RESOURCES *for the* FUTURE

What Is "Mineral Security" and What Policies Are Needed to Achieve It? Lessons from Oil Security

Michael A. Toman and Douglas R. Bohi



Working Paper 24-16
September 2024

About the Authors

Michael A. Toman returned to RFF as a senior fellow in 2021 after stints at the World Bank Development Research Group, RAND Corporation, and the Inter-American Development Bank. Mike served as a Senior Staff Economist at the White House Council of Economic Advisers from 1994–1996. His current research interests include reduction of agricultural greenhouse gas emissions, critical minerals for decarbonization, markets for emission reduction credits, and climate change policies in developing countries. Mike has a BA from Indiana University, a MSc in applied mathematics from Brown University, and MA and PhD degrees in economics from the University of Rochester.

Douglas R. Bohi was a Senior Fellow at RFF from 1978 to 1997, where he worked on a variety of issues related to energy supplies and demands, international oil security, and regulation in the power sector. During that time he was on leave for two years as Chief Economist at the Federal Energy Regulatory Commission. After leaving RFF, Doug worked for many years at Charles River Associates, focusing on industrial organization and regulation in the power sector, before his retirement.

About RFF

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. RFF is committed to being the most widely trusted source of research insights and policy solutions leading to a healthy environment and a thriving economy.

Working papers are research materials circulated by their authors for purposes of information and discussion. They have not necessarily undergone formal peer review. The views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors.

Sharing Our Work

Our work is available for sharing and adaptation under an Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0) license. You can copy and redistribute our material in any medium or format; you must give appropriate credit, provide a link to the license, and indicate if changes were made, and you may not apply additional restrictions. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. You may not use the material for commercial purposes. If you remix, transform, or build upon the material, you may not distribute the modified material. For more information, visit **https://creativecommons.org/licenses/by-nc-nd/4.0/**.

Abstract

The need to enhance US “critical mineral security” is a recurrent policy theme. In this paper we examine security issues for the critical minerals used to produce EV batteries. We examine those issues through the lens of concerns about international oil insecurity, a major energy policy concern for the United States in the past. We discuss similarities and differences between the factors affecting critical mineral security and international oil security, drawing on policy lessons from years of research on international oil security policy to find lessons for identifying and managing mineral security issues.

Contents

1. Introduction **1**

2. Critical Mineral Security Risks **1**

3. Oil Insecurity: Background **4**

4. Observations from Oil Security Research **5**

5. Battery Minerals Versus Oil **7**

6. Lessons for Battery Critical Minerals Security Policy **8**

6.1. Supply risks 8

6.2. Economic vulnerabilities 9

6.3. Potential policy responses 9

7. Concluding Remarks **11**

8. References **12**

1. Introduction

Critical minerals (CMs) are substances identified by unique properties that make them difficult to replace in the nearer term. Thus, their availability and affordability raises important concerns for mineral policies in the United States.[1] Several CMs, including cobalt, graphite, lithium, nickel, and manganese, figure prominently in the manufacture of batteries for electric vehicles (EVs). Other minerals known as rare earths play important roles in the design and manufacture of the electromagnets used in EV motors and large wind turbines. CMs thus are important for energy policy as well. Because such materials play important roles in advanced manufacturing and national defense technology, they also are relevant to economic and defense policy.

The need to enhance US "critical mineral security" is a theme underlying various proposed policies.[2] However, that term has several interpretations depending on the substances and usages involved. In this paper we examine security issues for the CMs used to produce EV batteries, as identified above.[3] We examine the issues for those minerals through the lens of concerns about international oil insecurity, a major energy policy concern for the United States. We discuss similarities and differences between the factors affecting CM security and international oil security, drawing on policy lessons from years of research on international oil security to find lessons for identifying and managing mineral security issues.

2. Critical Mineral Security Risks

Discussions of critical mineral security typically are directed at two risks: (a) an ongoing significant reduction or cutoff of supply by a hostile dominant supplier, motivated by geopolitical or other conflicts, that could affect military preparedness as well as economic interests; and (b) persistence of uncompetitively high prices from the exercise of market power by global suppliers with large market shares and the capacity to suppress competition. Some treatments of the subject also include a third risk, volatility of prices in CM markets, leading to uncertainties that can hamper new investments to diversify CM supplies (we return to this topic below).

1 The US critical mineral list as identified by the secretary of the Interior is found in the Federal Register, **https://www.govinfo.gov/content/pkg/FR-2022-02-24/pdf/2022-04027.pdf**. A more expansive list of critical materials identified by the Secretary of Energy under the Energy Act of 2020 is found in the Federal Register, **https://www.govinfo.gov/content/pkg/FR-2023-08-04/pdf/2023-16611.pdf**.

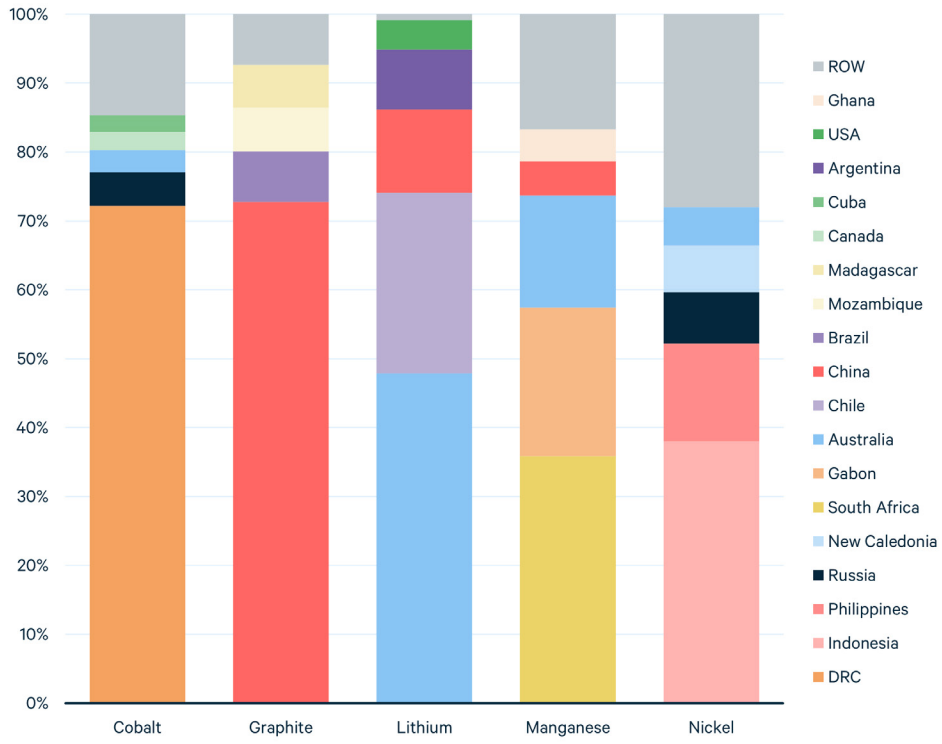
2 See, for example, Runde and Hardman (2023), Aspen Institute (2023), and OurEnergyPolicy (2024).

3 Rare earths have more complex production processes and play different roles in the economy and national security. The current domination of their extraction and processing by one country, China, implies different circumstances than apply to battery minerals.

Risks (a) and (b) require a high concentration (large market share) in extraction or processing of CMs. Figures 1-3 show national shares in battery minerals extraction and processing, as well as the spatial distribution of mineral reserves that can be used for future extraction. The figures show that China has large shares in the processing of several battery minerals, whereas production is more geographically diverse with the notable exception of graphite, which China also dominates. Reserves are more geographically diverse than current extraction.

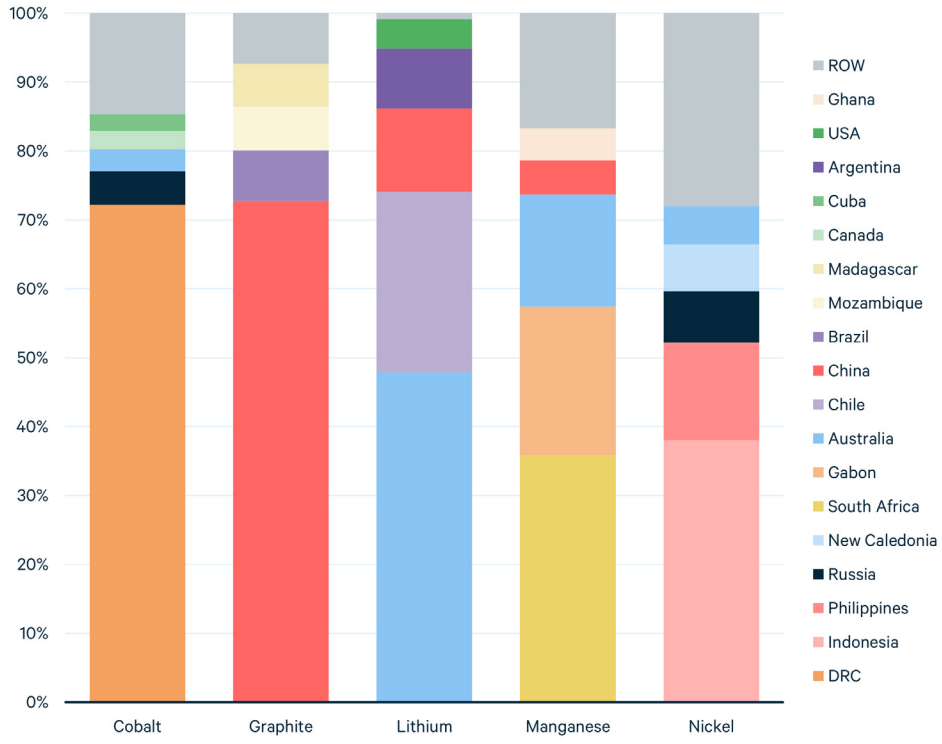
Figures 1 and 2 show that China's large shares in processing several battery minerals is not explained by a natural advantage from proximity to mineral deposits. As discussed below, China's shares in processing result from a long-term industrial policy. In addition, China's processing sector is not made up of a few Goliath enterprises. For example, China has about half a dozen large or medium lithium processing companies and dozens of smaller ones. Thus, for either geopolitical or market power risks to materialize, China would need to exert state power over the CM sector.

Figure 1. Distribution of battery critical mineral extraction, 2021



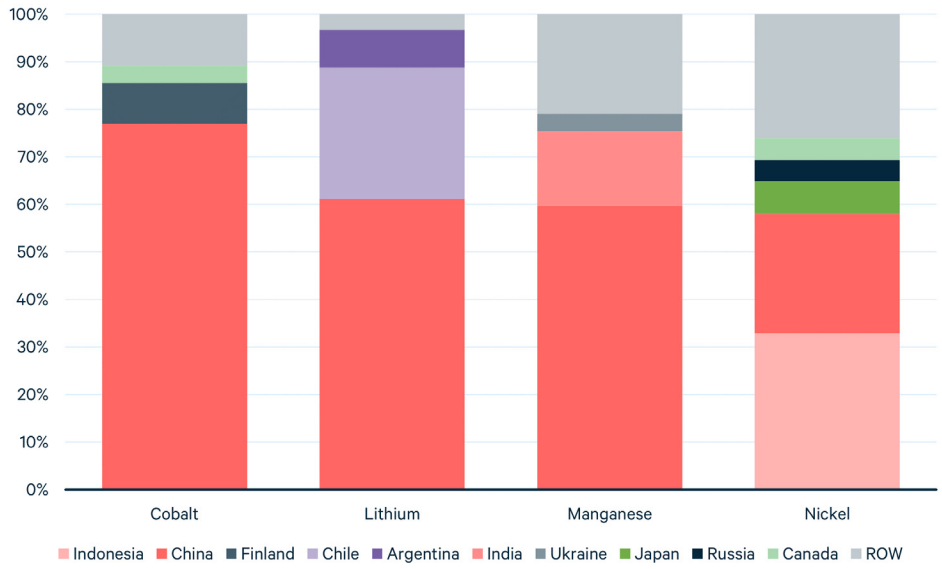
Sources: Estimates based on USGS (2023); NMIC (n.d.); Idoine et al. (2023); Reichl and Schatz (2023).

Figure 2. Distribution of battery critical mineral reserves, 2023



Sources: Estimates based on USGS (2023).

Figure 3. Distribution of battery critical mineral processing, 2021



Sources: Estimates based on USGS (2023); NMIC (n.d.); Idoine et al. (2023); Reichl and Schatz (2023).

3. Oil Insecurity: Background

Two elements characterized concerns about oil insecurity (Bohi and Toman 1993, 1996). The first was the high cost of oil imports because of high prices maintained by the Organization of Oil Exporting Countries (OPEC). Because of OPEC's large market share and reserve capacity, imports from OPEC were the marginal source of global oil supply. It was feared that OPEC would use its market power to set prices above the cost of production, thereby extracting economic rent from purchasers of its oil. Its market power, it was argued, also allowed "predatory pricing"—using reserve capacity to temporarily reduce prices by expanding output, thereby undercutting development of competing supply sources.

The second element of oil insecurity was the perceived vulnerability of oil-using economies to sudden jumps in oil prices. Although such jumps could have several causes, the main concern was instabilities in Middle Eastern OPEC countries. Even small reductions in the availability of imported oil from OPEC could cause significant price shocks, given the tightness in oil markets at the time. It was feared that those price shocks would cause businesses contractions and higher unemployment as well as jumps in the overall price level.

Concerns about excessively high payments for oil imports led to increased tax breaks for the domestic oil industry, more intensive oil leasing in public lands, and the ill-fated effort to provide alternatives to crude oil through the Synthetic Fuels Corporation (Díaz Anadón and Nemet 2013). Many analysts argued for a tariff on oil imports as a way to recapture the rents being captured by OPEC. Ultimately, however, both political and economic concerns about the effects of high oil prices, undercut support for that policy.

Less exposure to price shocks by reduced dependence on oil imports, it was argued, would reduce macroeconomic harms. This focus on imports obscured the fact that any macroeconomic vulnerability to oil price shocks would depend on the amount of oil consumption, implying a role for conservation and improved energy efficiency. Concern about moderating the size and potential duration of oil shocks also led to the establishment of the Strategic Petroleum Reserve (SPR). Originally set up as a response to the misplaced fear of a quantitative restriction in supply to the United States, the SPR came to be seen as a safeguard against especially large and persistent oil price shocks. However, to this day there is no accord on when and how the reserve should be used.

Changes in the structure of oil markets themselves were accelerated by the disruptions in the 1970s. The 1973 oil shock was not an embargo, despite frequent reference to it as such. Such a targeted reduction in oil supply to single countries was not possible, given the basic fungibility of oil and the spatially interconnected nature of international oil trade. Following the 1973 shock, movement away from bilateral long-term trading

between major oil suppliers and purchasers accelerated.[4] In place of bilateral trade with long-term pricing, there was major expansion in oil transactions through organized spot markets with more transparent, market-determined prices. Following these developments was the emergence by the 1980s of active derivatives markets for risk management, including futures and options contracts.

4. Observations from Oil Security Research

Perhaps the most important lesson from past oil shocks and policy responses to them is that oil markets actually worked to allocate available supplies.[5] Higher prices ultimately stimulated demand-side adjustments over time, as well as providing incentives for increasing non-OPEC sources of supply. As noted, the structure of oil markets also adjusted to reflect new realities.

Research has also called into question the characterization of OPEC as a cartel with strong power to set oil prices. At best, according to this research, OPEC could be called a "clumsy cartel" (Adelman 1980; see also Gately 1984 and Alhajji and Huettner 2000). Although coordination among its members could influence short-term trends, OPEC was not an effective longer-term price setter. In part this reflects longstanding differences in reserve holdings and national objectives, such as the desire to increase near-term revenues versus the desire to maintain market stability and mitigate development of competing oil and other energy sources to protect longer-term reserve values.[6]

Since the 1970s, moreover, oil price shocks have occurred for several reasons not related to OPEC behavior, including political instability and threats of conflict in the Middle East as well as demand surges due to weather or higher-than-predicted global demand growth. Moreover, oil price shocks are not just a consequence of changes in primary supplies. The 1978–1979 market disruption showed that a major potential

4 Long-term bilateral contracts with stable prices were popular so long as oil-producing countries played lesser roles in supply decision making, and so long as the United States had large excess production capacity and could play the role of swing producer. As global markets tightened in the early 1970s, excess US production capacity declined, and oil-producing countries insisted on more control over their resources. Bilateral contracting with stable prices then could not clear the market, given all the various sources of supply and demand uncertainty; nor could it provide options for buyers seeking more competitively priced supplies. Oil became a commodity, and the move to spot transactions followed.

5 This was true, though more difficult, even with the overlay of a complicated system of price controls and oil allocation in the 1970s.

6 The argument that OPEC is a cartel contradicts advocacy of an oil import tariff to recapture ostensible cartel rents. Disorganized suppliers with relatively limited influence on oil prices would have to accept the price effects of an oil tariff; an organized cartel could retaliate.

source of oil price instability is demand-side expectations of future oil market tightness, which can drive up inventory holdings (Bohi 1987, 1991a). Subsequent research has borne out that oil price shocks can be the result of macroeconomic conditions and oil demand behavior, rather than a driver of the macroeconomy (Barsky and Kilian 2004).

The mechanisms through which oil price shocks might adversely affect the macroeconomy are more complicated and ambiguous than previously realized. The share of oil in total economic value added was not so high that recession and jumps in the overall price level could be attributed just to oil price jumps and increased payments abroad for oil imports. However, time series models did seem to show a connection for the shocks (Hamilton 1983). This led to theories that because oil use is ubiquitous in the economy, a cascade of disequilibrium problems, including business contraction and unemployment, would follow oil price shocks.

Subsequent work revealed difficulties with this formulation. Bohi (1991b) provided evidence that the empirical link between oil price jumps and economic downturns was hard to separate from other influences, such as the role of anti-inflationary Federal Reserve monetary policy in the 1970s. Bohi and Powers (1993) showed that regional economic changes over the 1978–1980 period of rising prices and the 1985–1987 period of falling prices had more to do with monetary policy than oil price movements. Barsky and Kilian (2004) called into question the macroeconomic effects of large oil price changes (up and down) from the 1970s through the 1990s. Research by Brown and Yücel (2002) and Balke et al. (2010) indicated that any economic harm from oil price shocks seemed much weaker in subsequent episodes of oil price jumps than in the 1970s. Kilian (2014) showed that economic effects of oil price shocks depended on oil demand as well as supply behavior. A point emphasized by Kilian (2014), Balke et al. (2010), and Baumeister and Kilian (2016) is that oil price shocks are not a given but emerge from a complicated set of general equilibrium considerations.

In contrast to the substantial body of research on the macroeconomics of oil disruptions, research on policy for managing the SPR was sparse and has had no visible effect on actual SPR management. Research showed that the economically efficient size of the SPR depended in a systematic way on private-sector expectations of the severity and persistence of oil price shocks, as well as the economic vulnerability of the economy to those shocks. Economically efficient drawdown of the SPR in turn would depend on the same expectations and on the size of the reserve (Murphy et al. 1985, 1986).

In practice, however, the size of the SPR has been determined primarily by budgetary considerations and a desire on occasion to help boost domestic oil sales. Drawdown policy is left unstated out of fear that specifying plans in advance would invite hostile responses. There is a point to this fear—not with respect to oil exporters but rather with respect to speculators who would incorporate anticipated SPR drawdowns (or refills) into their plans. However, leaving drawdown policy unstated means that no one can anticipate the government's response to an oil price shock and build that into their own oil purchase decisions—in particular, to eschew panic buying. In practice, the SPR has been used on only a few occasions, and episodically its use has been a political football.

Horwich and Weimer (1984) proposed cutting this Gordian knot by, in effect, converting the SPR into a central storehouse for oil inventories that private sector actors could manage by purchasing call options from an authority in charge of the reserve. The call options would specify the strike price at which SPR oil would be delivered to contract holders (Horwich and Weimer suggested options working on a rolling basis with a strike price equal to 110 percent of the current price, nine to 12 weeks into the future). The exercise of the options would provide a hedge against rising oil prices without individual participants' having to pay the storage cost of individual inventory holdings.[7] However, since government officials saw the SPR as a national security asset requiring public sector control, this idea did not gain traction.

5. Battery Minerals Versus Oil

The focus in oil security analysis on effects of supplier market power and economic risks from price jumps will strike a familiar chord among those involved in studying and debating policy for mineral security. However, there are also differences that need to be recognized.

Extraction of CMs for use in EV batteries is much more geographically concentrated than crude oil extraction. Nevertheless, the numbers do not imply that economic competition is inherently lacking. Market power in refining battery minerals is possible, given the high geographical concentration in China for several CMs. (For comparison, imagine that 70 percent of global oil-refining capacity was located in and controlled by one country.) As noted, however, that concentration is a result of Chinese industrial policies rather than an inherent natural advantage.

There also are some differences in the relevant supply and demand elasticities. In the case of crude oil, advances in extraction and exploration, including hydraulic fracking, have increased elasticities of supply. Even when downturns in oil prices squeeze more marginal operators, production capacity tends to return fairly quickly when oil prices rebound. Near-term demand elasticities for oil products tend to be fairly low, but they can increase in the medium term (e.g., through carpooling and replacement of oil heat with heat pumps).

For battery CMs, short to medium elasticities for both supply and demand are low. Higher prices can lead to some increase in extraction from existing deposits, but development of new deposits can take a decade or more and involve major commitments of financial and human capital as well as time for permitting (IWG 2023). Ongoing research and development can increase the rate of resource recovery from existing mines, shifting outward mineral supply curves, but not necessarily increasing their price elasticities. Minerals processing also is a very capital-intensive process for which it is desirable in a market economy to maintain fairly high capacity utilization rates, thus implying low short- to medium-term price elasticities.

7 According to Horwich and Weimer (1984), the SPR authority would follow presidential directives to either use proceeds from the sales to refill the SPR or allow the reserve to decline.

Near-term demand elasticities for battery minerals tend to be low because at least some EV makers have ongoing commitments to certain designs with battery makers. This lock-in slows down and raises the cost of modifications to battery chemistries, the physical configuration of batteries, and their location in vehicles. Battery mineral demand elasticities can be nudged higher in the long term by varying battery characteristics. For example, the NMC (nickel-manganese-cobalt) battery and the LFP (lithium-iron phosphate) battery both rely on lithium and graphite, but the LFP uses only iron, phosphorus, and oxygen along with lithium and graphite.[8] Ongoing research into battery designs using different inputs or lower quantities of current inputs will further increase long-term demand elasticities for battery minerals, but the effects in the near term will be limited.

Markets like those for battery CMs, with relatively low near-term supply and demand elasticities, also tend to exhibit greater price volatility. However, unlike the global oil market, much of the trade in battery minerals occurs through bilateral contracts, though there is an increasing tendency to try to index prices to market conditions. This impedes price discovery and hampers development of derivatives markets for risk management (see, e.g., Wu 2024).

6. Lessons for Battery Critical Minerals Security Policy

6.1. Supply risks

If OPEC had exercised significant market power, an important reason would be the accident of geology that resulted in substantial oil reserves in its member countries. The case of battery CMs is different. For the most part, supplies of unprocessed raw materials are not dominated by one country. China's current dominance in processing several of those minerals can be reduced, if desired, by concerted industrial policies elsewhere.

Kannan and Toman (2024) analyze evidence on Chinese exercise of market power over processed minerals. They argue that the evidence is mixed on the extent to which China could selectively restrict supplies, given the current structure of the markets for these minerals.[9] They also note that China has a strong interest in secure CM supply

8 However, the LFP also has lower power and range.

9 China did apparently reduce exports of some rare earths for a short period of time in the fall of 2010 over an unrelated dispute with Japan. Prices increased tenfold and did not decline until partway through 2011. The price increases, likely exacerbated by speculative purchases of the rare earths, suggest China probably had not just selectively curbed deliveries to Japan. More direct evidence from data on Japanese imports during the period indicate no sudden and dramatic shortfall in deliveries (Johnston 2013, 24-26; Evenett and Fritz 2023, 32-33).

chains in support of its own battery- and EV-manufacturing sectors. This is a plausible alternative explanation for China's CM behavior. Restricting supplies would adversely affect its own industries.

China sometimes has excess mineral-processing capacity, and the use of that capacity depresses prices. However, China's industrial policies are not monolithic, and overinvestment in several other heavily promoted sectors of the economy (like the power sector) has been observed. Excess capacity in battery minerals may reveal inevitable errors from central planning, and a desire to protect downstream interests, as much as entry deterrence. At present, China's technological lead in minerals processing deters entry even in the absence of predatory pricing.

Price volatility in CM markets also can create rate-of-return risk for new investments in CM supplies, including processing capacities. This risk likely goes beyond what might be managed through derivatives in commodity markets, especially when risks of adverse price movements interact with risks from new investments in relatively unfamiliar technologies.

6.2. Economic vulnerabilities

The case for substantial vulnerability to price shocks in battery minerals is weaker than even the ambiguous evidence of macroeconomic vulnerability to oil price shocks. Somewhat higher prices or temporarily longer delivery times for processed battery minerals or battery components doubtless will slow, to a degree, the expansion of EVs. This is problematic for the industry and for achieving rapid and deep cuts in greenhouse gas emissions, but not for the economy as a whole. (EV conversions also can be accelerated later if it proves necessary to change battery designs for reduced CM vulnerability.)[10]

6.3. Potential policy responses

One analogy with the oil security case is that CM security cannot be achieved just by increasing production and processing in the United States. Diversification of supply sources internationally, considering geological, technological, and other advantages of different locations for extraction and processing, is necessary. This is not a trivial task, and US leadership will be beneficial to reduce legal, economic, environmental, and human rights barriers to increased global supplies.[11] As part of that effort, the US government can encourage market participants to pursue an evolution in CM markets that makes pricing more transparent and increases capabilities for derivative transactions. However, much of the effort for these changes will need to come from market participants themselves, as was the case in the evolution of the global oil market.

10 We emphasize that a different conclusion could hold for other critical minerals.

11 Runde and Hardman (2023), Aspen Institute (2023), and OurEnergyPolicy (2024) also emphasize a collaborative international approach.

Another important point inspired by the oil security case is the opportunity to improve the efficiency of materials use and increase the flexibility of demand . RD&D support to increase the portfolio of substitution possibilities—including different battery chemistries and low-carbon alternatives to electrifying vehicle transportation—is crucial (Htun et al. 2024).

Participants in CM markets seem to have limited interest in carrying the storage and opportunity costs of mineral inventories. This is understandable, given the difficulties of price discovery in these markets. In addition, the physical properties of some minerals make them unstable (e.g., from exposure to oxygen) and thus costly to store. One recent idea to address both price volatility and rate-of-return risk builds on but goes well beyond the idea of the SPR (Bipartisan Policy Center 2024). The proposal is for a quasi-private institution (e.g., government-chartered corporation) to maintain holdings of multiple CMs to stabilize the prices yet keep them high enough to protect new entrants in supplying the minerals.

The difficulties with SPR management indicate that policymakers should be wary of arguments that the government play a large role in stabilizing CM markets. Moreover, the need to defend price floors by purchasing supplies in the markets can be very expensive, even if there could be gains later from selling inventories to maintain price ceilings. For example, China and other suppliers would have little incentive to limit overbuilding of capacity when the US authority stands ready to purchase the excess. In addition, price floors help weak and strong competitors alike. Determining acceptable price bounds could become a never-ending political debate.

Government involvement in market stabilization also does not address the larger underlying problem, the possession by China of a substantial technological lead as a consequence of its past industrial policy. Developing a competitive industrial base for battery minerals processing outside China will be a multilateral challenge requiring a potentially significant degree of direct industrial support (preferably in ways that create incentives for efficiency and innovation, which output-based tax breaks do not).

This in turn raises two challenging issues. A considerable amount of public sector expenditure may be required to, in effect, create a whole new industry for battery minerals processing outside China. Consequently, it would make sense to be very confident in assessments of the economic risks posed by China's role in the status quo before undertaking huge investments with large sunk costs. As noted above, the evidence so far seems unclear. In the 1970s, overestimation of the long-term risk posed by OPEC led to unwise policy choices, notably the effort to start up a synthetic fuels industry.[12]

12 A basic principle in economics is that uncertainty about the actual cost or realized productivity of an irreversible investment in fixed capital is a disincentive for such investment; in effect, it gives up the valuable option of investing later when information on the value of the investment may be better. New investment in battery CM processing faces two relevant uncertainties: that associated with the capital investment, and that faced by purchasers of processed CMs because China's future pricing of processed minerals is unclear. Looking at the analogous issue of investment in fossil-fired versus more cap-

The other challenge is how a multilateral industrial policy to support expanded battery minerals processing outside China would function. Comparative advantage based on location, cost, and technological know-how should determine where investments are made (e.g., Australia would invest in hard-rock lithium-processing capacity near its mines). Based on the assumptions of a high collective value for the market to diversify sources of processed minerals, and understanding that new capacity would require considerable initial financial support to overcome China's current technical and cost advantages, how would the costs of public sector support for diversification be shared?[13] Past debates over burden sharing among oil importers through maintaining strategic oil stocks give some sense of the challenge.

7. Concluding Remarks

Sound CM security policy requires clarifying the different circumstances and risks for different minerals, weighing the seriousness of the risks, and evaluating the economic costs of alternative approaches for reducing risks relative to the potential benefits. Poorly designed mineral security policies could become costly and ineffective responses to uncertain-size risks. The United States cannot manage risks through unilateral actions. Our review of parallels (and differences) between oil security and CM insecurity urges caution against the possibility of overestimating the risks and underestimating the potential response costs. It also emphasizes the value of actions that work with and strengthen markets—including reducing institutional barriers to diversification of supplies, RD&D for diversifying demands, and better-functioning market institutions.

ital-intensive renewable power generation capacity, Prest and Wingenroth (2024) show that although the renewable investment faces investment-deterring capital expenditure risk, the investment also has the value of reducing operating cost risk. In our case, to be able to realize the value of more secure supply conditions in their investments, new entrants in battery minerals processing would need to receive a price premium from their customers. So far, it is difficult to judge from past behavior how purchasers would value that security.

13 One option could be direct transfers from national budgets. Another could be the imposition of a tariff on imports of Chinese-processed lithium to raise its price to the level needed for Australian processing capacity to be viable financially, with the tariff revenues then transferred. This approach would make the cost of the industrial policy directly visible.

8. References

Adelman, Morris A. 1980. The Clumsy Cartel. *Energy Journal* 1(1): 43–52.

Alhajji, A.F., and David Huettner. 2000. OPEC and World Crude Oil Markets from 1973 to 1994: Cartel, Oligopoly, or Competitive? *Energy Journal* 21(3): 31–60.

Aspen Institute. 2023. A Critical Minerals Policy for the United States: The Role of Congress in Scaling Domestic Supply and De-Risking Supply Chains. Energy & Environment Program. **https://www.aspeninstitute.org/wp-content/uploads/2023/06/A-Critical-Minerals-Policy-for-the-United-States-Final-Report.pdf**.

Balke, Nathan S., Stephen P. A. Brown, and Mine K. Yücel. 2010. Oil Price Shocks and U.S. Economic Activity: An International Perspective. Discussion Paper 10-37. Washington, DC: Resources for the Future. **https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1647807**.

Barsky, Robert B., and Lutz Kilian. 2004. Oil and the Macroeconomy since the 1970s. *Journal of Economic Perspectives* 18(4): 115–34.

Baumeister, Christiane, and Lutz Kilian. 2016. Forty Years of Oil Price Fluctuations: Why the Price of Oil May Still Surprise Us. *Journal of Economic Perspectives* 30(1): 139–60.

Bipartisan Policy Center. 2024. Resilient Resource Reserve: A Plan to Catalyze the American Critical Mineral Processing Industry. July. **https://bipartisanpolicy.org/report/critical-minerals-reserve/**.

Bohi, Douglas R. 1987. Evolution of the Oil Market and Energy Security Policy, Contemporary *Economic Policy* 5(3): 20–33.

———. 1991a. The Iraqi Invasion, Oil Price Behavior, and US Energy Policy. Southern Illinois *University Law Journal* 15(3) (Special Issue – Iraqi Symposium): 541–62. **https://heinonline.org/HOL/Page?handle=hein.journals/siulj15&id=563&collection=journals&index=**.

———. 1991b. On the Macroeconomic Effects of Energy Price Shocks. *Resources and Energy* 13(2): 145–62.

Bohi, Douglas R., and John R. Powers. 1993. Energy Price Shocks and Regional Output and Employment, *Review of Regional Studies* 23(2): 129–42. **https://rrs.scholasticahq.com/article/9108-energy-price-shocks-and-regional-output-and-employment**.

Bohi, Douglas R., and Michael A Toman. 1993. Energy Security: Externalities and Policies. *Energy Policy* 21(11): 1093–109.

———. 1996. *The Economics of Energy Security*. Boston: Kluwer.

Brown, Stephen P.A., and Mine K. Yücel. 2002. Energy Prices and Aggregate Economic Activity: An Interpretative Survey. *Quarterly Review of Economics and Finance* 42(2): 193–208.

Díaz Anadón, Laura, and Gregory Nemet. 2013. The US Synthetic Fuels Corporation: Policy Consistency, Flexibility and the Long-Term Consequences of Perceived Failures. In Arnulf Grübler and Charlie Wilson, eds., *Energy Technology Innovation: Learning from Historical Successes and Failures*. New York: Cambridge University Press.

Gately, Dermot. 1984. A Ten-Year Retrospective: OPEC and the World Oil Market. *Journal of Economic Literature* 22(3): 1100–14.

Hamilton, James D. 1983. Oil and the Macroeconomy since World War II. *Journal of Political Economy* 91(2): 228–48.

Horwich, George, and David Leo Weimer. 1984. The Next Oil Shock: Giving the Market a Chance. *Regulation* 8(2): 16–24.

Htun, Tinzar, Sangita Kannan, and Michael A Toman. 2024. Digging Deep: Critical Mineral Supply Chains, Electric Vehicles, and the Role of Technical Innovation. Issue brief, in preparation. Washington, DC: Resources for the Future.

Idoine , N. E., E. R. Raycraft, F. Price, S. F. Hobbs, E. A. Deady, P. Everett, R. A. Shaw, E. J. Evans, and A. J. Mills. 2023. *World Mineral Production 2017–21*. Nottingham, UK: British Geological Survey. **https://nora.nerc.ac.uk/id/eprint/534316/.**

Interagency Working Group on Mining Laws, Regulations, and Permitting (IWG). 2023. *Recommendations to Improve Mining on Public Lands*. Washington, DC: Department of the Interior. **https://www.doi.gov/sites/doi.gov/files/mriwg-report-final-508.pdf**.

Kannan, Sangita, and Michael A. Toman. 2024. Mineral Security Policy for Electric Vehicle Battery Minerals. Working paper, in preparation. Washington, DC: Resources for the Future.

Kilian, Lutz. 2014. Oil Price Shocks: Causes and Consequences. *Annual Review of Resource Economics* 6: 133–54

Murphy, Frederick H., Michael A. Toman, and Howard J. Weiss. 1985. International Cooperation in Stockpiles and Tariffs for Coping with Oil Supply Disruptions. *Journal of Policy Modeling* 7(4): 649–72.

NMIC (National Minerals Information Center). (Various years) *Mineral Yearbooks*. Vol. 1, Metals and Minerals. Washington, DC: US Geological Survey. Accessed 10/24/2023. **https://www.usgs.gov/centers/national-minerals-information-center/mineralsyearbook-metals-and-minerals**.

———. 1986. An Integrated Analysis of U.S. Oil Security Policies. *Energy Journal* 7(3): 67–82.

OurEnergyPolicy. 2024. Critical Minerals & National Security. June. **https://www.ourenergypolicy.org/resources/critical-mineral-national-security/**.

Prest, Brian C., and Jordan Wingenroth. 2024. Operational Versus Capital Expenditure Risk in a Clean Energy Transition. Report 24-4. Washington, DC: Resources for the Future. **https://media.rff.org/documents/Report_24-04.pdf**.

Reichl, C., and M. Schatz. 2023. *World Mining Data* 2023. Vol. 38, *Minerals Production*. **https://world-mining-data.info/wmd/downloads/PDF/WMD2023.pdf**.

Runde, Daniel F., and Austin Hardman. 2023. Elevating the Role of Critical Minerals for Development and Security. Center for Strategic and International Studies, September. **https://www.csis.org/analysis/elevating-role-critical-minerals-development-and-security**.

USGS (US Geological Survey) 2023. Mineral Commodities Summary 2023. https://doi.org/10.3133/mcs2023.

Wu, Alice. 2024. Critical Thinking on Critical Minerals. Federation of American Scientists, July. **https://fas.org/wp-content/uploads/2024/07/JULY-2024-CRITICAL-MINERALS.pdf**.

