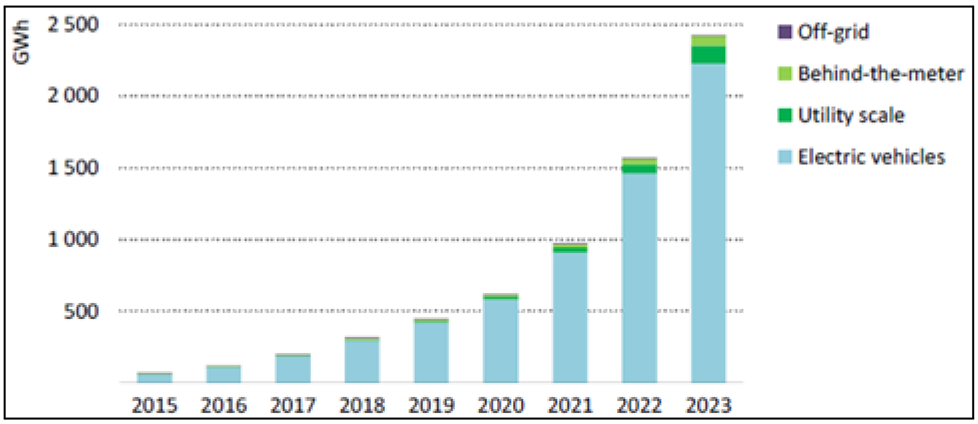
(Source: EIA (2023)

[226] International Energy Agency. (2024, October). *Energy Technology Perspectives 2024*. IEA. https://www.iea.org/reports/energy-technology-perspectives-2024

2. Production and Costs Trends

In 2023, the total volume of batteries deployed - including both EVs and renewable energy storage - exceeded 2,400 gigawatt-hours (GWh), representing a fourfold increase since 2020. Battery manufacturing is emerging as a pivotal industry in the global energy transition, driven by the rapid growth of renewable energy sources and the accelerating adoption of EVs. While new chemistries are under study, lithium-ion chemistries represent nearly all batteries in EVs and new storage applications today. In the past five years, over 2,000 GWh of lithium-ion battery capacity has been added worldwide, powering 40 million electric vehicles and thousands of battery storage projects.[227]

Figure 61. Lithium-Ion Battery Volumes in Use by Application Type, 2015-2023



Source: EIA (2023)

A lithium-ion battery cell is composed of four essential elements: the cathode, anode, electrolyte, and separator. The cathode and anode act as storage sites for lithium-ions while the separator prevents internal short circuits. The electrolyte enables the movement of lithium ions from the cathode to the anode during charging, and in reverse during discharging.

Over the past decade, the cost of lithium-ion batteries has dropped significantly from around $800/kWh to $115/kWh in 2024 (down 20% from 2023). This downward trend has been driven by advances in research and development, larger production scales, and technological improvements.[228] As a result, raw materials now represent a larger share of total battery costs, making prices more sensitive to fluctuations in critical mineral and metal markets. For instance, the spike in metal prices in 2022 led to the first recorded annual increase in battery prices. (see figure below) By contrast, 2024 price drops were primarily due to cell manufacturing overcapacity, economies of scale, low metal and component prices, adoption of lower-cost LFP batteries, and a slowdown in electric vehicle sales growth. On a regional basis, average battery pack prices were lowest in China, at $94/kWh (battery costs are quoted by the system capital cost divided by storage capacity in kWh's). Packs in the US and Europe were 31% and 48% higher, reflecting the relative immaturity of these markets, as well as higher production costs and lower volumes. The price differences for North America and Europe compared to China were higher

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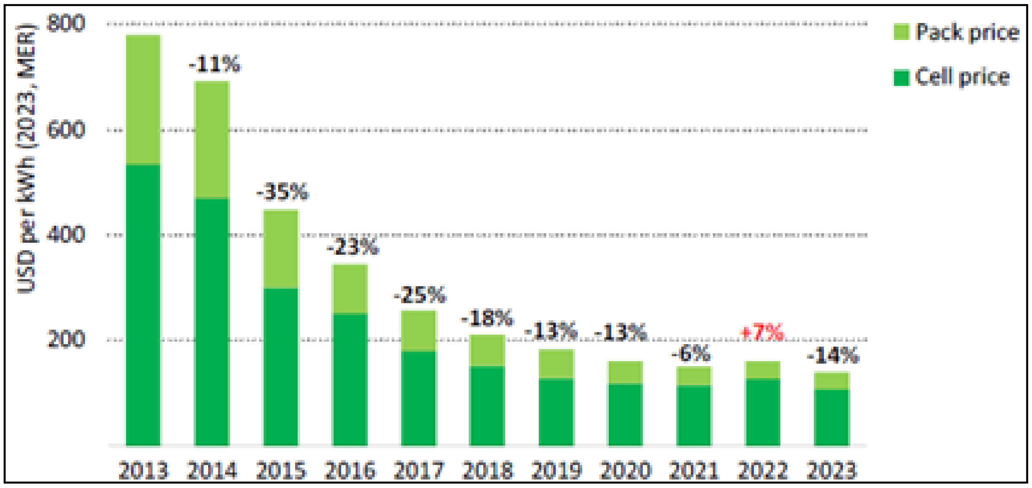
[227] Ibid.

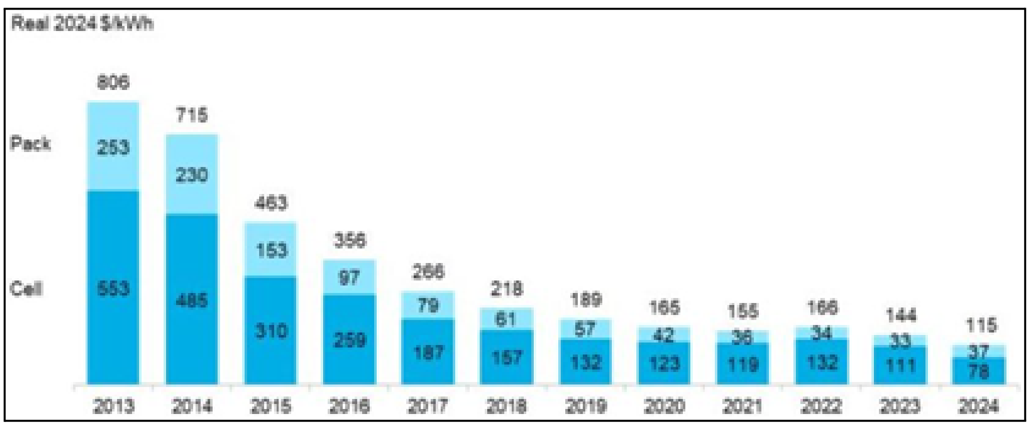
[228] BloombergNEF. (2024, December 10). *Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour*. BloombergNEF. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/

than in other years, implying the drop in prices was more accentuated in China.[229]

Figure 62. Lithium-ion Battery Pack and Cell Prices, EIA and BNEF



Source: EIA (2023)



Source: Bloomberg NEF (2024)

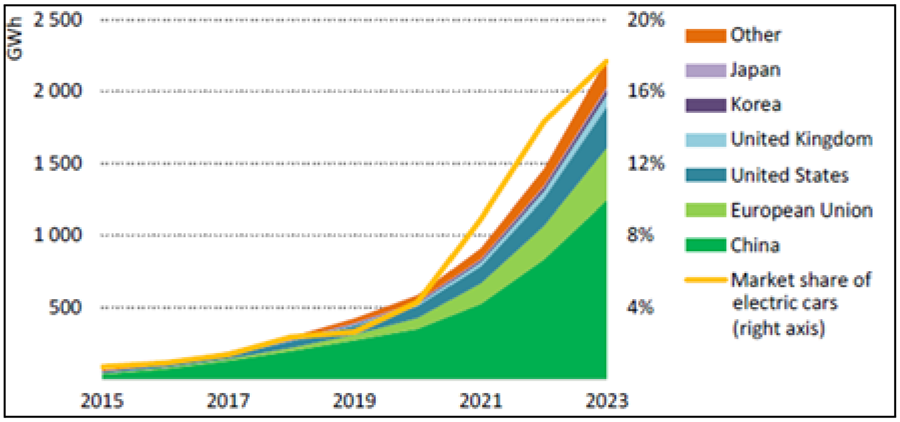
EVs comprise 90% of total lithium-ion batteries in use. Worldwide EVs sales are experiencing rapid growth worldwide rising by 25% to 17 million in 2024, and today nearly one-in-five new cars sold are electric.[230] China dominates the global EV battery market, accounting for more than half of total EV battery volumes in use in 2023 (see Figure 63 below). The European Union and United States together accounted for 30% of total EV battery volumes in use. The market share of electric cars has increased more than sevenfold over the past five years, reaching 18% in 2023. Today, nearly 40% of all new cars sold in China are electric, while in the European Union it is over 20% of all new car sales and 10% in the United States. Batteries used in electric cars in these three regions represent 80% of the global battery volumes in use today in the energy sector. There is huge untapped electrification potential in emerging markets and developing economies other than China, where electric cars currently constitute only 2% of sales.[231]

[229] Ibid.

[230] International Energy Agency. (2025, March 5). *The battery industry has entered a new phase*. IEA. https://www.iea.org/commentaries/the-battery-industry-has-entered-a-new-phase

[231] International Energy Agency. (2024, October). *Energy Technology Perspectives 2024*. IEA.

Figure 63. Battery Volumes in Use in EV Fleets by Region and Market Share, 2015-2023



Source: EIA (2023)

The distribution of EV batteries in use across countries largely mirrors their domestic battery production capacity and the scale of their automotive sectors. China, Europe, and the United States dominate the global EV market, together accounting for 90% of the total EV fleet. China alone produces 83% of the world's batteries, while Europe and the U.S. contribute a combined 13%, with the remaining 4% coming from Korea and Japan. China's dominant position in both battery manufacturing and EV production allows it to meet domestic demand efficiently, equipping the world's largest electric vehicle fleet with some of the most cost-effective batteries. Growing competition among battery manufacturers to secure market share is driving down EV prices in certain segments and regions, which is expected to further accelerate the adoption of electric vehicles.

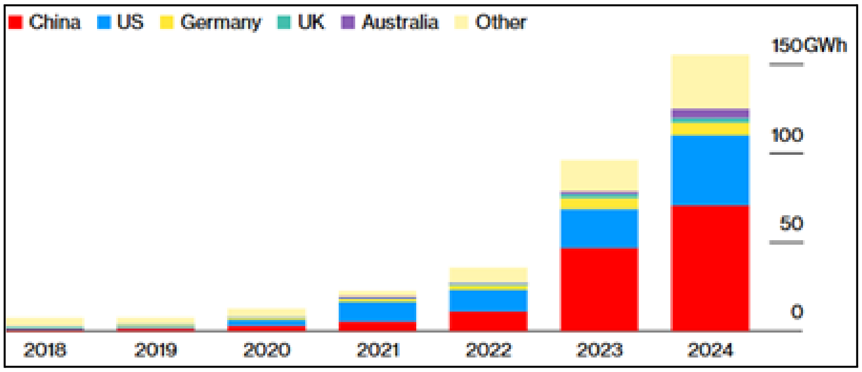
Battery Storage comprises 10% of total lithium-ion batteries in use. Over the course of the last decade, global installed battery storage capacity has increased exponentially. Additions doubled from 2022 to 2023 (40GWh) and increased by 76% to 169GWh in 2024 (see Figure 64 below).[232] The strong increase in annual battery storage capacity additions recorded over the last five years has been driven almost entirely by China, the European Union and the United States, which collectively accounted for nearly 90% of the capacity added in 2023. About 65% of the capacity additions are for utility-scale systems, with behind-the-meter battery storage (installed for residential, commercial or industrial end-user locations) responsible for about 35% of the annual additions on average.

…/…

https://www.iea.org/reports/energy-technology-perspectives-2024

[232] Cheung, A. (2025, January 9). *Five Energy Transition Lessons for 2025*. BloombergNEF. https://about.bnef.com/blog/five-energy-transition-lessons-for-2025/

Figure 64. Battery Storage Installations by Region, 2018-2024



Source: Bloomberg NEF (2024)

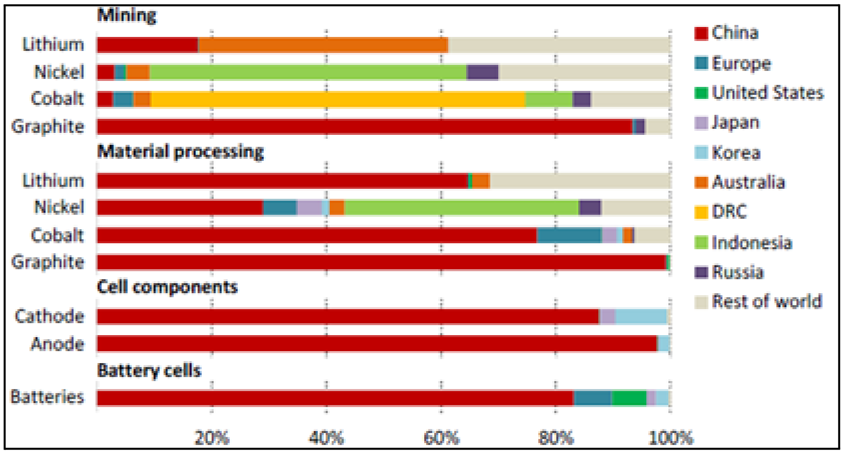
China solidified its position as the leading battery storage market, expanding its share of global annual additions from 20% in 2019 to around 55% in 2023. Capacity increased to over 65GWh, with around two-thirds coming from utility-scale projects driven by provincial mandates requiring energy storage alongside new solar or wind installations. Behind-the-meter storage also grew, primarily among commercial users, supported by subsidies and time-of-use electricity tariffs. The United States ranked second – with nearly 90% from utility-scale projects - led by states like California and Texas. Growth in the US was fueled by falling costs, market reforms, and tax incentives under the IRA. In the European Union, installed battery storage capacity rose by 70% in 2023. Most of this growth was in behind-the-meter systems, particularly in Germany and Italy, where high electricity prices and favorable incentives encouraged storage paired with rooftop solar PV.

3. Supply Chains and Demand Forecast

Most importantly, China controls every stage of the battery production supply chain. The supply chain starts with mineral ores extraction, processing, battery components production (anode, cathode, etc.), cells/packs fabrication, battery application in EVs or storage systems, and recycling. As noted already in this report, more than half of the global processing of raw materials like lithium, cobalt, and natural graphite takes place in China.[233][234] China holds close to 85% of global battery cell manufacturing capacity, along with 90% of cathode and 98% of anode active material production (see figure below). China also leads the graphite anode supply chain with 90% of global graphite mining and plays a dominant role across all stages. Despite producing nearly 20% of the world's electric vehicles, Europe has a limited role in the broader battery supply chain, except for 7% of battery cell manufacturing - mainly located in Poland and Hungary - and about 10% of cobalt refining, which is mostly done in Finland. The U.S. contributes around 10% to global EV production and 6% to battery cell manufacturing (see figure below). Both the United States and Europe are currently unable to meet their battery domestic demand, whereas China's battery manufacturing exceeds domestic demand, with a 20% surplus available for export markets (see figure below). Lastly, South Korea produces nearly 10% of the world's cathode active materials, Australia controls 40% of the world's lithium, and Congo controls 65% of the world's cobalt.

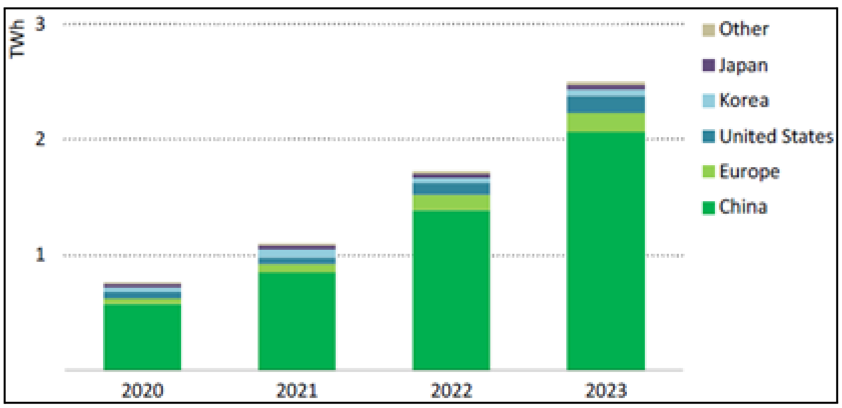
[233] International Energy Agency. (2024, April). *Batteries and Secure Energy Transitions*. IEA. https://www.iea.org/reports/batteries-and-secure-energy-transitions.
[234] International Energy Agency. (2024, October). *Energy Technology Perspectives 2024*. IEA. https://www.iea.org/reports/energy-technology-perspectives-2024

Figure 65. Geographical Distribution of the Global Battery Supply Chain, 2023



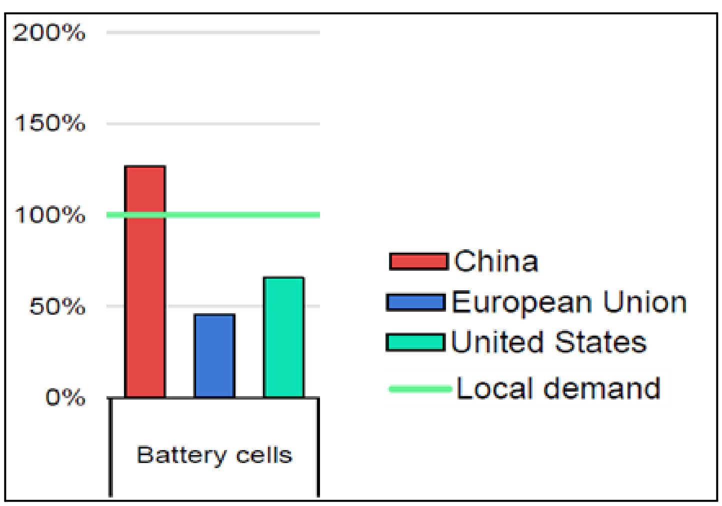
Source: EIA (2023)

Figure 66. Lithium-Ion Battery Manufacturing Capacity by Region, 2023



Source: EIA (2023)

Figure 67. Battery Cells Production Compared to Local Demand by Region, 2023



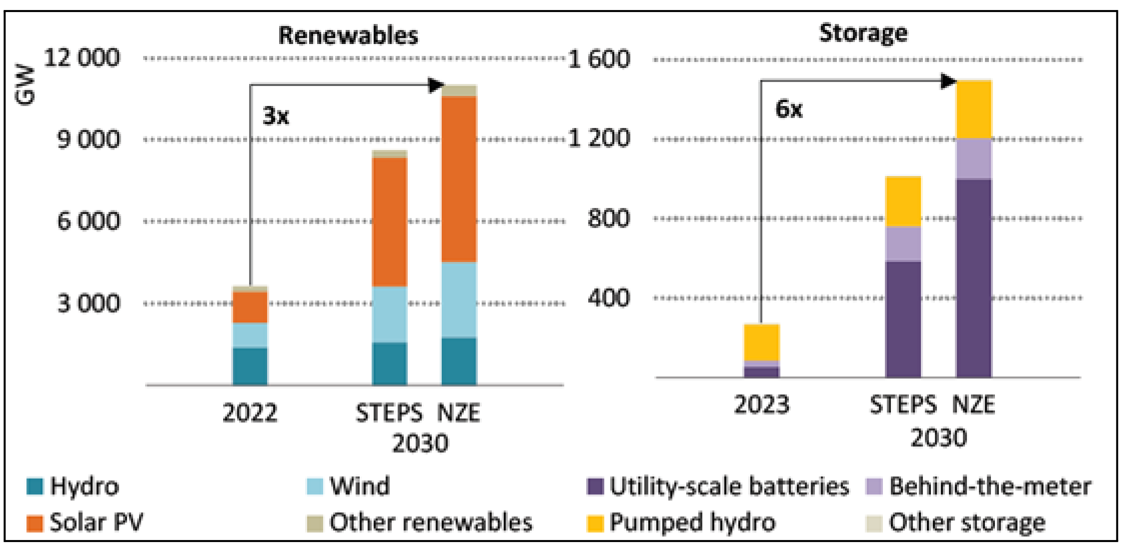
Source: EIA (2023)

Governments around the world are reshoring their battery manufacturing capabilities. While many countries are providing clean tech manufacturing tax credits. As explained more fully further below, the leading example of battery manufacturing policy incentives is the IRA which significantly influences the economics of battery production in the U.S. by offering incentives that encourage both supply-side investments and demand-side purchasing behaviors.

Battery demand is expected to increase over the next decades as it leads the transition away from fossil fuels through energy storage and mobility electrification. In December 2023, nearly 200 governments at COP28 agreed on a global target to *triple renewable energy capacity* and *double energy efficiency* by 2030. Batteries are essential to achieve both targets as they integrate solar and wind power and power EVs which are two-to-four times more efficient than internal combustion engines.[235]

The IEA estimates battery demand increases along two scenarios. In the *Net Zero Emissions by 2050 (NZE) Scenario,* which meets the Paris Agreement target of limiting global average temperature increases to 1.5 degrees Celsius (°C) or less in 2100, the tripling of global renewable capacity is accompanied by a sixfold increase in total energy storage from 300GWh in 2023 to 1,500 GWh in 2030. Battery storage leads the way, with utility-scale and behind-the-meter projects combined rising to 1 200 GWh by 2030, accounting for 90% of overall growth in storage. Total energy storage in the NZE Scenario is 50% higher than in the *Stated Policies Scenario (STEPS),* which reflects current policy commitments, assuming countries do not implement significantly stronger climate measures.

Figure 68. Global Installed Renewable Energy and Energy Storage Capacity by Scenario, 2022 - 2030



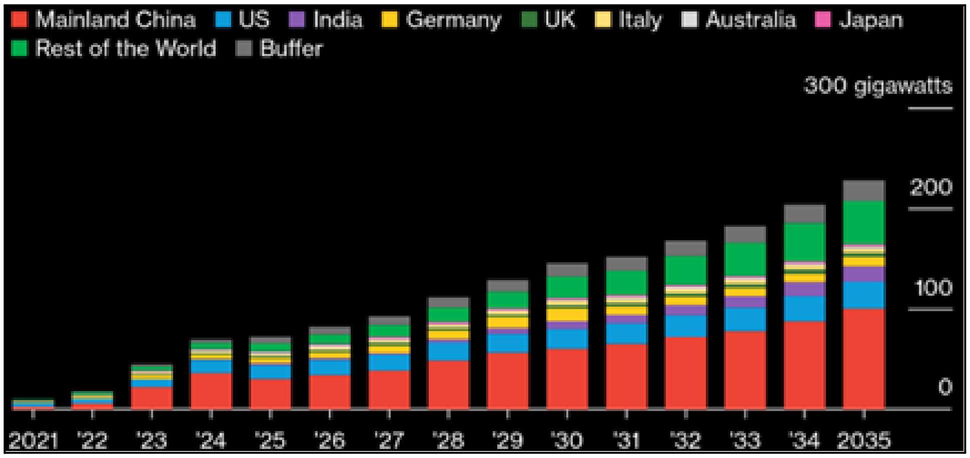
Source: IEA (2024)

With a similar outlook, BloombergNEF (BNEF) expects the energy storage market (excluding Pumped Hydro) to grow by ten times in 2035, expanding to 965 gigawatt-hours (228 gigawatt) cumulatively. China leads, while the US stays second. Other main markets are India, Germany, Italy, UK, Italy, Australia and Japan.[236]

[235] International Energy Agency. (2024 April). *Batteries and Secure Energy Transitions*. IEA. https://www.iea.org/reports/batteries-and-secure-energy-transitions

[236] BloombergNEF. (2024). *Headwinds in Largest Energy Storage Markets Won't Deter Growth*. BloombergNEF. https://about.bnef.com/blog/headwinds-in-largest-energy-storage-markets-wont-deter-growth//

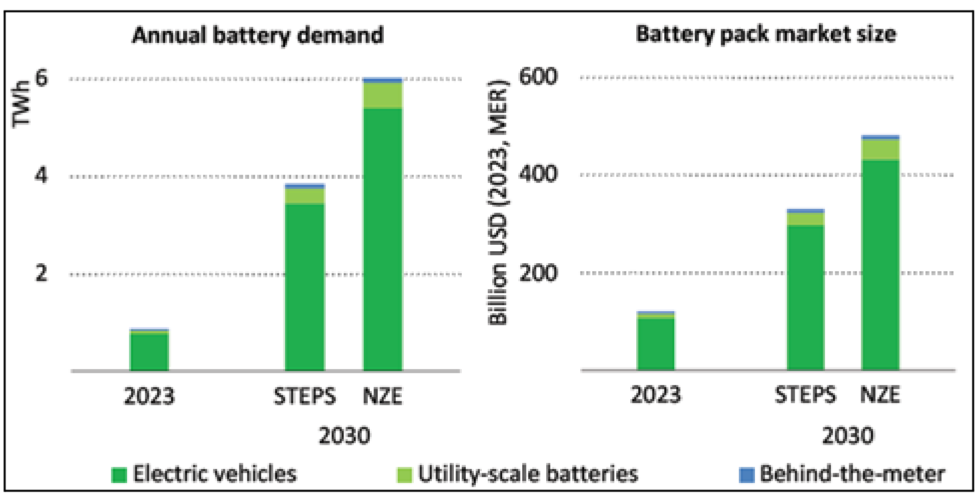
Figure 69. Global Gross Energy Storage Additions by Market, 2021-2035



Source: Bloomberg NEF (2024)

Despite the rapid expansion of battery storage, EVs are expected to represent about 90% of total battery demand by 2030. As mentioned above, electric motors are essential to achieve COP28's target to double energy efficiency as they are two-to-four times more efficient than combustion alternatives. In the STEPS scenario, EVs are projected to make up about 45% of the auto market by 2030, increasing to 70% in the NZE Scenario. To support this, annual EV battery production must grow significantly - from around 0.8 TWh today to 3.5 TWh in STEPS, and up to 5.5 TWh in NZE. In the STEPS, the battery market expands from roughly \$120 billion today to \$330 billion in 2030, while the NZE Scenario propels it to nearly \$500 billion – about 1.5 times the current size of the solar PV market.[237]

Figure 70. Annual Battery Demand and Battery Pack Market Application and Scenario, 2023 – 2030



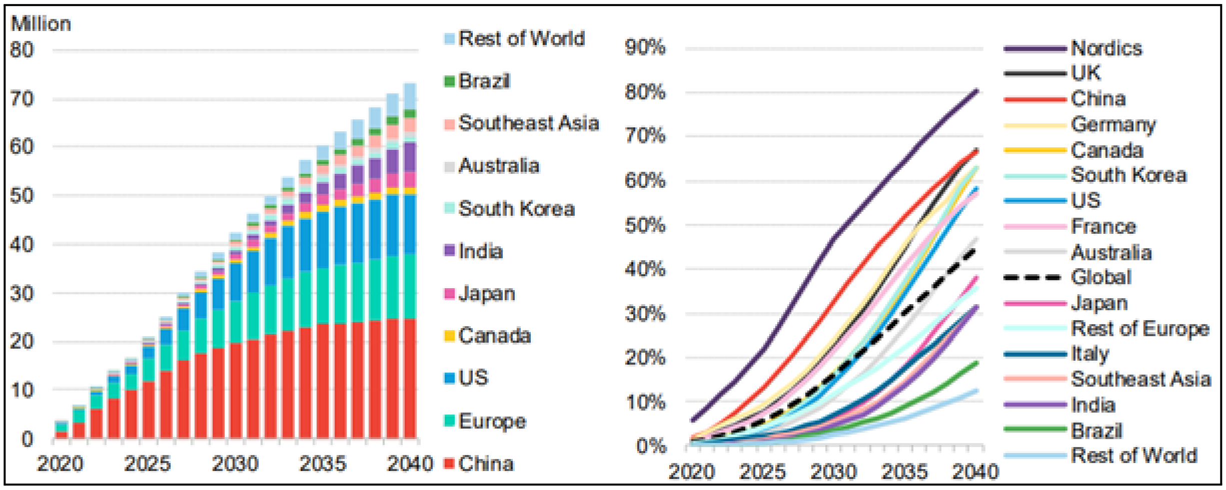
Source: EIA (2023)

With similar estimates, BNEF expects EV sales to reach 45% penetration by 2040 (the IEA predicts that it will happen in 2030). EV sales are set to rise from 17ml in 2024 to over 30 million

[237] International Energy Agency. (2024 April). *Batteries and Secure Energy Transitions*. IEA. https://www.iea.org/reports/batteries-and-secure-energy-transitions

in 2027 (under BNEF's STEPS Scenario equivalent). The EV share of global new passenger vehicle sales jumps to 33% in 2027, from 17.8% in 2023. Only China (60%) and Europe (41%) are above that global average by then, but some European car markets move even faster, with the Nordics at 90% and Germany, the UK, and France all well above 40% (see figure below). The fleet of electric cars grows fast, rising to over 132 million by 2027, from 41 million passenger EVs on the road at the end of 2023.[238]

Figure 71. EV Sales and Market Share by Region, 2020-2040



Source: Bloomberg NEF (2024)

4. Impact of Trade Related Policies

As already noted, the IRA significantly influences the economics of battery production in the U.S. by offering incentives targeting both domestic investment in supply-side manufacturing and demand-side purchasing favoring domestic content.

On the supply side, similar to other clean energy initiatives, battery manufacturers have the option to pursue either a PTC (45X) or an ITC (48C). Prior sections have already described how the 45X Advanced Manufacturing credit provides a 10% credit on production costs for critical mineral extraction and refining. The 45X production tax credit also offers direct financial incentives for manufacturing. It provides $35 per kWh for battery cells produced within the U.S., $10/kWh for domestically manufactured battery modules, and for the creation of electrode active materials such as cathodes and anodes. The alternative 48C ITC can cover up to 30% of a project's capital expenditure, provided the project meets specific labor standards, including wage and apprenticeship criteria. If these conditions are not met, the credit is reduced to 6%. Developers seeking this credit must submit an application to the DOE and receive approval from the Internal Revenue Service (IRS). The total allocation available under the 48C program is limited to $10 billion.[239] In contrast, the 45X credit does not require prior approval from either the DOE or IRS and is not subject to a funding cap, allowing all qualified producers to benefit.

On the demand side, the U.S. government supports electric vehicle adoption (30D and 45W respectively for private and commercial vehicles) and storage installations (48). While the commercial vehicle credit (45W) has no local content requirements, the consumer vehicle credit

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[238] BloombergNEF. (2024). *Electric Vehicle Outlook 2024*. BloombergNEF. https://about.bnef.com/electric-vehicle-outlook/

[239] *Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818 (2022).*

(30D) does. Buyers of eligible battery electric or plug-in hybrid vehicles can receive up to $7,500 in tax credits, split evenly between $3,750 for meeting critical mineral sourcing requirements and $3,750 for using domestically manufactured battery components. Vehicles may qualify for only one portion of the credit depending on compliance. Importantly, consumers can transfer the credit to the dealership, effectively reducing the vehicle's purchase price at the point of sale. Lastly, storage installations - including residential, commercial, and utility-scale battery systems - are eligible for the Section 48 ITC, which can cover up to 30% of installation costs.

These credits are designed to work together. Without strong demand for EVs and charging infrastructure in the United States, demand for U.S.-made components would be insufficient to sustain those facilities. In other words, the consumer credits support the production credits by fostering U.S. demand for domestically sourced charging equipment, vehicles, and their associated components. By targeting both supply and demand, these credits help build a robust domestic supply chain in the United States capable of delivering vehicles that Americans want to buy.

Table 7. IRA Incentives Fostering Domestic Battery Manufacturing

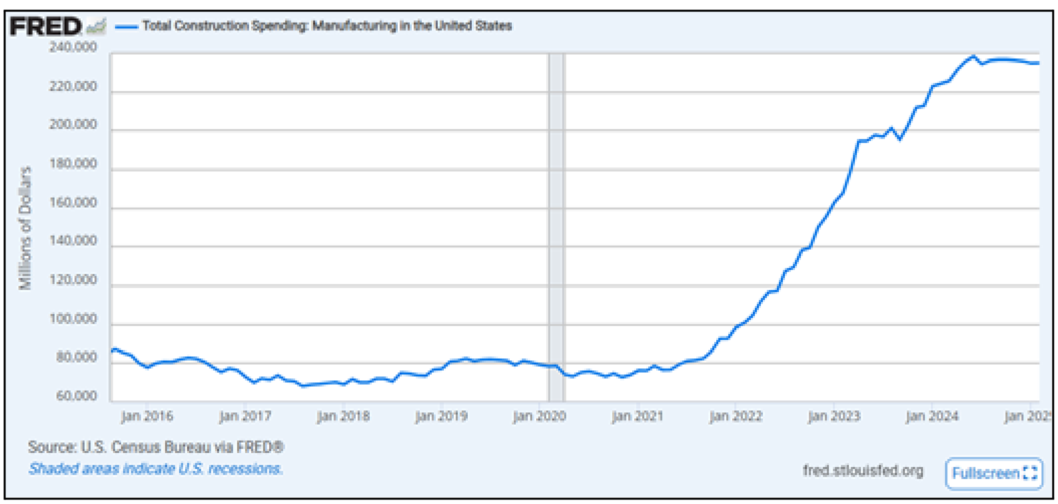
	Supply	
Tax Credit	**Claimant**	**Description**
Advanced Manufacturing Production Credit (45X)	Manufacturer operating in the United States	**10%** for electrode active materials **10%** for critical mineral production **$35/kWh** for battery cells **$10/kWh** for battery modules (or $45/kWh for modules without cells)
Advanced Energy Project Credit (48C)	Manufacturer operating in the United States	**Up to 30%** of qualified investment in facilities that manufacture clean energy components (e.g., batteries, solar panels, carbon capture equipment, etc.)**. $10bn cap reached** in January 2025
	Demand	
Tax Credit	**Claimant**	**Description**
Commercial Clean Vehicle Credit (45W)	Customer	**30%** for electric vehicles placed in service for commercial purposes (including to be leased by an end-user). **Up to $7,500** for vehicles under 14,000 pounds. **Up to $40,000** for electric vehicles over 14,000 pounds

New Clean Vehicle Credit (30D)	Customer	**Total credit up to $7,500** per vehicle ($3,500 if critical mineral requirements are met, $3,500 if components requirements are met). Income limits: $300,000 (married filing jointly), $225,000 (head of household), $150,000 (all other filers)
Used Clean Vehicle Credit (25E)	Customer	**30% up to $4,000** for purchasing a used electric vehicle under $25,000 Income limits: $150,000 (married filing jointly), $112,500 (head of household), $75,000 (all other filers)

Source: Capstone analysis

After the IRA enactment in 2022, the US has been experiencing an upsurge in battery manufacturing. The IRA's incentives have catalyzed both supply-side investments - such as battery production facilities (45X, 48C) - and demand-side adoption, including electric vehicles (30D, 45W) and energy storage systems (48, 48E). Together with the Bipartisan Infrastructure Law (2021), which supports charging station deployment, and the CHIPS and Science Act (2022), which backs domestic semiconductor production, these policies have significantly enhanced U.S. industrial capacity and global competitiveness. (see figure below). As a result, global companies are building new battery facilities in the United States at a pace unseen in decades.

Figure 72. Construction Spending Manufacturing, 2016-2025



Source: FRED[240]

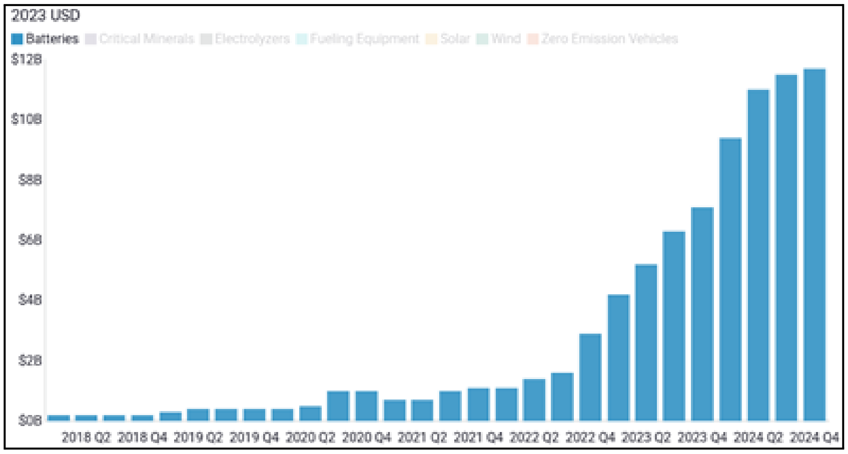
Over the past two years, battery manufacturing increased by $69.3 billion, nearly seven times the $10.9 billion invested over the previous two years. New manufacturing plants are clustering in the Midwest and Southeast with some big projects in California.[241] The investment manufacturing plant credit alone (48C) has generated "250 projects across more than 40 states, with project

[240] U.S. Census Bureau. *Total Construction Spending: Manufacturing in the United States [TLMFGCON]*. FRED; Federal Reserve Bank of St. Louis. Retrieved May 2, 2025, from https://fred.stlouisfed.org/series/TLMFGCON

[241] Clean Investment Monitor. (2025). *Clean Energy and Clean Tech Investment Trends Report*. Clean Investment Monitor. https://cleaninvestmentmonitor.org/

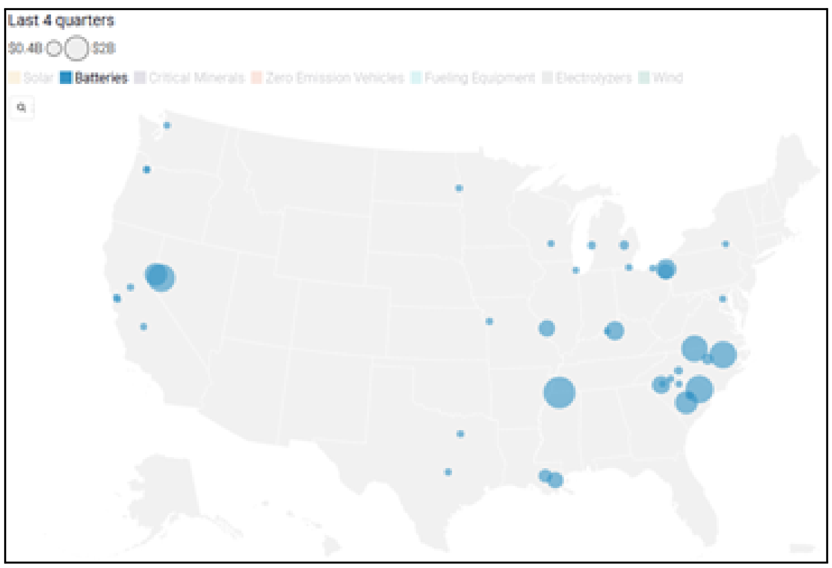
investments over $44 billion dollars".[242]

Figure 73. Battery Manufacturing Investment in the U.S,, 2018-2024



Source: Clean Investment Monitor (2025)

Figure 74. Manufacturing Investment Announcement Locations, 2024



Source: Clean Investment Monitor (2025)

Over the past two years storage installations rose by $44.55bn, three times higher than the $15bn invested over the previous two years.[243] Storage investments are heavily concentrated in California (CAISO) and Texas (ERCOT). California relies on batteries to smooth supply-demand imbalances of its vast solar capacity and reduce curtailment. Whereas Texas' deregulated market structure allows batteries to capitalize on price volatility, offering revenue through arbitrage and ancillary services. Lastly, American businesses and households invested $92bn in EVs in the past year, a 14% increase from the previous year.

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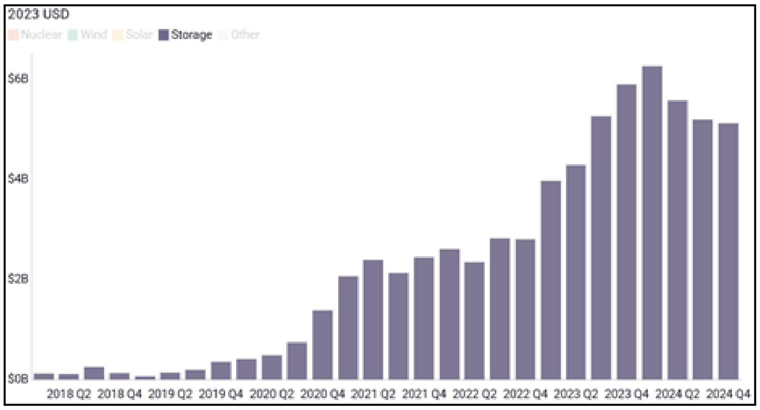
[242] U.S. Department of the Treasury. (2025, January 10). *U.S. Department of the Treasury and IRS Announce $6 Billion in Tax Credit Allocations for the Second Round of the § 48C Qualifying Advanced Energy Project Tax Credit*. U.S. Department of the Treasury. https://home.treasury.gov/news/press-releases/jy2779

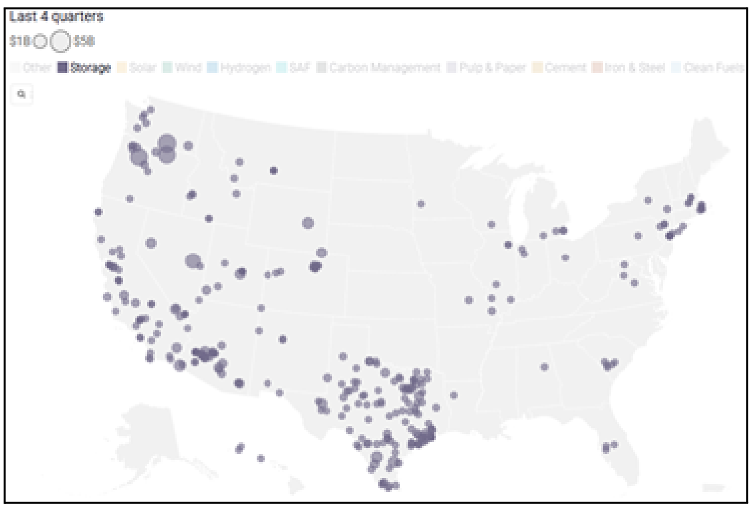
[243] Clean Investment Monitor. (2025). *Clean Energy and Clean Tech Investment Trends Report*. Clean Investment Monitor. https://cleaninvestmentmonitor.org/

Figure 75. US Energy Storage Deployment, 2018-2024



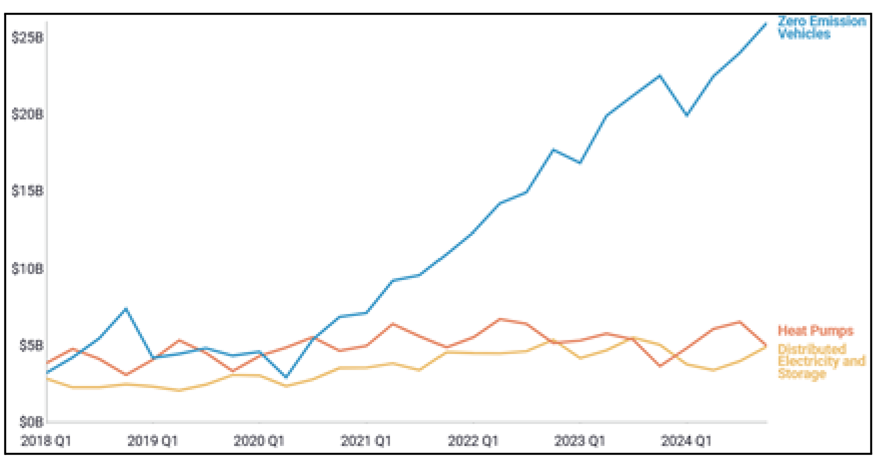
Source: Clean Investment Monitor (2025)

Figure 76. Geographical Distribution of Energy Storage Deployment, 2024



Source: Clean Investment Monitor (2025)

Figure 77. Retail Investment in Electric Vehicles, 2019-2024

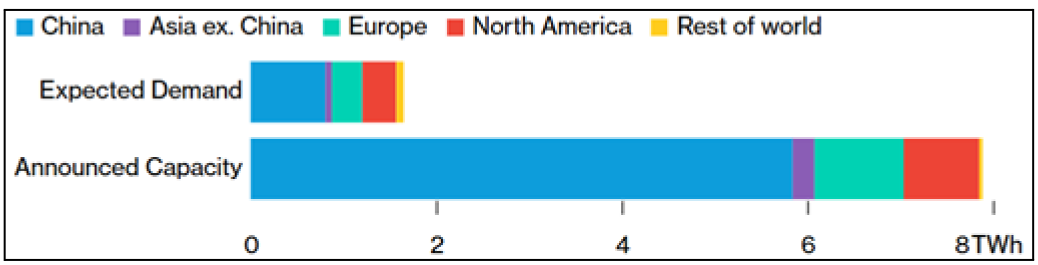


Source: Clean Investment Monitor (2025)

Tailwinds: Oversupply, Potential IRA Reform, Tariffs

Oversupply: However, the recent advances of the US manufacturing sector face three main challenges. First, a global oversupply of batteries depresses prices and erodes profitability. As countries like the US and Europe invest billions to onshore battery production, China already manufactures more lithium-ion batteries than the entire world currently needs.[244] In 2023, global demand for EV and stationary storage batteries was around 950 GWh, yet total manufacturing capacity exceeded 2,600 GWh - with China alone producing close to global demand levels. This imbalance is intensifying, with BNEF tracking nearly 7.9 terawatt-hour (TWh) of capacity announced for 2025, against demand projections of only 1.6 TWh. Even accounting for delays and cancellations, overcapacity remains severe. The consequences are profound. As outlined above, in 2024 battery prices fell to $115/kWh (down 20% from 2023), due to cell manufacturing overcapacity, economies of scale, low metal and component prices, adoption of lower-cost LFP batteries, and a slowdown in electric vehicle sales growth.[245] This figure represents a global average, with prices varying widely across different countries and application areas. U.S. and European battery pack prices were 31% ($123/kWh) and 48% ($139/kWh) higher than China's $94/kWh. For new players, especially those backed by the US IRA or Europe's subsidy programs, this environment is very challenging. Building a plant is only the beginning; ramping up efficient production with low scrap rates is an even steeper hill. Meanwhile, Chinese firms like BYD and CATL are acting like startups, investing heavily in R&D and rolling out advanced technologies.

Figure 78. Announced Lithium-Ion Battery Manufacturing Capacity and Demand, 2025



Source: Clean Investment Monitor (2025)

IRA Reform: Second, investors' confidence is deterred by Trump's potential modification of the IRA credits. As already noted, the House Republicans are expected to scale back IRA incentives. However, this effort faces resistance within the party, as over 75% of recent clean energy investments - worth nearly $125bn - have gone to GOP districts, according to Atlas Public Policy.[246] The Trump administration has already revoked Biden-era 50% EV target by 2030 and halted the distribution of unspent government funds for vehicle charging stations from a $5bn fund allocated by the Bipartisan Infrastructure Law.[247] The administration is also seeking to eliminate the $7,500 consumer tax credit for EV purchases (30D, 45W), eroding an already softened EV

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

[245] BloombergNEF. (2024, December 10). *Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour*. BloombergNEF. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/

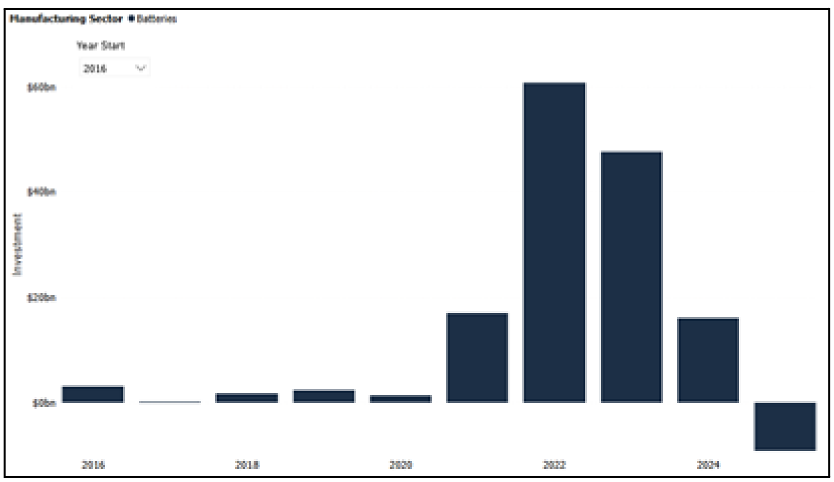
[246] Clean Investment Monitor. (2025). *Clean Energy and Clean Tech Investment Trends Report*. Clean Investment Monitor. https://cleaninvestmentmonitor.org/

[247] Shepardson, D. (2025, January 20). *Trump revokes Biden 50% EV target, freezes unspent charging funds*. Reuters. https://www.reuters.com/business/autos-transportation/trump-revokes-biden-order-that-set-50-ev-target-2030-2025-01-21/

demand. Princeton University estimated a 30% decline in EV sales by 2027 if these incentives are repealed.[248] Additionally, the $10 billion in 48C tax credits for clean energy manufacturing has already reached its allocation cap, making it unavailable for new applicants.[249]

This tax uncertainty is already deterring new battery manufacturing investments. Recent estimates from Atlas Public Policy and Utah State University show the first $9.2bn compression of battery manufacturing investment announcements in Q1 2025 (see figure below).[250] With reduced visibility into future incentives, investors are less willing to commit long-term capital. Bankers interviewed by our team are tightening their sponsor requirements for battery manufacturers demanding full guarantees to finance bridge loans. In the context of EV battery plants, lenders are changing their contracts to face two different scenarios. On the one hand, bankers are renegotiating off-take agreements to face a potential repeal of 45X. For example, automakers may agree to pay a higher price for the batteries produced by the finance manufacturer, with contractual clauses that automatically adjust pricing if credits are removed. On the other hand, if Foreign Entities of Concern (i.e. China) becomes ineligible for 45x, the financial burden becomes entirely a sponsor issue.[251] In such cases, the battery manufacturer is expected to issue a guarantee, such as a letter of credit to cover additional costs. Since this additional policy risk can only be absorbed by large sponsors with enough liquidity, there might be a trend in financing mostly large projects of established developers. Such a fly-to-quality might reduce the market share of small manufacturers.

Figure 79. Battery Manufacturing Investment Announcement, 2016-2025



Source: Bloomberg NEF (2024)

Nearly half of the $30 billion in climate-linked factories announced for 2025 are now predicted to face delays or cancellations, according to BNEF. New plants and expansions spanning battery, solar, wind turbine, and electrolyzer manufacturing were largely initiated in response to the IRA's

[248] Jenkins, J. (2025, March 10). *Potential impacts of electric vehicle tax credit repeal on US vehicle market and manufacturing*. Zenodo. https://doi.org/10.5281/zenodo.15001499

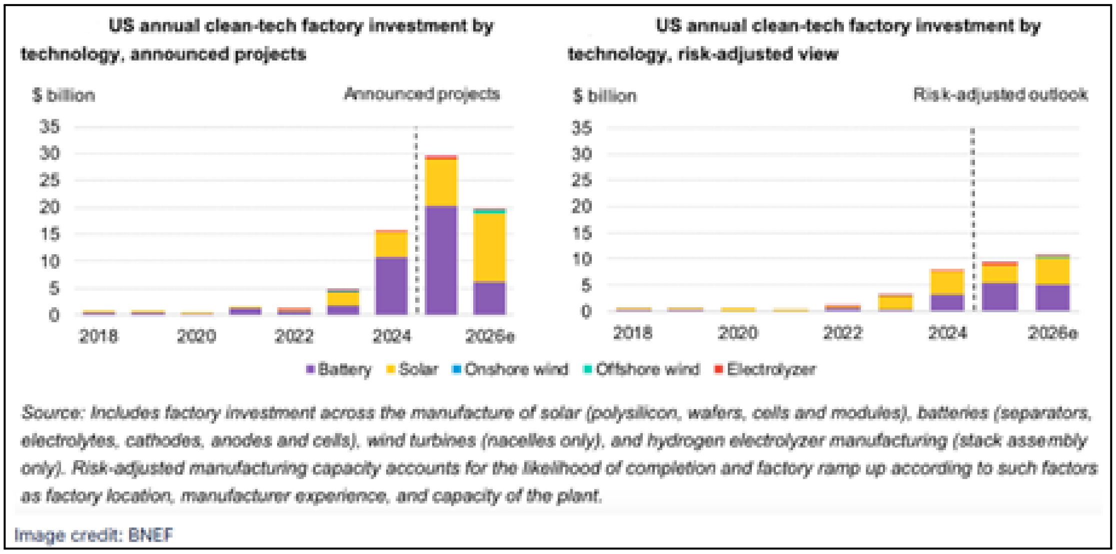
[249] U.S. Department of the Treasury. (2025, January 10). *U.S. Department of the Treasury and IRS Announce $6 Billion in Tax Credit Allocations for the Second Round of the § 48C Qualifying Advanced Energy Project Tax Credit*. U.S. Department of the Treasury. https://home.treasury.gov/news/press-releases/jy2779

[250] Clean Investment Monitor. (2025). *Clean Energy and Clean Tech Investment Trends Report*. Clean Investment Monitor. https://cleaninvestmentmonitor.org/

[251] U.S. Department of Energy. (2024, May 3). *DOE Releases Final Interpretive Guidance on the Definition of Foreign Entity of Concern*. U.S. Department of Energy. https://www.energy.gov/articles/doe-releases-final-interpretive-guidance-definition-foreign-entity-concern

financial incentives. According to Antoine Vagneur-Jones, head of trade and supply chains at BNEF and a lead author of the report, these delays are "rampant," and come even before factoring in potential for new and threatened tariffs on steel, aluminum, other metals and equipment for manufacturing plants. "A lot of factories that are supposed to be coming online this year or next year are either going to get canceled, they'll be put on hold, or they'll be delayed to next year, or even beyond prediction," Vagneur-Jones told Latitude Media.[252]

Figure 80. BNEF Expects Half of Clean Tech Manufacturing to Stall



Source: Bloomberg NEF (2024)

Moreover, generation market participants are tapping into IRA demand-side credits for storage installations (48, 48C) and believe the administration is likely to grandfather operating projects and those under construction. The industry representatives interviewed by the team expressed confidence that most storage installations currently under construction will be grandfathered - meaning they will remain eligible for existing IRA incentives even if the law changes. Public companies are not expected to absorb margin compression from IRA credit reduction or repeal. Generators would instead try to renegotiate their power purchase agreements (PPAs) with off-takers to account for lost subsidies or increased costs under different trade policy scenarios. Developers are reported to be adopting strategies to launch as many projects as may possibly qualify for the "safe harbor" conditions to be grandfathered for eligibility for tax credits. Potential resulting energy prices increases would likely be passed on to ratepayers by utilities or to product customers by off taker corporations. A new forecast from BNEF predicts a reduction of more than 200 gigawatts of new solar, wind and storage deployment in the US by 2035 under a scenario in which the IRA investment and production tax credits are fully repealed.[253]

Potential Tariffs: Third, tariffs increase battery cost and price volatility of critical minerals. Over the past two years, the battery industry has benefited from low raw material prices. These could rise in the next few years, as geopolitical tensions, tariffs on battery metals and low prices stall new mining and refining projects.[254] President Trump's tariffs threaten to materially raise costs for

[252] Giacobone, B. (2025, February 4). *'Rampant' delays are coming for US clean energy manufacturing*. Latitude Media. https://www.latitudemedia.com/news/rampant-delays-are-coming-for-us-clean-energy-manufacturing/

[253] BloombergNEF. (2025, January 9). *Five Energy Transition Lessons for 2025*. BloombergNEF. https://about.bnef.com/blog/five-energy-transition-lessons-for-2025/

[254] BloombergNEF. (2024, December 10). *Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour*. BloombergNEF.

imported batteries and their inputs. In principle tariffs on imported batteries could protect US manufacturers and allow for higher domestic battery prices but the net practical effect on profit margins will depend on tariff levels on imported inputs. As for whether tariffs on imported batteries would stimulate more domestic battery manufacturing, the present uncertainty about the durability of the threatened tariffs plus IRA reform would need to abate.

5. Recent Announcements and Players Matrix

While America's battery manufacturing advances, a tough macroeconomic backdrop, combined with overproduction in China, slowing demand for electric vehicles and policy uncertainty has chilled further progress.[255] Nearly $8bn in investments and 16 new clean tech plants (not only battery) and other projects were cancelled, closed, or downsized in the first three months of 2025 as Congress begins debate on repealing the tax credits. The $7.9bnin investments withdrawn since January are more than three times the total investments cancelled over the previous 30 months, according to E2.[256] Some battery plant cancellations include:

In March 2024, ***Albermarle*** canceled its planned $1.3 billion lithium processing plant in South Carolina.[257]

In August 2024, battery parts manufacturer ***Anovion*** delayed its $800 million battery parts factory in Georgia by a year, citing a lack of clarity over the IRA's electric vehicle regulations.[258]

AESC is a Japanese battery technology company that has promised to build three U.S. facilities before the end of the decade. The company's Tennessee plant has been in operation for some time. AESC broke ground at its Kentucky and South Carolina plants in August 2022 and June 2023, respectively. In March 2024, AESC said it would expand its South Carolina operations, bringing total investment in the project up to $3.12bn. But in February 2025, AESC paused those expansion plans.[259]

In February 2025, battery cell and module developer ***Kore Power*** has canceled a $1bn lithium-ion battery plant in Arizona, despite receiving an $850mn loan from the DOE in 2023. This facility was touted as potentially the first lithium-ion plant fully owned by a U.S. firm. Now, Kore's plans are to sell its construction-ready property in Buckeye and instead search for an existing factory to retrofit into a battery plant.[260]

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https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/

[255] Financial Times. (2024). *Delays hit 40% of Biden's Major IRA Manufacturing Projects*. Financial Times. https://www.ft.com/content/afb729b9-9641-42b2-97ca-93974c461c4c

[256] E2. (2025). *Announcements*. E2. https://e2.org/announcements/

[257] Holdman, J. (2024, March 18). *Major electric vehicle lithium project paused. Other SC battery recycling investments continue*. South Carolina Daily Gazette. http://scdailygazette.com/2024/03/18/major-electric-vehicle-lithium-project-paused-other-sc-battery-recycling-investments-continue

[258] IANS. (2024, April 14). *40 per cent of Biden's major IRA manufacturing projects delayed: Report*. The Economic Times. https://manufacturing.economictimes.indiatimes.com/news/industry/40-per-cent-of-bidens-major-ira-manufacturing-projects-delayed-report/112522442

[259] Wynder, J. (2025, February 5). *South Carolina EV battery manufacturer pauses expansion*. Spectrum News. https://spectrumlocalnews.com/sc/south-carolina/news/2025/02/05/south-carolina-news-aesc-loses-incentives

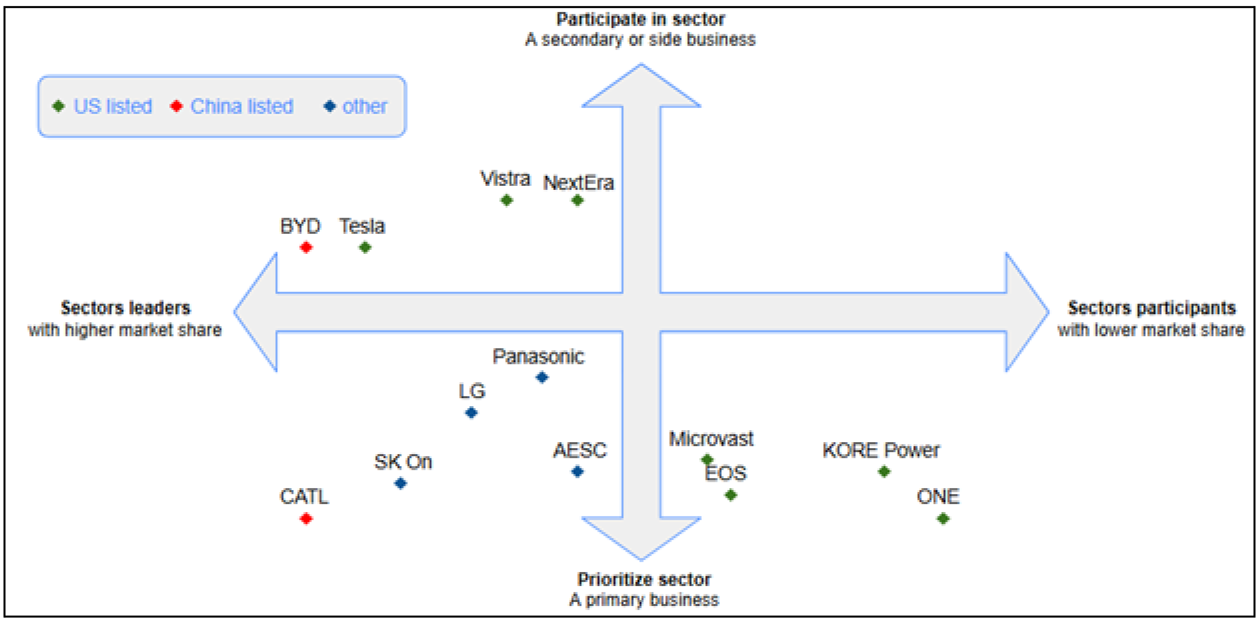
[260] Spector, J. (2025, February 7). *Kore Power has a new plan after canceling $1.2B battery plant in Arizona*. Canary Media. https://www.canarymedia.com/articles/energy-storage/kore-power-has-a-new-plan-after-canceling-1-2b-battery-plant-in-arizona

Despite receiving a $670mn DOE loan, ***Aspen Aerogels*** announced in February 2025 that it's canceling its planned facility in Georgia and shifting manufacturing to Mexico and China. The company makes thermal barriers for electric vehicle batteries, including for General Motors.[261]

Freyr Battery announced it was halting plans for a $2.6 billion, 700-employee battery factory in Georgia. Freyr moved its corporate headquarters from Norway to Newnan in part to maximize its benefits under Biden's climate law.[262]

The final section of this report presents a sorting matrix that categorizes major battery manufacturers and energy companies active in the U.S. based on two key dimensions: market share (horizontal axis) and strategic focus on the battery sector (vertical axis). This visualization provides a snapshot of how various companies are positioned in the evolving U.S. battery ecosystem, helping to identify core players, emerging challengers, and diversified participants.

Figure 81. Matrix of Key Batteries Players Globally



Source: Capstone analysis

On the horizontal axis, companies are grouped based on their market share in battery manufacturing. Those on the left side of the chart - such as CATL, Tesla, BYD, LG, Panasonic, and SK On - are recognized as sector leaders, holding significant global or domestic market share in battery cell or pack production. In contrast, players on the right side - including Microvast, KORE Power, Eos, and Our Next Energy (ONE) - have lower market share but remain active participants in the industry, often focusing on niche segments, innovation, or domestic content strategies to gain traction.

The vertical axis measures how central the battery business is to the company's overall strategy. Companies near the bottom of the chart are those that prioritize battery manufacturing as a core business, investing heavily in scaling production capacity and R&D. This includes names like CATL, AESC, Microvast, Eos, and KORE Power - firms that are either fully specialized battery

[261] Allsup, M. (2025, March 10). *Why Aspen Aerogels cancelled its LPO loan – and its Georgia factory*. Latitude Media. https://www.latitudemedia.com/news/why-aspen-aerogels-cancelled-its-lpo-loan-and-its-georgia-factory
[262] Amy, J. (2025, March 11). *Battery firm abandons plan for a $2.6 billion plant in Georgia.* AP News. https://apnews.com/article/georgia-freyr-electric-battery-plant-newnan-5b718f627462bb1d5cc3bf4d835ae879

manufacturers or have strategically pivoted toward energy storage as a central growth area.

Conversely, those located near the top — such as Vistra and NextEra — are primarily utility or energy infrastructure firms that participate in battery storage as a complementary business, often to support grid-scale deployment, energy arbitrage, or decarbonization targets. These players are less focused on cell or module manufacturing itself, but their investment decisions are pivotal to downstream demand.

A few notable companies appear in central positions, reflecting a balanced or transitional stance. For instance, Panasonic and LG are established players with sizable market share and growing U.S. footprints, especially through partnerships with automakers like Tesla and GM. However, their broader corporate strategies encompass a wider range of electronics and energy technologies, placing them between prioritization and participation.

Tesla and BYD, meanwhile, are unique in that they both maintain vertically integrated models and high battery demand internally for their EV production, but they differ in terms of scale and regional dominance. Tesla, while a U.S.-listed firm, is closer to the sector leadership cluster but doesn't prioritize external battery supply as aggressively as Chinese peers like CATL.

2.4 Solar Manufacturing

1. Global Overview

Among renewable sources of energy, solar generation still enjoys many advantages. Solar energy is clean and abundant[263] with superior accessibility and low operating costs.[264] Solar panels can be installed either in large-scale farms or on the rooftop of homes. Solar panels require minimal maintenance, and are increasingly deployed in regions with abundant sunshine.

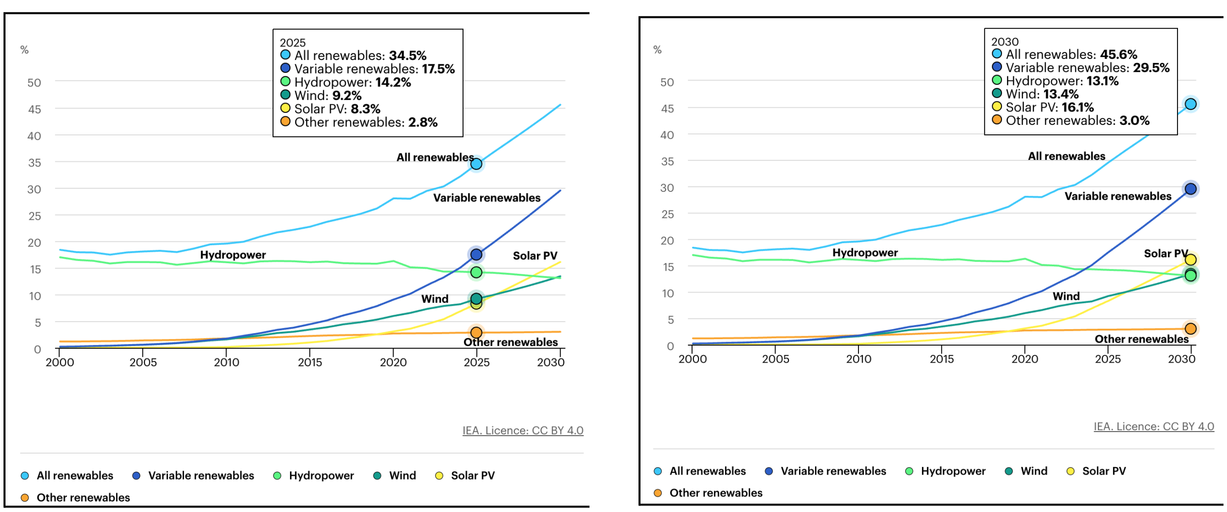
The IEA, predicts that policy support and declining installation costs support an increase in the share of electricity generation by solar PV from 8.3% in 2025 to 16.1% in 2030 (Figure 82). This will make up around 80% of the global renewable capacity growth from 2024 to 2030, when solar is expected to surpass hydropower as the largest renewable energy source in 2029.

2. Production and Cost Trends:

Precedence Research estimates the global market share of solar PV panels will increase from $198.51 billion in 2025 to $384.44 billion in 2034 (Figure 83) at a compound annual growth rate of 7.62%.

The North America market accounts for 22% (Figure 84) of the global solar PV panels market in 2024. North America is expected to be the leading region in solar generation growth with a compound annual growth rate of 7.93%. Accordingly, solar energy should remain one of the most attractive renewable energy investment opportunities in the next decade.

Figure 82. Global Renewable Electricity Generation by Technology, 2000-2030

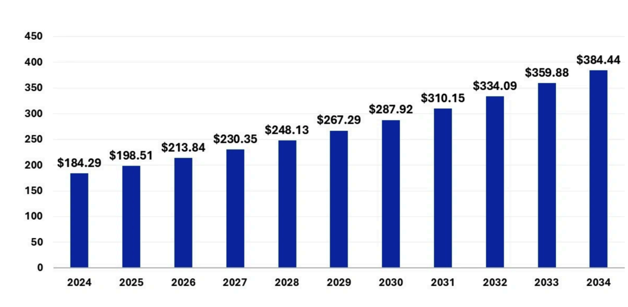


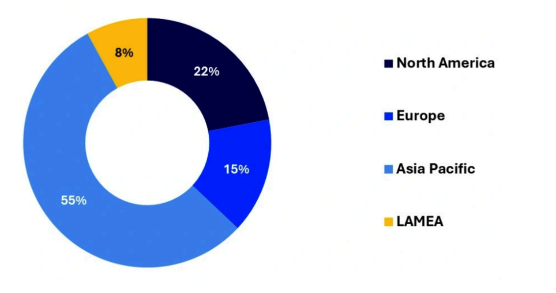
Source: International Energy Agency[265]

[263] Solar Energy Industries Association. *Solar Energy.* SEIA. https://seia.org/initiatives/about-solar-energy/
[264] Wattmonk. (2024, June 20). *Solar vs. Other Renewables: Is Solar Energy the Best Choice? Compared to other renewable energy sources.* Wattmonk. https://www.wattmonk.com/solar-other-renewables-is-solar-energy-the-best-choice/
[265] International Energy Agency. *Solar PV.* IEA. https://www.iea.org/energy-system/renewables/solar-pv

Figure 83. Global Solar PV Panels Market Size, 2024-2034 ($ bn)

Figure 84. Global Solar PV Panels Market Share by Region, 2024





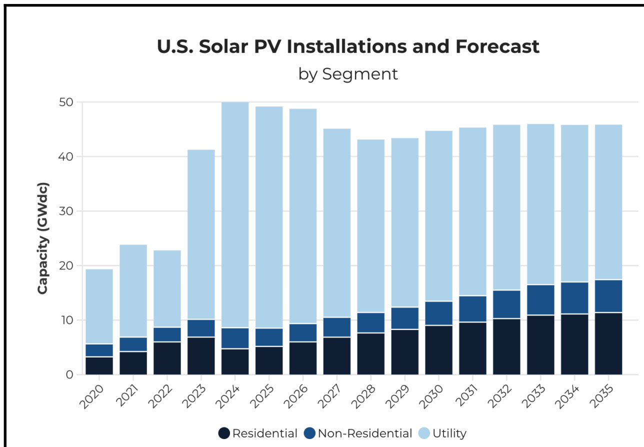
Source: Precedence Research (2025)[266]

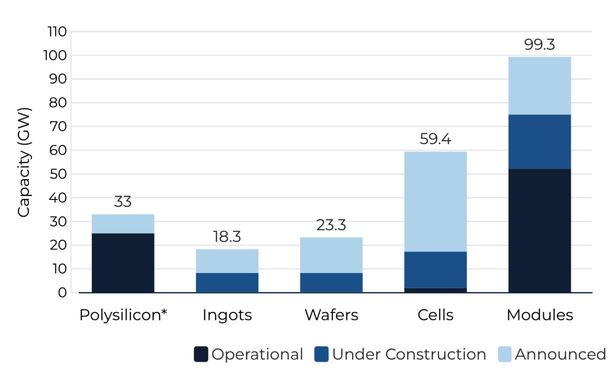
The U.S. solar industry is growing in both demand and supply. On the demand side, according to statistics by Solar Energy Industries Association (SEIA), 49.99 gigawatts direct current (GWdc) of solar PV capacity was installed in 2024 (Figure 85), which accounted for 66% of all electricity generation capacity newly installed in the year. The SEIA predicts new installations of solar PV capacity to be more than 43 GWdc each year from 2025 to 2035, but a slow down in installation growth is predicted for the utility-scale segment in 2026, owing to restraints from labor availability and the federal interconnection system.

On the supply side, as of April 2025, according to SEIA, total US manufacturing capacity under operation includes 25 GWdc of polysilicon, 2 GWdc of cells, and 52.3 GWdc of modules (Figure 86). Compared to the module demand of 49.99 GWdc in 2024 and expected 49.17 GWdc in 2025, the U.S. module manufacturing capacity can already cover all domestic demand. In 2025, the first ingot and wafer facilities in the U.S. will become operational, and more capacity of cells and modules are under construction, leading the U.S. solar industry to develop toward a full supply chain.

Figure 85. Annual U.S. Solar PV Installations, 2020-2035

Figure 86. Total U.S. Module Supply Chain capacity, April 2025





Source: Solar Energy Industries Association[267]

[266] Precedence Research. (2025, February 6). *Solar PV Panels Market Size, Share, and Trends 2025 to 2034.* Precedence Research. https://www.precedenceresearch.com/solar-pv-panels-market

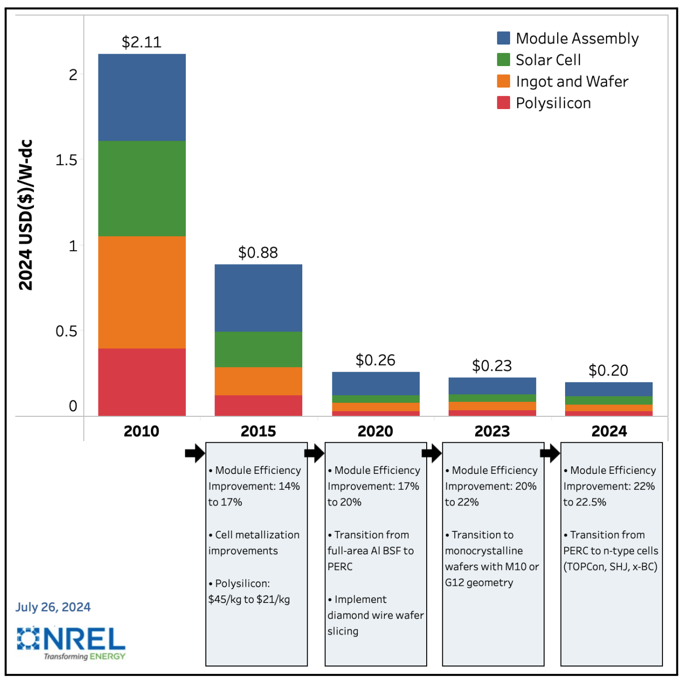
[267] Solar Energy Industries Association. *Solar Industry Research Data.* SEIA. https://seia.org/research-resources/solar-industry-research-data/

Components Prices

Module and module component prices have been going through continuous decline due to technological advances over time and periods of Chinese overproduction[268] (Figure 87). According to Oil Price Information Service,[269] the global polysilicon market was challenged in 2024 by weak demand, with little room for further price reductions. This prompted manufacturers to cut production. Large-scale production cuts by wafer companies since Q3 2024 led to a slight increase in wafer prices at the end of 2024. Cell and module prices remained low due to the high downstream inventories.

Looking forward to 2025, on January 27, the Chinese government announced that electricity prices for renewable energy projects commissioned on or after June 1, 2025 shall be determined through bidding, and continued projects can still benefit from the subsidized policy-determined prices.[270] TrendForce predicts this policy will cause a demand and price peak in March and April which starts from modules and passes on to cells, wafers, and polysilicon, followed by a sharp reverse starting in May.[271]

Figure 87. Module Manufacturing Costs, 2010-2024



Source: National Renewable Energy Laboratory (2025)[272]

[268] CPA EconomicsTeam. (2025). *The U.S. Solar Supply Chain 2025: Building a Strong and Resilient American Solar Industry.* Coalition for a Prosperous America. https://prosperousamerica.org/wp-content/uploads/2025/01/US-Solar-Supply-Chain-2025.pdf

[269] Oil Price Information Service. (2025, January 7). *SOLAR WEEKLY.* OPIS. https://www.opisnet.com/wp-content/uploads/2024/07/OPIS-Solar-Weekly-Report.pdf

[270] National Development and Reform Commission (NDRC), People´s Republic of China, & National Energy Administration. (2025, January 27). 国家发展改革委 国家能源局关于深化新能源上网电价市场化改革 促进新能源高质量发展的通知. The State Council, People's Republic of China. https://www.gov.cn/zhengce/zhengceku/202502/content_7002959.htm

[271] Jowett, P. (2025, March 27). *Solar module, cell, wafer prices to rise in Q2 2025, says TrendForce.* PV Magazine. https://www.pv-magazine.com/2025/03/27/solar-module-cell-wafer-prices-to-rise-in-q2-2025-says-trendforce/

[272] National Renewable Energy Laboratory. (2025, April 3). *Solar Manufacturing Cost Analysis.* NREL. https://www2.nrel.gov/solar/market-research-analysis/solar-manufacturing-cost

Figure 88. Polysilicon Prices Trends, 2024

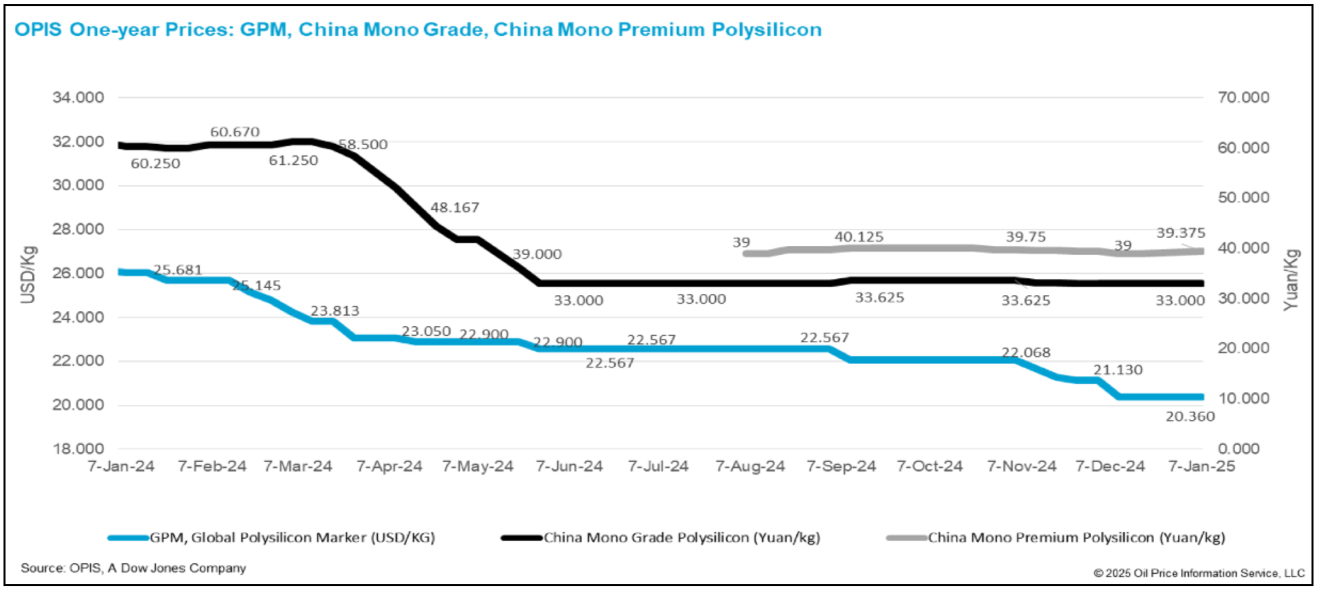


Figure 89. Wafer Prices Trends ($), 2024

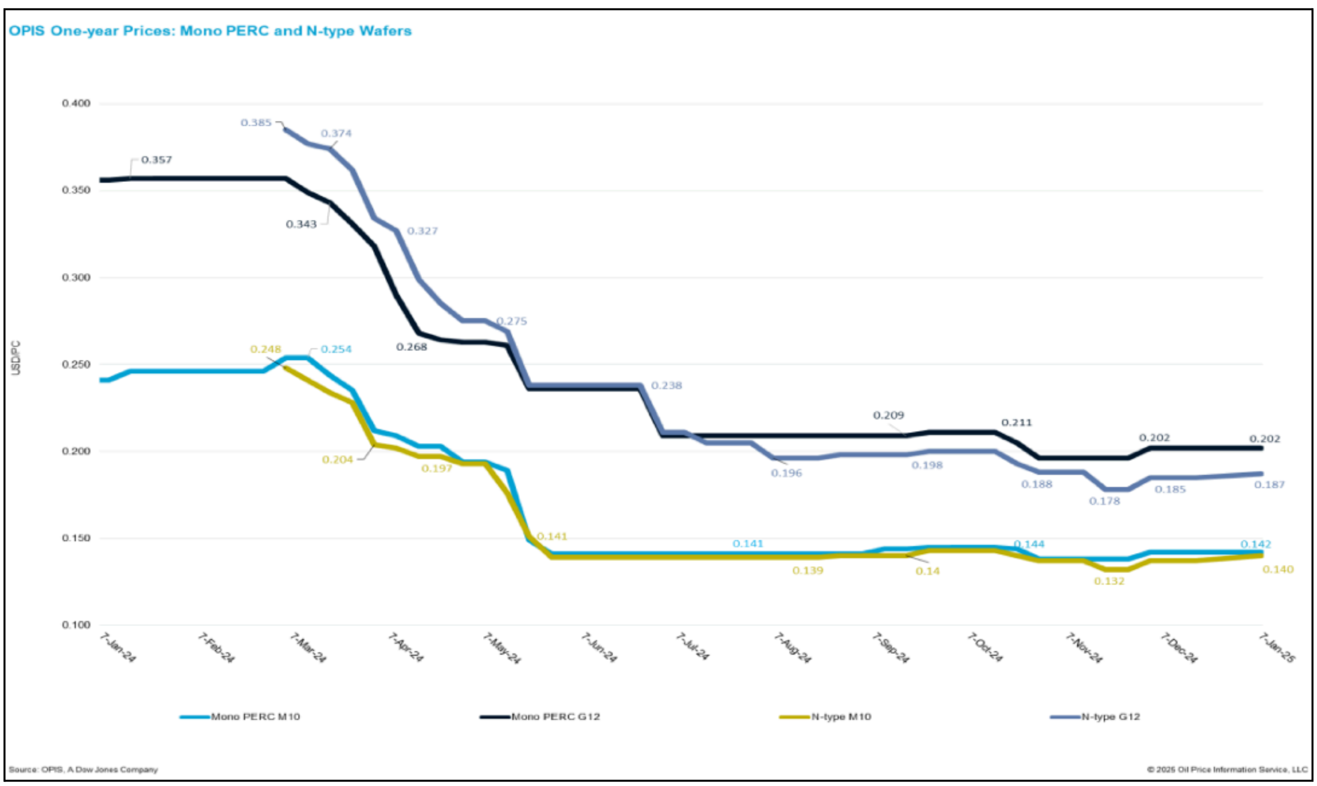


Figure 90. Cell Prices Trends ($), 2024

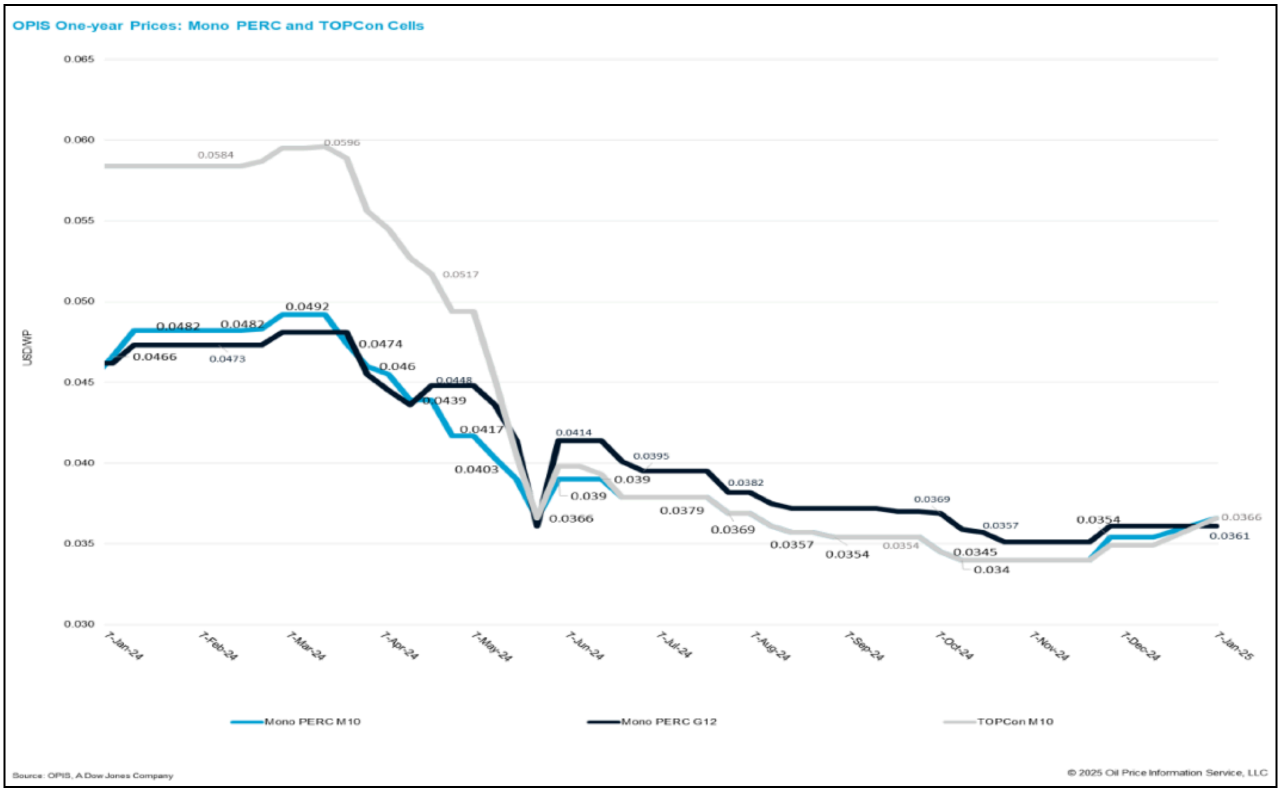
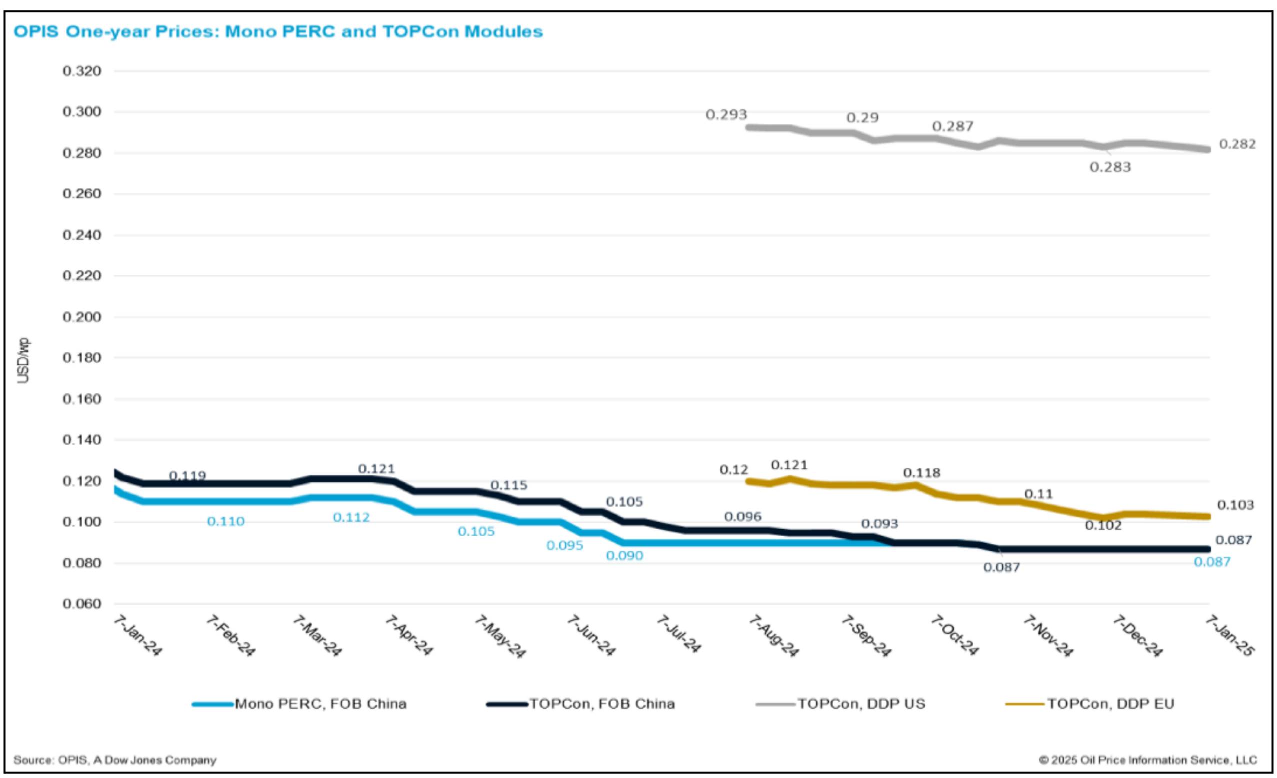


Figure 91. Module Prices Trends ($), 2024



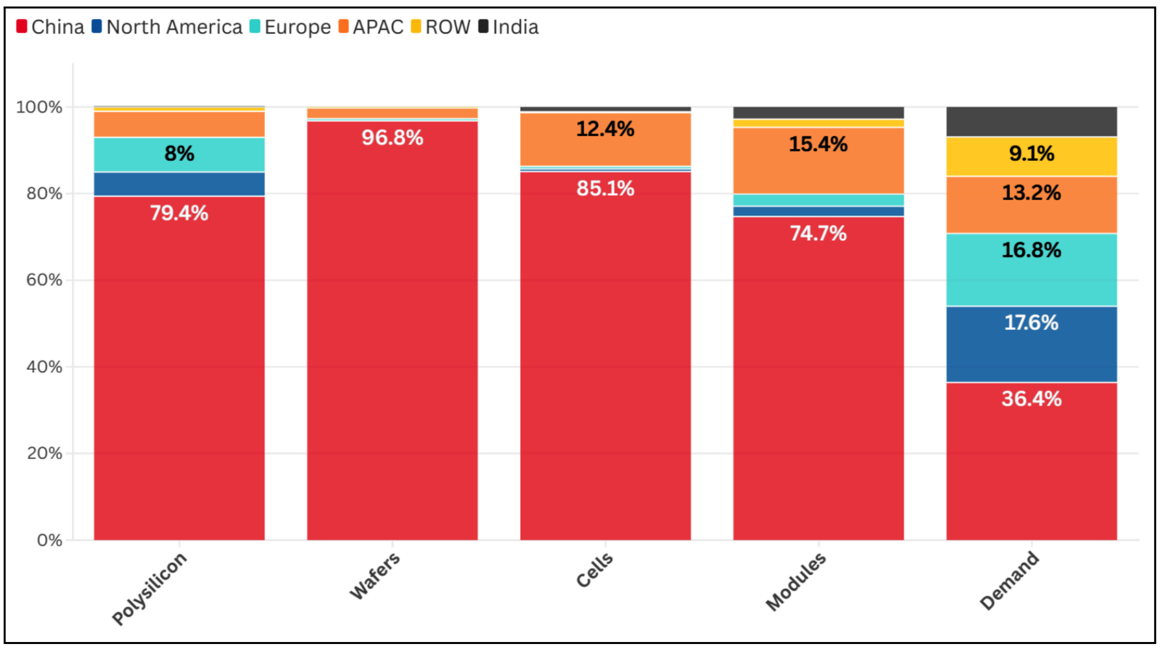
Source: Oil Price Information Service (2025)[273]

[273] Oil Price Information Service. (2025, January 7). *SOLAR WEEKLY.* OPIS.

3. Supply Chains

China has been dominating, and will continue to dominate, the world's solar industry across the value chain for years. According to statistics by IEA (Figure 92), in 2021, while China accounted for 36.4% of the global demand of solar PV, which made it the biggest solar market in the world, China's share of global production in polysilicon, cells, and modules were around 80%, and its share in wafers was as high as 96.8%, making China the biggest exporter as well. In 2023, China's share of global cell and module production increased to relatively 91.8% (Figure 93) and 84.6% (Figure 94). Wood Mackenzie predicts the high shares will last through 2026 with China's advantages in advanced technology, low costs, complete supply chain, and a total of more than 1 terawatt direct current (TWdc) of capacity coming online by 2024 to enable China to cover all of the annual global demand through 2032.[274] Analysts conclude that with this extent of control, China can set global prices.[275]

Figure 92. Global Solar Value Chain Manufacturing Capacity Share by Region, 2021



Source: International Energy Agency (2022),[276] Coalition for a Prosperous America (2025)[277]

https://www.opisnet.com/wp-content/uploads/2024/07/OPIS-Solar-Weekly-Report.pdf

[274] Wood Mackenzie. (2023, November 7). *China to hold over 80% of global solar manufacturing capacity from 2023-26.* Wood Mackenzie. https://www.woodmac.com/press-releases/china-dominance-on-global-solar-supply-chain/

[275] Calabrese, J. (2024, November 19). *US-China solar power rivalry: A global battleground.* Illuminem. https://illuminem.com/illuminemvoices/uschina-solar-power-rivalry-a-global-battleground

[276] International Energy Agency. (2022, July). *Solar PV Global Supply Chains: Executive summary.* IEA. https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary

[277] CPA EconomicsTeam. (2025). *The U.S. Solar Supply Chain 2025: Building a Strong and Resilient American Solar Industry.* Coalition for a Prosperous America. https://prosperousamerica.org/wp-content/uploads/2025/01/US-Solar-Supply-Chain-2025.pdf

Figure 93. Global Cell Production Share by Region, 2023

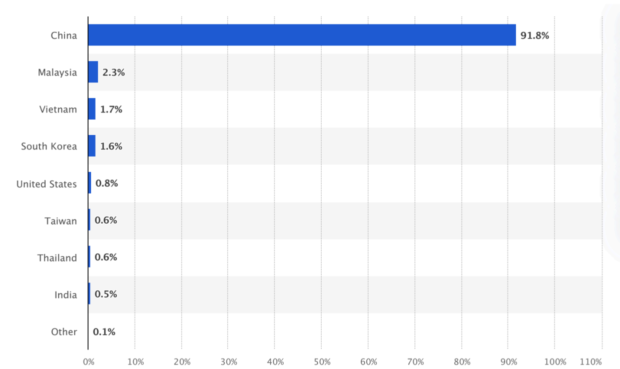
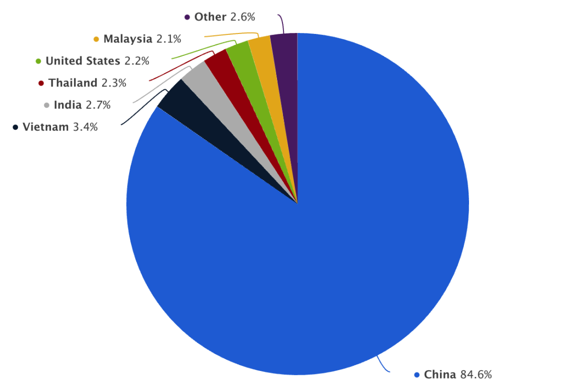


Figure 94. Global Module Production Share by Region, 2023



Source: IEA, PVPS (2024)[278] [279]

US Solar Equipment Manufacturing

At its current stage of rapid deployment growth, the U.S. solar market still heavily relies on imports across the value chain. According to statistics visualized by National Renewable Energy Laboratory, in 2023 and 2024 (as of Q3), the US imports of c-Si and CdTe modules (Figure 95) mainly come from Southeast Asian countries including Vietnam, Thailand, Malaysia, and Cambodia. India is also establishing a stronger presence. In 2024 (as of Q3), the imports of cells (Figure 96) mainly come from Malaysia, South Korea, Thailand, and Vietnam. A shift of solar equipment sourcing from China to Southeast Asia has been ongoing since the Obama administration imposed 36% tariffs as well as antidumping and countervailing duties (AD/CVD) on Chinese modules in 2012. This shift is largely the same for Chinese producers changing facility location.[280]

…/…

[278] IEA, & PVPS. (October 22, 2024). *Regional distribution of solar photovoltaics cell production worldwide in 2023, by country [Graph]*. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/268682/regional-distribution-of-solar-cell-manufacturing/

[279] PVPS, & IEA. (October 22, 2024). *Distribution of solar photovoltaic module production worldwide in 2023, by country [Graph]*. In Statista. Retrieved May 02, 2025, from https://www.statista.com/statistics/668749/regional-distribution-of-solar-pv-module-manufacturing/

[280] CPA EconomicsTeam. (2025). *The U.S. Solar Supply Chain 2025: Building a Strong and Resilient American Solar Industry.* Coalition for a Prosperous America. https://prosperousamerica.org/wp-content/uploads/2025/01/US-Solar-Supply-Chain-2025.pdf

Figure 95. Quarterly US Module (c-Si + CdTe) Imports, 2020- Q3 2024

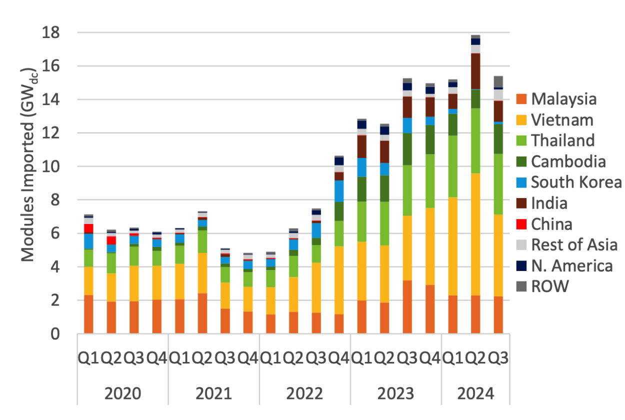
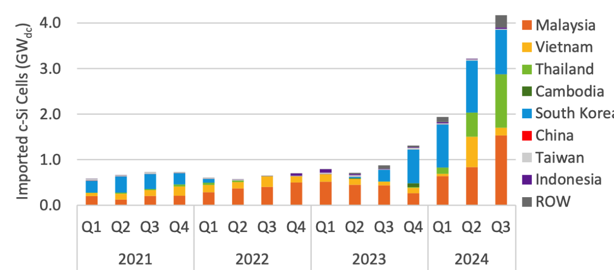


Figure 96. Quarterly US Cell Imports, 2021-Q3 2024



Source: National Renewable Energy Laboratory (2024) [281]

4. Impact of Trade Related Policies

The US has been implementing trade policies aiming at securing domestic manufacturing across the solar PV value chain. Policies supporting domestic manufactures are represented by the IRA sections, and restraints on international suppliers consist of tariffs and case-by-case AD/CVD.

IRA Incentives:

Similar to the IRA incentives explained already for battery manufacture, the IRA has both supply-side and demand-side tax credits to promote domestic manufacture of solar equipment.

On the supply-side (manufacturing) IRA's Section 45X provides for units of production linked tax credits and its Section 48C provides for an investment tax credit based on the capital cost of a manufacturing facility.

IRA's Section 45X provides a per-unit tax credit for each clean energy component domestically produced and sold by a manufacturer. On the solar module value chain, solar-grade polysilicon ($3/kg), wafers ($12/m^2), cells ($0.04/Wdc), modules ($0.07/Wdc), and polymeric backsheets (¢ 40/m^2) are all eligible for Section 45X (Table 8). Inverters (Table 9) and trackers (Table 10) are also eligible for 45X.

.../...

[281] Feldman, D., Zuboy, J., Dummit, K., Stright, D., Heine, M., Grossman, S., Narayanaswami, M., & Margolis, R. (2024, October 30). *Fall 2024 Solar Industry Update.* NREL. https://www.nrel.gov/docs/fy25osti/92257.pdf

Table 8. Module and Subcomponents Eligible for Section 45X

Eligible Components	Definition	Credit Amount
Solar-grade polysilicon	Silicon that is suitable for photovoltaic manufacturing and is purified to a minimum purity of 99.999999 percent silicon by mass.	$3 per kilogram (kg)
PV wafer	A thin slice, sheet, or layer of semiconductor material of at least 240 square centimeters that comprises the substrate or absorber layer of one or more photovoltaic cells. Produced by a single manufacturer either i) directly from molten or evaporated solar grade polysilicon or deposition of solar grade thin film semiconductor photon absorber layer, or ii) through formation of an ingot from molten polysilicon and subsequent slicing. For purposes of the 45X credit, ingot and wafer manufacturing are considered part of single production process (per the IRS's October 2024 final rules). Therefore, if wafers are produced from ingots made at a facility that received a 48C allocation, the wafers would be ineligible to receive 45X credits.	$12 per square meter ($m^2$)
PV cell (crystalline or thin-film)	The smallest semiconductor element of a solar module that performs the immediate conversion of light into electricity.	4¢ per watt-direct current (W_{dc})
Polymeric backsheet	A sheet on the back of a solar module that acts as an electric insulator and protects the inner components of such module from the surrounding environment.	40¢ per m^2
PV Module	The connection and lamination of photovoltaic cells into an environmentally protected final assembly that is suitable to generate electricity when exposed to sunlight, and ready for installation without an additional manufacturing process.	7¢ per W_{dc}

Source: U.S. Department of Energy[282]

Table 9. Inverters Eligible for Section 45X

Eligible Components	Definition	Credit Amount
Central inverter	Suitable for large utility-scale systems. >1 megawatt-alternating current (MW_{ac})	0.25¢ per watt-alternating current (W_{ac})
Utility inverter	Suitable for commercial or utility-scale systems. ⩾125 kW_{ac}, ⩽1 MW_{ac}, with a rated output ⩾600 volt three-phase power.	1.5¢ per W_{ac}
Commercial inverter	Suitable for commercial or utility-scale applications. ⩾20kW_{ac}, ⩽125 kW_{ac} with a rated output of 208, 480, 600, or 800 volt three-phase power >600 volt three-phase power.	2¢ per W_{ac}
Residential inverter	Suitable for a residence. ⩽20 kW_{ac}, with a rated output of 120 or 240 volt single-phase power.	6.5¢ per W_{ac}
Microinverter	Suitable to connect with one solar module. ⩽650 W_{ac} with a rated output of i) 120 or 240 volt single-phase power, or ii) 208 or 480 volt three-phase power. For purposes of the 45X credit, a direct current optimized inverter system (DC optimized inverter system) may qualify as a microinverter (per the IRS's October 2024 final rules).	11¢ per W_{ac}

Source: U.S. Department of Energy[283]

[282] U.S. Department of Energy. *Federal Tax Credits for Solar Manufacturers.* U.S. DOE. https://www.energy.gov/eere/solar/federal-tax-credits-solar-manufacturers
[283] Ibid.

Table 10. Tracking System Subcomponents Eligible for Section 45X

Eligible Components	Definition	Credit Amount
Torque tube	A structural steel support element (including longitudinal purlins) that is part of a solar tracker, is of any cross-sectional shape, may be assembled from individually manufactured segments, spans longitudinally between foundation posts, supports solar panels and is connected to a mounting attachment for solar panels (with or without separate module interface rails), and is rotated by means of a drive system.	87¢ per kg
Structural fasteners	A component that is used to connect the mechanical and drive system components of a solar tracker to the foundation of such solar tracker, to connect torque tubes to drive assemblies, or to connect segments of torque tubes to one another.	$2.28 per kg

Source: U.S. Department of Energy[284]

Section 48C provides an alternative supply-side credit to Section 45X. As with battery manufacture explained already, the 48C ITC is claimed as “a percentage of eligible investment costs” on federal corporate income taxes and can be transferred to unrelated taxpayers. Module and module subcomponent facilities that satisfy the Treasury Department’ labor requirements can apply for a 30% ITC, otherwise they can only apply for a 6% ITC. Section 48D is an addition to Section 45X or Section 48C, also claimed as a percentage of eligible investment costs but not transferable. Wafer facilities can apply for a 25% ITC.[285]

On the demand or deployment side, the ITC provides a base amount of 6% for the installation of solar generation projects. Generation facilities that meet the Prevailing Wage and Apprenticeship (PWA) requirements or have a maximum net output of less than one megawatt of electrical energy (One Megawatt Exception) can apply for a 30% ITC. An alternative is the PTC, the base amount of which is ¢0.55/kWh, and projects that meet the PWA requirements are eligible for ¢ 2.75/kWh.[286] These demand-side ITC or PTC incentives are increased with a 10% adder if the generation facility has sufficient domestic content.[287]

In the two-year period following the passage of the IRA, analysts have noted 334 clean energy projects attributed to the IRA, creating “at least 109,278 new jobs and bringing a minimum of $126 billion in direct private investment to 40 states.”[288] The SEIA also estimated that “the solar industry has added 75 GW of new capacity to the grid, representing over 36% of all solar capacity built in U.S. history. Nearly 1.5 million American homes have installed solar since the IRA was passed.”[289]

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[284] Ibid.
[285] Ibid.
[286] Potomac Law Group. (2024, September 18). *Qualifying for the 10% Domestic Content Renewable Energy Tax Credit.* Potomac Law Group. https://www.potomaclaw.com/news-Qualifying-for-the-10Percent-Domestic-Content-Renewable-Energy-Tax-Credit
[287] Internal Revenue Service. (2025, January 23). *Domestic content bonus credit.* IRS. https://www.irs.gov/credits-deductions/domestic-content-bonus-credit
[288] E2. (2024, August 14). *NEW Report: 334 Major Clean Energy, Clean Vehicle Projects Announced in First Two Years of IRA – $126B in Investments, 109K Jobs Across 40 States.* E2. https://e2.org/releases/new-report-334-major-clean-energy-clean-vehicle-projects-announced-in-first-two-years-of-ira-126b-in-investments-109k-jobs-across-40-states/
[289] Solar Energy Industries Association. (2024, September 9). *REPORT: U.S. Solar Panel Manufacturing Capacity Grows Nearly 4x Under New Federal Incentives.* SEIA. https://seia.org/news/report-u-s-solar-panel-manufacturing-capacity-grows-nearly-4x-under-new-federal-incentives/

Potential IRA Reform:

As already noted, the Trump Administration has an unfavorable attitude toward renewable energy.

President Trump expressed his attitude toward the solar industry in an interview with Sean Hannity of Fox News: "You know what people also don't like, those massive solar fields built over land that cover 10 miles by 10 miles, I mean they are ridiculous, the whole thing."[290] Just five days later on January 28, 2025, the Environmental Protection Agency sent letters to recipients of the Solar for All program, which is part of the IRA, informing about the pause of their grants.[291]

The outlook on IRA reforms remains uncertain as budget reconciliation legislation moves through Congress. On March 9, 2025, 21 House Republicans from California, Ohio, Arizona, New York, Indiana, Nevada, Georgia, Virginia, Iowa, Pennsylvania, Michigan, Colorado, New Jersey, Washington, and Nebraska signed a letter addressed to House Ways and Means Committee Chair Jason Smith to oppose wholesale repeals of the IRA's clean energy tax credits.[292] Many of the states these House members represent have high installation rankings in the State Solar PV Installation Rankings 2024 developed by the SEIA and Wood Mackenzie, Indiana ranked at 10, and Pennsylvania ranked at 20.[293]

Advocates for retaining IRA's incentives on solar have noted how Republican congressional districts are benefitting most. "In its full two-year history, about 60 percent of all projects were in Republican districts. Nineteen of the top 20 congressional districts for clean energy investments are held by Republicans."[294] Whether these advocates will sway the budget process in favor of IRA's solar incentives is hard to answer. Policy observers interviewed for this report foresee three potential scenarios:

- Best case: IRA credits remain unadjusted
- Compromised case: partial repeal of IRA credits
- Worst case: whole repeal of IRA credits

As noted already in the analysis of battery manufacture, industry representatives interviewed by the team also expressed confidence that solar equipment manufacturing facilities that are operating or have reached defined levels of construction will be grandfathered for IRA incentives under the various expected scenarios of Congressional reform. It is expected that these grandfathering terms ("safe-harbors") will also apply to solar deployments that are currently under construction. In 2025, developers are reported to be adopting strategies to launch as many projects as may possibly qualify for the "safe harbor" conditions to be grandfathered for eligibility for tax credits. When prior congresses have reduced or given sunset dates to solar incentives, the definition of "under construction" was liberal and involved incurring just 5% of project costs, so inverters are especially being pre-ordered. As noted already, BNEF predicts a reduction of more than 200 gigawatts of new

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[290] Fox News. (2025, January 23). *Trump reveals "one very big power" the US has over China.* YouTube. https://www.youtube.com/watch?v=RN0nR8Rx0KI

[291] Chemnick, J. (2025, January 30). *EPA cuts off IRA solar money already under contract.* E&E News by POLITICO. https://www.eenews.net/articles/epa-cuts-off-ira-solar-money-already-under-contract/

[292] Johnson, L. (2025, March 11). *21 House Republicans oppose cutting clean energy credits to pay for tax cuts.* Utility Dive.https://www.utilitydive.com/news/21-house-republicans-oppose-cutting-ira-clean-energy-credits-in-reconciliation/742404/

[293] Solar Energy Industries Association. (2025, March 11). *Solar Market Insight Report 2024 Year in Review.* SEIA. https://seia.org/research-resources/solar-market-insight-report-2024-year-in-review/

[294] E2. (2024, August 14). *NEW Report: 334 Major Clean Energy, Clean Vehicle Projects Announced in First Two Years of IRA – $126B in Investments, 109K Jobs Across 40 States.* E2. https://e2.org/releases/new-report-334-major-clean-energy-clean-vehicle-projects-announced-in-first-two-years-of-ira-126b-in-investments-109k-jobs-across-40-states/

solar, wind and storage deployment in the US by 2035 under a scenario in which the IRA investment and production tax credits are fully repealed.

Existing and Threatened Tariffs:

As for tariffs, Section 201 and Section 301 tariffs on solar equipment imports were imposed in 2018 during the Trump Administration. Section 201 rate for cells and modules was 14.25% as of 2024, "with a yearly decrease of 0.25%, set to expire on February 6, 2026."[295] Products exempted from Section 201 include thin-film PV products produced from a-Si, CdTe, and CIGS; Certain CSPV cells, not exceeding 10,000 mm2 in surface area; CSPV cells manufactured in the US.[296] Exemption of bi-facial modules was revoked in June, 2024.[297] Countries exempted include Brazil, Cambodia, Indonesia, South Africa and Ukraine.[298] Moreover, the Tariff Rate Quota (TRQ) limit on cells was expanded from 5 GWdc to 12.5 GWdc from August 1, 2024, through February 6, 2025.[299]

Section 301, which is imposed exclusively on Chinese exports, experienced further increases during the Biden administration, following the release of "Notice of Modification: China's Acts, Policies and Practices Related to Technology Transfer, Intellectual Property and Innovation" by the United States Trade Representative (USTR).[300] Rates on Chinese exports were increased, from 25% to 50% on cells and modules, and from 0% to 50% on polysilicon and Mono-Si wafers (Table 11). Fourteen equipment for ingot, wafers, and cell manufacturing were exempted from Section 301 (Table 12), "aimed at boosting US production and reducing reliance on Chinese equipment."[301]

…/…

[295] InfoLink Consulting. (2024, August 15). *How will the increase of Section 201 tariff rate quota to 12.5 GW impact the market?* InfoLink Consulting. https://www.infolink-group.com/energy-article/solar-topic-how-will-the-increase-section-201-tariff-rate-quota-125-gw-impact-the-market

[296] Office of the United States Trade Representative. (2018). *Procedures To Consider Additional Requests for Exclusion of Particular Products From the Solar Products Safeguard Measure.* Federal Register, 83(31).

[297] Executive Office of the President. (2024, June 26). *Proclamation 10779 of June 21, 2024: To Further Facilitate Positive Adjustment to Competition From Imports of Certain Crystalline Silicon Photovoltaic Cells (Whether or Not Partially or Fully Assembled Into Other Products).* Federal Register. https://www.federalregister.gov/documents/2024/06/26/2024-14143/to-further-facilitate-positive-adjustment-to-competition-from-imports-of-certain-crystalline-silicon

[298] Clark, H., & Hume, G. I. (2024, May 20). *Frenetic Activity Regarding Solar Energy Equipment Import Duties.* Orrick. https://www.orrick.com/en/Insights/2024/05/Frenetic-Activity-Regarding-Solar-Energy-Equipment-Import-Duties

[299] U.S. Customs and Border Protection. (2024, August 13). *QB 24-507 2024 Solar Cells and Modules Amended August 13, 2024.* U.S. Customs and Border Protection. https://www.cbp.gov/trade/quota/bulletins/qb-24-507-2024

[300] Office of the United States Trade Representative. (2024, September 18). *Notice of Modification: China's Acts, Policies and Practices Related to Technology Transfer, Intellectual Property and Innovation.* Federal Register. https://www.federalregister.gov/documents/2024/09/18/2024-21217/notice-of-modification-chinas-acts-policies-and-practices-related-to-technology-transfer

[301] InfoLink Consulting. (2024, September 17). *Impact of adjusted Section 301 tariffs on solar industry.* InfoLink Consulting. https://www.infolink-group.com/energy-article/solar-topic-section-301-tariffs

Table 11. Adjustments in Section 301 Tariffs on Chinese Exports

Products	HTS Code	Effective Date	Previous Tariffs	New Tariffs
Modules (Photovoltaic cells, assembled in modules or made up into panels)	8541.43.00	Sep 27, 2024	25.0%	50.0%
Cells (Photovoltaic cells, not assembled in modules or made up into panels)	8541.42.00	Sep 27, 2024	25.0%	50.0%
Mono-Si wafers (Chemical elements doped for use in electronics, in the form of disc. Wafers etc., chemical compounds doped for electronic use)	3818.00.00	Jan 1, 2025	0.0%	50.0%
Polysilicon (Silicon containing by weight not less than 99.99 percent of silicon)	2804.61.00	Jan 1, 2025	0.0%	50.0%

Table 12. Tariff Exemption List for Solar PV Equipment Under Section 301

No.	Category	HTS Code	Equipment	Previous Tariffs	New Tariffs
1	Ingot	8486.10.0000	Silicon growth furnaces	25.0%	0.0% (~May 31,2025)
2	Wafer		Band saws		
3			Machines to align and adhere silicon ingots		
4			Diamond wire saws		
5			Wire guide roller machines		
6			Coolant fluid recycling machines		
7			Degumming machines		
8	Automatic	8486.40.0030	Machines for transporting polysilicon material		
9			Machines for lifting, handling, loading, or unloading solar wafers		
10	Cell	8486.20.0000	Texturing and cleaning machines		
11			Thermal diffusion quartz-tube furnaces		
12			Plasma enhanced chemical vapor deposition machines		
13			Physical vapor deposition (PVD) machines		
14			Screen printing line machines		
15	Module	8486.20.0000	TBA	25.0%	25.0%
16			TBA		
17			TBA		
18			TBA		
19			TBA		

Source: Infolink Consulting (2024)

As noted already, the application of tariffs on imported solar equipment is quite dynamic. As mentioned in Part 1, tariffs were implemented for all imports from Canada and Mexico, as well as for China in March of 2025.[302] The tariffs on Chinese imports have escalated further since then. However, these three countries currently do not represent a large share of US module and cell imports. According to statistics by Sunhub, in 2024, the US imports of modules from Canada, Mexico, and China, are respectively 122.8 megawatts direct current (MWdc), 621.4 MWdc, and 68.3 MWdc.[303] Accordingly, these tariffs will not have a major impact on import shares of solar equipment from these sources.

[302] Saccomanno, I., & Scoles, S. (2025, March 4). *US Tariffs on Canada and Mexico Enter into Effect; Tariff on China Rises from 10% to 20%.* White & Case. https://www.whitecase.com/insight-alert/us-tariffs-canada-and-mexico-enter-effect-tariff-china-rises-10-20

[303] Ahmed, D. (2025, March 13). *Where do U.S. solar panels come from? A look at 2024 imports.* Sunhub. https://www.sunhub.com/blog/where-do-u-s-solar-panels-come-from-a-look-at-2024-imports/?srsltid=AfmBOopvsCy1Ie3WTbwsQsP9m-LQb5-Pyt7GTVaTIvdOhGYwS3ZDIydF

The largest source countries for solar equipment were threatened by different rates among the now-paused April 2 Reciprocal tariffs: Vietnam 46%, Thailand 37%, Malaysia 24%, Cambodia 49%, India 27%, South Korea 26%.[304] On top of this tariff initiative, a section 232 process began on May 15th, 2024, with AD/CVD investigations of cells and modules from Vietnam, Thailand, Malaysia, and Cambodia were announced by the U.S. Department of Commerce with tariff rates reaching up to 3,521%.[305]

In principle, durable tariffs on imported solar equipment would benefit domestic manufacturers, allowing them to raise prices but the higher costs of imported inputs such as steel, aluminum and critical minerals would have to be factored in to measure if the sector profitability would improve as a practical matter. As with threatened tariffs on batteries, the issue of whether even higher tariffs on imported solar equipment would stimulate more domestic battery manufacturing depends on reducing the present level of market uncertainty about the level and durability of the threatened tariffs -- plus uncertainty about IRA reform.

5. Recent Announcements and Players Matrix

A number of US-based solar PV facilities are expected to commence operations in 2025 and 2026 (Table 13). Hanwha Qcells is bringing the first ingot and wafer facility to the U.S. with a capacity of 3.3 GWdc each. Cell and module manufacturing is also expecting an increase in capacity.

Table 13. Major Solar PV Facilities Expected to be Operational in the U.S. in 2025/2026

Ingots & Wafers		
Company	**Capacity**	**Notes**
Hanwha Qcells	3.3 GW of ingots 3.3 GW of wafers	Cartersville factory
Cells & Modules		
Company	**Capacity**	**Notes**
ES Foundry	3 GW of cells	South Carolina cell factory
Hanwha Qcells	12.2 GW of cells 11.2 GW of modules	Cartersville factory
Silfab Solar	1 GW of cells 1.3 GW of modules	South Carolina facility
Boviet Solar	2 GW of modules cells TBA	Greenville facility
First Solar	3.5 GW of modules	5th factory in Iberia Parish, Louisiana

304 Lowell, M. J., Heeren, P., Angotti, J., Rodriguez-Johnson, L., Lowell, K., & Fisher, C. E. (2025, April 29). *Trump 2.0 tariff tracker.* Reed Smith. https://www.tradecomplianceresourcehub.com/2025/04/18/trump-2-0-tariff-tracker/

305 International Trade Administration, U.S. Department of Commerce. *Commerce Initiates Antidumping and Countervailing Duty Investigations of Crystalline Silicon Photovoltaic Cells from Cambodia, Malaysia, Thailand, and the Socialist Republic of Vietnam.* International Trade Administration. https://www.trade.gov/commerce-initiates-antidumping-and-countervailing-duty-investigations-crystalline-silicon

Source: Company websites [306,307,308,309,310]

Key Players

The MAC Global Solar Energy Index (ticker: SUNIDX), owned by MAC Indexing, LLC., tracks the global solar stock sector. The inclusion of companies has to meet various criteria:[311]

- Stocks must be listed on a primary exchange;
- Liquidity threshold: 1) initial inclusion: float-adjusted market capitalization of at least $75 million and a 3-month average daily trading value of at least $250,000; 2) continued inclusion: $125 million of float-adjusted market capitalization and a 3-month average daily trading value of $375,000
- Annual exclusion: engaged in the business of the extraction of coal, petroleum, or natural gas; engaged in the business of generating electricity for sale to third parties using coal, petroleum (oil), or nuclear fuel; according to S&P Trucost Limited (Trucost) business activity data;
- Quarterly exclusion: revenue exposure in business including adult entertainment, gambling, alcohol, tobacco, defense & weapons, fossil fuels, and nuclear; Governance & Economic dimension score less than 5.00;
- At least 20 constituent stocks, ot the criteria shall be relaxed.

The Invesco Solar ETF (ticker: TAN) tracks SUNIDX and is traded on the New York Stock Exchange ARCA. Companies in the fund holdings are engaged in business ranging from module manufacturing to solar power plant operation. We have summarized the U.S manufacturers (Table 14) and non-U.S. manufacturers (Table 15) in the fund holdings separately, highlighting companies on the module manufacturing value chain in blue. Ticker and market cap information are extracted from Yahoo Finance and business activities are summarized based on each company's official website.

Table 14. U.S. Manufacturers in TAN - Invesco Solar ETF Fund Holdings as of April 17, 2025

US Manufacturers			
Company	**Ticker**	**Market Cap**	**Business**

[306] ES Foundry. (2025, February 3). *ES Foundry Launches New Solar Cell Factory in Greenwood, South Carolina: A Game-Changer for U.S. Solar Manufacturing.* ES Foundry. https://esfoundrycorp.com/es-foundry-launches-new-solar-cell-factory-in-greenwood-south-carolina-a-game-changer-for-u-s-solar-manufacturing/

[307] Hanwha. (2024, May 17). *Hanwha Qcells' new Cartersville factory set for 3.3 GW of solar module production per year.* Hanwha. https://www.hanwha.com/newsroom/news/press-releases/hanwha-qcells-new-cartersville-factory-set-for-33-gw-of-solar-module-production-per-year.do

[308] Silfab Solar. (2024, December 17). *Silfab Solar, Nexamp Announce U.S.-Made Solar Supply Agreement.* Silfab Solar. https://silfabsolar.com/silfab-solar-nexamp-announce-u-s-made-solar-supply-agreement/

[309] Boviet Solar. (2025, January 15). *BOVIET SOLAR IS ON TRACK TO BEGIN SOLAR MODULE MANUFACTURING AT NORTH CAROLINA FACILITY BY MID 2025.* Boviet Solar. https://bovietsolar.com/boviet-solar-is-on-track-to-begin-solar-module-manufacturing-at-north-carolina-facility-by-mid-2025

[310] First Solar. *First Solar: Investing in America since 1999.* First Solar. https://www.firstsolar.com/Technology/Manufacturing

[311] S&P Dow Jones Indices. (2025, March). *MAC Global Solar Energy Index Methodology.* S&P Global. https://www.spglobal.com/spdji/en/documents/methodologies/mac-global-solar-energy-index.pdf

Enphase Energy Inc	**ENPH**	**8.17B**	**Microinverter, storage**
First Solar Inc	**FSLR**	**13.63B**	**Thin film module**
NEXTracker Inc	**NXT**	**6.28B**	**Tracker**
Sunrun Inc	**RUN**	**1.34B**	**Storage**
Clearway Energy Inc	**CWEN**	**3.48B**	**Power plant operation**
Array Technologies Inc	**ARRY**	**772.23M**	**Tracker**
Shoals Technologies Group Inc	**SHLS**	**553.30M**	**Electrical Balance of System (EBOS)**
Altus Power Inc	**AMPS**	**792.48M**	**Power plant operation**

Source: Invesco,[312] Yahoo Finance (2025), Company websites (2025), Capstone analysis

Table 15. Non-U.S. Manufacturers in TAN - Invesco Solar ETF Fund Holdings as of April 17, 2025

Non-US Manufacturers			
Company	**Ticker**	**Market Cap**	**Business**
GCL Technology Holdings Ltd (China)	**3800 HK**	**3.33B**	**Polysilicon, wafer**
Xinyi Solar Holdings Ltd (China)	**968 HK**	**3.37B**	**PV glass**
Enlight Renewable Energy Ltd (Israel)	**ENLT**	**1.92B**	**Power plant operation**
Daqo New Energy Corp ADR (China)	**DQ**	**1.13B**	**Polysilicon**
SolarEdge Technologies Inc (Israel)	**SEDG**	**931.70M**	**Inverter, storage**
JinkoSolar Holding Co Ltd ADR (China)	**JKS**	**966.00M**	**Module**
Solaria Energia y Medio Ambiente SA (Spain)	**SLR**	**890.90M**	**Power plant operation**
Flat Glass Group Co Ltd (China)	**6865 HK**	**42.46B**	**PV glass**
OY Nofar Energy Ltd (Israel)	**NOFR**	**-**	**Power plant operation**
Canadian Solar Inc	**CSIQ**	**610.79M**	**Module, cell**

[312] Invesco. (2025, April 29). *TAN - Invesco Solar ETF Fund Holdings.* Invesco. https://www.invesco.com/us/financial-products/etfs/holdings?audienceType=Investor&ticker=TAN

Non-US Manufacturers			
Company	**Ticker**	**Market Cap**	**Business**
(Canada)			
Scatec ASA (Norway)	SCATC	1.13B	Power plant operation
Grenergy Renovables SA (Spain)	GRE	1.14B	Power plant operation
United Renewable Energy Co Ltd (Taiwan, China)	3576 TT	15.80B	Cell, module
Energix-Renewable Energies Ltd (Israel)	ENRG	5.51B	Power plant operation
Doral Group Renewable Energy Resources Ltd (Israel)	DORL	2.15B	Power plant operation
TSEC Corp (Taiwan, China)	6443 TT	9.64B	Cell, module
Xinyi Energy Holdings Ltd (China)	3868 HK	-	Power plant operation
West Holdings Corp (Japan)	1407 JP	65.68B	Power plant operation
Motech Industries Inc (Taiwan, China)	6244 TT	8.46B	Cell, module
ReNew Energy Global PLC (India)	RNW	2.18B	Power plant operation
SMA Solar Technology AG (Germany)	S92	614.19M	Inverter
RENOVA Inc (Japan)	9519 JP	93.99M (RENB)	Power plant operation

Source: Invesco,[313] Yahoo Finance (2025), Company websites (2025), Capstone analysis

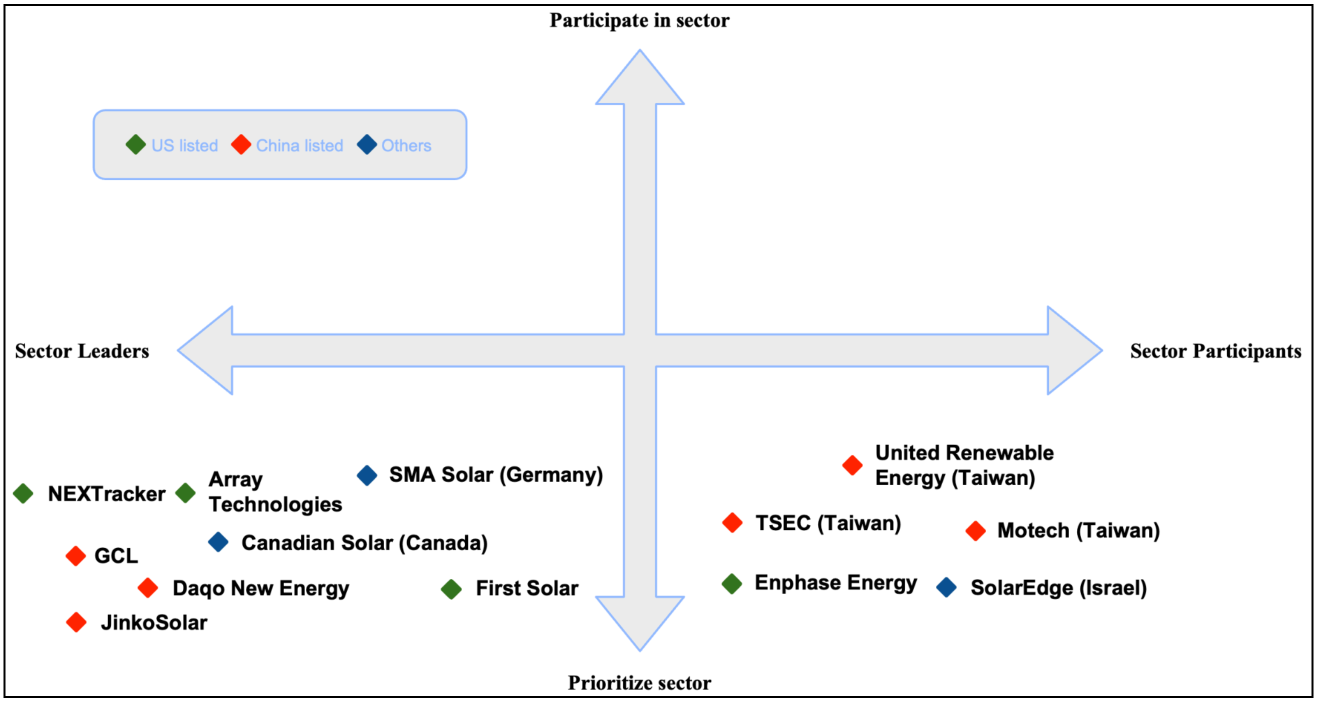
Sorting Matrix

Solar module and module component manufacturing is a very centralized sector, top 10 suppliers accounting for more than 80% of the global market.[314] Similar sector concentration applies among

[313] Ibid.
[314] Jin, J. (2024, February 14). *Solar PV module supply chain accelerates consolidation in the top 10 suppliers.* S&P Global.

the tracker[315] and inverter[316] suppliers as well. Based on the Invesco Solar ETF fund holdings, the matrix below has been populated with the following companies, all of which prioritize one or two sectors.

Figure 97. Matrix of Key Solar PV Players Globally



Source: Capstone analysis

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https://www.spglobal.com/commodity-insights/en/research-analytics/solar-pv-module-supply-chain-accelerates-consolidation

[315] Jowett, P. (2024, July 25). *WoodMac says global solar tracker shipments grew by 28% in 2023.* PV Magazine. https://www.pv-magazine.com/2024/07/25/woodmac-says-global-solar-tracker-shipments-grew-by-28-in-2023/

[316] Chopra, S. (2023, September 19). *Top 10 solar PV inverter vendors cornered 86% of the market in 2022.* Wood Mackenzie. https://www.woodmac.com/news/opinion/top-10-solar-pv-inverter-vendors-cornered-86-of-the-market-in-2022/

PART 3

Conclusion

Conclusion

The second Trump Administration has ushered in a shifting and often unpredictable policy landscape. The IRA, which has played a catalytic role in accelerating clean energy industries, now faces the risk of repeal or significant amendment. In parallel, heightened trade protectionism—primarily implemented through tariffs—and broader policy uncertainty are reshaping investment opportunities in the greening economy. These developments have introduced headwinds for industries that deploy renewable energy technologies or rely heavily on imported components affected by evolving tariff regimes. The present uncertainty on where the tariff rates will settle and on which products and countries they will apply complicates investment decisions further.

Nevertheless, this analysis identified four strategic sectors that are likely to remain resilient within this uncertain environment, owing to their alignment with three enduring bipartisan policy priorities: securing strategic supply chains, expanding energy generation capacity, and protecting and increasing domestic manufacturing capacity and employment. These priorities—shared across political lines and sustained across successive administrations—are already evident in ongoing tariff investigations, renewed emphasis on grid resilience, and continued efforts to onshore critical supply chains away from Chinese dominance.

As a result, the most investable opportunities within the greening economy are concentrated in sectors where demand is expected to remain robust, policy support is likely to persist despite a less favorable broader environment, and the U.S. holds—or is actively pursuing—a strategic advantage. The sectors identified include: critical mineral supply, nuclear energy generation, and the domestic manufacture of battery and solar components.

Particular emphasis was placed on critical minerals—specifically copper, nickel, aluminum, cobalt, and lithium—which are foundational to clean energy technologies and central to reducing reliance on Chinese refining capacity. While each mineral presents unique supply and pricing dynamics, common themes include upstream concentration outside the U.S. and potential Section 232 tariffs. Whether these tariffs on minerals will be tailwinds or headwinds for particular players along the supply chains will depend on their levels and the countries to which they apply. Analysts predict domestic players in the mining sector may be well-positioned for higher profitability if import tariffs on what they mine become settled at high levels.

Nuclear generation, supported by 45U and 45Y tax credits, stands to benefit from growing demand driven by AI-related electricity consumption and bipartisan recognition of nuclear energy as a clean, reliable baseload power source. Meanwhile, domestic battery and solar component manufacturing—despite their exposure to foreign inputs and IRA subsidy risks—remain strategically significant due to their contributions to job creation and national energy security. In principle, tariffs on battery and solar equipment imports would protect domestic manufacturing, but higher costs for imported inputs may become an offset in practice.

The report employed a structured sorting framework that combined firm-level market share with strategic alignment to the aforementioned national priorities. Sector-specific matrices (presented in Part 2) identified the publicly listed companies in the U.S., China, and other international markets best positioned to benefit under current and emerging policy conditions. Table 16 below summarizes key findings across market drivers, supply chain origins, potential policy impacts, and the number of investable targets identified through company-level analysis.

This report does not provide a definitive set of investment recommendations. Rather, it offers a roadmap to help Citi Global Wealth Management and its clients navigate near-term volatility and portfolio positioning for long-term structural change. As trade policy becomes increasingly intertwined with industrial strategy, understanding sectoral resilience is critical to interpreting the direction and durability of policy tailwinds. By spotlighting sectors with the strongest geopolitical relevance and policy alignment, this research offers a forward-looking lens for investments in the energy transition.

Table 16. Summary Table

Sector	Market Drivers		Supply Chain Origins		Potential Policy Impacts		Investible Targets	
	Demand Sources	**Market Pricing**	**Upstream**	**Midstream**	**Risk of Amendment Reducing IRA Support**	**Import Tariff likelihood & Impact**	**US & International**	**China listings**
Copper	Broad industrial uses	Sufficiently high to support production growth	Chile, Peru, Mexico, Indonesia, Other	China controls 50% of refining	Not presently covered by IRA; could be added	25% tariff likely result of pending Sec 232 process; could help domestic mining	13	5
Nickel	Linked to greening economy	Needs to cycle higher	Indonesia dominates	Indonesia leads; balanced diversified	Risk on 45X tax credit reduction viewed as low	Potential for tariffs on imports; could help domestic mining if economically feasible	11	2
Aluminum	Broad industrial uses	Sufficiently high to support production growth	Diversified, China self-sufficient	China dominates	Not presently covered by IRA; could be added	25% tariff likely result of pending Sec 232 process; could help domestic mining	15	3
Cobalt	Linked to greening economy	Needs to cycle higher	DRC 76% share	China dominates	Risk on 45X tax credit reduction viewed as low	Potential for tariffs on imports; could help domestic mining if economically feasible	11	6
Lithium	Linked to greening economy	Needs to cycle higher	Australia, Chile, others	China 60%-70% share	Risk on 45X tax credit reduction viewed as low	Potential for tariffs on imports; could help domestic mining if economically feasible	13	4
Nuclear Generation	increasing digital age demand	Higher cost than other sources	N/A	Uranium fuel largely from imports	Risk on 45X tax credit reduction viewed as low	Potential for tariff on uranium imports; higher electric rates could result	13	N/A
Battery Component Manufacturing	Linked to greening economy	Sufficiently low cost to support demand growth	N/A	China dominates	Risk on 45X credit reduction viewed medium	High potential for tariffs to protect domestic manufacture; partially offset by tariffs on inputs	11	2
Solar Component Manufacturing	Linked to greening economy	Needs to cycle higher	China dominates	China dominates	Risk on 45X credit reduction viewed medium	Longstanding tariffs protect domestic manufacture; partially offset by tariffs on inputs	13	N/A

Source: Capstone analysis