CRITICAL TECHNOLOGY SUPPLY CHAINS IN THE ASIA-PACIFIC

OPTIONS FOR THE UNITED STATES TO DE-RISK AND DIVERSIFY

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Taylore Roth, Samuel Naumann, Sarah Mortensen, Peter Heine, Amanda Sayre, John VerWey, and Adam Attarian

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Critical Technology Supply Chains in the Asia-Pacific

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EXECUTIVE SUMMARY

This report uses an econometric approach to identify several chokepoints within critical technology supply chains, draws key policy implications, and considers several options for policymakers to diversify U.S. trade relationships with countries in the East Asia-Pacific region.

MAIN ARGUMENT

The People's Republic of China controls key nodes throughout U.S. critical technology supply chains, intensifying pressure for U.S. policymakers to diversify and establish alternatives. This analysis leverages an econometric approach to evaluating critical technology supply chains, as defined by the U.S. Department of Commerce's International Trade Administration, with the intention of identifying U.S. supply chain vulnerabilities and opportunities for trade diversification. As the Biden administration's Indo-Pacific Economic Framework looks to bolster investment and trade relationships with allies and partners in the region, trade analysis can help identify specific areas of mutual interest and opportunity. In particular, four critical technologies are key to future advances in computing and clean energy (fuel cells, nuclear power, neodymium magnets, and semiconductors), while specific supply chain nodes present strategic vulnerabilities.

POLICY IMPLICATIONS

- Raw materials underlying numerous critical technology supply chains are considered global chokepoints with fewer options for diversification. Policies to alleviate these chokepoints can act as a multiplier for supply chain security across multiple sectors.
- The East Asia-Pacific region presents ample opportunities for critical technology supply chain diversification. South Korea, Taiwan, and Japan already possess a foundation from which to scale up production of many chokepoint commodities, while growing manufacturing hubs in Southeast Asia are prime candidates for U.S. investments and supports for trade diversification.
- The U.S. is making historic investments in domestic industry to alleviate perceived national and economic security concerns surrounding critical technology supply chains. The U.S. cannot fully onshore each of these supply chains, however, and a data-driven approach, such as the one adopted in this report, can help policymakers understand where strategies like friend-shoring or trade facilitation may most effectively support U.S. policy objectives.

Emerging technologies are rapidly shaping the global trajectory of economic growth and national security. Near-term advances in technologies like biotechnology, artificial intelligence (AI), quantum computing, and microelectronics will confer asymmetric national security advantages to nations leading their development and deployment while unlocking and expanding new commercial markets. Each of these emerging technologies relies on complex supply chains of products and services that support their overall innovation ecosystem, making critical and emerging technology innovation contingent on the security and resilience of these supply chains.

The United States, like the rest of the world, relies on firms in the East Asia-Pacific region (EAP) for raw, intermediate, and finished goods that support many of these critical technology supply chains.[1] For example, recent reports estimate that firms in the People's Republic of China (PRC) produce 97% of silicon wafers for solar power and control 80% of electric vehicle battery cell manufacturing capacity, Taiwanese firms produce 92% of the world's leading-edge logic semiconductors, and Japanese firms control 73% of the world's supply of select electronic-grade chemicals.[2]

Supply chain disruptions, whether due to a pandemic or economic coercion by a trade partner, can have wide-ranging impacts even when only disrupting the supply of minor inputs. Compounding supply chain risks have highlighted the importance of granularly quantifying and characterizing U.S. dependence on EAP countries for critical technology supply chains. In 2021, the Biden administration issued Executive Order 14017, which undertook a whole-of-government review of critical supply chains to identify risks and policy options.[3] Many of the reports generated in response to the executive order emphasized the need to further map U.S. supply chain reliance on EAP countries, looking for risks where chokepoints may lead to an interruption and opportunities where collaboration with allies could mitigate these risks.

Moreover, recognizing the geopolitical importance of emerging technologies to both national and economic security, particularly in an era of intensifying strategic competition with the PRC, U.S. policymakers are engaged in ambitious efforts to protect and promote U.S. leadership in critical technologies.[4] Simultaneously, U.S. policymakers are pursuing strategies to increase critical technology supply chain security and resilience.[5] Landmark legislation like the CHIPS and Science Act, the Inflation Reduction Act, and the Bipartisan Infrastructure Law demonstrates a renewed national focus on industrial policy, with the U.S. government investing billions of dollars in bolstering U.S. innovation and manufacturing capacity for critical technologies.

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1 This region is defined based on the U.S. Department of State's Bureau of East Asian and Pacific Affairs country list. This list includes the following countries: Australia, Brunei, Burma, Cambodia, Cook Islands, Fiji, Indonesia, Japan, Kiribati, Laos, Malaysia, Marshall Islands, Micronesia, Mongolia, Nauru, New Zealand, Niue, North Korea, Palau, Papua New Guinea, People's Republic of China, the Philippines, Samoa, Singapore, Solomon Islands, South Korea, Taiwan, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, and Vietnam.

2 "The Biden-Harris Plan to Revitalize American Manufacturing and Secure Critical Supply Chains in 2022," White House, Press Release, February 24, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/24/the-biden-harris-plan-to-revitalize-american-manufacturing-and-secure-critical-supply-chains-in-2022; "Chinese Photoresist Companies See a Rise in Their Share Price after Report of an Impending Ban from Japan," Gizmochina, March 15, 2023, https://www.gizmochina.com/2023/03/15/chinese-photoresist-companies-rise-share-price-after-ban-from-japan; U.S. Department of Energy, *Grid Energy Storage: Supply Chain Deep Dive Assessment* (Washington, D.C., February 2022), https://www.energy.gov/sites/default/files/2022-02/Energy%20Storage%20Supply%20Chain%20Report%20-%20final.pdf; and U.S. Department of Energy, *Solar Photovoltaics: Supply Chain Deep Dive Assessment* (Washington, D.C., February 2022), https://www.energy.gov/eere/solar/solar-photovoltaics-supply-chain-review-report.

3 Joseph R. Biden, "Executive Order on America's Supply Chains," White House, February 24, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains.

4 "Critical and Emerging Technologies List Update," White House, February 8, 2022, https://www.whitehouse.gov/wp-content/uploads/2022/02/02-2022-Critical-and-Emerging-Technologies-List-Update.pdf.

5 Biden, "Executive Order on America's Supply Chains."

Such investments have the potential to alter the structure of supply chains by onshoring and nearshoring manufacturing of the emerging technologies that are expected to dictate the course of economic growth and national security.

In addition to investments in domestic competitiveness, cooperation with like-minded allies and partners, including in the EAP, will be essential for efforts to improve the resilience of critical technology supply chains by identifying vulnerabilities (chokepoints) and opportunities (alternative sources).[6] The analysis presented in this report can inform U.S. policymakers of opportunities for collaboration with EAP countries to increase critical technology supply chain security, including through the Indo-Pacific Economic Framework for Prosperity, the G-7 Coordination Platform on Economic Coercion, the Minerals Security Partnership, and the Asia-Pacific Economic Cooperation (APEC).

This report presents an econometric approach to characterizing vulnerabilities and opportunities in the EAP region for policymakers interested in increasing the resilience of U.S. critical technology supply chains. While other studies leverage econometric methods to highlight trade concentrations and dependencies within select sectors or commodities,[7] this report is the first to use the Harmonized System (HS) codes in the U.S. International Trade Administration (ITA) list of critical technologies to demonstrate how international trade data can be used to identify vulnerabilities in critical supply chains. The following analysis finds that the United States is in some cases heavily reliant on imports from the region for raw, intermediate, and finished critical technology products. Vulnerabilities can occur when one country or a subset of countries is responsible for a significant share of worldwide trade in a critical technology commodity or U.S. imports of that commodity. This report also demonstrates how international trade data can be used to identify opportunities in supply chains: in the event that a vulnerability is observed, this methodological approach can highlight alternative sources of critical technology commodities and instances where collaboration with allied countries could mitigate a vulnerability.

Methodology

Data

This report uses 2021 BACI international trade data in combination with a list of critical technologies (and their intermediate inputs) generated by the ITA within the U.S. Department of Commerce.[8] Trade data is used to calculate several metrics that are used to assess U.S. supply chain resiliency and identify potential risks, dependencies, and opportunities associated with U.S.-EAP trade.

BACI data.[9] Compiled by the Centre d'Études Prospectives et d'Informations Internationales, BACI data provides information on the bilateral trade flows between 200 countries using six-digit

6 Biden, "Executive Order on America's Supply Chains."

7 See, for example, Olivia White et al., "The Complication of Concentration in Global Trade," McKinsey, January 12, 2023, https://www.mckinsey.com/mgi/our-research/the-complication-of-concentration-in-global-trade; and Eliana Zeballos, Xiao Dong, and Ergys Islamaj, "A Disaggregated View of Market Concentration in the Food Retail Industry," U.S. Department of Agriculture, Economic Research Report, no. 314, January 5, 2023, https://www.ers.usda.gov/publications/pub-details?pubid=105557.

8 U.S. International Trade Administration (ITA), "Draft List of Critical Supply Chains," https://www.trade.gov/data-visualization/draft-list-critical-supply-chains.

9 Centre d'Études Prospectives et d'Informations Internationales (CEPII), "BACI: International Trade Database at the Product Level," http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37.

HS codes. BACI data is sourced from the UN Commodity Trade Statistics Database and processed through a mirror analysis to correct reporting errors and fill missing gaps.[10]

Critical technologies. In response to Executive Order 14017, "Executive Order on America's Supply Chains," the ITA drafted a list of products within four critical sectors: public health and biological preparedness, information and communications technology (ICT), energy, and critical minerals.[11] Within each of these sectors, subsectors of critical technologies were identified. For example, within the energy sector, subsectors related to commodities like large-capacity batteries, neodymium magnets, nuclear power, platinum group metals, solar, and wind were identified. This report focuses on the fuel cell, nuclear energy, neodymium magnet, and semiconductor subsectors. These subsectors are particularly relevant for industries critical to U.S. economic and national security, such as aerospace, defense, clean energy, and automotives.

This report focuses on items within the ICT and energy sectors as well as their associated subsectors. **Table 1** enumerates the number of items of interest per subsector imported by the United States. The ITA critical technologies list presents the items according to the eight- and ten-digit tariff lines as detailed within the U.S. Harmonized Tariff Schedule. This report, by contrast, uses six-digit BACI data, truncating the more specific eight- and ten-digit level codes within their corresponding six-digit codes based on the products within the ITA list.

TABLE 1 U.S. Department of Commerce critical technology sectors and subsectors

Sector	Subsector	Number of HS codes that the United States imports
Energy	Carbon capture	17
	Electric grid	53
	Fuel cells	107
	Hydropower	24
	Large-capacity batteries	49
	Neodymium magnets	22
	Nuclear power	32
	Platinum group metals	17
	Solar	51
	Wind	54
ICT	Audiovisual equipment	26
	Computer equipment	20
	Other electronic components	38
	Semiconductors/electronic components	1
	Telecom/network equipment	31
	Semiconductors	97

10 The UN Comtrade Database is available at https://comtradeplus.un.org.

11 Biden, "Executive Order on America's Supply Chains"; and U.S. ITA, "Draft List of Critical Supply Chains."

Countries. This study focuses on exports to the United States from countries within the East Asia-Pacific as defined by the U.S. Department of State's Bureau of East Asian and Pacific Affairs (see **Table 2**). The scope does not include intraregional trade but is limited to the exports of critical technologies and materials to the United States and its reported imports.

Metrics

This study uses the following metrics to analyze the trade flows of critical technologies to observe trends in country-level competitiveness (market share and comparative advantage) and commodity-level dependence (import and export market concentration): Relative Market Share (RMS), Normalized Revealed Comparative Advantage (NRCA), and the Herfindahl-Hirschman Index (HHI). Together, these three metrics lend insight into the structure and competitiveness of a given market. For example, analyzed in conjunction with one another, these data points can illustrate whether a market is dominated by a few large players with a high market share or is highly competitive between many suppliers with low individual market share.

Relative Market Share. Market share calculations show a specific country's share of worldwide exports for a particular commodity. This calculation takes the value of a country's exports of a commodity and divides it by the worldwide exports of that commodity. Market share is useful for making general observations about a country's export competitiveness in a specific product. For example, one method of estimating U.S. competitiveness in the market for commercial aircraft is to calculate U.S. exports of aircraft as a percentage of worldwide exports of aircraft.

RMS improves on basic market share by comparing a country's exports of a commodity with those of its top competitor. To compute this metric, the market share of the top supplier is divided by the next largest supplier's market share. The market share of every other supplier is then divided by that of the top supplier. In this way, an RMS score can be generated for each country in a market. The top supplier's RMS indicates how many times as large its market share is as that of its largest competitor. The RMS scores of all other countries indicate the size of their market shares relative to the score of the top supplier.

TABLE 2 U.S. State Department list of countries and areas in the EAP

Australia	Kiribati	North Korea	Taiwan
Brunei	Laos	Palau	Thailand
Burma (Myanmar)	Malaysia	Papua New Guinea	Timor-Leste
Cambodia	Marshall Islands	Philippines	Tonga
People's Republic of China	Micronesia	Samoa	Tuvalu
Fiji	Mongolia	Singapore	Vanuatu
Indonesia	Nauru	Solomon Islands	Vietnam
Japan	New Zealand	South Korea	–

SOURCE: U.S. Bureau of East Asian and Pacific Affairs, https://www.state.gov/bureaus-offices/under-secretary-for-political-affairs/bureau-of-east-asian-and-pacific-affairs.

NOTE: Not on the State Department list but also included in this study are the Christmas Islands and Hong Kong, as they are broken out in BACI trade data and treated as their own countries. The Cook Islands and Niue are not included in this analysis, although they appear in the State Department's country list.

Assuming that market share is an indication of control over a market, RMS can offer insight into the relative strength of any market participant against its leading rival. The market leader's RMS helps characterize its level of dominance over the market. An RMS score greater than 1 indicates a market leader, while a score below 1 represents a country's market share as a percentage of the leader's. Broadly, RMS scores above 0.5 suggest a significant player in the market, while scores below 0.3 suggest that suppliers will suffer from significant competitive disadvantages due to the economies of scale and economies of experience enjoyed by bigger players. For example, the U.S. RMS for heavy aircraft exports (HS 8802.40 airplanes and other aircraft, of an unladen weight exceeding 15,000 kilograms) is 0.53, while France's RMS for these exports is 1.73. This means that the United States' market share for that commodity is slightly more than half of France's and that France enjoys a 73% lead over its top competitor (Germany).

Normalized Revealed Comparative Advantage. This report uses NRCA, which is based on calculations of Revealed Comparative Advantage (RCA), a metric derived by comparing a product's share of a country's exports to that product's share of all world exports. NRCA improves upon the RCA metric by standardizing scores along a scale from -1 to +1, enabling the comparison of a country's comparative advantage across different commodities.[12] A positive NRCA value suggests that a country has a comparative advantage for a good, a negative value suggests a comparative disadvantage, and a score of 0 means that a country's market share is equal to the average global market share. A larger NRCA absolute value indicates a greater advantage or disadvantage, with an absolute value above approximately 0.7 suggesting a significant comparative advantage or disadvantage.

Herfindahl-Hirschman Index. This report uses HHI to measure market concentration.[13] HHI is calculated by squaring the market share of each supplier in a given market and then adding them together.[14] The index varies between 0 and 1, indicating perfect diversification and total monopolization, respectively. The higher the score, the more concentrated the market for a particular commodity. A commodity with a high HHI score is likely produced by only a few countries. HHI increases both as the number of countries supplying a commodity decreases and as the disparity between those countries' market shares increases.

For this analysis, HHI illustrates the market concentration for commodities across two different markets: global exports to all countries (HHI World) and global exports to the United States (HHI U.S.).[15] After scoring both markets using the same metric, it is possible to identify commodities where the United States imports from a more concentrated set of partners than the global market as a whole and could therefore diversify without the introduction of new suppliers. HHI scores above 0.25 indicate a concentrated market with relatively few suppliers, while HHI scores below 0.15 indicate a diversified market with many potential suppliers. Looking again at the market for heavy aircraft (HS 8802.40), the United States' import market for this commodity has a concentration of 0.24, while the world market is slightly more diverse at 0.21.

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12 Run Yu, Junning Cai, and PingSun Leung, "The Normalized Revealed Comparative Advantage Index," *Annals of Regional Science* 43 (2009): 267–82.

13 See UN Conference on Trade and Development, "Indicators Explained #1: Export Market Concentration Index," https://unctadstat.unctad.org/en/IndicatorsExplained.html.

14 U.S. Department of Justice, Antitrust Division, "Herfindahl-Hirschman Index," https://www.justice.gov/atr/herfindahl-hirschman-index.

15 In certain markets, U.S. exports contribute significantly to global market concentration. If the United States is an important market participant among several influential suppliers, then its contributions will decrease concentration. If it is a dominant market leader that dwarfs other competitors, it may increase concentration. If policymakers seek to diversify U.S. imports using the HHI World metric, they should adjust for the way U.S. contributions to HHI World may impact diversification targets.

The United States can decrease market concentration in two ways. First, it can increase the number of suppliers to the market. Second, it can increase the contributions of small market participants and decrease those of large participants. In the market for heavy aircraft, the top U.S. supplier (France) would need to lose 4.5% of its U.S. market share to a new competitor to decrease HHI U.S. by 0.03 and reach parity with the world market.

Commodity Analysis

U.S. imports for most critical technology subsectors are highly concentrated. A number of them have an HHI score above 0.25, which indicates that the United States relies on a small number of supplier countries for these critical technologies. A comparison of worldwide imports of these critical technology subsectors through HHI scores indicates that U.S. import dependence exceeds the worldwide average in all subsectors analyzed. While variance between the world and U.S. HHI scores is statistically predictable, the magnitude of this difference suggests that some supply chains will be more easily diversified than others (see **Table 3**). For example, the average difference between HHI U.S. and HHI World for the carbon capture subsector is 0.300, indicating multiple opportunities within the supply chain for the United States to pursue diversification strategies with other partners. In contrast, the difference between U.S. and global trade concentrations in

TABLE 3 Average HHI scores for subsectors within the energy and ICT sectors

Sector	Subsector	Average HHI U.S.	Average HHI World	Difference (HHI U.S. and HHI World)	Label
Energy	Hydropower	0.282	0.105	0.177	1
	Carbon capture	0.413	0.113	0.300	2
	Fuel cells	0.258	0.125	0.132	3
	Electric grid	0.363	0.133	0.230	4
	Solar	0.368	0.153	0.215	5
	Nuclear power	0.351	0.191	0.160	6
	Wind	0.381	0.171	0.211	7
	Neodymium magnets	0.268	0.169	0.098	8
	Large-capacity batteries	0.317	0.185	0.133	9
	Platinum group metals	0.435	0.245	0.190	10
ICT	Telecom/network equipment	0.215	0.178	0.037	11
	Semiconductors	0.282	0.185	0.096	12
	Computer equipment	0.266	0.186	0.080	13
	Audiovisual equipment	0.331	0.234	0.096	14
	Semiconductors/ electronic components	0.311	0.162	0.149	15
	Other electronic components	0.194	0.126	0.068	16

the semiconductor subsector is nearly one-third that (0.096), meaning that greater diversification throughout the supply chain will be more difficult to achieve.

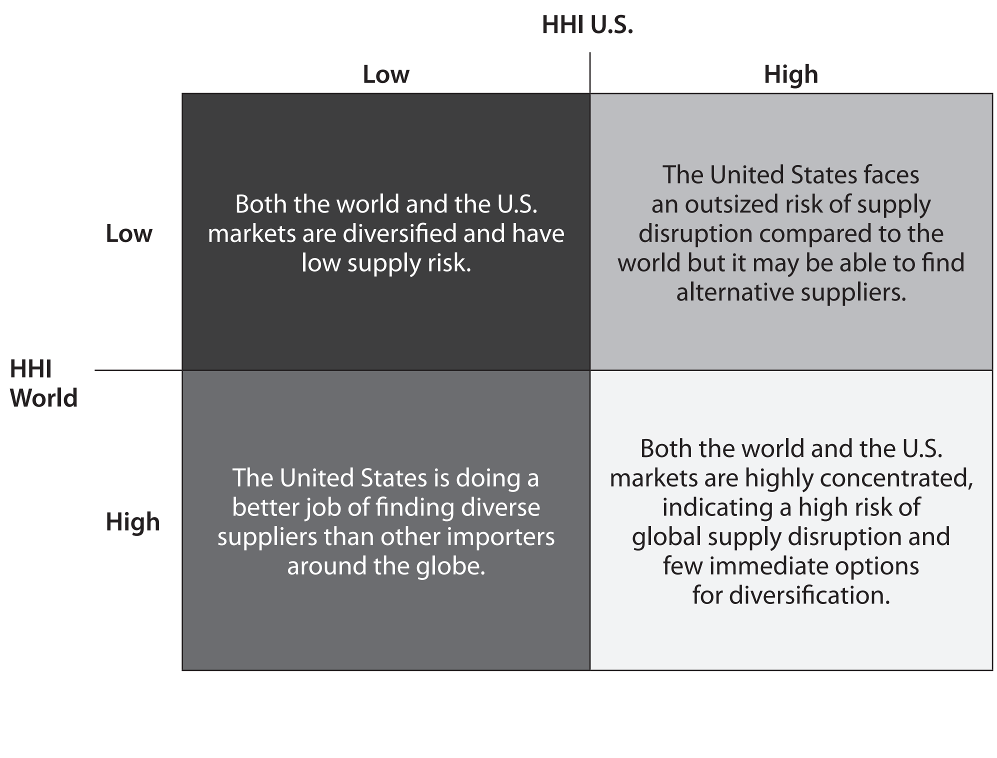
The following sections analyze U.S. chokepoints and market concentrations with EAP suppliers among key subsectors. This report provides analysis for the fuel cell, nuclear energy, neodymium magnet, and semiconductor subsectors, which are included within the ITA's ICT and energy sectors. To identify chokepoint commodities in the tables below, we selected commodities with annual exports to the United States above $1 million and identified all commodities for which a single EAP supplier held at least 33% of the U.S. market share. The individual commodities analyzed for each subsector are a subselection of these.

Patterns of Interest

The analysis in this report investigates four primary patterns of market concentration with implications for U.S. domestic and foreign economic policy (see **Figure 1**). In general, U.S. trade within the critical technology supply chains examined demonstrates room for diversification, though some subsectors present more opportunities than others (see **Figure 2**).

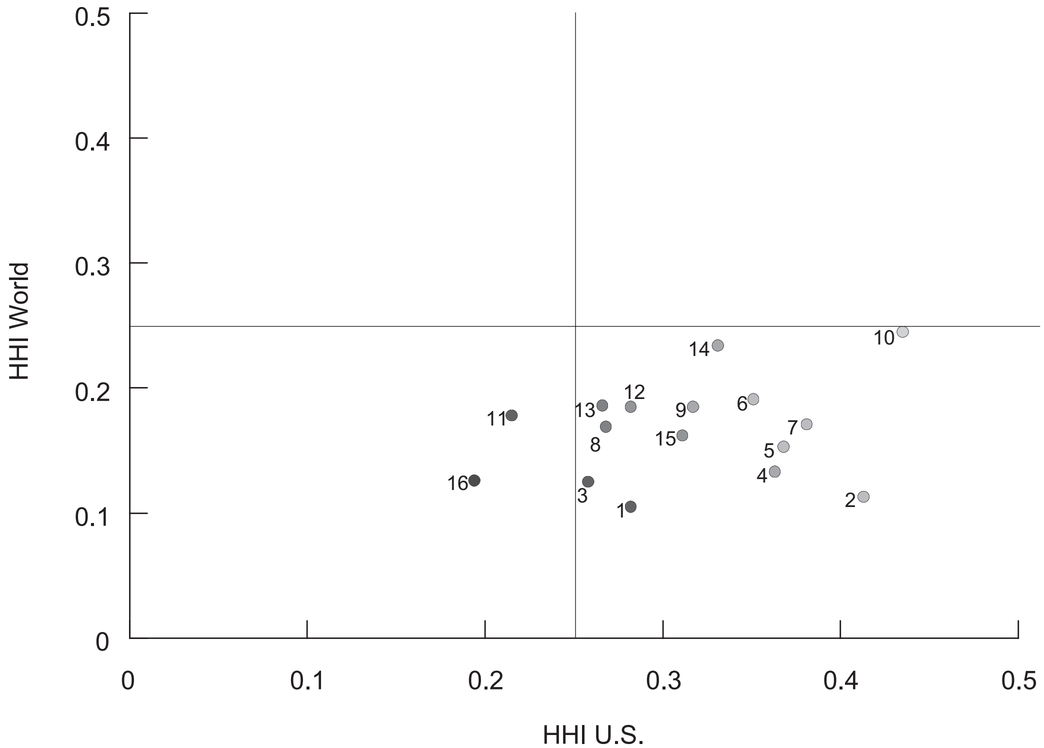
Commodities with room to diversify (high HHI U.S. vs. low HHI World). For some commodities, U.S. imports are highly concentrated (HHI U.S. greater than 0.25), while global supply remains relatively diversified (HHI World less than 0.15). Of the 47 HS codes that qualify for this study's prerequisites,[16] 5 exhibit a high HHI U.S. with a low HHI World and are therefore candidates

FIGURE 1 Patterns of interest based on market concentration



[16] These criteria require that a commodity account for more than $1 million in U.S. imports, have an EAP supplier that controls at least 33% of the U.S. market, and be within a subsector of interest (fuel cells, nuclear power, neodymium magnets, or semiconductors). Based on this criteria, specific commodities were selected for deeper analysis in the appendix.

FIGURE 2 Subsector average market concentrations



NOTE: This figure depicts U.S. and global market concentrations for subsectors within the ITA's list as indicated by HHI scores for the U.S. and global markets. Darker shading indicates greater market diversification, while lighter shading suggests greater market concentration.

for potential diversification. The PRC is the leading supplier to the United States for one of these commodities (HS 2811.19 other inorganic acids and other inorganic oxygen compounds of non-metals, other). The others were supplied by Japan (HS 8458.11 lathes: for removing metal, horizontal, numerically controlled), South Korea (HS 8404.10 auxiliary plant for use with steam or other vapor generating boilers; and HS 8458.99 lathes: for removing metal, other than horizontal or numerically controlled lathes), and Malaysia (HS 8542.31 electronic integrated circuits: processors and controllers).[17] **Table 4** identifies alternative suppliers within the EAP region that could scale up existing exports to the United States.[18] Diversification of suppliers of these commodities could

[17] Between 2005 and 2016, an average of 75% of U.S. imports of integrated circuits from Malaysia were actually produced by subsidiaries of U.S. firms. Furthermore, Malaysian companies primarily provide assembly, test, and packaging (ATP) services within the semiconductor supply chain. ATP services contribute about 10% of an integrated circuit's value; however, as the last step in the value chain, bilateral trade statistics tend to overstate the manufacturing capacity and value-added contributions of Malaysian firms within this supply chain. See John VerWey, "Global Value Chains: Explaining U.S. Bilateral Trade Deficits in Semiconductors," U.S. International Trade Commission, Executive Briefing on Trade, March 2018, https://www.usitc.gov/publications/332/executive_briefings/ebot-semiconductor_gvc_final.pdf; and Mihir P. Torsekar and John VerWey, "East Asia-Pacific's Participation in the Global Value Chain for Electronic Products," *USITC Journal of International Commerce and Economics*, March 2019, https://www.usitc.gov/publications/332/journals/east_asia-pacifics_participation_in_the_global_value_chain_for_electronic_products.pdf.

[18] Alternative suppliers include those jurisdictions that already export some level of the chokepoint commodity identified in the table to the United States. The analysis in this report does not account for distortions in trade data arising from transshipment, and further analysis is needed to determine the manufacturing capacity present in alternative supplier jurisdictions.

TABLE 4 Select critical technology commodities and alternative sources

HS code and description	Affiliated critical technology	Leading U.S. supplier in the EAP	Alternative suppliers in the EAP
2811.19 - Inorganic acids (Arsenic acid)	Semiconductors and critical minerals	PRC	Japan, Taiwan, Malaysia, Indonesia, South Korea, Singapore, Thailand
8404.10 - Boilers	Nuclear power	South Korea	Japan, Taiwan, Philippines, Malaysia, Thailand
8458.11 - Lathes	Neodymium magnets	Japan	South Korea, Taiwan, Singapore
8458.99 - Lathes	Neodymium magnets	South Korea	Japan, Singapore, Thailand
8542.31 - Electronic integrated circuits	Semiconductors	Malaysia	Vietnam, Taiwan, South Korea, Japan, Philippines

strengthen U.S. supply chain resilience while capitalizing on growing manufacturing sectors among suppliers such as Taiwan, Malaysia, and Vietnam.

Global chokepoint commodities (high HHI U.S. and high HHI World). For some chokepoint commodities, the United States and its allies and partners may need to co-invest in building entirely new alternative supply chains. These commodities are characterized by high HHI scores for both the world and U.S. markets, which indicate high levels of global concentration. Within the EAP region, the PRC is the leading U.S. supplier for five of the seven global chokepoint commodities identified, many of which fall within the semiconductors subsector.[19] Critical mineral commodities support diverse technology supply chains like semiconductors and neodymium magnets, which is why HS codes often co-occur in those subsectors. As a result, vulnerabilities generated by raw material and mineral import dependencies can ripple throughout several critical supply chains, increasing the potential impact of disruptions. Conversely, due to the ubiquitous demand for critical minerals across supply chains, efforts to diversify suppliers could act as a supply chain resilience multiplier. With the global supply of such commodities already heavily concentrated among a few suppliers, efforts to diversify will likely require additional investment and trade support to help new suppliers enter the market or scale up existing production. Furthermore, efforts to diversify trade might focus on countries like Japan and South Korea, where a strong existing industrial base could be scaled up. Additional trade diversification opportunities for countries of interest are presented in **Table 5**.

Figure 3 demonstrates the average market concentration of different subsectors in the ITA's list, as well as the individual commodities within them. The *x*-axis indicates U.S. market concentration (HHI U.S.), with commodity imports becoming increasingly concentrated toward the right of the axis. The size of each data point indicates the value of U.S. imports for that commodity (relative to the subsector). The vertical lines indicate the average U.S. market concentration for each subsector. The HS codes highlighted in the plot are analyzed in the **Appendix**.

[19] Although China may be the leading U.S. supplier for these commodities in the EAP, in some instances, overall worldwide concentration in a commodity is not due to Chinese market share. For example, though China is the United States' leading supplier of fluorine and bromine (HS 2801.30), the leading supplier countries worldwide are Israel, Jordan, and India.

TABLE 5 Select chokepoints for critical technology commodities and alternative sources

HS code and description	Affiliated critical technology	Leading U.S. supplier in the EAP	Potential alternative sources in the EAP
2504.10 and 2504.90 - Graphite: in powder, flakes, or other forms	Fuel cells, large-capacity batteries, semiconductors, and critical minerals	PRC	Japan, South Korea
2801.30 - Fluorine: bromine	Semiconductors and critical minerals	PRC	Japan, South Korea
2825.80 - Antimony oxides	Semiconductors and critical minerals	PRC	Thailand, Japan, South Korea
3701.99 - Photographic plates and film	Semiconductors	Japan	Singapore, Malaysia, Taiwan, South Korea
3707.90 - Photographic goods	Semiconductors	Japan	South Korea, Taiwan, Vietnam
8505.11 - Magnets	Neodymium magnets and wind energy	PRC	Japan, Philippines, Vietnam, Thailand, Malaysia

Fuel Cells

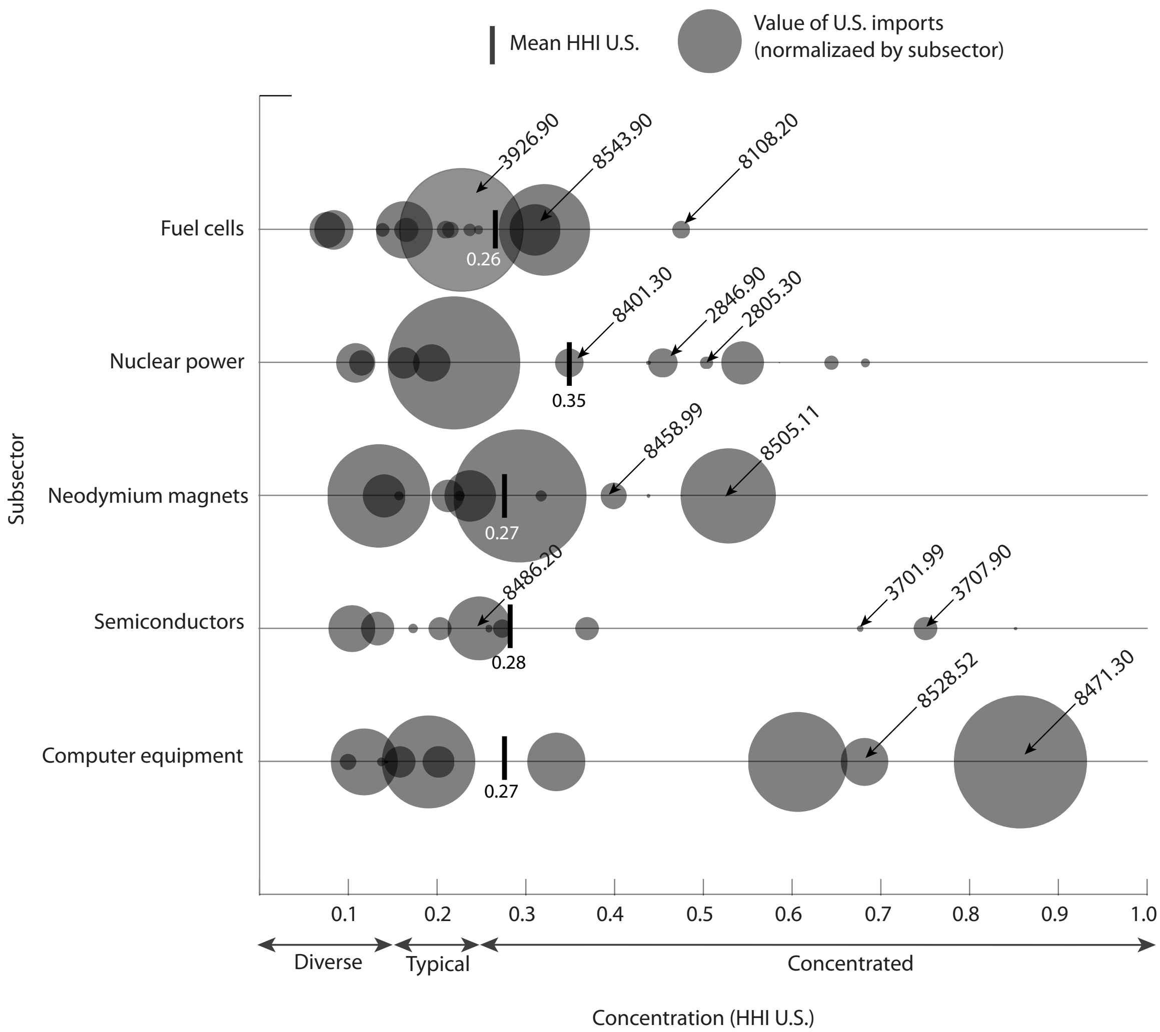
Fuel cells are technologies that convert chemical energy into clean and efficient electricity, employing a variety of fuels and feedstocks and providing power for a wide range of applications.[20] While fuel cells can be used to produce energy from numerous renewable energy sources, they are a critical technology for enabling hydrogen to become a viable economy-wide source of energy. The United States currently has manufacturing capabilities across most nodes of the fuel cell supply chain, from processed materials and subcomponent manufacturing to final product manufacturing. Because the global development of hydrogen technologies and applications is still in its relative infancy, the U.S. manufacturing base for enabling technologies like fuel cells remains relatively small.[21] This is expected to change over the coming years as a growing number of countries implement policies incentivizing investment in hydrogen technologies, while the cost of producing hydrogen from renewable energy is predicted to decrease by 30% by 2030.[22] As global demand for hydrogen technologies grows, it will be critical for U.S. policymakers to support the scaling up of domestic fuel cell manufacturing while maintaining visibility into new or growing chokepoints within the supply chain. According to the U.S. Department of Energy, over-the-horizon challenges include expanding the relatively small number of U.S. suppliers for key

[20] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Fuel Cells," https://www.energy.gov/eere/fuelcells/fuel-cells; and U.S. Department of Energy, Office of Policy, *America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition* (Washington, D.C., February 2022), https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain.

[21] U.S. Department of Energy, *Water Electrolyzers and Fuel Cells Supply Chain: Supply Chain Deep Dive Assessment* (Washington, D.C., February 2022), https://www.energy.gov/sites/default/files/2022-02/Fuel%20Cells%20%26%20Electrolyzers%20Supply%20Chain%20Report%20-%20Final.pdf.

[22] International Energy Agency, "The Future of Hydrogen: Seizing Today's Opportunities," June 2019, https://www.iea.org/reports/the-future-of-hydrogen.

FIGURE 3 U.S. market concentration across subsectors



NOTE: This figure demonstrates the average market concentration of different subsectors in the ITA's list, as well as the individual commodities within them. The *x*-axis indicates U.S. market concentration (HHI U.S.), with commodity imports becoming increasingly concentrated toward the right of the axis. The size of each data point indicates the value of U.S. imports for that commodity. The black vertical lines indicate the average U.S. market concentration for each subsector. HS codes listed in the plot are those analyzed in the appendix.

processed materials and avoiding overreliance on foreign suppliers of raw materials like graphite, iridium, platinum, strontium, and yttrium.[23]

The United States imports 105 ITA fuel cell HS codes from EAP countries. In 2021, total U.S. imports of commodities within this subsector amounted to $143 billion. Of this amount, $64 billion originated from the EAP region, with the largest volumes coming from the PRC ($32.0 billion), Japan ($8.9 billion), and Taiwan ($5.53 billion). Fifteen of these commodities had a total value

[23] U.S. Department of Energy, *Water Electrolyzers and Fuel Cells Supply Chain*.

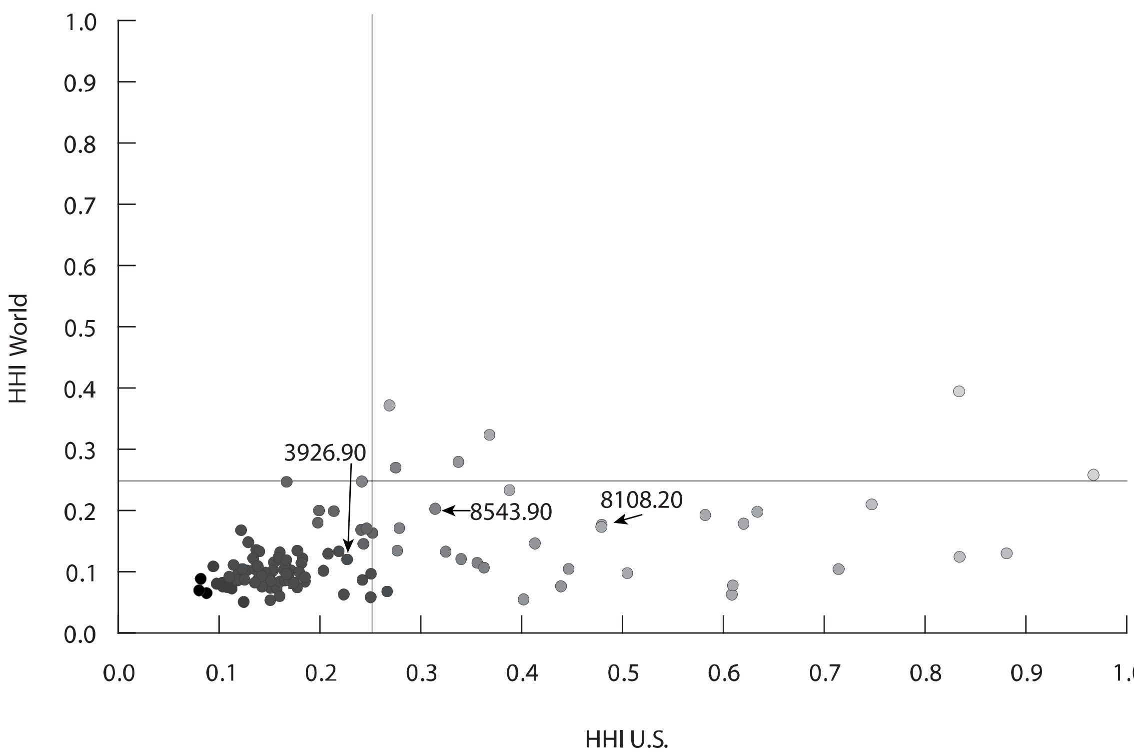
exceeding $1 million and an EAP supplier that accounted for over one-third of U.S. imports. The PRC was the market leader for 23 fuel cell commodities, the most of any EAP country.

Additionally, 28 of the commodities in this subsector have a market leader whose RMS is greater than 1.33, indicating that they supply the United States with at least 33% more than the second-largest supplier. Combined with a relatively low average HHI World score (0.12), the global fuel cell supply chain exhibits intense competition between many suppliers, with a few strong leaders. Despite a competitive global market, U.S. imports of some commodities in this supply chain are concentrated even when the global supply is diverse, as indicated by the subsector's higher average HHI U.S. score of 0.26 (see **Figure 4**). Overall, this difference suggests that there may be room for diversification within the fuel cell subsector.

Nuclear Power

The nuclear power subsector includes the raw materials, components, and technologies used to produce and power nuclear reactors. Nuclear energy currently supplies around 20% of U.S. electricity. The U.S. nuclear fleet will need to maintain its current capacity and likely expand to

FIGURE 4 Fuel cell subsector market concentration



NOTE: This figure depicts U.S. and global market concentrations for commodities within the fuel cell subsector, as indicated by HHI scores for the U.S. and global markets. Darker shading indicates greater market diversification, while lighter shading suggests greater market concentration. HS code callouts in the figure are further analyzed in the appendix.

meet U.S. goals of achieving net-zero carbon emissions by 2050.[24] Despite the growing importance of the industry, the U.S. Department of Energy has identified nuclear reactor components as a U.S. manufacturing-capability area of concern. An aging workforce, a shortage of certified domestic vendors, and persistent dependence on Russian enriched uranium imports intensify the need for proactive U.S. policy for the industry.[25] Following sanctions on Russia due to its ongoing invasion of Ukraine, the U.S. government has implemented numerous measures to expand the domestic production of enriched uranium and reduce reliance on the Russian market. With the commissioning of new advanced nuclear reactors having stalled, however, the domestic fuel industry has few market incentives to ramp up production.[26] This is exemplative of challenges felt throughout critical U.S. supply chains in which atrophied downstream infrastructure or still emergent market demand prevents the strengthening of the upstream supply chain. For the nuclear industry, U.S. policymakers should look to couple support for the upstream supply chain with efforts to deploy new reactors that can build downstream demand.

The United States imports 31 different commodities with HS codes falling within the ITA's nuclear energy subsector from EAP suppliers, totaling $650 million in 2021. The top suppliers within this subsector are the PRC ($259.3 million), Japan ($159.9 million), and South Korea ($103.5 million). Among U.S. imports from the region within the nuclear power subsector, seven commodities have EAP countries supplying over one-third of U.S. imports where the export value is greater than $1 million. Moreover, global supply for commodities from this subsector is relatively diversified, with an average HHI World score of 0.164. The U.S. market remains highly concentrated, however, with an HHI U.S. score of 0.35 (see **Figure 5**). Most U.S. nuclear-affiliated trade occurs with countries outside the EAP region, and efforts to diversify may benefit from expanding trade with some regional suppliers.

Neodymium Magnets

Neodymium magnets are among the strongest magnets in the world, and their global consumption is increasing across the energy, defense, and electronics sectors. Examples of neodymium magnet applications range from electric vehicle batteries, wind turbines, computer hard drives, drones, missile systems, and rotors for aircraft, making them a critical input supporting several key U.S. industries.[27] Presently, the majority of the neodymium supply chain is concentrated in foreign countries and is highly opaque. Substitutions along the supply chain are difficult due to the unique performance metrics of neodymium magnets and the rare earth minerals used to produce them.[28] In its neodymium magnet supply chain report in response to Executive Order 14017, the U.S. Department of Energy specifically calls out U.S. supply chain vulnerabilities due to the PRC's virtual monopoly over rare earth separation, warning that PRC "firms can exert control over international and U.S. domestic markets for raw materials, metals,

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24 U.S. Department of Energy, *Nuclear Energy: Supply Chain Deep Dive Assessment* (Washington, D.C., February 2022), https://www.energy.gov/sites/default/files/2022-02/Nuclear%20Energy%20Supply%20Chain%20Report%20-%20Final.pdf.

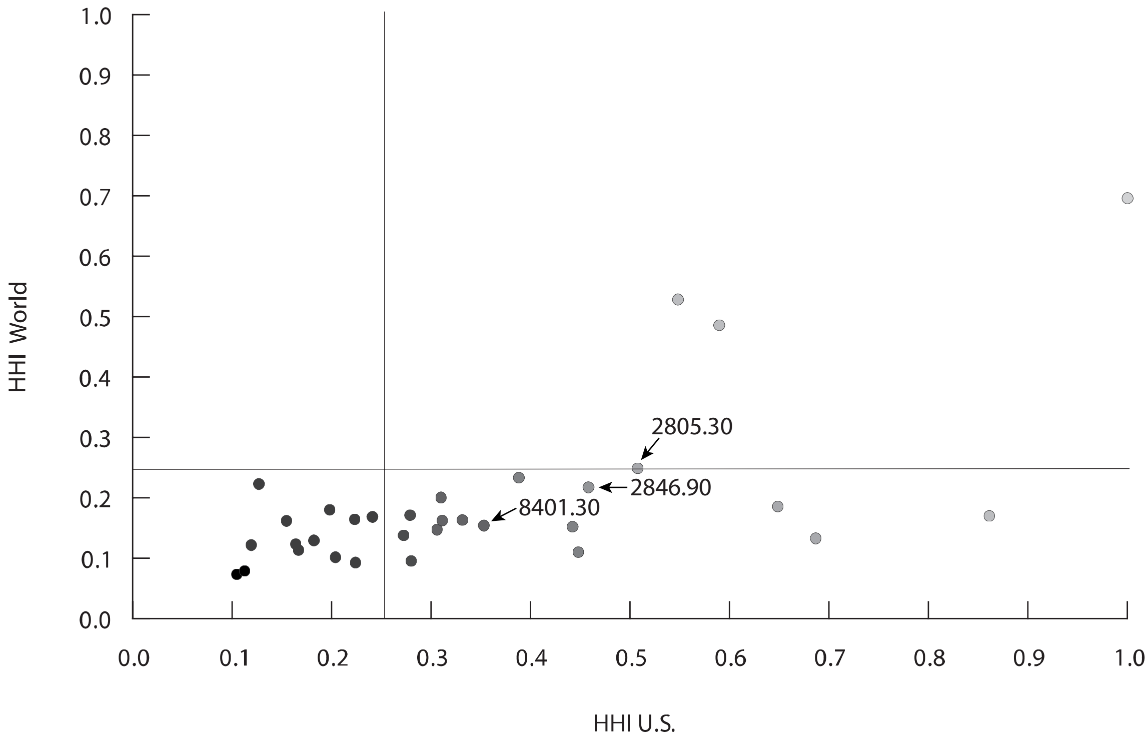
25 U.S. Department of Energy, *America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition*; and U.S. Department of Energy, *Nuclear Energy: Supply Chain Deep Dive Assessment*.

26 Paul Day, "U.S. Ramps Up Advanced Fuel Production Capabilities," Reuters, February 16, 2023, https://www.reuters.com/business/energy/us-ramps-up-advanced-fuel-production-capabilities-2023-02-16.

27 "Neodymium," American Chemical Society, https://www.acs.org/greenchemistry/research-innovation/endangered-elements/neodymium.html; and "Application of Neodymium Magnets in Aerospace Industry," Stanford Magnets, https://www.stanfordmagnets.com/application-of-neodymium-magnets-in-aerospace-industry.html.

28 U.S. Department of Energy, "Achieving American Leadership in the Rare Earth Magnets Supply Chain," February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Fact%20Sheet%20Final.pdf.

FIGURE 5 Nuclear power subsector market concentration



NOTE: This figure depicts U.S. and global market concentrations for commodities within the nuclear power subsector, as indicated by HHI scores for the U.S. and global markets. Darker shading indicates greater market diversification, while lighter shading suggests greater market concentration. HS code callouts in the figure are further analyzed in the appendix.

magnets, and components through market manipulations like restricting output to increase prices and price dumping to lower prices to discourage investment or make competing firms outside of the PRC less profitable."[29] The Department of Energy's concerns are based on historical instances of PRC economic coercion using its rare earths monopoly. In 2010, for example, the PRC leveraged this monopoly against Japan during a rift over sovereignty in the East China Sea, and in 2019, it threatened to cut off exports to the United States amid ongoing trade tensions.[30]

At present, U.S. policies affecting the neodymium magnet supply chain are largely focused on solving the challenge of access to critical minerals. The Biden administration has already invested billions of dollars in projects intended to shore up the U.S. domestic supply of critical minerals as well as to develop new refining and recycling capacities. For example, in 2022, the U.S. Department of Defense's Industrial Base Analysis and Sustainment Program awarded U.S. company MP Materials $35 million to establish heavy rare earth element separation and processing capabilities

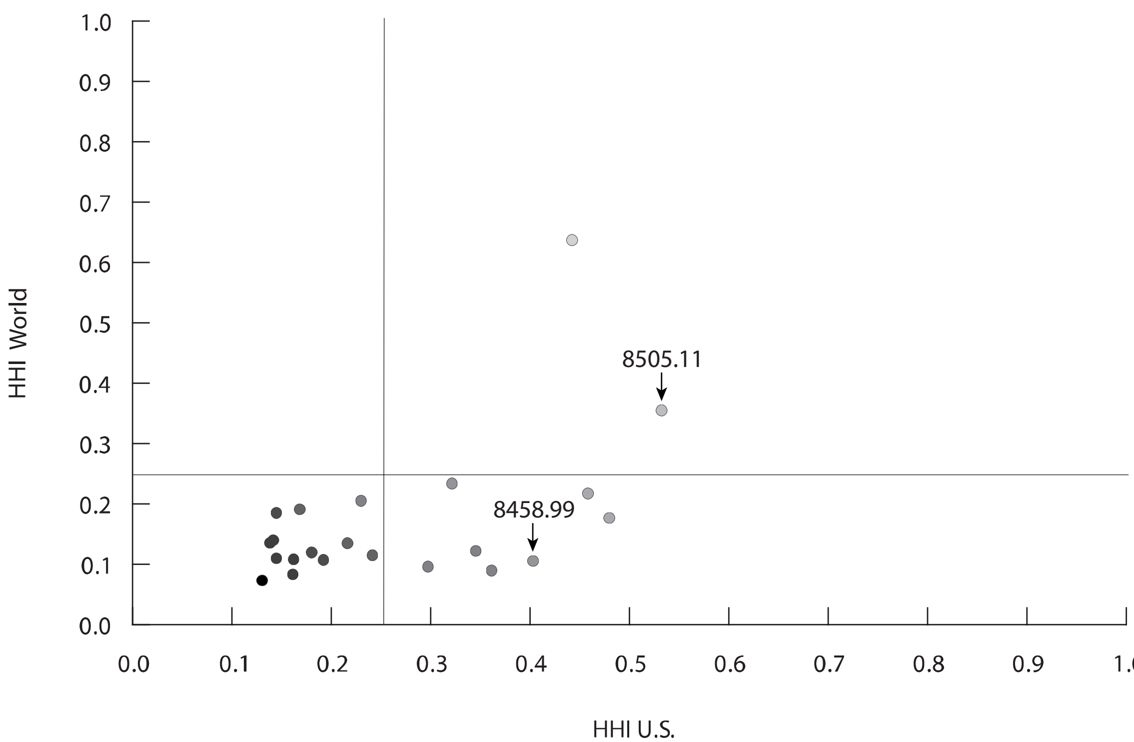
[29] U.S. Department of Energy, *Rare Earth Permanent Magnets: Supply Chain Deep Dive Assessment* (Washington, D.C., February 2022), https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[30] Panos Mourdoukoutas, "China Threatens to Cut Rare Earths Supplies to the U.S.—Bad Idea," *Forbes*, May 16, 2019, https://www.forbes.com/sites/panosmourdoukoutas/2019/05/16/china-threatens-to-cut-rare-earths-supplies-to-the-us-bad-idea/?sh=23cb7ee67486; and "Does China Pose a Threat to Global Rare Earth Supply Chains?" Center for Strategic and International Studies, ChinaPower, https://chinapower.csis.org/china-rare-earths.

at its Mountain Pass facility in California.[31] While this investment is lauded as restoring a wholly domestic and vertically integrated U.S. magnet supply chain, continued U.S. government support will likely be needed to unlock additional capacity as commercial demand continues to expand.

The United States imports 22 commodities from EAP suppliers with HS codes falling within the ITA's neodymium magnet subsector, totaling $1.8 billion in 2021. The top suppliers within this subsector are the PRC ($668.5 million), Japan ($658.5 million), and South Korea ($244.9 million). Within the subsector, there are six commodities for which an EAP supplier accounts for over one-third of U.S. imports and the value of the export exceeds $1 million. Of these six chokepoints, the PRC dominates two, as demonstrated by an RMS greater than 7.0. For the subsector, U.S. imports are relatively concentrated among a few suppliers, as illustrated by an average HHI U.S. of 0.268 across all relevant commodities. The average HHI World for the subsector is 0.169, demonstrating opportunities for U.S. diversification (see **Figure 6**).

FIGURE 6 Neodymium magnet subsector market concentration



NOTE: This figure depicts U.S. and global market concentrations for commodities within the neodymium magnet subsector, as indicated by HHI scores for the U.S. and global markets. Darker shading indicates greater market diversification, while lighter shading suggests greater market concentration. HS code callouts in the figure are further analyzed in the appendix.

31 "Securing a Made in America Supply Chain for Critical Minerals," White House, Fact Sheet, February 22, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-minerals.

Semiconductors

Semiconductors are foundational electronic components that enable everyday computing capabilities for products like cell phones and cutting-edge advances in AI. Due to their ubiquity, the semiconductor supply chain is critical to key U.S. industries like automotive, health, defense, energy, and aerospace. Advances in the semiconductor industry are also critical for enabling advances in next-generation technologies like AI and quantum computing—key arenas of intensifying economic, technological, and military competition between the United States and the PRC.[32] As such, in addition to maintaining supply chain security, the United States has a long-term competitive interest in maintaining industrial leadership within the semiconductor industry.

The Covid-19 pandemic created enormous strains on the global semiconductor industry, with fabrication plants in multiple countries pausing production as global demand for consumer electronics skyrocketed to accommodate a transition to virtual life. Initially, semiconductor supply chain interruptions most severely affected the U.S. automotive industry, causing auto inventories to dwindle and prices to soar.[33] While the severity of the global semiconductor shortage has been somewhat alleviated, strategic competition between the United States and the PRC has caused U.S. policymakers to double down on calls for developing a domestic semiconductor supply chain. The resulting CHIPS and Science Act represents a once-in-a-generation investment to accomplish this goal by channeling $52.7 billion into U.S. semiconductor R&D, manufacturing, and workforce development. Highlighting the role of strategic competition in modern U.S. industrial policy, the law also includes provisions that prevent recipients from channeling their investments back into the PRC or other countries of concern.[34]

Based on the ITA's list, the United States imports 97 different commodities falling within the semiconductor subsector from the EAP region, for a total of $46.3 billion. In 2021, the greatest value was imported from Malaysia ($13.2 billion), Japan ($8.84 billion), and the PRC ($7.02 billion).[35] Within this list, 43 commodities have HHI U.S. scores greater than 0.25. This indicates that the U.S. market is concentrated among a few suppliers for almost half of all commodities along the semiconductor supply chain. Fortunately, sixteen of these commodities have HHI World scores below 0.15, suggesting there are opportunities to diversify (see **Figure 7**).

Findings and Policy Implications

The United States maintains highly concentrated supply chain relationships for commodities used to produce critical technologies. This concentration results in a preponderance of commodity chokepoints in which one supplier country—usually the PRC—provides over one-third of U.S. imports for a commodity. Fortunately, the United States has room to diversify its suppliers for some of these commodities. This report identifies five important chokepoint commodities for

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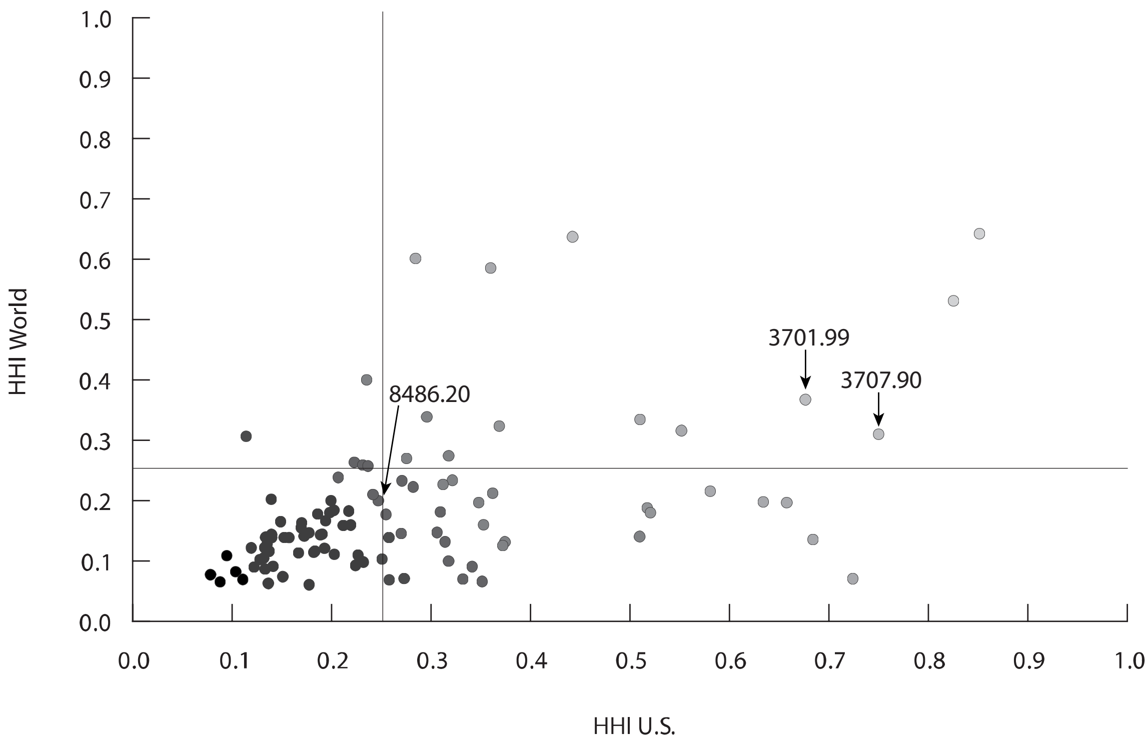
32 U.S. Department of Energy, *America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition*.

33 Ondrej Burkacky et al., "Semiconductor Shortage: How the Automotive Industry Can Succeed," McKinsey, June 10, 2022, https://www.mckinsey.com/industries/semiconductors/our-insights/semiconductor-shortage-how-the-automotive-industry-can-succeed.

34 "CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China," White House, Fact Sheet, August 9, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china.

35 Malaysia's large export values overstate its role in the semiconductor value chain. The country is a hub for final assembly of integrated circuits rather than high value–added design and manufacturing. As the final node along the semiconductor supply chain, Malaysia's exports register the full value of the good despite the fact that most of its value was contributed by the firms that designed and manufactured the integrated circuits before it arrived in Malaysia for ATP. See VerWey, "Global Value Chains."

FIGURE 7 Semiconductor subsector market concentration



NOTE: This figure depicts U.S. and global market concentrations for commodities within the semiconductor subsector, as indicated by HHI scores for the U.S. and global markets. Darker shading indicates greater market diversification, while lighter shading suggests greater market concentration. HS code callouts in the figure are further analyzed in the appendix.

which the United States could relatively easily diversify its suppliers, given a highly unconcentrated global market. Diversification could strengthen select U.S. supply chains by capitalizing on robust and expanding manufacturing sectors in Taiwan, Malaysia, Vietnam, and other countries. U.S. policymakers should pursue efforts to encourage U.S. firms to diversify their supply chains for these materials to preemptively mitigate disruption risks.

Of the commodity chokepoints facing the United States, some have very few options for diversification. This analysis identifies seven important U.S. imports that can be considered global chokepoints (high U.S. and global market concentration), of which the PRC is the dominant supplier for five. Of these chokepoints, four are critical minerals used to produce key technologies like semiconductors and neodymium magnets. These commodities represent prime areas for additional investment by the United States and like-minded partners in establishing alternative supply chains to mitigate the risks of disruption.

U.S. policymakers should consider strategies to diversify trade with key allies and partners in the EAP region. U.S. allies Japan and South Korea offer multiple options for trade diversification. Both countries already export most of the chokepoint commodities identified and maintain an existing industrial base to support production scale-up. Encouraging this increased diversification will alleviate some dependence on PRC imports. Statistics used within this report, such as Normalized

Revealed Comparative Advantage, can be used to identify these opportunities. For example, the PRC currently supplies about 72% of the permanent magnets and metal articles intended to become magnets after magnetization (HS 8505.11) used in both the neodymium magnet and wind subsectors. Japan has a positive NRCA for these articles, suggesting an opportunity for the United States to expand trade with a regional ally to alleviate this chokepoint.

Policymakers should also consider economic strategies that enable Vietnam, Malaysia, Thailand, and Indonesia to scale up exports of key chokepoint commodities. At present, these countries supply small amounts of chokepoint commodities to the United States because of ongoing challenges in cultivating high-end talent, improving local infrastructure, and accessing markets, which limit their role in U.S. critical technology trade. Policies supporting educational exchange, infrastructure development, regulatory capacity building, commercial investment, and improved terms of trade could help these countries better meet U.S. demand under a supply chain diversification strategy. Cultivating these trade relationships would enable EAP countries to increase their exports of raw materials and components for critical technologies while decreasing market monopolization within key sectors. Further research should examine the degree to which other EAP suppliers can provide cost-effective substitutes in the time horizon necessary to achieve adequate diversification. Policymakers engaging with leaders throughout the region should identify priority industries and commodities for regional partners as well as synergies with U.S. goals for diversification.

The United States cannot and should not seek to domestically produce all commodities used throughout critical supply chains. Strategies to drive investments in domestic manufacturing capacity with the goal of reducing supply chain vulnerabilities should employ rigorous analysis that goes beyond the identification of supply chain chokepoints to understand which investments along the supply chain align with U.S. comparative advantages and strategic goals. For example, statistics identified in this report, such as NRCA, can pinpoint areas where the United States could expand an existing advantage or bolster an area of weakness. Combined with a survey of U.S. policy objectives, such research could identify specific supply chain nodes where domestic investments should be concentrated.

Conclusion and Next Steps

Overall, U.S. imports of commodities listed within the ITA's energy and ICT sectors are highly concentrated among a few suppliers. This concentration necessitates a dynamic set of trade-offs for the United States. Supplier concentration can increase efficiency and reduce transaction costs for advanced inputs, but it can also produce vulnerabilities to supply chain disruptions or economic coercion by trading partners. Not every concentrated relationship should be seen as a vulnerability, and close trade relationships with trusted partners can be a source of economic and geopolitical resilience. For example, while Japan supplies 67% of the U.S. titanium powder (HS 8108.20) imports used to produce fuel cells, this trade relationship presents fewer vulnerabilities given the strong U.S.-Japan alliance. U.S. producers may also benefit from fewer transaction costs and collaborative relationships with Japanese exporters.

Over the last decade, U.S. policymakers have steadily incorporated supply chains into a new conception of economic and national security. Disruptions to critical technology supply chains have wreaked havoc on critical domestic industries, while a broadening conception of technological competitiveness emphasizes the need for both localized innovation and manufacturing capacity.

In response to these evolving dynamics, U.S. policymakers are involved in an ambitious effort to modernize the U.S. toolkit for protecting and promoting U.S. technology competitiveness as a facet of national security. In devising industrial policy investment strategies, trade negotiations, and even export-control regulations, U.S. policymakers require a data-driven approach to characterizing supply chain concentrations, dependencies, and comparative advantages. The analysis in this report establishes an initial step in this process, with future research required to match the opportunities identified with strategic priorities in both the United States and partner countries.

The United States will not be able to diversify every supply chain through the substitution of trade partners. In some cases, alternative suppliers may not have the capacity to fulfill U.S. demand and improving production capacity will require significant investments and lead times. In other cases, as highlighted in this report, some industries are too concentrated on a global scale for this to be a solution. The analysis in this report provides a first step in identifying where the United States should consider alternative suppliers, but further analysis is required to evaluate the viability of this strategy for individual commodities and suppliers.

Researchers should seek to quantify and understand the degree to which supply chains in the sectors analyzed are shifting among U.S. trade partners. This report presents a snapshot in time of U.S. trade dependencies with EAP partners and thus does not capture the ongoing dynamics of evolving supply chains. Future research should incorporate trend analyses to understand which markets are becoming increasingly concentrated or diverse, as well as which countries are gaining and losing shares in critical supply chains. Whereas market forces may already be driving diversification in some commodities, the United States should prioritize interventions targeting critical commodities where vulnerabilities appear to be increasing. For commodities where the United States seeks diversification, further research should examine the degree to which other suppliers in the EAP region can provide substitutes and along what timeline and at what price point. Policymakers engaging with leaders throughout the region should look to target priority industries and commodities for regional partners and identify synergies with U.S. goals for diversification. To provide just one example, the United States could support investments to build Thailand's capacity for lathe production as a means of alleviating existing dependencies while simultaneously supporting Thailand's goal to develop competitiveness in the new-generation automotive industry.[36]

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[36] Akshay Prasad and Hirotaka Uchida, "Unleashing Thailand's Electric Mobility Potential," Arthur D. Little, November 2022, https://www.adlittle.com/en/insights/report/unleashing-thailand's-electric-mobility-potential.

APPENDIX

Several chokepoint commodities exist within each subsector analyzed in this report. A selection of these commodities is discussed below. Each commodity was selected for meeting the following two criteria: (1) a single supplier with a market share above 33%, and (2) a total U.S. import value greater than $1 million.

Chokepoint Commodities in the Fuel Cell Subsector

HS 8108.20 (unwrought titanium; powders). HS 8108.20 contains high-grade titanium powders, a key component in the fuel cell manufacturing process. Titanium powders are used to create porous titanium or titanium foam, which is used to manufacture electrodes found in polymer electrolyte membrane fuel cells.[37]

Japan supplies about 67% of U.S. imports of HS 8108.20. Japanese exporters maintain a market share nearly six times as large as the next largest global competitor, expressed by an RMS of 5.807. The United States has other EAP trading partners, but they currently supply negligible amounts of this commodity (less than 1% relative and absolute market share). The U.S. import market for this commodity is significantly more concentrated than the global market, with an HHI U.S. score of 0.48 compared to the HHI World score of 0.17. While the global market is more diversified, Japan is the leading global supplier, suggesting that the United States may be capitalizing on Japan's comparative advantage (NRCA 0.808) in titanium production. Due to the dearth of alternative suppliers in the EAP, the United States may need to look to other regions if it chooses to reduce its dependence on Japanese exports for titanium powders. Furthermore, negative NRCA values among all other EAP suppliers of titanium powders suggest that they have disadvantages in this export market and may not be viable alternatives for U.S. demand.

HS 8543.90 (parts of electrical machines and apparatus, nes). This commodity heading includes electrical machines that are designed to convert electrical energy into mechanical work. More specifically, this subheading includes parts and components of physical vapor deposition apparatuses. These machines are used in factory lines for fuel cell production or in fuel cell–powered generators and vehicle drives.[38]

The PRC supplies 53% of U.S. imports of this HS code, totaling over $1.1 billion in trade in 2021. Chinese exporters maintain a U.S. market share advantage that is nearly four times as large (RMS 3.921) as the next largest competitor (Japan). U.S. market concentration exceeds global concentration by about 0.11, suggesting that there is some room for diversification. While the PRC does have a comparative advantage in the production of electric machines (NRCA 0.449), the United States could diversify its market through an increase in exports from Japan. Currently, Japan exports 13.6% of the total U.S. imports of electric machines. Japan's NRCA is valued at 0.521, suggesting a larger competitive advantage, which could accommodate an increase in production. Alternative suppliers within the EAP that demonstrate positive NRCA values, though

[37] "Titanium Porous Material for Pem Fuel Cell Electrodes," Baoji Highstar Titanium Metal, https://www.bjhighstar.com/titanium-porous-material-for-pem-fuel cell-electrodes/; Chul Min Hwang et al., "Effect of Titanium Powder Loading in Gas Diffusion Layer of a Polymer Electrolyte Unitized Reversible Fuel Cell," *Journal of Power Sources* 202 (2012): 108–13; and N. Abdullah and S.K. Kamarudin, "Titanium Dioxide in Fuel Cell Technology: An Overview," *Journal of Power Sources* 278 (2015): 109–18.

[38] At the six-digit level, this HS code represents seven different sub-commodities, of which the ITA is only concerned with one: HS 8543.90.12.

smaller in magnitude, include Thailand, Singapore, and Malaysia. These countries already export this commodity to the United States and globally. Vietnam, Indonesia, and Singapore are other potential candidates for diversification, as these countries hold a higher absolute market share globally than for the United States. This characteristic suggests that these countries may have capacity to supply the U.S. market. Some of the production in these countries already may be due to the presence of U.S. firms with facilities in the region, creating a potential basis for U.S. policymakers to facilitate more investments that help scale up production.[39]

HS 3926.90 (other articles of plastics and articles of other materials, nes). A subset of specialized plastics is used in fuel cell production.[40] Specialized plastics can serve as a lightweight skeleton for other critical materials and can be used to construct electrolyte membranes, membrane electrode assemblies, bipolar plates (electrode plates), end plates, gaskets, and other parts used in fuel cell production.[41] Recent research also suggests that these plastics could be used as a future fuel source within fuel cells.[42]

With U.S. imports totaling $5.5 billion in 2021, specialized plastics are an important share of the subsector's value. The PRC provides nearly 45% of U.S. imports of this commodity, which is almost four times as large (RMS 3.668) as the next global competitor and nearly twelve times as large (RMS 11.7) as Taiwan, the region's second-largest supplier. With an NRCA of 0.297, the PRC has a comparative advantage in the production of plastics. Overall, the U.S. plastics import market is more concentrated than the global market, with an HHI U.S. score of 0.23 compared with the HHI World score of 0.12. This difference suggests that the United States can diversify its supply of this commodity. Within the EAP region, Taiwan, Japan, Vietnam, and Thailand have existing trade relationships with the United States for specialized plastics (all supplying between 1% and 4% of the U.S. market). Most of these suppliers have a negative NRCA score, indicating a disadvantage in plastics production. Taiwan is the only supplier within the region to demonstrate a positive value (NRCA 0.020) and may be the best option for expanding supply.

Chokepoint Commodities in the Nuclear Power Subsector

HS 2846.90 (compounds, inorganic or organic [excluding cerium], of rare-earth metals, of yttrium, scandium, or of mixtures of these metals, nes); HS 2805.30 (rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed). The PRC supplies about 67% of U.S. imports of HS 2846.90 and 63% of HS 2805.30, two categories of rare earth metals. Rare earths like gadolinium are used to capture neutrons in nuclear reactors, while other rare earth elements provide luminescence to screens and other electronic devices used within nuclear power plants.[43] HHI U.S. scores for both HS codes are around 0.25 points higher than HHI World scores, meaning that the United States could potentially diversify its rare earths suppliers.

While the PRC dominates the U.S. market for HS 2846.90 rare earth compounds (RMS 7.192) and has a small comparative advantage for compounds (NRCA 0.139), some of the United States' other

39 "Singapore Overview," Applied Materials, https://www.appliedmaterials.com/sg/en/about/singapore-overview.html; and "DOE Awarding $1.16B to 9 Battery Component Manufacturing Projects as Part of $2.8B Funding," Green Car Congress, October 20, 2022, https://www.greencarcongress.com/2022/10/20221020-doecomponents.html.

40 The ITA only lists one of the 26 eight-digit subcodes for HS 3926.90 as critical for fuel cells: 3926.90.45.

41 "Polymers for Fuel Cells and Fuel Cell Systems: Renewed Interest in Hydrogen Fuel Cells for Long-Range E-mobility," CHEManager, January 31, 2014, https://www.chemanager-online.com/en/news/polymers-fuel-cells-and-fuel cell-systems.

42 Tetsuya Hori et al., "Fuel Cell and Electrolyzer Using Plastic Waste Directly as Fuel," *Waste Management* 102 (2020): 30–39.

43 Nikk Ogasa, "How Rare Earth Elements' Hidden Properties Make Modern Technology Possible," *Science News*, January 16, 2023, https://www.sciencenews.org/article/rare-earth-elements-properties-technology.

trading partners have a larger comparative advantage than the PRC, which presents opportunities for import diversification. Japan, Malaysia, and South Korea supplied rare earths to the United States in 2021, with market shares of 9%, 4%, and 2%, respectively, for HS 2846.90. Both Japan and Malaysia have larger NRCA values (0.229 and 0.843, respectively) and existing trade relationships with the United States. Malaysia's strong advantage makes it a potential U.S. partner for imports. Increasing the market shares of these two countries presents diversification options to reduce the current dependency on the PRC within the U.S. market. As of 2021, the United States was the world's fourth-largest exporter of these compounds. Reducing U.S. dependency on Chinese imports could also involve scaling up domestic production.

Like the market for rare earth compounds, the U.S. market for HS 2805.30 rare earth metals is much more concentrated (HHI U.S. 0.508) than the global market (HHI World 0.25). The PRC remains the leading supplier, providing 89% more rare earths than the next global supplier (RMS 1.894). With an NRCA of 0.253, the country has a strong comparative advantage, while each of its EAP competitors has a negative NRCA score that demonstrates comparative disadvantage. Efforts to diversify rare earth imports are particularly warranted. The importance of rare earths to multiple critical supply chains is evidenced by their inclusion in the ITA's nuclear power, neodymium magnet, and critical minerals subsectors.

HS 8401.30 (fuel elements [cartridges]: non-irradiated, and parts thereof). Japan supplies around 55% of U.S. imports of non-irradiated fuel cartridges, which are used to contain nuclear material that is inserted into a reactor core. With an RMS of 2.6, Japan has a significant lead over its main competitor, Taiwan. U.S. imports indicate a level of concentration (HHI U.S. 0.534) that exceeds the overall worldwide concentration (HHI World 0.354), meaning there are alternative suppliers in the market. Nonetheless, diverting imports between suppliers is difficult in the case of nuclear fuel cartridges, which must be designed and certified for each specific reactor model. It thus can be incredibly difficult for a new supplier to take over production for a specific reactor.

In addition to Japan, Taiwan supplied approximately 21% of U.S. imports of non-irradiated fuel cartridges in 2021, and South Korea supplied around 8%. However, only South Korea demonstrates a positive NRCA value (NRCA 0.288), whereas Japan (NRCA -0.340) and Taiwan (NRCA -0.597) have disadvantages with cartridge production. Depending on the trajectory of the U.S. nuclear buildout and the specific reactor models chosen, the United States could look to expand trade with these suppliers, particularly South Korea, or look to other key suppliers around the world, including Sweden, Spain, Germany, or France. In addition, as of 2021, the United States exports about 8.5% of the global supply of this commodity, and companies like Global Nuclear Fuel supply a large proportion of domestic nuclear fuel element needs.[44] Policymakers could invest in scaling up this production capacity to further meet domestic demand.

Chokepoint Commodities in the Neodymium Magnet Subsector

HS 8505.11 (electromagnets; permanent magnets and articles intended to become permanent magnets after magnetization, of metal). The PRC has a strong comparative advantage in magnet production (NRCA 0.576) and supplies 72.4% of U.S. imports of HS 8505.11. Chinese exporters of these commodities maintain a U.S. market share 12.8 times as large (RMS 12.8) as the next biggest competitor, Japan, which supplies 5.7% of U.S. imports. Combined with high HHI scores

[44] U.S. Department of Energy, *Nuclear Energy: Supply Chain Deep Dive Assessment*.

for both U.S. and global imports, it is clear that the PRC heavily dominates this market. But the HHI U.S. score (0.532) for this commodity is 0.178 points higher than the HHI World score (0.354), indicating that there are opportunities for the United States to diversify its suppliers. The PRC accounted for 58% of global permanent magnet exports in 2021, while Japan, the Philippines, and Vietnam were the next largest exporters, representing 10.2%, 7.8%, and 4.7% of global supply, respectively.[45] The United States could increase permanent magnet imports from these countries and facilitate U.S. investments to help increase production.

Although the PRC's comparative advantage in the production of these goods scores high (NRCA 0.576), other EAP suppliers present options for supply chain diversification, particularly Japan, Vietnam, and the Philippines. Both Japan and Vietnam have positive NRCA values of 0.494 and 0.459, respectively, demonstrating high levels of comparative advantage. The Philippines even exceeds the PRC's comparative advantage in magnet production (NRCA 0.896) and is another potential supplier.

HS 8458.11 (lathes: for removing metal, horizontal, numerically controlled); HS 8458.19 (lathes: for removing metal, horizontal, other than numerically controlled); HS 8458.91 (lathes: for removing metal, numerically controlled, other than horizontal lathes); HS 8458.99 (lathes: for removing metal, other than horizontal or numerically controlled lathes). U.S. imports of lathes (machine tools used for cutting metal) are highly concentrated among a few suppliers in the EAP region, namely South Korea, Japan, Taiwan, and the PRC. Each supplier dominates U.S. imports for a different lathe type (RMS greater than 1.2), with categories denoting the lathe configuration (horizontal, vertical, multi-axis, etc.) and the presence of automation (numerically controlled or non-numerically controlled). Overall, the global supply for each type of lathe is considered diverse, with HHI World scores all falling below the 0.15 threshold, meaning that the United States could pursue multiple options for diversification. Furthermore, the United States can build upon existing production capacity in multiple EAP countries for lathes, as all partners have some comparative advantage in their production (positive NRCAs). In addition to diversifying lathe imports from Japan, South Korea, Taiwan, and the PRC, the United States could look to increase imports from Thailand and the Philippines, which supplied small quantities of HS 8458.11 and HS 8458.91 to the United States in 2021.

For three of the four lathe types (HS 8458.11, HS 8458.91, and HS 8458.99), increasing exports from Japan and South Korea could reduce U.S. reliance on a single country for a single type of lathe. Both markets have comparative advantages for these goods (NRCA greater than 0.35), while other EAP suppliers like Taiwan (HS 8458.11 and 8458.99), Thailand (HS 8458.11), and the Philippines (HS 8458.91) also have some capacity to meet U.S. demand. By contrast, HS 8458.19 lathes are limited in additional EAP suppliers, with only the PRC and Taiwan demonstrating positive NRCA scores.

Chokepoint Commodities in the Semiconductor Subsector

HS 3707.90 (photographic goods: chemical preparations for photographic uses; unmixed products for photographic uses other than sensitized emulsions); HS 3701.99 (photographic plates and film: [for other than color photography], in the flat, sensitized, unexposed, with no side exceeding 255 mm, of any material other than paper, paperboard, or textiles). Photographic plates and goods

[45] "Metal Permanent Magnets, Articles Intended as Magnets," Observatory of Economic Complexity, https://oec.world/en/profile/hs/metal-permanent-magnets-articles-intended-as-magnets.

are used by the semiconductor industry in the photolithography process, a subset of the broader semiconductor fabrication process. Out of EAP suppliers to the United States, Japanese exporters of photographic commodities (HS 3707.90 and 3701.99) exhibit the highest market share, supplying 86% and 82% of U.S. imports, respectively. HHI U.S. scores for both commodities (0.750 and 0.656) predictably reflect significant U.S. market concentration, while HHI World scores (0.310 and 0.367) indicate that alternative suppliers exist, despite a relatively concentrated global market.

Japan supplies over 23 times as much as its leading competitor for HS 3797.90 commodities (RMS 23.231) and over 9 times as much for HS 3701.99 commodities (RMS 9.336). This dominance is further highlighted by the country's strong comparative advantage in the production of both goods (NRCA 0.874 and NRCA 0.885). Despite a strong U.S.-Japan alliance, Japan's market dominance could create vulnerabilities for the United States should supply disruptions occur. To diversify this market, the United States could look to South Korea and Taiwan. Both suppliers have positive NRCA values for HS 3707.90 photographic goods (NRCA 0.327 and NRCA 0.577, respectively). Of all other EAP suppliers, only Taiwan has a slight positive trade advantage (NRCA 0.075) for HS 3701.99 photographic plates. The United States currently imports these goods from South Korea and Taiwan and could seek to scale up these relationships. Finally, the United States is the world's third-largest exporter of chemical preparations for photographic goods, so efforts to improve supply chain resilience could involve investments to expand domestic production.

HS 8486.20 (machines and apparatus of a kind used solely or principally for the manufacture of semiconductor devices or of electronic integrated circuits). HS 8486.20 contains machines used for semiconductor production, including dicing machines, probing machines, polish grinders, and sliced wafer demounting and cleaning machines.[46] Japan supplies nearly 44% of U.S. imports of HS 8486.20 and enjoys a strong comparative advantage within the market (NRCA 0.759). The Japanese share of the U.S. market is almost three times as large (RMS 2.691) as the next largest competitor, Singapore. Singapore's higher comparative advantage (NRCA 0.764) indicates the country likely has the capacity to increase its exports to support U.S. demand. Currently, Singapore holds a U.S. market share of 16.3% and is closely followed by the Netherlands at 13.4%.[47] Taiwan, the PRC, and Malaysia are other significant exporters of HS 8486.20 machines to the United States (around 5%). Of these suppliers, only Taiwan has a positive NRCA value (NRCA 0.075). Looking at the metrics of overall market concentration, the HHI U.S. score sits at the edge of the middle range (0.15–0.25) for market diversification at 0.247, suggesting a moderate level of concentration. Compared with the HHI World score of 0.199, only marginal diversification may be possible given current market conditions.

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[46] "Products: Semiconductor Manufacturing Equipment," ACCRETECH, https://www.accretech.jp/english/product/semicon/index.html.

[47] U.S. semiconductor manufacturing equipment firms maintain a global presence, including facilities in Japan, Singapore, Taiwan, and the Netherlands. As a result, some of the volume of U.S. imports from these countries may be the result of domestic U.S. firms importing equipment from non-U.S.-based overseas subsidiaries. See "Singapore Overview."

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