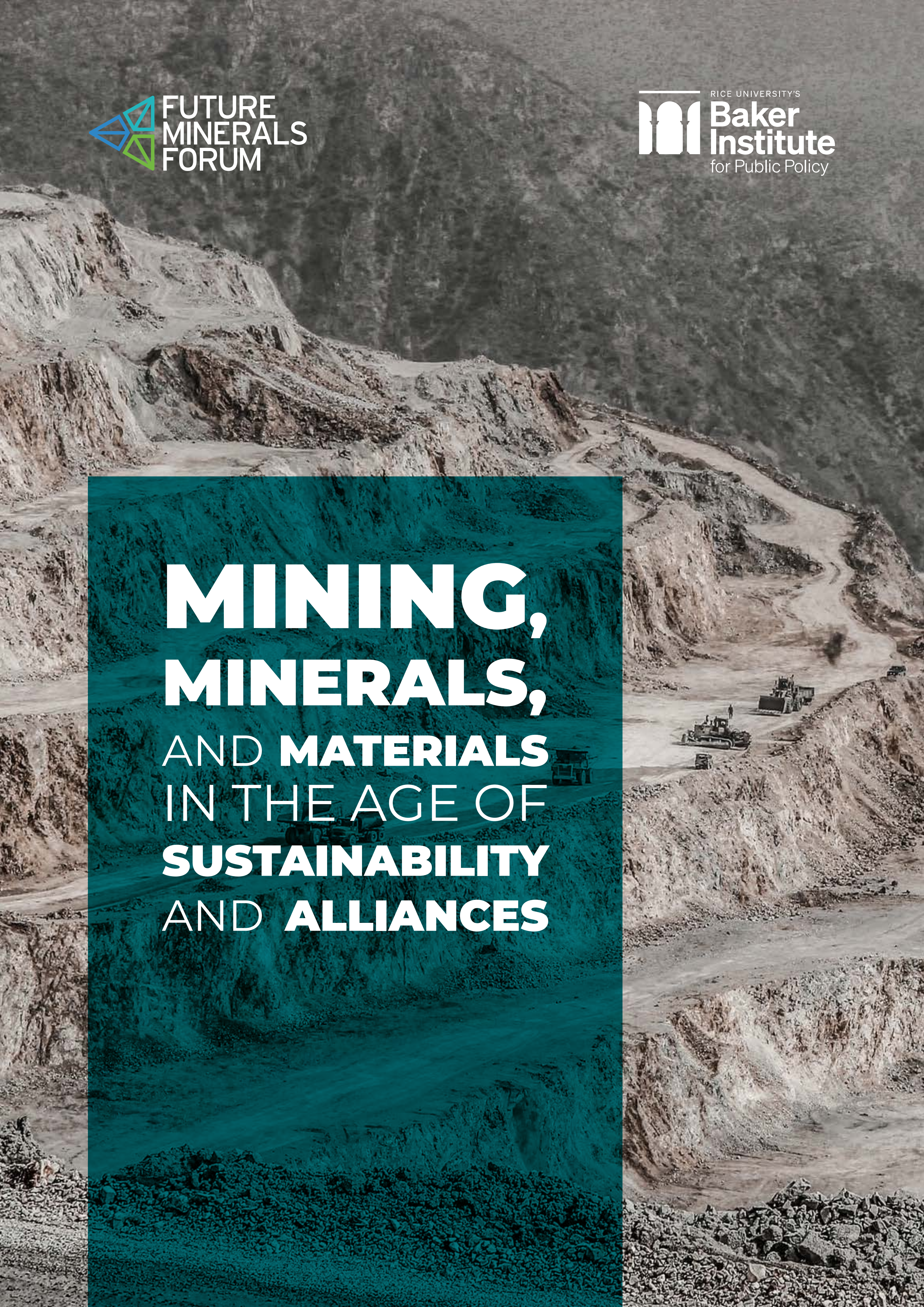
FUTURE MINERALS FORUM

RICE UNIVERSITY'S Baker Institute for Public Policy



MINING, MINERALS, AND MATERIALS IN THE AGE OF SUSTAINABILITY AND ALLIANCES

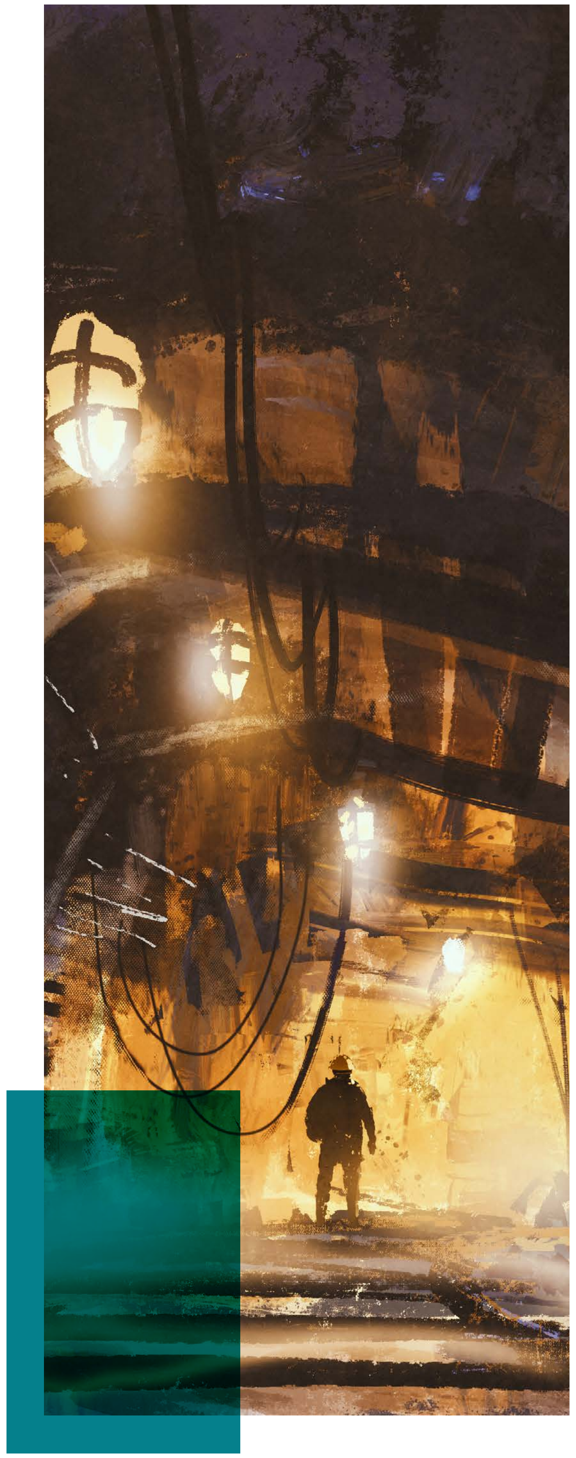
PREMISE

As the world bumps toward energy transitions that vary widely in approach, cost, and political commitment certain realities are becoming manifest. One is the sheer level of effort entailed in building materials supply chains that can support displacement of legacy fuels and systems to the extent, and within the time frames, imagined.[1] Replacing legacy fuels and systems that have been the backbone of global prosperity is a complex endeavor of historic proportions. Moreover, ensuring "sustainability" of materials supply chains themselves has come to be recognized as crucial if the spirit and intent of the promised energy future are to be met. ***For many, the question of whether humans will be better off in the process can only be answered if both energy and materials supply chains are fully vetted in open, transparent ways using widely accepted, if not uniform, principles and standards.***

None of these conditions or outcomes are assured. Pressures from expectations are enormous. And so, governments and societies are engrossed in the equally complex endeavor to reach agreement on what "sustainability" in energy and materials supply chains is all about, how it is to be measured and communicated and, most important, to whom.

1. For background to this knowledge paper, see M. Michot Foss, 2022, Defining the ‹Minerals Heartland› of the Future — From Africa to Central Asia, Rice University's Baker Institute for Public Policy, Center for Energy Studies Research Paper, prepared in partnership with Future Minerals Forum for FMF 23, https://www.bakerinstitute.org/research/defining-minerals-heartland-future-africa-central-asia.

WHY DO WE CARE?



Alternative energy technologies slated for attention and investment are ***materials intense***, an artifact of distinct attributes.[2]

One is the requirement for large capital obligations relative to energy delivered per unit of investment. We tend to describe this as a tradeoff between "energy density" and "materials intensity".

Why is this the case? **Table 1** provides the best estimates of "capacity factors" (CFs) associated with all electric power generation technologies and sources currently in use in the United States. Admittedly, the U.S. represents only one example but the size of the American market and availability of data and information on the electric power fleet enables an understanding of the acute tradeoffs. The very low CFs associated with wind and solar contrast strongly with the near 100% efficiency of nuclear, high efficiency of geothermal, and the higher CFs for coal and natural gas.

2. See M. Michot Foss, 2021, Minerals and Materials for Energy: We Need to Change Thinking, Policy Brief – Recommendations for the New Administration, Rice University's Baker Institute for Public Policy, file:///C:/Users/mmf10/Downloads/bi-brief-012421-ces-minerals.pdf.

- It takes a great deal more installed capacity for wind and solar to deliver comparable amounts of electric power as do natural gas, coal, and certainly nuclear energy facilities, a fact that belies the notion that wind and solar are "cheap".
- Optimal locations for wind, solar, hydro, geothermal and other "alt energy tech" are rarely where other energy infrastructure already exists, creating needs for new high voltage electric power transmission.
- Humans always have struggled to harness earth's natural forces like wind and solar given their "intermittency". The problem is not simply if, and when, these sources are available but at what intensity, with infinite variations around the globe. Every energy delivery system can face reliability challenges but the constant, incessant intermittent character of wind and solar creates unique demands. In sensitive economies and for sensitive end users this means backup (reserve) energy sources that can approach 100 percent of generation[3] along with massive additions of energy storage and retrofits, or expansion, of power grids.

3. Estimated reserve margins for electric power systems are often moving targets depending upon differences among nameplate power generation capacity and generation capacity available for seasonal peaks.

The upshot is that the very large capacity additions required for wind and solar relative to economic dispatched energy means commitment of materials for less efficient energy output. In Texas, where about one-quarter of U.S. wind capacity is installed, dispatched energy from wind can swing from 0 to 60% of the power market. Solar is less variable but the absence of solar during evening and some morning peak periods and across seasons strains grids across Texas and the U.S. Neither wind nor solar are located to population and/or economic centers, for the most part, meaning that high voltage transmission, HVT, must be built at considerable expense and controversy. HVT is one of the most difficult infrastructure systems to build. Investors in expensive HVT would like that capacity to be fully utilized, which wind and solar projects cannot satisfy. Commercially available stationary battery storage is costly, while limited in duration and cycling and imposing many prerequisites for safe operations.

Natural gas generation is a special case in point. State of the art combined cycle gas turbines can operate at lower heat rates and higher efficiencies, requiring less fuel, than either gas or coal steam turbines, or gas combustion (single cycle) turbines. Gas reciprocating engines and gas cogeneration afford similar advantages. The expansion of wind and solar in the U.S. triggered a wave of cheaper but higher heat rate gas combustion "peakers" that could quickly ramp up to follow the extreme variability of wind. Other countries have experienced similar dynamics and turned to natural gas as a solution while pursuing options such as battery storage. It would be far more preferable to build high efficiency natural gas generation that could operate consistently. Yet luring investment into natural gas generation capacity that is dropped from grids when subsidized wind and solar are dispatched is a nonstarter.

Every alternative energy choice embodies similar tradeoffs. Tidal and wave, geothermal, hydrogen – the latter has long been held up as an ideal substitute for the economic power of hydrocarbons and coal – all have fundamental characteristics that burden reliability. And they all are characterized by sometimes very large development footprints that, as with wind and solar, have never been fully analyzed.

They also all have specific materials constraints and sometimes impose new conditions on materials supply chains. Describing alt energy tech as "renewable" has always mis-characterized and mis-represented what is entailed to build and use wind, solar and other natural assets. "Scaling up" any energy technology requires often-large volumes of bulk commodities like aggregates, cement, steel, and aluminum. Much attention is centered on particular metals and materials essential for performance. Concerns range from rare earth elements contained in magnets for wind turbines and electric vehicle powertrains to elements like gallium (the aluminum value chain) and germanium (the zinc value chain) for solar (and our smart phones) to high quality nickel for batteries. The largest and fastest growing commodity group – plastics and resins –

is integral to every energy technology (and every product in modern life). Plastics and resins are especially useful for alt energy tech because they reduce weight while preserving strength and durability. Indeed, these characteristics underlie energy efficiency gains in vehicles and appliances around the world. From wind turbine blades to solar PV to the roughly 50% of content by volume for conventional and more for electric vehicles, plastics and resins are vital materials. This means that hydrocarbons and other carbonaceous minerals must remain available and accessible to build our energy future.

Materials that we rely upon for energy systems must withstand often brutal conditions. Wind and solar are pummeled by dust and impacted by hail, heat, and salt. Power grids and pipelines must operate safely through fair weather and foul. Conventional energy infrastructure, alt energy tech, technologies for "decarbonizing" fossil fuels and handling captured carbon dioxide, and nuclear all bear materials prerequisites that include: staving off corrosion; preventing failure; ensuring safe handling and containment; facilitating ultimate end use; and much more.

Mobility is burdened by pronounced tradeoffs (see **Figure 1**). Internal combustion engine or ICE vehicles are specific targets for emissions and the centerpiece of energy transition dreams. Yet electrification of transport, the only strategy deemed worthy by policy makers and activists, is burdened by materials realities and constraints. This is because even the best, state of the art battery chemistries today can provide only a fraction of the energy content of conventional fuels **(Figure 2)**. As measured in terms of specific energy, watthours per kilogram (Wh/Kg), the most energy dense commercial battery in the market today, NMC 811 (lithium-ion with roughly 80% nickel, 10% manganese and 10% cobalt oxide) has specific energy of about 270-300 Wh/Kg. Gasoline and diesel exceed 12,000 Wh/Kg. Estimates are that electric vehicles or EVs, fully battery enabled EVs or BEVs especially, will use orders of magnitude more metals and material than ICE vehicles.[4] They certainly will encompass more plastics content, the only solution for countering the weight of batteries. The larger the vehicle and more demanding the performance – to haul loads, move freight, climb hills, conquer longer distances – the heavier and more materials intensive the battery. Battery chemistries are evolving and new ideas along the way could easily upend the enormous investments currently underway. But EVs and BEVs, the latter preferred by many policy makers and regulators, cannot function without adequate support from electric power grids. And the preference, of course, is for those grids to be heavily populated by the choice technologies of wind and solar. The burden of building, expanding, bolstering, protecting adequate electric power system robustness to accommodate fully electrified fleets is not even close to proper analysis and estimation for cost, materials inputs and full environmental impacts.

4. For elaboration beyond Figure 1, see https://elements.visualcapitalist.com/visualizing-the-growing-demand-for-nickel-and-copper/.

Taken altogether, the large capacity increments for wind and solar plus HVT, storage and other system support explain the very large tonnages of minerals needed if the world accelerates adoption and expansion of these technologies. Every major institution and flagship report on minerals needed for energy transitions reaches this conclusion.
Figure 1 provides a typical, and influential, example. The clear implication is that "clean" or "green" energy tech faces a penalty when it comes to materials.

Meanwhile, a parallel, powerful trend is unfolding – "digitization" of energy and materials that mimics digital commerce. The belief is that integrating digital controls across materials supply chains and energy systems offers the best path for optimizing energy and materials management and use. The "digital field" for oil and gas and "digital mine" are established concepts, if in widely diverse stages of adoption. Among many other things, "digitization" incorporates emerging artificial intelligence (AI) for a range of applications along with attendant cloud storage/retrieval. Digital approaches are viewed to be essential especially for dealing with challenges inherent in wind, solar and other alt energy tech and to achieve the full promise of electrified transport with vehicle-grid interactions for both exchange of electricity and data. "Smart cars" with "smart batteries" will include a range of sophisticated microprocessors and electronics to ensure batteries remain in safe operating thermal zones, control how the vehicle performs and even, in the vision of automated transport, vehicle-driver and vehicle-road system interactions.

Yet a digital world represents another enormous "call" on resources. Digitization is both materials and energy intense, commanding raw materials to build and operate the vast information technology (IT) architecture involved in data collection, protection, retrieval, and storage for the human-digital interface. As with our energy and materials futures, outcomes are not assured and pressures from expectations are huge. A risk is that materials and energy intensity, as the information age continues to evolve, could outweigh the hoped for gains in materials and energy efficiency and optimization, at least for some time to come.

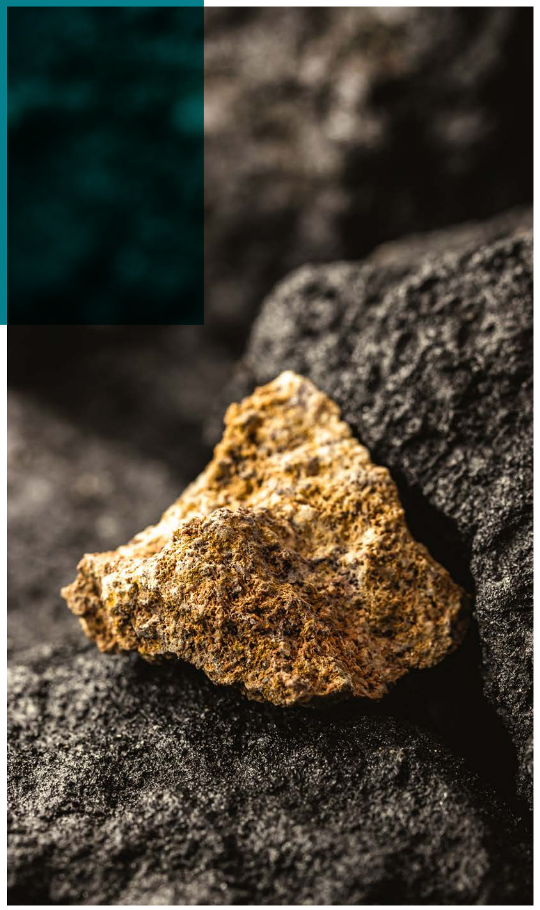
This is not to say that materials intensity will not be reduced through inventions, including new materials, new designs advances in the IT realm and elsewhere. Humans are nothing if not inventive. A great deal depends upon how alt energy tech is integrated – what power sources and storage are available to balance wind and solar, what power sources will be used to recharge EVs, how the energy and materials supply chains and their expansive logistics are operated.

What we do face are roadblocks for the foreseeable future, given the push to accelerate deployment of, and adoption of, alt energy tech using the toolkit that we have on hand.

Moreover, left out of most conversations on "critical materials" are those that are essential for the extractives industries and manufacturing. Many of these – solvents, reagents, catalysts, and so on – are derived from the oil, gas, mining, and chemicals value chains. Many have no substitutes. Many are targets for regulatory action out of health and safety concerns. For that matter, many essential processes are regulatory targets – pyrolysis, gasification, hydrometallurgy and more. A focus on extraction without attention to the key ingredients for processing shortchanges dialogues. Lack of awareness of the materials essential for fabricating semiconductors, building batteries, making components for industrial equipment and appliances for consumer use undermines efforts to bolster supply chains.

As the dominoes from these multiple, converging trends have cascaded ***a first worry has been how best to build and maintain vital materials supply chains needed to make it all work***. Beyond procurement and logistics, concerns increasingly have become centered around the ***character*** of materials supply chains. After all, "clean" and "green" energy in "clean" and "green" economies ought to compel "clean" and "green" materials supply chains. But what are the best ways to utilize our natural resources and raw materials – for which energy technology options? We simply do not know, at present, whether the aggregation of alternative energy technologies deployed at large scale, combined with digital trends, with all the inputs properly accounted for, will represent an improvement in sustainability. Are they environmentally sound, "socially" acceptable? Are their footprints manageable? Are they financially sustainable? Are we making things better in our pursuit of materials intense energy technologies, or making them worse? Will digitization improve the balance, or not? How will we know?

WHAT DOES IT ALL MEAN FOR "SUSTAINABILITY"?

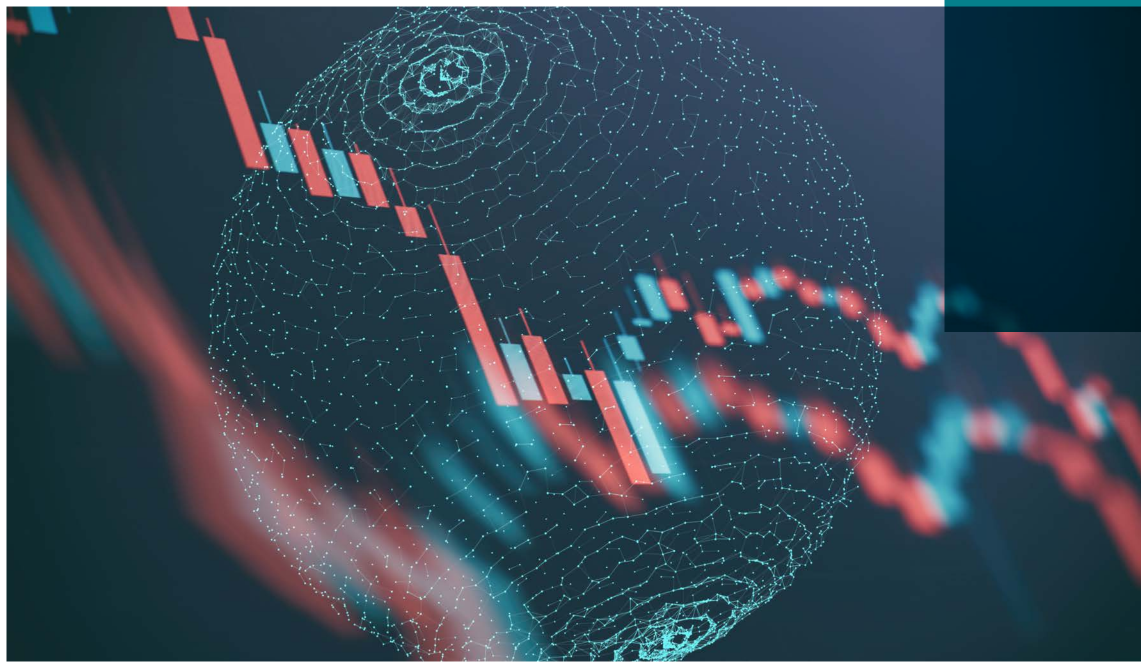


Given the landscape, it is no surprise that the push for "sustainability" is taking on new emphasis. Such is the case in materials and final product supply chains, from responsible sourcing to end of life and including "Re-X" (reuse, repurpose, recycle). A great deal of uncertainty swirls around what "sustainability" really means for energy and materials. More questions swirl around definitions, meanings, metrics, measurement, data, information, transparency, and transferability.[5]

One point of clarity is our need to broadly define "sustainability" rather than narrowly silo it around greenhouse gas (GHG) emissions.

Far too many views are that sustainability is all about "climate", whatever one's opinion might be, and "emissions". These views are unsupported by public opinion and other data, information and analysis on how various public audiences view their priorities and values. In the U.S., Canada, Europe, elsewhere and even in emerging economies in Latin America and Southeast Asia, sustained opposition persists and is growing against large scale wind, solar and other projects. This has caught many off-guard.

5. For example, see R.A. Meidl, et.al., 2022, Waste Management of Alternative Energy Supply Chains, Rice University's Baker Institute for Public Policy, Center for Energy Studies report, https://www.bakerinstitute.org/research/call-action-recycling-and-waste-management-across-alternative-energy-supply-chains. We address the gaps in waste management associated with both alt energy tech and materials and challenges for expanding materials recovery and recycling.



Why should the public not want what is deemed best for societies? As usual, it turns out that people have many values, many preferences, and many different priorities.[6]

More holistic definitions of sustainability, as in **Figure 3**, strike more chords but also place inordinate pressure on governments, societies, industries, and other market participants to figure out how, exactly, to define, implement, and execute broader visions. A harsh "realpolitik" inquiry is whether "sustainability" necessarily boosts profits or whether commercial success and profitability are necessary precursors to the higher order values that more holistic definitions encompass. In other words, can governments, societies, and industry indulge in sustainable Utopias as a ramp to profitability or does profitability need to come first? This is no small matter when it comes to the demanding, volatile nature of energy and non-fuel minerals commodities and the underlying businesses. Our times are hallmarked by debates about redefining "profit" to compensate for the nonmonetary costs and benefits that many assume are not properly captured in our conventional financial measures. Taken to extreme, some contentions are that physical, chemical, engineering realities can be subjugated to parameters that reflect sociopolitical agendas. These ideas have cycled in and out of fashion for generations but are resonant in our post-2009 financial collapse and post-

6. See Susskind, et.al., Sources of opposition to renewable energy projects in the United States, Energy Policy, Vol. 165, June 2022, https://www.sciencedirect.com/science/article/pii/S0301421522001471.

pandemic era. Steering too far from generally accepted financial metrics has proven hazardous, in the least. Harsh lessons are being learned as investors experiment with and markets respond to schemes, such as "ESG" (environment, social governance) directed investing. The bottom line is that engineering and economic fundamentals matter.

Importantly, ***none of these issues are new***. Rather, long-time dilemmas are being amplified by the extreme context for energy and materials today and going forward. The natural resource, extractives industries along with the associated logistics, processing and manufacturing businesses and value chains have long been subjected to intense scrutiny. The potential for energy and materials commodities to create immense economic wealth guarantees public and political interest. As a result, over the decades, a host of organizations and practices have emerged to "shine light" on many aspects of the extractives industries. This pattern will continue as the many versions of energy transition evolve.

As efforts unfold to define "sustainability" it will be important to properly understand the energy and nonfuel raw materials development cycle as well as the full life cycle of use. **Figure 4** and **Figure 5** provide general illustrations of the key considerations for extractives industries as they related to technical pathway and nontechnical risks. Each phase bears its own combination of technical and nontechnical risks and uncertainties, all keenly influenced by the location and geologic quality of native endowments, operating conditions and background, strengths and weaknesses of supporting infrastructure, workforces, political/legal/policy/regulatory regimes, and much more. Every phase must be executed to achieve technical and commercial success. A "one-size-fits-all" approach to sustainability and rigid construction of standards and principles make little sense in light of these dynamics.

Assuming projects conquer development cycle hurdles and reach commercialization, monetary flows can dominate reactions and responses. Creation, capture, and distribution of economic rents and the "fiscal regimes" (taxes, royalties and other rent and value capture mechanisms) that tend to be associated with revenue management have been targets for research and multilateral intervention since the commodity boom of the 1970s. Political and fiscal regimes can be moving targets, "evolving bargains"[7], that shift, change, "obsolesce"[8] as projects proceed through exploration and development cycles.

A tension underlying many of the concerns about social and governance conduct is disposition of the wealth and value created from energy and materials commodities. A fleet of nongovernmental organizations (NGOs) along with multilateral institutions and others have targeted "economic rents", the intrinsic value created when natural resources are extracted and brought to market, and attendant fiscal regimes with attention to proper accounting and revenue management in hopes that benefits are accorded to societies.[9]

7. Taken from W. Emmons, 2000, Evolving Bargain: Strategic Implications of Deregulation and Privatization, Harvard Business School Press, https://www.hbs.edu/faculty/Pages/item.aspx?num=17920.
8. The notion of "obsolescing bargains" between sovereign (resource owning) governments and multinational corporations is well established. The idea originated with R. Vernon, 1971, Sovereignty at Bay, Basic Books, https://www.amazon.com/Sovereignty-Bay-Harvard-multinational-enterprise/dp/0465080960/ref=sr_1_1?keywords=9780582410480&linkCode=qs&qid=1697308335&s=books&sr=1-1. See R. Vernon, 1981, Sovereignty at Bay Ten Years After, International Organization, Vol. 35, No. 3, https://www.jstor.org/stable/2706434?typeAccessWorkflow=login. See F.J. Monaldi, 2020, The Cyclical Phenomenon of Resource Nationalism in Latin America, Oxford Research Encyclopedias, https://www.bakerinstitute.org/research/cyclical-phenomenon-resource-nationalism-latin-america. See M. Michot Foss, et.al., 2007, Hydrocarbon sector organization and regulation in Energy Cooperation in the Western Hemisphere, S. Weintraub, A. Hester, V.R. Prado, eds, CSIS, https://www.csis.org/programs/economics-program/simon-chair-archive/energy-cooperation-western-hemisphere-benefits-and.
9. The cluster is very large and professionalized, ranging from Extractive Industries Transparency Initiative, EITI, https://eiti.org/ to Natural Resource Governance Institute, NRGI, https://resourcegovernance.org/ (note that author served on the technical advisory board for a precursor organization, Natural Resource Charter) and many smaller and spin off organizations. Many groups maintain partnerships with foreign aid offices, such as U.S. Agency for International Development, USAID (the author was engaged in implementing several contracts that involved these partnerships), and Canada Global Affairs (which now incorporates the former Canadian International Development Agency, CIDA) and all of the large economy international development assistance entities. They also have partnerships with the multilateral banks such as World Bank, InterAmerican Development Bank and so on.

While there are succes scases, these efforts remain a work in progress, across the board over wide swaths of the globe.[10] In far too many locations, too much effort has been expended with too little to show in improvement in economic development and the quality of lives of citizens. Too little reliance on open markets persists, encumbering disposition of benefits. Yet, disagreements exist over the importance of monetary flows when it comes to social acceptance of projects and the ultimate "license to operate" in the eyes of host communities. Indeed, social values and parameters relative to industrial scale projects can vary considerably[11], and not just in places like the U.S. that more easily lend themselves to investigation. That said, monetary flows can be prominent in negotiations and critical to operational and financial sustainability and for sheltering "license to operate" privileges.[12]

10. See J. Otto, et.al., 2006, Mining Royalties : A Global Study of Their Impact on Investors, Government, and Civil Society, World Bank, https://openknowledge.worldbank.org/entities/publication/332253e5-2493-6a31-a01f-c19260d7abcd.
11. See footnote 6.
12. Regarding importance of monetary considerations for communities, "there is definitely more interest when portions of taxes/royalties are hypothecated back to regions/communities, as happens in some countries" (anonymous industry commentator). The Albemarle CORFO (Corporación de Fomento de la Producción) royalty of %3.5 of annual sales for both lithium carbonate and hydroxide reflects new arrangements deemed essential.

Nor are economic rents the only source of potential static. Control of operations, the ability to exercise technical and commercial judgments and make decisions free of political influence have long been key to investors and operators. Degree of control often diminishes in the obsolescing bargain as host governments attain more knowledge, technical capacity, and leverage.

An emerging nuance is social self-determination, especially vis-á-vis indigenous groups, expressed in the form of engagement with projects. A new pattern in the extractives industries is facilitation of equity interests for indigenous groups whose lands are in play in a variety of value chain segments. Those interests must be financed and managed, and presumably would come under the same scrutiny through the sustainability lens as corporate and/or government partners. Equity agreements have come into play as project developers sought to break through stringent negotiations and opposition. For many, these approaches represent the (and possibly only) way forward in locations where indigenous interests are tantamount.[13]

Beyond the well-trod ground of fiscal regimes and disposition of economic rents, a major unknown is how "sustainability" overall will play in the greater scheme of things. Can resource owning governments use sustainability levers to influence negotiations and shares of economic rents, exert control, assuage communities and indigenous groups, or offset NGO activism? In many countries, evidence is accumulating that this may become

13. A private roundtable on "resource nationalism" in Latin America, hosted by Rice University's Baker Institute, in September 2023 included discussion of equity agreements used to achieve permissions for major LNG projects in British Columbia and opinions that these kinds of arrangements will become more common throughout the energy and mining businesses to address indigenous interests.

the case – a new form of "resource nationalism" rooted in pressures mounting around responsible sourcing and practices, extending to certification and traceability.14 Governments that desire premium pricing for production from their endowments are seeking ways of using certification to add to other fiscal levers. In fact, a distinct take is that it is fair to ask whether raw materials deemed strategic and critical should be "cheap".

When it comes to commodities of any sort, resource owning governments and companies are price takers. Governments tend to constantly seek ways of compensating for low price events, the bane of resource dependent economies. They often will deploy stiffer fiscal terms (which tend to discourage investment) or engage in contract terms that introduce flexibility and are designed to support investment flows (such as fiscal terms that adjust with price and may include incentives for new capital spending that ordinarily would not occur). Many host governments desire to capture value added (including use of export bans and other measures to force processing at home, as is happening in various countries today) and/or achieve economic development by seeking manufacturing of finished goods. Nearly every government that has at least some essential minerals for electric vehicle powertrains wants to also host battery making and the associated supply chains. Many envision full scale EV manufacturing. Yet no country contains all essential minerals and materials within its borders meaning even more pressure on supply chains as host countries, their trading partners among the larger economies, and companies all position for sourcing.

At minimum, resource owning governments and companies that sell key materials are moving to obtain premium pricing on the basis of responsible sourcing and "green" certifications. A good example is aluminum. Aluminum smelters are mainly fed by coal fired power, but many are based at large hydroelectric facilities. Procurements with up to 30% premiums on finished aluminum sourced from hydroelectric based smelters have been reported.[15] Another example are political shifts in Chile, Peru and other countries that reflect government positioning to use sustainability and responsible sourcing criteria in order to justify premiums for their copper production.[16]

14. See footnote 13. At the same event, there was general agreement about this tendency.
15. Based on input from large customers at a Rice University event in spring 2023. Also see https://www.iea.org/energy-system/industry/aluminium#tracking.
16. Based on input from various interviews, records, and events. See footnote 13.

WHAT IS THE STATE OF KNOWLEDGE FOR SUSTAINABILITY PRINCIPLES AND STANDARDS?

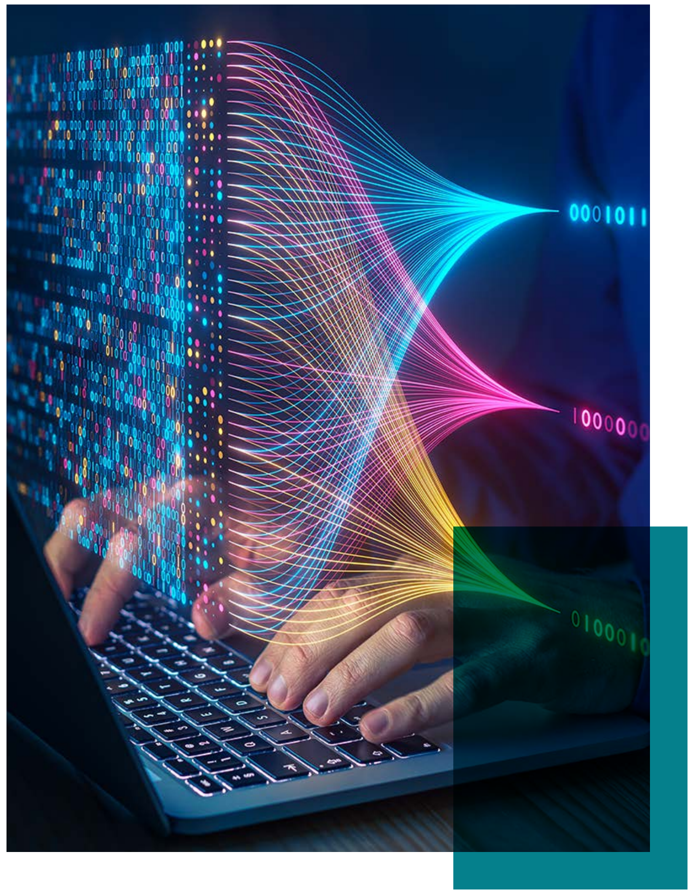
Every assessment for establishing sustainability principles, certifications, traceability and so on ultimately hinge on data and information regarding production, operating conditions and performance. As noted in **Figure 4**, "all value chains begin upstream" and upstream entails detailed data on minerals occurrences and potential resources. Exploration activity cannot ensue without sufficient information provided either by governments or by scouting as prospecting unfolds. Increasingly, that initial scouting is dependent upon whether "sustainability deal killers" might exist in the form of unclear ownership with indigenous groups, sensitive issues that affect host and surrounding communities, sensitive environmental concerns and the like. ***The first order is adequate data and information to support exploration and development activity and clear access rights for regional studies and drilling.***

Operating companies that are publicly traded disclose holdings, exploration activity, and production, but the public interest is best served by reporting from governments themselves.[17] This is a distinct weak link in the extractives industries in many countries. While some governments are adept at providing data rooms for prospectors and eventual licensing, they often do not provide reliable, ongoing reporting on production. As the need

17. The U.S., Canada, Australia, UK and other large economies have well-established minerals and mining data and information. Most are undergoing sometimes substantial revisions in how and what data is collected and how information presented in the public domain. The U.S. Geological Survey, USGS, is widely relied upon for information not only on US minerals resources and operations but the world. See https://www.usgs.gov/centers/national-minerals-information-center and https://www.usgs.gov/products/web-tools/interactive-maps. The World Mining Congress, World Mining Data provides an extensive summary of production by country and region, https://www.world-mining-data.info/. For an example of how data can be combined for public access see https://www.bakerinstitute.org/global-minerals-production-dashboard.

grows for better understanding of supply-demand balances for key materials, integral to market fundamentals and investment decision making, data and information flows become a central element. We are entering a phase in which serious questions are raised about what governments report whether in potential resources, reserves (associated with production) and production. Minerals occurrences are complex which, of course, makes it all that much more difficult. Ultimately, production data translates into revenue flows, linking upstream activity to fiscal terms and revenue balances for government treasuries along with the myriad questions about distribution of economic rents.

An analogy exists to the long effort to improve transparency and reliability for oil and gas supply reporting, a huge factor in price movements with deep implications for geopolitics. A big question for mining and minerals is whether international entities and initiatives will need to step to the plate to ensure robust data and information going into the future in similar vein.[18]



Worse, there are very few organized, public domain sources for information related to the "midstream", minerals processing worldwide. Given the interest among governments in value capture, and the exposure among customers to pricing and price premiums, along with the sustainability burdens inherent in midstream activities, improving data and transparency around the midstream segment would go a long way toward bolstering transparency. Market participants are served by the various

18. See JODI, the Joint Organisations Data Initiative, https://www.jodidata.org/ for the history of cooperation to improve oil and gas reporting, hatched during the 7th International Energy Forum in Riyadh, 2001.

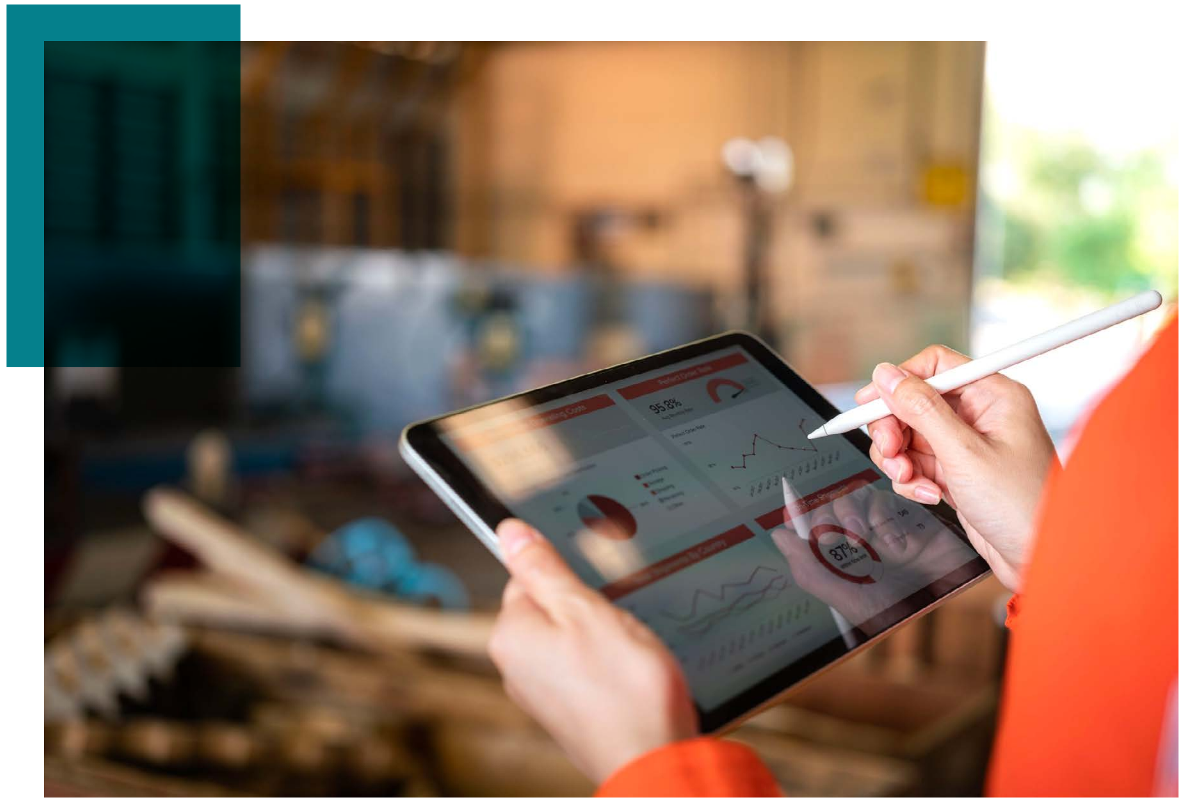
organizations for specific metals, of course, and policy makers are often engaged in these organizations. Specific constraints exist to information, encumbering midstream transparency.[19]

Finally, when it comes to sustainability reporting, data and information are nascent. Companies, mainly publicly traded corporations, have adopted sustainability reporting or are moving to do so. Sustainability reporting, along with ESG reporting in general, are plagued by inconsistencies in key performance indicators, KPIs, and associated metrics. An illustration of the problem is provided in **Table 2**, based on a survey of well-known organizations involved in collecting and reporting data on sustainability across a variety of industries and companies worldwide. An example of a provider's aggregate ratings for industries and companies under coverage is provided in **Table 3**. Consumer-facing businesses will differ in available data and results from heavy industries, and differences accumulate accordingly. It should be evident that building KPIs to reflect operational performance across countries will be no small undertaking.

An almost overwhelming array of documented opinions, arguments, suggestions, examples and so on exist for what companies can or should do or consider doing when it comes to sustainability reporting. Company reporting has inferences for principles and standards – ultimately what can be expected depends upon what the extractives industries businesses can absorb and accommodate. Across industry demographics, from majors to juniors, ability to measure, map, and document operations with eyes to sustainability metrics varies hugely. Here is where hopes are high for digital solutions. To the extent that operators adopt and benefit from digital tracking, sustainability reporting and tracking will benefit.[20]

19. China's dominance of the minerals midstream cannot be ignored, especially because of the link to final pricing that must flow into trading and procurement. China's influence over metals and other minerals trading and market positions also cannot be underestimated. The London Metals Exchange, LME, is the main source for prices and questions about oversight and surveillance, stemming from events in nickel trading during Match 2022, along with ownership and transparency of ownership of LME-certified warehouses are all integral to well-functioning metals and minerals markets.
20. While not directly related to digital solutions for sustainability metrics, operational efficiency and optimization certainly play into the ability for companies to achieve their corporate goals and manage expectations of stakeholders. Digitization of operations can feed data into reporting. See https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/how%20we%20help%20clients/impact%20stories/freeport%20mcmoran/rewired-in-action-freeport-mcmoran-june-2023.pdf for an example. As well, widespread evidence exists for use of digital ledgers and blockchain technology to facilitate data collection across operations as companies track everything from their own

However, as stated earlier, precision beyond very broad goals, principles, is likely to be difficult given that every situation is contingent upon local conditions. We are unlikely to converge on common understandings of KPIs any time soon, much less standards that underlie responsible sourcing and attendant certification and traceability. And any/all sustainability metrics, reporting, standards, principles, and verifications stem from the quality of data and information at the outset.



procurement to energy and water use. Again, this varies greatly across the industry, from major to junior, across primary commodities and locations. See https://www.bhp.com/news/prospects/12/2021/three-big-questions-blockchain-is-helping-us-answer, reflected in company comments during private meetings at Rice University and elsewhere.

Three "I's" – Ideas, Initiatives, and Issues

While certainly not representative of the universe of ideas regarding sustainability principles, standards, data and reporting, several opportunities are worth consideration.

USGS Rock-to-Metal Analysis

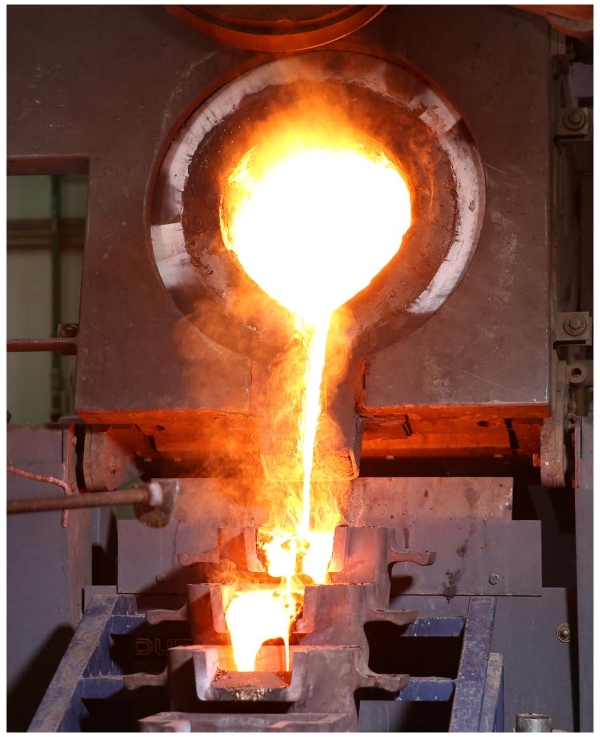
The USGS effort to measure and document rock-to-metal ratios offers a possible "back door" for understanding potential sustainability factors for mining operations. The higher the ratio, the lower the ore grade and higher the waste. From that information, it could be possible to infer not only waste but also potential inputs (land disturbance, energy, water, and other) that would need to be managed. It could also be used to anticipate potential nontechnical public interest risks.[21]

Intelligence of the kind undertaken by USGS is data intensive. As shown in **Figure 6**, the demonstration of wide variations across commodity and location have tremendous bearing on performance and sustainability metrics. It also feeds better understanding within the US of consequences associated with additional supply from foreign sources, upon which US customers rely heavily.[22] Finally, the rock-to-metal analysis and better understanding of supply capacity and potential abroad is

21. See https://www.usgs.gov/publications/rock-metal-ratio-a-foundational-metric-understanding-mine-wastes including supporting data and information.
22. See N. Nassar, et.al., 2020, Investigation of U.S. Foreign Reliance on Critical Minerals—U.S. Geological Survey Technical Input Document in Response to Executive Order No. 13953 Signed September 30, https://pubs.usgs.gov/of/1127/2020/ofr20201127.pdf. Note their Figure 9, the agency's use of scenarios to project incremental supply from a variety of strategies that could be available.

feeding USGS analysis of environmental risks, including natural hazards to which mining operations are exposed.

Government Initiatives to Develop Sustainability Indicators

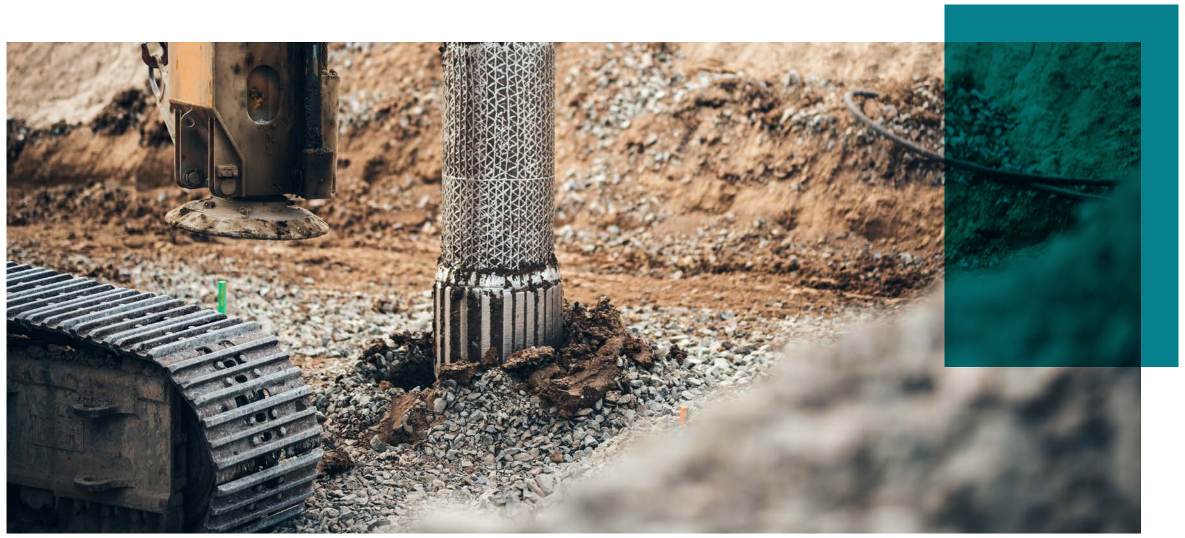


Various countries, in particular among the large economies, are looking at how best to improve public access to minerals and mining data and information that would incorporate sustainability indicators, both for performance and, as mentioned earlier, for due diligence during prospecting and eventual mitigation. A case study is the effort underway at Natural Resources Canada, NRCan, which entails overall public information access, from production to revenues earned across the provinces (which are the resource owners and responsible jurisdictions).[23] NRCan is reviewing how to convert from analog to digital platforms; authorizations among its divisions for data gathering from industry; whether and how to bolster industry data gaps with provincial and/or other public information; and, importantly, who the critical audiences are and their interests and needs. Unlike the USGS, which provides an annual report to the U.S. Department of the Interior and Congress on mining activity and economic value of minerals across the states, NRCan has no official reporting requirement to the Canadian Parliament.

23. NRCan is expected to launch a new portal in early 2024. The existing site is https://mmsd.nrcan-rncan.gc.ca/expl-expl/sta-eng.aspx.

NRCan data on production covers about 80% of the industry, with vetting from the provinces. The agency is limited by confidentialities with industry and so only reports aggregate information (as does USGS). The reconstructed portal will provide a public display of work phases for exploration and development with funding levels such as aggregate exploration capex or capital expenditures based on industry surveys that the agency is authorized to conduct. Minerals groupings reflect the major lines: precious metals, base metals, iron, uranium, and critical minerals based on Canada's federal list, for domestic supply chains (all of the economy),and batteries, a strategic interest. The portal tracks top ranked minerals for exploration, reflecting industry intent and thus indicative of future output.

NRCan's data and information revamp is receiving considerable industry input. Of interest are industry requests through the main trade groups for "responsible sourcing metrics" such as a special category for consultations, community development and more. Conversations incorporate what data NRCan already has and what could be developed. Discussions parallel the push to initiate or expand company reporting and thus represents a push from industry to government. The participants recognize that it could be possible to connect what companies are revealing in sustainability reports with asset level information that could be on government portals. Execution is a long way off. Until then, as in so many other cases, NRCan and industry groups rely on third party reporting from NGOs. All of these indications are consistent with Canada's Extractive Sectors Transparency Act.



The NRCan example poses a singular question – to the extent NGOs are taking on the mantle of sustainability monitoring, tracking, and reporting, is this a good thing? Certainly, in the interim, NGOs are satisfying a desire from key constituents for information that cannot be obtained elsewhere.[24] The organizations that have experience interacting with governments on revenue transparency have easily crossed to sustainability. Yet, the risk is that they become a crutch for inadequate transparency from governments themselves. The latter has been a dilemma for responsible revenue management. ***Who should tell the people?*** NGOs or the governments responsible to their citizens?

International and Multilateral Agencies and Institutions

World Bank, IEA and many other formal institutions in the international arena already are active researching, analyzing, tracking, monitoring, mining and minerals activity, policies, trade, and other issues. This will continue and, so far, largely is viewed to be constructive. As with the oil and gas data experience, coordinating mechanisms are needed to close data and information gaps, build trust, and satisfy public interests. These institutions already have prominent programs focused on sustainability and responsible sourcing, but too often their efforts are dominated by the focus on emissions to the exclusion of other values.[25]

The downside is that none of these organizations are free from political influence and interference. Too much of a heavy-handed approach, and tensions will rise in an already over-hyped and tense materials world.

How do strategic partnerships fit into the picture?

Finally, how will cooperative arrangements influence the industries and their customers, affect priorities, help (or constrain) data and information flows, and affect sustainability concepts?

The world is becoming Balkanized around these arrangements as import dependent economies with sensitive positions, like the US, Canada, Australia, and European Union, stake out

24. A favorite example is the Global Tailings Portal, https://tailing.grida.no/about.
25. For instance, see IEA's "net zero" tracking, https://www.iea.org/energy-system/industry#tracking, the dominant theme in its energy transition analysis.

their claims, so to speak, including for defense imperatives. Sometimes separate and parallel alliances are emerging as resource rich nations position for more prominence in supply chains to meet their own ambitions, along with desires for more influence and control. Most partnerships are couched in terms of responsible sourcing and sustainability, with language to that affect incorporated into the various projects being backed. Details are not forthcoming on many, if any, of the announced partnerships.[26]

Any number of observations could be, have been made about these partnerships. Do they weaken commitments to open, global trade? The parties involved clearly emphasize their strategic interests – with what impact to other countries and customers? Are counterparties able to perform as hoped, in the spirit of responsible sourcing? Will these partnerships dampen those commitments in the rush to originate and finance projects, and to realize the inevitable economic rents? What about the domestic industries in countries like the US that still have resources to capture and mining industries and investors that seem willing to engage in pursuit? ***We only know that the chess board is being set for a long term state of play.***

26. Coverage of a recent announcement on the U.S. Minerals Security Partnership or MSP implemented by the U.S. Department of State stated that "the group is pursuing 11 upstream mining projects, four processing plants and two projects focused on recycling and recovery of minerals. One of those projects is focused on lithium, three on graphite, two on nickel, one on cobalt, one on manganese, two on copper and seven on rare earth elements. The group also revealed that five of the projects are in the Americas and seven in Africa, while three projects are located in Europe and two projects are in Asia-Pacific". See H. Northey, 2023, U.S., allies reveal details around global EV minerals strategy, Energywire, October 11, https://subscriber.politicopro.com/article/eenews/11/10/2023/u-s-allies-reveal-details-around-ev-minerals-strategy-00120877. Subscription required for access. See IEA's policies database for some coverage on the mix of approaches, https://www.iea.org/policies. Notably, the US MSP is not included.

Table 1. The "Clean Energy" Conundrum – A U.S. Illustration

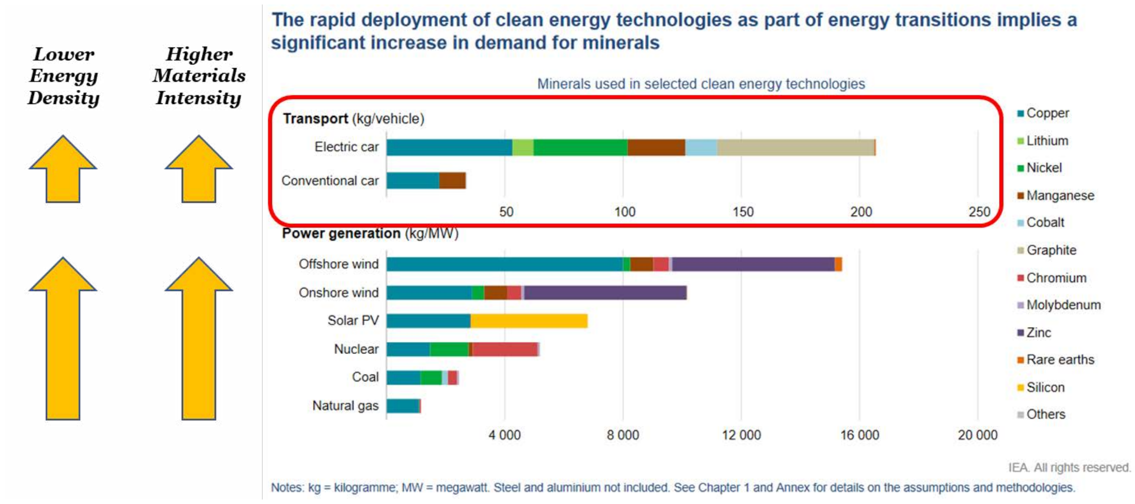
The heavily promoted, favored technologies of wind and solar have the lowest CFs, an artifact of the intermittent nature of these resources. Neither adding capacity nor adding "deliverability" (additional HVT) help to counter low CFs. For both technologies, investment must be made in 100% of the nameplate capacity, but with only a portion of the capacity monetized, government subsidies must close the gaps. Installed capacity must be fully backed by reserve generation, usually natural gas. While battery storage is assumed to be the best option for system support, cost and effectiveness are impacted by ***short durations of cycling, the need for recharging and other limitations.*** Petroleum capacity, almost all for peaking, and petroleum's share of net generation have increased in recent years as various markets have struggled to add critical reserve generation. Natural gas (and coal) CFs are relatively low because wind and solar must be dispatched when resources are available, impacting performance of natural gas units in particular. Both coal units and older natural gas and petroleum units have been retired in recent years, a response to stiffer environmental rules. Recent electric power system disruptions, such as the intense February 2021 Polar Vortex event that affected the U.S. midcontinent and Texas, and energy demand for new economic activity, such as electric vehicle battery manufacturing, have delayed or permanently halted some retirements. Low natural gas prices and subsidized wind and solar have discouraged new investment in natural gas generation nationwide.

Utility Scale Energy Source/Fuel	2021 Plant Locations	2021 Operating Units	2021 Share of U.S. Total Nameplate Capacity, %	2022 Net Generation Per Plant Location, '000 MWh	2022 Share of Total U.S. Net Generation, %	2021 Construction Cost $/kW	2021 Capacity Factor by Source	2017 Footprint
Nuclear	55	93	8	14,028	19		92.7	12.7
Petroleum	1,104	3,992	3	1	1>	1,158		
Natural Gas	2,020	6,312	45	836	41	920	54.4	12.4
Coal	269	569	18	3,082	20		49.3	12.2
Wind*	1,485	72,731	11	293	10	1,428	34.6	70.6
Solar PV*	5,257		5	27	3	1,561	24.6	43.5
Hydro	1,449	4,017	6	6,550	6		37.1	315.2
Geothermal	171		1>	99	1>		71.6	
Wood and Other Biomass	2,088		1	125	1	2,592		

*Wind and solar excluding energy storage support (battery or other) as well as other system integration requirements (such as backup reserves or technology solutions such as inverters).

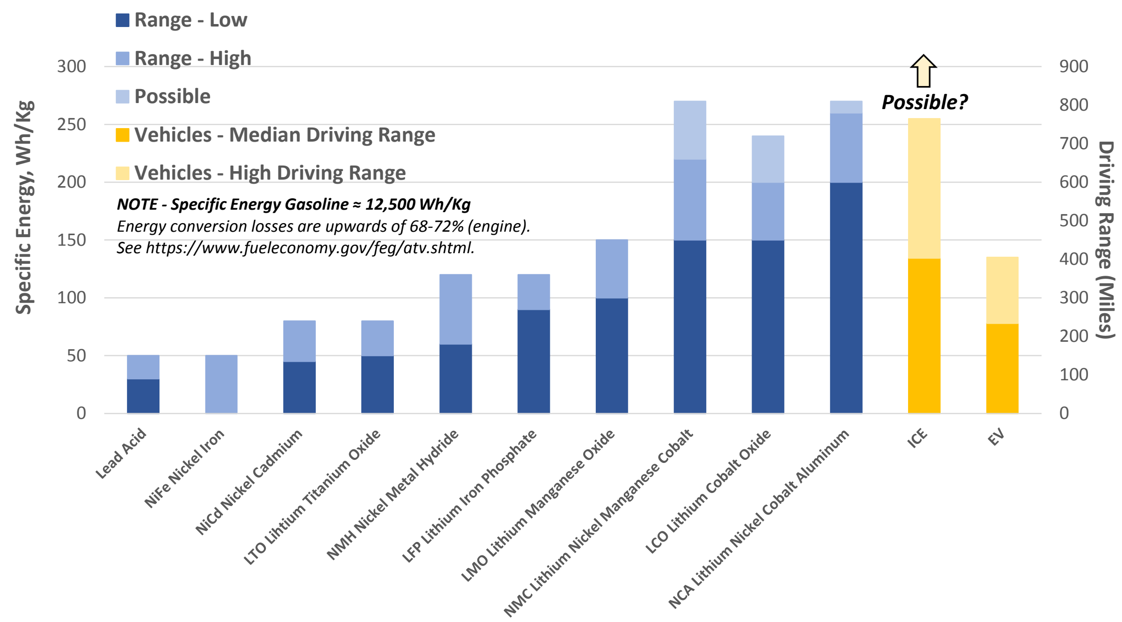
Sources: *Compiled by author using U.S. Energy Information Administration and U.S. Department of Energy data. Footprint is land use per MW and "approximates the land used during resource production, by energy plants, for transport and transmission, and to store waste materials. Both one-time and continuous land-use requirements are considered". See https://docs.wind-watch.org/US-footprints-Strata-2017.pdf. Also see https://ourworldindata.org/land-use-per-energy-source for similar results.*

Figure 1. Understanding the "Energy Density, Materials Intensity" Tradeoffs



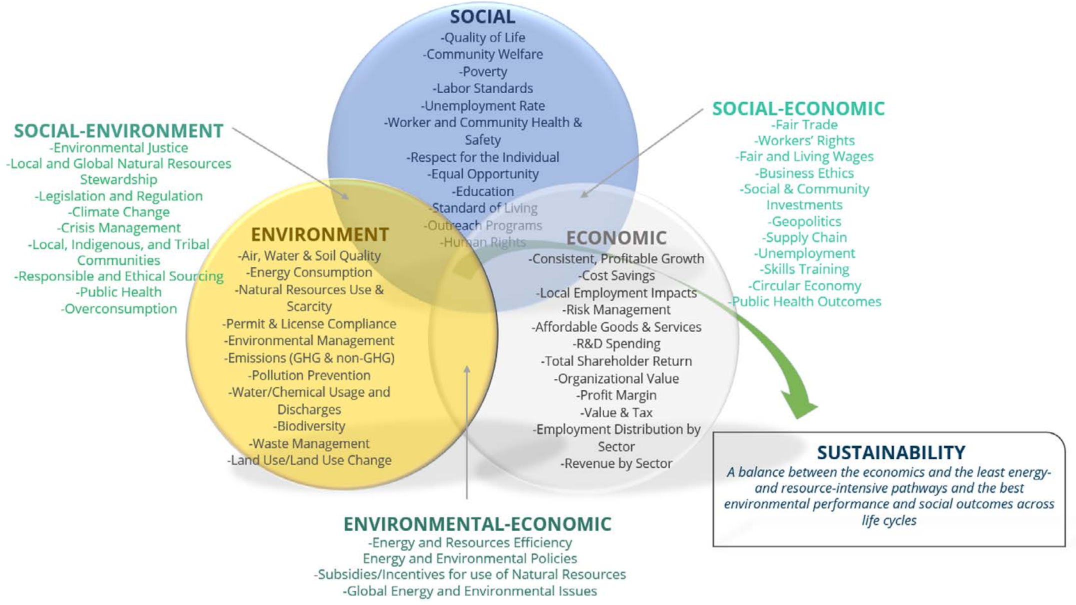
Source: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions. Annotations by author (author was a peer reviewer).

Figure 2. Battery Specific Energy and Typical Vehicle Driving Ranges (2021 Model Year, U.S.)



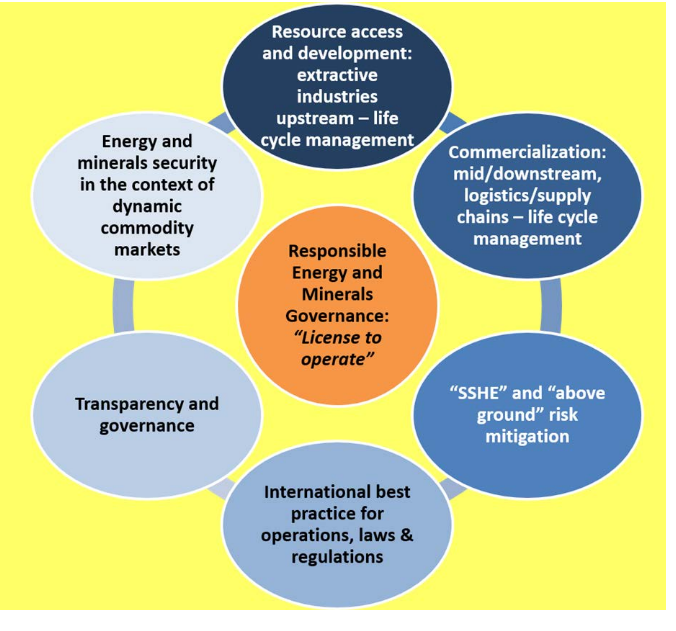
Sources: Compiled by author based on Battery University, https://batteryuniversity.com/, Nickel Institute, https://nickelinstitute.org/ and U.S. Department of Energy, https://www.energy.gov/eere/vehicles/articles/fotw-1221-january-17-2022-model-year-2021-all-electric-vehicles-had-median.

Figure 3. A Conceptual Framework for "Sustainability"



Source: *Rachel A. Meidl, from The Pride and Prejudice of Sustainability: Rethinking Sustainability From a Systems Perspective, November 8, 2023, Rachel A. Meidl and Kenneth B. Medlock III. https://www.bakerinstitute.org/research/pride-and-prejudice-sustainability-rethinking-sustainability-systems-perspective*

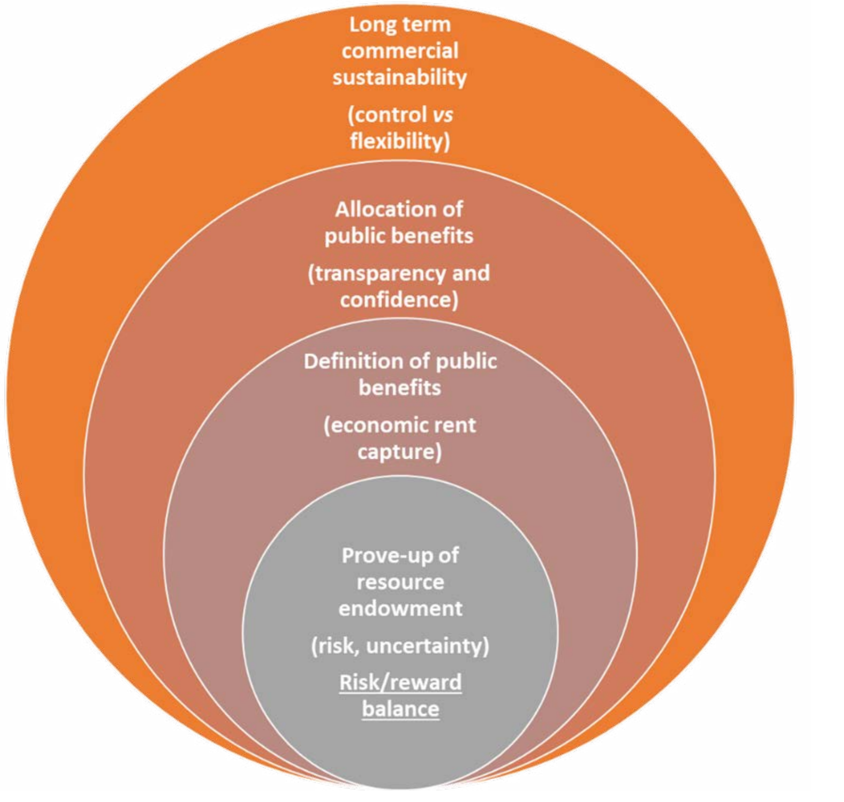
Figure 4. "All Value Chains Begin Upstream"[27] – the Energy and Nonfuel Materials Development Cycle



Source: M. Michot Foss, see https://www.t20saudiarabia.org.sa/en/briefs/Pages/Policy-Brief.aspx?pb=TF10_PB12 for background. Note – "SSHE" is safety, security, health, environment. "Above ground" is typical industry parlance for nontechnical risk factors.

27. Taken from book chapter title. See M. Michot Foss, 2021, Chapter 1, All value chains begin upstream in *Monetizing Natural Gas in the New "New Deal" Economy*, M. Michot Foss, A. Mikulska, G. Gülen eds., Palgrave Macmillan; 1st ed. 2021 edition, https://www.amazon.com/Monetizing-Natural-Gas-Deal-Economy/dp/3030599825#detailBullets_feature_div.

Figure 5. Typical Phases of Extractives Industry and Their Requirements



Source: M. Michot Foss, see file:///C:/Users/mmf10/Downloads/ces-research-minerals-112020-5_rTQPIrW.pdf for background.

Table 2. All the Sustainability Variability Fit to Print

Criteria Type	Criteria	Sustainalytics	S&P Global	Refinitiv	Moody's	MSCI	KLD
Environmental	Biodiversity	1	1	3	1	1	2
Environmental	GHG emissions	5	0	5	1	0	1
Environmental	Hazardous waste	1	1	1	0	1	0
Environmental	Waste	3	2	4	1	0	3
Environmental	Water	2	2	3	1	1	2
Social	Child labor	0	0	1	1	0	1
Social	[1]Community engagement	3	6	10	1	0	1
Social	Community relations	3	6	10	1	0	1
Social	Corruption	0	0	2	1	1	1
Social	Employee engagement	No data					
Social	Equal opportunities/discrimination	No data					
Social	Forced labor	No data					
Social	Freedom of association and collective bargaining	2	0	1	1	0	0
Social	Gender and diversity	2	0	9	1	0	3
Social	Health and safety	7	1	7	1	1	2
Social	Human Rights	2	1	5	1	0	5
Social	Labor Standards	3	1	16	4	1	3
Social	Local employment	No data					
Social	Operates an ethical supply chain	21	3	4	4	3	6
Social	[2]Responsible and ethical sourcing	21	3	4	4	3	6
Social	Secure living conditions	2	0	1	0	1	1
Social	Skills training	1	2	13	1	1	3
Social	Social benefits/social security	6	3	1	0	1	1
Social	[3]Supplier relationships	21	3	4	4	3	6
Social	[4]Women in managerial positions	2	0	9	1	0	3

NOTES:
[1]No distinction between community engagement and relations.
[2]No distinction between supply chain, ethical sourcing, and operations.
[3]No distinction between relationship and operation under ethical supply chain metrics.
[4]No specific criteria for women.

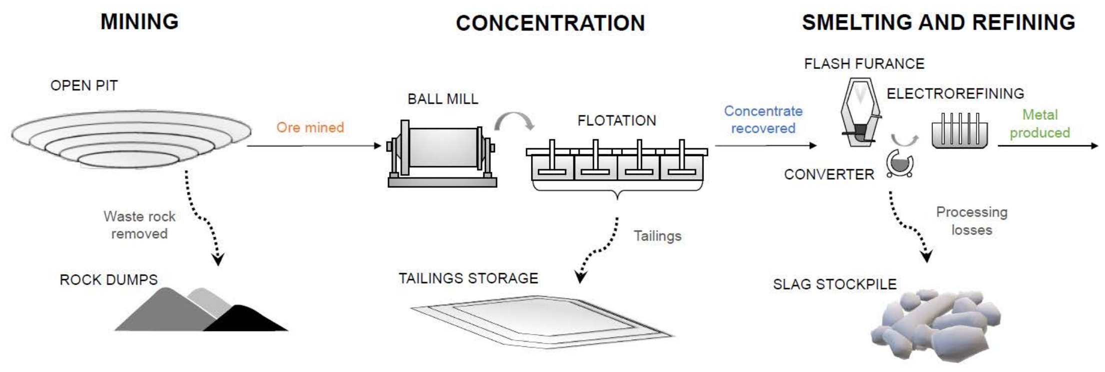
Source: Unpublished research by M. Beauplat-Saada, R.A. Meidl, M. Michot Foss, Rice University's Baker Institute for Public Policy, Center for Energy Studies, based on public information from the reporting entities. As of September 2022.

Table 3. Example of ESG Analysis by Proprietary Service

Industry	Total Count in SPG Coverage	Business Involvement Screens	Climate Analytics - Carbon Earnings at Risk	Climate Analytics - Paris Alignment	Climate Analytics - Physical Risk	Environmental Analytics - Environmental (Public Cos)	ESG Scores
Communications Services	1319	57%	64%	78%	93%	67%	41%
Consumer Discretionary	3091	64%	73%	84%	92%	76%	47%
Consumer Staples	1565	62%	70%	77%	89%	72%	46%
Energy	1333	48%	50%	59%	91%	47%	31%
Financials	4015	42%	49%	54%	96%	48%	37%
Health Care	2572	61%	45%	77%	90%	69%	48%
Industrials	4209	59%	71%	79%	93%	72%	45%
Information Technology	3225	61%	68%	83%	92%	74%	45%
Materials	2523	56%	67%	74%	94%	68%	41%
Real Estate	1644	63%	75%	82%	94%	72%	51%
Utilities	1122	50%	44%	48%	92%	42%	34%
All	26618	57%	62%	73%	93%	66%	43%

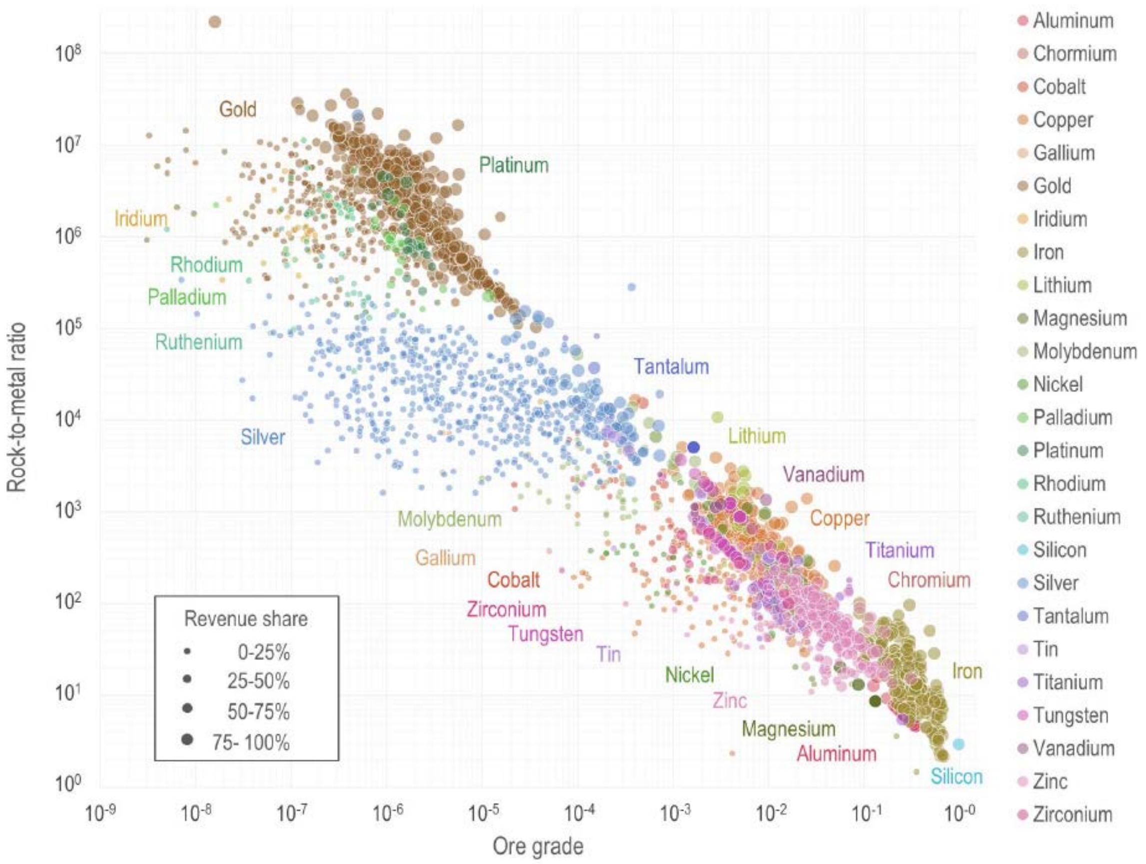
Source: Unpublished research by M. Beauplat-Saada, R.A. Meidl, M. Michot Foss, Rice University's Baker Institute for Public Policy, Center for Energy Studies, based on data using S&P Global, accessed under license, September 2022. See https://www.spglobal.com/_assets/documents/ratings/esg/esg_evaluation_brochure_digital.pdf for information on the SPG service.

Figure 6. The USGS Rock-to-Metal Assessment and Global Distribution



$$Rock - to - metal\ ratio = \frac{(Waste\ rock\ removed\ +\ ore\ mined) \cdot revenue\ allocation}{metal\ produced}$$

Nassar, N.T., Lederer, G.W., Brainard, J.L., Padilla, A.J., and Lessard, J.D., 2022, Rock-to-Metal Ratio: A Foundational Metric for Understanding Mine Wastes: Environmental Science & Technology, v. 56, no. 10, p. 6710–6721.



Source: https://pubs.acs.org/doi/10.1021/acs.est.1c07875#.

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