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ORIGINAL PAPER

The global mining industry: corporate profile, complexity, and change

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Abstract

The continuation and increasing importance of mining is inevitable as society embraces both the transition to a low-carbon economy and application of circular economy concepts. However, across many parts of society, there is an ongoing sense that those who are carrying many of the costs and risks related to mining particularly over the long term (often host communities and countries) are not seeing a level of benefit that seems fair. In contrast, there is frustration within the industry that mining is not being given due credit for the importance of its role in contemporary society by those who would criticize industry practices. Over the past several decades, dozens of initiatives aimed at strengthening mining's social and environmental performance have been mounted from both within and outside the industry. These generally depend on a "leadership-trickle-down" change model. While progress has been achieved, the society-industry trust deficit continues. The global mining community comprises a corporate core and a complex range of other surrounding interests. We suggest that some key questions regarding the nature of this community and its appetite and capacity for change have not been explored thus impeding the effectiveness of change management. We offer (1) an estimate of the number of companies that lie at the core of the global mining community: some 25,000 operating in about 140 countries (using data from the mid-2010s); (2) a profile of these companies as an initial step towards understanding the "culture" of the global mining community; and (3) a listing of additional complexities and observations important to bringing global-wide improvement to mining's social and environmental performance. We argue that building on work to date, a fresh approach is required. We are calling for a dialog to reflect on the ideas presented here, refine them as appropriate, and develop the needed strategies and action plans. Such a process must build from a comprehensive understanding of the global mining community and its culture. It must be collaborative in nature and involve not only the range of mining companies but also with surrounding interests and governments. If this is not done, the change that is needed to align actions of all mining actors with social values will not occur and the trust deficit will remain.

Keywords Mining industry profile · Theory of change · Industry structure · Mining performance improvement

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Introduction

Mined materials play a critical role in supporting life in both developed and emerging nations. This was the case historically, is true for contemporary society, and will remain so in the future. With pursuit of the transition to a low-carbon global economy and implementation of circular economy concepts, even with greatly enhanced recycling, the demand for mined materials will only increase.

The nature of the positive and negative implications of mining ripples out across space and time—for people and ecosystems. However, these implications are not fully understood and addressed. Often, the distribution of costs, risks, and benefits is skewed. A sense of unfairness has emerged that many carrying significant costs and risks—particularly the host communities and countries—are not seeing a fair level of benefit. In contrast, within the industry, there is frustration—and also a sense of unfairness—that they are not receiving recognition for the important role mining plays in society.

Much effort has been put to addressing this lack of synchronicity from both within and outside the industry. These have all been accompanied by a dependence on a "trickle-down" model of change in which leadership companies develop new approaches that are then made available to the rest of the industry in the hopes that performance improvement will, in due course, trickle down or ripple out across the whole industry to bring industry-wide change. However, aspirations have not always been reflected by industry action and in spite of some improvements, a trust divide continues, something that has been labeled one of the most significant risks facing the industry.

It is apparent that the following questions have not been adequately addressed: (1) what and who is the mining industry? (2) what is the appetite and capacity for change within the mining industry? and (3) what are the keys to achieving efficient and effective change across a whole complex industry like mining, not just individual companies? Comprehensive answers to these questions will take time to fully develop. Doing so must involve the full "global mining community" which includes not only the complex array of companies that lie at its core, but also the surrounding supporting, dependent, and affected interests. Without seeking, finding, and acting on the answers, the trust deficit will continue. A key element of this quest lies in examining and better understanding the culture of the global mining community as a foundation for change.

This paper offers a start to addressing this challenge. Our objectives are (1) to estimate the number of companies that lie at the core of the global mining community and whose profiles contribute to understanding the mining community's "culture"; (2) to identify some of the key additional complexities that characterize the industry and that are important to the challenge of strengthening social and environmental performance; and (3) to draw together a number of observations that lead to a call for a fresh dialog aimed at developing and implementing the needed set of integrated, collaboratively-created change strategies for strengthening environmental and social performance across the full global mining industry.

Overview of the global mining community

Definition of a "mine"

A mine is "an excavation made in the earth to extract minerals." Mining is "the activity, occupation, and industry concerned with the extraction of minerals" (Hartman and Mutmansky 2002, p. 3).

The global mining community is more than "mining companies"

In addition to the "mining" companies at the core of the global mining community, there are many additional interests that drive performance including contract miners; trading companies; maintenance providers and other technical support companies; service providers particularly financial services and technical support services (a broad range of consultancies providing specialized knowledge including business and administration, law, geological sciences, engineering, social sciences, and marketing); energy providers; construction companies; providers of needed equipment, reagents, and other supplies; organized labor; academia and research entities; and industry professional associations. This complex ecosystem is deeply intertwined and interdependent.

Society is focused on the actions and performance of the core mining companies. However, to bring the sought change, the role of all interests that comprise the global mining community—not just the companies—must be considered.

Products of mining

Table 1 provides a typical list of products which are produced by mining. Table 2 gives an estimate of the volume and relative value of major mined commodities in the 2018 global economy. Together, these tables illustrate the importance of the mining industry to all walks of contemporary society.

Table 1 Examples of mined commodities

Construction materials	Sand, gravel, crushed rock, cut stone/dimensional stone
Fertilizers	Potash and phosphates
Fuel minerals	Coal, uranium, oil sands (oil, gas, and peat are not included in this study)
Gemstones	Diamond, ruby, emerald, sapphire, tanzanite, many others
Metals	Precious metals such as gold, silver, and platinum; steel raw materials iron ore, chromite, manganese, and others; base metals such as copper, lead, zinc, and nickel; light metals aluminum (bauxite) and magnesium; all other metals such as lithium (including from brines) and rare earth elements
Nonmetals	Selenium, tellurium, sulfur, and others
Industrial minerals	Silica, industrial (non-gemstone) diamonds, limestone, diatomite, kaolin, bentonite, salt (sodium chloride), barite, gypsum, pumice, talc, and many others

Table 2 Estimate of the volume and value of major mining products in the world economy 2018 (figures may not add due to rounding)(*Source*: Updated from Ericsson and Löf 2017)

Commodity	Mined	Unit	Price	Unit	Value (US$ bn)
Coal	7964	Mt	94*	US$/t	750
Iron ore	2870	Mt	70	US$/t	157
Gold	3352	t	1269	US$/oz	137
Copper	20,614	kt	6530	US$/t	104
Potash	43	Mt	750	US$/t	32
Zinc	12,444	kt	2922	US$/t	23
Nickel	2233	kt	13,114	US$/t	20
Phosphate rock	232	Mt	88	US$/t	20
Diamond	150	Mcts	-	-	14
Silver	28,037	t	512,000	US$/t	14
Others	Not applicable				137
Top 10	11,144				1273
Total					1409
			*Average		

The project and product life cycles

All mine projects follow a multi-phase project life cycle that includes (1) exploration and discovery; (2) site investigation, design, and estimating; (3) regulatory review and approvals; (4) operation; (5) closure; and (6) post-closure.[1] Very few targets of mineralization that are identified in the exploration phase ever become mines—in the order of 1 in 1000 or less.

At many points along this path, activities can be temporarily suspended and placed in a state of "care and maintenance" (ICMM 2016). Sometimes termination is abrupt because of accidents, extreme natural events (floods, earthquakes), or unexpected market or corporate conditions. The overall time horizon of a mine project's life cycle can range significantly from a few years through decades and centuries depending on the size of the ore body and the natural conditions governing extraction.

The industry's treatment of this life cycle has evolved significantly as pressures have mounted to address long-term social and environmental concerns. Treatment of closure began in the 1970s with a focus on infrastructure removal and land "reclamation," mainly land grooming and revegetation. Treatment of long-term physical stability and the deep-seated bio-geochemical processes that can lead to long-term contaminant migration in surface and groundwater systems were in their infancy.

[1] The closure phase of activities formally starts with the end of operations and includes implementation of worker and community transition plans, removal of extraneous physical plant, site grooming, construction of treatment facilities, implementation and testing of the site monitoring system, and overall preparation of the site for the long term. However, many aspects of closure design, planning, approvals, decision-making, and implementation begin long before starting with mine design and related approvals. These are captured in the concept of design- and management-for-closure which have been evolving for several decades building on early ideas of "progressive reclamation." Post-closure is the phase of a mine project that takes place after the site has been fully prepared for the long-term. It includes long-term operation of any treatment facilities; monitoring of ecological (physical, biological, bio-geochemical) and social conditions; assessment of performance against socio-economic and environmental obligations; system adjustment if performance is not as projected; and any required public reporting.

It was not until the late 1990s even early 2000s that post-closure concerns related to long-term ecological health (physical, chemical, and biological) began finding their way into company and government decision-making, management systems, and related regulation and policy.[2] Key was a realization that significant efficiencies could be achieved through progressive implementation throughout the project life cycle. Unfortunately, to this day, there remains uneven application of best closure and post-closure practices across the mining industry.

The potential extended time horizon (sometimes centuries) of a mining project sets it apart from many other human activities in terms of environmental and social implications and related financial obligations. It gives rise to challenges to regulatory approaches that were originally developed to govern much more short-term human activities and related perspectives of decision-making and public policy.

In addition, various interests carry different senses of time. These range from the quarterly and annual perspective of the investor through 2–5-year election cycle of politicians, and the multi-generational perspective of indigenous people,[3] families, and communities. For their part, companies must address both short-term financial obligations (particularly pressures from investors and shareholders to achieve an adequate return-on-investment) and the longer-term need to maintain a project pipeline to ensure the company's future. These different time perspectives and related capacities add to the tension between interests. Management guru Michael E. Porter bluntly suggests that company leaders who focus on short-term financial goals and ignore values decisive for long-term success are to be blamed for the trust deficit (Porter and Kramer 2011).

In addition to the project life cycle, the metals and minerals obtained through mining are simultaneously part of the equally important product life cycle. For metals, exploration leads to the identification of (1) *reserves* of varying degree of certainty that are mined and milled into (2) *concentrates*. In turn, these are further processed (through, for example, smelting and refining) into (3) *primary or first products* and through manufacturing become *(4) final products* for distribution in the wholesale and retail systems.

Throughout both the project and product life cycles, site-specific environmental and social effects ripple out over space and time greatly expanding the area-of-influence, well beyond the immediate operational footprint.

Recycling

Recycling occurs throughout both the project and product life cycles. Particularly for metals, recycling and the significant efficiency gains that are engendered align well with sustainability concepts, the transition to a low carbon economy, and implementation of circular economy ideas. As the price of materials increases and societal demands for enhanced recycling occur, even more scrap will be integrated into supply chains.

Metals such as steel and copper have been long recycled. The recycling rate for steel globally varies considerably between countries. In the USA, 70% of steel produced is based on scrap. In contrast, the figure is only 20% in the world's largest steel producer China but increasing rapidly (BIR 2020). More recently, recycling of lead batteries and discarded electronic devices has become important sources of lead and precious metals. Approaches to recycling rare earths are also advancing.[4]

"Urban mining" is an approach to recycling that seeks to systematically reclaim compounds, elements, and energy from anthropogenic stocks. It has increasingly come into focus in the last two decades as it can be highly energy efficient and environmentally advantageous. (Zhang et al. 2019).

The number of companies that lie at the core of the global mining community

This part of our analysis is limited to developing an overall estimate of the number of mining companies that comprise the corporate core of the global mining industry. Our data are drawn from the 2014–2016 time period but with the nature of change in the mining industry; we are comfortable that the resulting estimate is indicative of today's situation. At the end of this section, we provide a brief listing of evolving conditions that will either increase or decrease mining company numbers.

We include metallic minerals and industrial minerals including fertilizer minerals as well as coal, uranium, and oil sands of the fuel minerals as these are produced with production methods similar to those used to extract metals and industrial minerals.

[2] This evolution of attitude within the industry towards closure and post-closure concerns was tracked by John Gadsby as a practicing geotechnical engineer. Gadsby's professional assignments spanned North America, Latin America, Australia, and South Africa. His focus was on the practical design, construction, and management of tailings facilities. His insights led to a call for "design and management for closure" in the 1980s and 1990s.

[3] For example, Anishinaabe Elder Wally Chartrand talks of weaving the 21 strands of ceremonial sweetgrass into three groups of seven, the first representing 7 generations past, the second representing 7 sacred teachings (love, respect, honesty, courage, wisdom, truth, and humility), and the third representing the 7 unborn generations ahead of us (Chartrand 2022).

[4] For example, see https://www.energy.gov/science/bes/articles/rare-earth-recycling.

In contrast, we do not address the extraction of oil, natural gas, peat, sand, gravel, and crushed rock. Nor do we include companies primarily focused on recycling or urban mining. And finally, we do not attempt inclusion of artisanal and small-scale mining (ASM).

This choice of analysis boundaries—particularly related to ASM[5]—is not an indication of relevant importance. Rather it is based on a belief that the cultures of the industrial mining industry, the oil and gas industry, the recycling industry, ASM, and construction materials, though overlapping, are different enough from classical large-scale mining to merit separate treatment.

We take as "mining companies" those identified as "mining" within the industrial classifications used in countries across the world. As a result, these companies are used in reporting national mining production statistics.

These industrial classifications emerged post World War II as part of the ongoing effort to develop national accounts across the world for tracking a country's economic activity—much motivated by a desire to avoid the kind of economic collapse that led to the economic depression in the early 1930s. For an insightful review of this history, see Waring (1988).

Today, there are a number of classifications in use across the world such as the Global Industry Classification Standard or GICS (MSCI Inc 2021), the International Standard Industrial Classification of All Economic Activities or ISIC (United Nations 2008), Statistical Classification of Economic Activities in the European Community or NACE from the French nomenclature (Eurostat 2008), and the North American Industry Classification System or NAICS (Statistics Canada 2019) among others.

In this work, we have not undertaken a detailed analysis of the way that "mining" is categorized and defined in each of the above classifications. Such an analysis, while interesting and useful, is outside our scope. Furthermore, we are targeting an overall approximation of the size and nature of the industry, a task that can be adequately discharged by simply grouping all companies assigned to the "mining" category by any of the classifications. In future, careful review of the various classifications may well lead to refinement of the approximations offered here.

In this study, we used two alternative approaches to estimate mining company numbers in the global mining industry. We then compared and merged the two to develop an overall estimate of the number of companies comprising the global mining industry. These approaches are summarized below and described in more detail in Appendices 1 and 2.

[5] See Mutemeri et al. (2016) for a useful discussion and introduction to the ASM sector.

Approach 1 using company registers and stock exchange data

The first approach was completed in two stages. Initially, the number of trading platforms was calculated using the International Organization for Standardization (ISO) Standard 10,383 database (ISO 2016). In total, we identified 1777 trading platforms in 140 countries worldwide. In a second stage, the Mergent Online database (FTSE Russell 2016) was used to access a comprehensive global company listing. This database is created from company reports disseminated to both central governments and the investing public and was used to obtain an overall mining company number using the standard industrial classification identifier. This approach led to the identification of some 20,000 mining companies operating in 141 countries.

Approach 2 using national mine and company production statistics

The second approach started with national mine production statistics and publicly available company data. The production numbers and company data were then compared on a country-by-country and a commodity-by-commodity basis in several loops until all or most of a country's reported production was identified on a company basis. This method led to the identification of some 10,000 mining companies operating in 101 countries.

Synthesis: comparing and merging the two approaches

The figures from the two approaches differed considerably and required reconcilliation. Several factors became apparent that facilitated the needed resolution. These include:

1. Type of commodities. Approach 1 covers all types of mining including sand, gravel, crushed rock, and dimensional stone while the second is confined to metals (including uranium), coal, and two major industrial minerals phosphates and potassium and boron. Limestone mining is a large sector of the mining industry which is often integrated into cement manufacturing. However, available databases do not always clearly note if all these companies are covered in the companies compiled in Approach 1. In contrast, none are included in Approach 2. Similarly, of all companies in the gemstone industry, only those mining diamonds are included in Approach 2.
2. Country omissions. Some countries with known mining production are not included in Approach 1: Burkina Faso, Cameroon, Cuba, North Korea, Kyrgyzstan, Laos, Myanmar, Mongolia, New Caledonia, Niger, Pakistan, Serbia, Sudan, and Tadjikistan are

the most important ones. Approach 2 has also omitted several countries, where limited mining of the products mentioned above takes place. However, the omitted countries are not the same in the two approaches. Also, in Approach 2, holding companies and national companies set up for regulatory, tax, or other reasons—but are not actively mining—have been omitted as far as possible.

3. Overlap between mining and smelting/refining. Neither of the two clearly differentiates between mining and smelting/refining. If this delineation was available, it might have led to minor changes in both approaches.
4. Business cycle. When commodity prices are rising, speculative junior exploration companies emerge to take advantage of the price increases on development targets that might be new, less known, or previously closed for a range of reasons. The number of such companies can vary dramatically, when metal prices fall, they simply close shop. In numbers, they account for a large proportion of the total mining companies—perhaps as much as 75%—and are particularly significant for countries such as Canada and Australia. For example, for 1993–1994, a low year, the Register of Australian Mining for 93/94 registered 573 mining companies while in 2008–2009, a high year, registered 1011 companies, close to a doubling (Register of Australian Mining 1993 and 2009). Similarly, in 1994–1995 (a low year), the Canadian Mines Handbook listed 1515 companies, while for 2008–2009 (a higher year), it listed 2295 companies (Canadian Mines Handbook 1994 and Canadian & American Mines Handbook 2008)

Our data sets are for a single year (2016) and variations will certainly occur over time.

5. Ongoing structural changes. Fundamental structural changes are also occurring. First, the consolidation of the mining industry is continuing particularly in China. This trend would lead to a reduction in the estimate for China from Approach 2. Second, an overlying process is the growth of exploration companies in general as large companies seeking to maintain their project pipeline, avoid risk, and focus on production off-load the riskiest phases of exploration. This trend would contribute to an increase in the overall estimate of company numbers. Third, new companies without relations to the "old" mining industry and its heritage are emerging as part of the transition to a fossil-free future. These may become attractive to investors when business opportunities related to the green economy arise.

Observations arising from the merging process

Comparison of the data sets from the two approaches led to the following observations:

For some countries, the two approaches are consistent. In many countries, the number of companies is quite comparable even if it is likely that there are some companies missing in both the estimates; hence, the "real" number in both approaches should probably be slightly higher than estimated. However, when both approaches yield roughly the same estimate, a partial review of data gives us confidence in our numbers.

For a few countries, there are large discrepancies in the two approaches. A few countries stand out with huge discrepancies between the two databases including Algeria, China, Egypt, India, Morocco, and Vietnam. In all these countries, Approach 1 resulted in a much higher figure 8460 than the Approach 2 estimate of 845. A significant factor was that Approach 1 includes a large number of quarries and sand/gravel pits for the three North African countries, because of the way the national statistics are collected, which should not be included in the estimate. Therefore, for these three countries, the estimates from the second approach were used when calculating the global figure.

China requires particular consideration. The company estimate for China from both approaches is lower than actual. The Chinese mining industry has long been more fragmented than in other parts of the world (Golas 1999). There is however an intensive consolidation process underway. According to a recent study (China Steel Development & Research Institute 2019) of the Chinese iron ore industry, the number of iron ore mining companies has evolved from 3321 in 2008 to 1307 companies in 2018. Of these companies, the category "large companies" included 10% of the total number but accounted for a third of the total production. In a 2013 zinc industry analysis, the number of "large" zinc companies was around 75 implying around 1000 zinc companies (Beijing Antaike Information Development Co and Raw Materials Group 2013). In 2015, 5924 coal mining companies (with revenues > 20 million RMB) were reported and by 2020 the number had been reduced to 4253 through mergers and closures.[6] There are also a large number of very small coal producers that we have excluded as part of the ASM sector. Taking into consideration all of these factors, we are left with an estimate of somewhere between 10 and 15,000 mining companies in China. This number is decreasing rapidly.

India requires particular consideration. For India also, both approaches gave company numbers lower than actual. India, like China, has a mining sector with many small companies even if the structure is not as fragmented as in

[6] China National Coal Association, personal communication 2021.

China. The Indian Bureau of Mines estimates 1500 mining and exploration companies including private, public, federal, and state government–owned companies (Indian Bureau of Mines 2019, pp. 1–5).

Vietnam requires particular consideration. Approach 2 missed several Vietnamese mining companies captured in Approach 1 and thus the Approach 1 company estimate for Vietnam is used when calculating the total world figure.

Summary estimate: there are approximately 25,000 mining companies globally

In coming up with an overall estimate of the number of mining companies in all countries of the world, a detailed company-by-company comparison of the two approaches has not been possible. We have therefore assumed that all companies in Approach 2 are included in Approach 1. Also, there are a number of countries that are not present in Approach 1 but appear in Approach 2. In this later case, the additional Approach 2 companies in these countries have been added to the total from Approach 1.

Merging these two approaches and adjusting for the independent estimates for China and India above (1500 mining companies in India and 12,500 from China (middle of the 10–15,000 estimate)), we reach an overall estimate of about 25,000 companies as a starting point for more detailed follow-up analysis.

This estimate includes metals, industrial minerals, and coal as defined above but excludes gemstones other than diamonds, limestone, sand and gravel, and crushed rock.

Expected future changes in mining company numbers

Some current trends are driving an increase in the number of mining companies while others are driving the numbers down.

Factors tending to increase mining company numbers include:

- Continuing population growth and related growth in demand.
- Increasing physical standards of living in emerging economies.
- Increasing demand for mined materials in support of the transition to a carbon-reduced society and continuing expansion of the information (Hund et al. 2020), communications, and technology industries has led to, for example, auto manufacturers and battery producers seeking to invest directly into mining companies in order to secure their future supplies (Unctad 2020).
- The potential start of deep sea-bed mining could bring new companies into the industry.

Factors tending to decrease mining company numbers include:

- Mergers and closures of small mines in several countries but particularly in China.
- Increased concentration in fewer large mines pursuing traditional concepts of economies of scale.
- The expanded use of artificial intelligence and digital innovation.
- Overall increased production and processing efficiencies.
- The recognition of significant closure and post-closure liabilities that are increasingly difficult for financially weak companies to address.[7]

A "profile" of the corporate core of the global mining community

An early effort in this regard was provided by Alistair MacDonald in his report *Industry in Transition – A Profile of the North American Mining Industry* (MacDonald 2002).[8] MacDonald, though limited to a North American focus, made several important advances. His work provides:

[7] As noted in "Overview of the global mining community" section, concern about post-closure (including abandoned mines) is driven by environmental, social, and economic factors particularly related to physical stability and contaminant migration into the environment along surface and groundwater pathways. Most prominent of the mechanisms (but not the only one) is bacterially driven oxidation of sulfide minerals (commonly labeled Acid and Metalliferous Drainage or AMD which is now used in favor of the earlier term, Acid Rock Drainage or ARD). Once these bio-geochemical process are unleashed through mining, they cannot be fully stopped, though active management can bring varying degree of control depending on the site. As a result, long-term costs for water treatment and active site management can arise that stretch out for centuries. Estimating the nature of this closure liability and integrating it into company and government financial statements is both difficult and contentious. These costs have not been fully integrated into the price of mined materials. Until they are, they must be carried either by the company or, in the case of bankruptcy, by government. If left unaddressed, the result is a severely degraded environment that, in addition, can carry significant and ongoing human health and safety implications. This issue is far from resolved. Neither government nor companies want to assume responsibility for the costs. Local communities certainly do not want to carry either the costs or the resulting effects. So, there is significant tension which continues to undermine industry credibility. Treatment of this topic is well-beyond the scope of this paper. However, closure costs will continue to rise—driven both by the growth in large mines and society's recognition of the cost of inaction. Smaller corporate entities may not have the financial strength to cover large closure liabilities and this factor may also add to an expected reduction in the number of small mining companies world-wide.

[8] Macdonald's work was much influenced by the experience and insight of Dr. Ian Thomson (now of Hornby Island, British Columbia) who, starting in the 1980s, focussed on understanding the nature of the "junior" mining component of the industry and its relationship to the "seniors." Thomson has been a central figure in the exploration of practical applications of "social licence to operate" concepts.

1. An organized and hierarchical classification of companies within the industry that includes global giants, seniors, intermediates, and a number of categories of "juniors" that included production juniors, exploration juniors, and investment juniors.
2. A mining company classification based on a combination of factors such as financial strength, employment numbers, objectives, and priority concerns.
3. A basis for demonstrating how this complex, interconnected maze of actors are mutually interdependent and work together to find and produce the minerals needed by society.

Guided by MacDonald's work, we undertook a rough categorization of the estimated 25,000 companies in the world based on size, asset base (market capitalization), number of employees, production volumes, corporate objectives, and focus.

We started with the company equities listings from the 68 trading platforms owned by the 64 members of the World Federation of Exchanges (WFE) and then checked the proportions of each category against the proportions provided byMacDonald (2002).[9] The WFE-listing data set was then further expanded (e.g., total assets, SIC codes, ticker symbols) by reviewing company websites, corporate disclosures (e.g., annual reports), and the Mergent Online database (FTSE Russell 2018).

Using the above data and information, we built the global mining industry profile shown in Table 3 below for our estimate of 25,000 mining companies active in 140 mining countries. There are six categories based on approximate asset base and number of employees. These categories with rough estimate of numbers are (1) 50 global giants (0.2%); (2) 250 seniors (1%); (3) 3200 intermediates (13%); (4) 10,500 production juniors (42%); (5) 8500 exploration juniors (34%); and (6) 2500 investment juniors (10%).

Additional complexities

Table 3 clearly illustrates the complex array of mining companies. They vary in market capitalization, number of employees, production volumes, and corporate objectives. The juniors live with high risk and uncertainty. They are strongly competitive and highly mobile. Their role is transitory and episodic by nature. In contrast and relative terms, the large companies operate with lower economic risk and uncertainty, though still buffeted by market swings. Their operations are continuous and take place at locations fixed over long periods of time (sometimes centuries).

[9] We used WFE-listing information because of the integrity and completeness of their database which includes (1) strong disclosure requirements, (2) adequate breadth of data elements, and (3) timely reporting which gave us access to a full 2016 data set.

But the complexities go far beyond a large-small mining company comparison. Some of these are addressed below.

Mining company ownership is variable: public, private, state-owned, hybrid

Company ownership adds a significant element of complexity. The mining company universe spans four overlapping categories of ownership: (1) fully publicly traded ("public") companies, (2) fully private ("private") companies, (3) fully state-owned companies ("SOEs"), and (4) a number that are some mix of public and state-owned, and private and state-owned.

There are also SOEs and private companies which are operated as public companies or following some of the rules and regulations set up by stock exchanges and meet requirements demanded by investors in fully publicly traded companies.

The Company Research Guide (2019) offers the following definitions:

Public companies sell stock to the general public on one of the major stock exchanges. Such sales are triggered by an initial public offering (IPO). Anyone who purchases stock in a company owns part of that company. In the USA, the Securities and Exchange Commission (SEC) and the equivalents in other countries require public companies to disclose financial and other information to their owners (in this case the public), so that investors can determine for themselves if their company's securities are a good investment and that ongoing company management is sound. This data-availability makes researching public companies much easier than private companies.

Private businesses are those for which there is no public ownership of its shares or assets. Although closely held businesses tend to be small, family owned, or jointly owned by a small group of people, they can also be large or wholly owned subsidiaries of major publicly traded companies. In the USA, the majority of businesses are private. And because privately held companies do not sell shares to the public, they are not required by law to report financial information to the SEC or equivalent. As a result, it is more difficult to locate detailed information about a private company's operations.

State-owned enterprises (SOEs). In the early 1950s, government equity holdings were insignificant but in the mid-1980s, SOEs controlled about half the mineral capacity in the "Third World." In the centrally planned economies (labeled the "Second World" in the 1950s), 100% of production was controlled by SOEs. Also in some industrialized countries, mining SOEs have been and remain important producers of metals such as Swedish iron ore miner LKAB and Finnish non-ferrous miners Outokumpu and Terrafame.

Table 3 Profile of the corporate core of the global mining community

Category	Approximate total assets in USD[1]	Approximate number of employees	Approximate number of companies	Descriptive comments
Production				
Global giants	Above 12 billion	Tens of thousands	50 (0.2%)	• Have multiple operations in multiple countries • Generally, publicly traded • Control most of the capital available to the mining industry • Can be vertically integrated to some extent with activities extending from exploration through mining and smelting into manufacturing • Focus on growth and expansion to increase value • Strategically take into account both their own and global production and trading of mineral products • Have a perspective that spans the whole industry • Image (reputation) conscious
Seniors	6–12 billion	Thousands	250 (1%)	
Intermediates	3–6 billion	Hundreds	3200 (13%)	• Can have a few operations in a few countries • Includes three types: (1) producers who focus on growing reserves, (2) management groups who are technically skilled and produce for others, and (3) "royalty" companies who are often publicly traded; have substantial revenues from mines in which they hold royalties on; and can buy and sell the royalties they hold or wish to hold as a commodity • Often expansionary and seek to grow their project pipeline • Focus is on their operations with an eye to the global industry
Production juniors	1–3 billion	Tens to hundreds	10,500 (42%)	• Small, often one-mine producers, some growing, some shrinking • One country often where owners are • Capital access more limited than large companies • Focus is on their mine though they continue to explore for additional potential projects
Exploration				
Exploration juniors	0.5–1 billion	A few to fifty	8500 (34%)	• Finders not producers: goal is to sell up to producer • Highly mobile, competitive, accepts that their involvement is transient, very focused, and used to living with a high degree of uncertainty (only about 1 in 1000 targets move into production and ownership can often change); communicate selectively; seek a low profile to protect their interests; and believe that their activity is low impact • Can operate in several countries but generally have at least a regional focus • Includes at least five types: (1) site accumulators, (2) one site, (3) one state/province/country, (4) regional niche either within one country or on one continent, (5) focus on a particular mineral or geology • Volatile and market dependent • Focus is on their exploration project(s)
Investment				
Investment juniors	Below 0.5 billion	A few to tens	2500 (10%)	• Highly volatile and market dependent • Focus is on accessing venture capital and growing their stock price
Total				
Global total			25,000 (100%)	

Sources: modified from Macdonald 2002 based on compiled data by the authors, and Ian Thomson 2022, personal communication

[1] "Total assets" is all the assets, or items of value, a company owns including cash, accounts receivable, inventory, equipment, and tools

State control over world mining peaked in the early 1980s when almost half of world mine production was produced by SOEs. A period of privatizations followed in the 1990s. With Chinese mine production gaining significance, it reached 24% in 2008 (Raw Materials Group 2011).

A recent preliminary update by RMG Consulting of the 2011 study indicates that SOE's control over global mineral and metal production reached a peak in the mid-2010s at around 28–30% of the total value of all metals and industrial minerals including diamonds and uranium and has since then declined somewhat to 27%.[10] The key factor behind this decline is the relative reduction in Chinese domestic production compared to the rest of the world. The increase in control over production by Chinese companies outside China has not been sufficient to compensate for this decline and the result is a total decline in control by SOEs. Non-Chinese SOEs maintain a relatively stable 10% share of the value total world production over the past 15 years.

The internal governance structures of SOEs can be dominated by nation-based political interests that carry priorities and values markedly different than those which are publicly traded. Many SOEs are designed according to the needs, policies, and operating cultures of the host nation. They vary greatly in their nature across the world (Radetzki 1985). Many resource-rich countries operate SOEs as a significant part of government policy (Corporate Finance institute 2019) including China, India, Chile, and Saudi Arabia. As described above, the importance of the SOEs is changing with political tides but it is clear that they will remain a significant force among international mining companies for the foreseeable future.

The Chinese mining SOEs are approaching their international peers in size, geographical extension, and the range of minerals and metals mined. This process affects not only the world markets, host countries, and competing international companies but also the Chinese companies themselves. Slowly, they are adjusting their behavior in reaction to pressures from the international mining community: commodity markets, host countries, and transnational companies. Also, Chinese multi-nationals operating in other countries must abide by local law and regulation. In the long-term, this may lead to influences flowing both ways.

However, though closing, a gap in social, environmental, technical, and economic performance continues to exist between the practices of Chinese companies and emerging international norms. This is particularly true for domestic Chinese operations of these companies (Ericsson and Löf 2020).

Junior-senior company interdependence exists

Within this corporate ecosystem, the exploration and production juniors of the industry serve as a feeder system for the larger or "senior" companies in terms of discovery of new reserves and resources. There is a kind of important interdependence in this regard, even though many larger companies also have exploration divisions. The nature of this interdependence has never been carefully explored in terms of its role in bringing improved social and environmental improvement across the full global mining industry.

The variable and critical role of government

Mining and related activities are guided by the laws, regulations, policies, and strategies set by government. Government is central to any strengthening of social and environmental performance.

A significant complicating factor in addressing change across the full global industry is that across governments, there is a vast variation in interest, capacity, and strategic approach to effectively manage change in pursuit of enhanced social and environmental performance for the common good. The role of state-owned enterprises is similarly variable as is trust in government by industry and the public alike.

Furthermore, government plays a dual role in management of natural resources. One is incentivizing mining development as an economic driver, the other is regulating mining in favor of a host of competing social, cultural, environmental, and economic values. This dual role sometimes leads to internal conflicts within governments and conflict between government and other interests. However, the double role also provides a number of unique opportunities for facilitating performance improvement. Society has moved past the over-simplified perspective that pits the benefits of voluntary action of companies against action required by government regulation. Both are clearly needed but they must be strategically targeted. Government has an important role in incentivizing both approaches to achieve best results.

To this end, the creation and growth of the Extractive Industries Transparency Initiative (EITI 2022) and Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development (IGF) closely following the 2002 World Summit on Sustainable Development in Johannesburg, South Africa, both represent significant steps. Today, EITI brings together over 50 countries committed to strengthening transparency and accountability of their extractive sector management by implementing the EITI Standard (EITI 2022). The IGF now links 79 countries from around the world, providing a mechanism for interaction between governments on mine-related issues (IGF 2022).

The ongoing efforts of the World Bank Group in this arena are significant. In 2013, the World Bank Group

[10] RMG Consulting personal communication 2022.

reported support for 41 mining sector reform projects in 24 countries since 1988 (World Bank Group 2013). Many more have been supported since. De Sa (2019) provides a brief overview of the evolution of World Bank policies, approaches, and key policy events from the 1980s onward.

Several United Nations organizations are actively engaged in bringing improved social and environmental performance to the global mining industry. Among these are the following: the United Nations Environmental Programme (UNEP) which set up the International Resource Panel in 2007 which has subsequently published a range of reports on, among other topics, trade, resource efficiency, green technology, and global materials flows and the United Nations Commission for Africa (UNECA) who together with the African Union Commission has sought development of a mining industry for the benefit of Africa (see for example UNECA 2011).

The European Commission issued its first major mining-related policy document in 2008 establishing the Raw Materials Initiative. It has since carried out major mining-related research programs and policy coordination projects among its member countries (Tiess 2010; STRADE 2018; Janikowska and Kulczycka 2021).

A full treatment of the variable and critical role of government to bringing change across the full global mining industry is well beyond the scope of this paper. However, it is an essential ingredient of the change process that is needed to ultimately bring synchronicity between the evolving values of society and actions of the mining industry.

The rapidly evolving push for gender equity

This evolution varies significantly from country-to-country. Historically, the mining industry has been male dominated for example with laws forbidding women underground. However, women have proven to increase productivity and improve company-community relationships. With increased gender balance, the nature as well as pace of a successful change strategy may well change (Abrahamsson and Johansson 2021).

The checkerboard of written and un-written rules

In principle, all aspects of the mining industry are subject to written rules (the law, regulation, policy) and unwritten rules (cultural norms) of the host community, region, and country. Mining commonly takes place in peripheral regions where indigenous people and their organizations play an increasingly important role. At any given location, written and unwritten rules have a history that is important to understand.

These rules in turn may be influenced by or in conflict with "internationally accepted" rules and guidelines such as the IFC Environmental and Social Performance Standards (IFC 2012); the *CRIRSCO* Guidelines for Reporting of Mineral, Exploration Results, Mineral Resources and Mineral Reserves (CRIRSCO 2019); the United Nations Framework Classification for Resources (UNFC 2019); or the Global Industry Standard on Tailings Management (Global Tailings Review 2020).

Multi-cultural operating environments

Some mining companies operate locally, in a single region of a single country. Yet others operate in countries across the world. In principle, those operating in more than one culture must adjust to both the rules and cultural norms of where the legal base of the company is (typically where the head office is located, but not always), as well as the rules and cultural norms of any region or country in which they operate. Mining companies have not always been successful operating in a multi-cultural mode.

The culture of the global mining community—the foundation for change

One apt description of culture is "shared assumptions and values as well as expected behaviors and symbols" (Network for Business Sustainability 2010).

Interestingly, while there is a large literature on business organization culture (for example, see Grayson et al 2018) and related strategies for change management, the literature exploring the culture of the mining *industry* is limited (see for example, Kudelko et al. 2014 and Gunningham and Sinclair 2017). And we know of no literature that examines barriers and incentives for change and change management approaches that would address fundamental adjustments right across that complex global mining community—a community that includes not only the companies at its core but also the many surrounding interests that feed and are affected by those core companies. However, surely if culture embodies values and expected behaviors, it is understood that culture is the needed starting point for effectively and efficiently triggering change.

Mining is an ancient activity. It is our sense that reflecting those ancient roots, there is a discernable culture that lies like a thin veil across the entire global mining community.[11] That community includes not only the 25,000 mining companies at the cores of the industry but also the surrounding complex array of service, supply, and support industries (financial, technical, social), industry associations, host communities, land holders (indigenous and non-indigenous), research and teaching organizations, and non-government organizations.

[11] We are indebted to Jim Cooney for the analogy of a "thin veil.".

Kudelko et al. (2014) use the "Competing Values Framework" (created by Quinn and Rohrbaugh 1983) in an analysis of mining company culture.[12] While their data set are limited, it points towards a dominant management approach that emphasizes "control." Success factors include delivery reliability, meeting deadlines, low costs, and market penetration. In short, its principal feature may simply be a desire for financial gain and a "control" management style while generating products and services demanded by society. They contrast this control-dominant approach with one that is more flexible, open, cooperative, more open to risk-taking, and in which leaders are innovators and visionaries.

They also suggest that other typical mining characteristics are the weight of inertia that resists change (long history, heavy investments, human tendency to resist change) and overall psychological tendency that compels people to stay close to the norm.

Understanding this inertia may be the key barrier to change that is currently impeding progress. It likely exists not only within individual companies but also systemically across the global mining community. For example, innovative companies with innovative leadership may serve as inspired examples of improvement but if education systems are teaching old approaches or investors and politicians are demanding business as usual, the nature and pace of cross-industry improvement of social and environmental practices will inevitably be impeded.

The above comments are cursory at best and significant research is needed to understand the culture of the global mining community, its characteristics, and the related barriers and effective incentives for change. These features are essential ingredients for developing an overall set of change strategies for bringing strengthened social and environmental performance across the global mining community.

The industry profile presented in Table 3 is an early step in understanding mining's culture.

The larger companies control the majority of production but do not necessarily drive the culture of the global mining community

Analysis of unpublished data (excluding coal) shows that in 2013, the largest 10 companies in the world controlled 29% of the total value of all mine production (Raw Materials Data 2014). Today, of the 14,000 core producing companies, the largest 650 mining companies control some three-quarters of the value of production. In contrast, the smaller producing companies, some 13,350 that comprise the remaining 96% of the industry by numbers, likely contribute only a quarter of the total value of the world's mine production.

However, while the large companies dominate production, their similar domination of industry culture does not necessarily follow. And similarly, a change strategy appropriate to a large company operating in a number of jurisdictions may not be an effective change process for a smaller company operating in a single jurisdiction.

Furthermore, company actions are deeply influenced by other interests within the global mining community.

Bringing improved social and environmental performance across the entire global mining industry is a "sticky" or "wicked" problem

Bringing improved social and environmental performance to the global mining industry clearly lies within the domain of what some call "sticky" or "wicked" problems. Drawing on the work of Rosen (1999), Baker (2017) points out that these problems go above and beyond challenges faced during normal business and are characterized by variable temporal and spatial boundaries and many stakeholders with their own frame of values. He notes that any solution will depend on participating individuals who are creative, pragmatic, flexible, and collaborative. This is exactly the case faced here.

Key observations and next steps

Historic context

The last half of the twentieth century proved difficult for the mining industry. Coming out of the post World War II development boom, it was hit with dramatically increased public environmental and social concerns coupled with a retreat by investors as the "dot.com" phenomenon unfolded. Mining companies' need for access to capital, access to land for exploration, and access to the needed stream of incoming talent was threatened.

Faced with a significant erosion of what by then had been labeled their "social licence to operate",[13] a number

[12] See also https://www.quinnassociation.com/en/robert_e_quinns_competing_values_framework for an overview of the Competing Values Framework.

[13] The term "social license to operate" was first used in 1997 by Placer Dome Ltd. senior executive Jim Cooney, at a World Bank meeting to explain the challenge of addressing the rising risk to the mining industry of conflict with host communities. It is now the subject of significant ongoing debate and is addressed in a vast literature. Its application has spread to at least 30 commercial activities around the world from aquaculture to tourism and wind farms, as well as other resource industries such as forestry, oil, and gas. It has entered the lexicon of indigenous peoples, civil society, communities, academia, and government. The legalistic concept of "licence," which implies a formal right to always act, was never intended for this idea. Rather, it implies a kind of soft agreement with proceeding. L. Freeman of Idaho Hills, Colorado (2022, personal communication) points out that far from the idea of granting rights to a (mining) company, its real power lies in its capacity to facilitate (1) social action that helps compensate for the time lag between transformative change in societal values and legislative action and (2) input from special stakeholders that may not be effectively represented in majority-based legislative actions.

of senior mining companies came together in 1999 and mounted the Global Mining Initiative (GMI) with its landmark study, Mining Minerals and Sustainable Development (MMSD). MMSD set out to explore concrete ways that would synchronize the global mining industry's values and aspirations (as reflected in their day-to-day actions) with those of the broader global community. A collaborative, global examination of industry environmental and social practices was mounted.

The unprecedented 2-year MMSD exercise involved extensive dialog among many interests including large and small mining companies, service providers, non-government organizations, indigenous people, organized labor, mining communities, think tanks, and academia across the world.

MMSD delivered an action plan for addressing a large number of key issues. In sum, it provided direction for how mining and minerals could best contribute to the global transition to sustainable development (MMSD 2002 p. xiv, MMSD North America 2002, p. 7).

The GMI/MMSD leadership change model

MMSD was issue-oriented by design. For implementation, a "leadership change model" was informally adopted. In this model, a small group of committed and financially robust leadership companies would work with various interests to develop improved practices, develop the needed guidance and documentation, and freely share the results across the broader industry. The idea was that through this sharing and modeling of improved practices, industry improvements would ripple out or trickle down to other mining companies to generate overall performance improvement across the whole industry.

Building on a decade of earlier effort by the International Council on Mining and the Environment, a new organization—the International Council on Mining and Metals (ICMM)—was constituted to lead this change process. Importantly, ICMM would serve as a platform of analysis and ongoing dialog and cooperation among key stakeholders. Today, ICMM membership includes 26 companies, mainly global giants who play a dominant part in the production of certain minerals such as iron-ore, copper, aluminum, and gold.

In addition, ICMM convenes 37 international, national, and commodity-specific industry associations. These associations are typically oriented to advocating for and defending the interests of their member companies. In principle, ICMM can reach out to several thousand companies through these associations. However, associations and their members, though free to draw from ICMM-generated approaches, are not bound by ICMM decisions or policies. The role of these associations in serving as a key element of change is worthy of careful review.

Progress achieved but societal expectations not met

Just over 20 years have passed since completion of the Global Mining Initiative. Subsequent adoption of commitments in ICMM's internally binding position statements on Protected Areas (2003), Mercury Risk Management (2009), Partnerships for Development (2010), Indigenous People (2013), Climate Change (2011, 2015, 2019, 2021), Tailings Governance (2016), and Water Stewardship (2017) (see ICMM 2022, Position Statements) all signal progress.

In the meantime, many other significant initiatives within and outside the industry have been mounted to improve the mining industry's environmental and social performance and related systems of governance. Resolve Solutions Network and the World Economic Forum (2016) and Hodge (2018) document some 50 such initiatives from both within and outside the industry. In the 5 years since this work was completed, others have been mounted. In a few cases, industry-wide standards have been created. Development of the International Cyanide Code (Cyanide Code 2022) and the Global Industry Standard on Tailings Management (Global Tailings Review 2020) are two good examples. In addition, a number of countries have completed significant revisions to mining law and regulation. Several leadership companies have demonstrated noteworthy progress and industry aspirations remain high.

Despite this impressive level of effort and a degree of progress achieved, evidence continues to accumulate that suggests the nature and pace of performance improvement in the mining industry has been too slow and not pervasive enough to meet society's hopes and expectations. Accidents, infrastructure failures, and management failures have undermined confidence.

Unfairness in the distribution of costs, risks, and benefits, the "trust deficit"

Of great concern is that the distribution of costs, risks, and benefits is often skewed. In particular, the host communities and host countries carrying many of the costs and risks, particularly over the long term, are not seeing a level of benefit that seems fair. Cases abound in which they and the enveloping ecosystem are left to address social and environmental liabilities long into the future. Systems to track this distribution and facilitate dialog for resolving differences are rarely put in place, if ever.

This sense of unfairness was heightened by the 2014–2019 tailings failures at Imperial Metals' Mt Polley, Canada, in August 2014, at Vale and BHP's Samarco Mine, Brazil, in 2015 and Vale's Brumadinho in 2019, also in Brazil. It has been significantly exacerbated by Rio Tinto's destruction in May 2020 of the sacred Juuken Gorge Cave site in western Australia in favor of iron ore mining.

Other examples continue to mount suggesting mining practices are far from adequate. For example:

- In June 2020, a major oil spill occurred from a power-generating subsidiary of Norilsk Nickel discharging over 20,000 tons of oil into an arctic lake, compared by some to the 1989 sinking of the Exxon Valdez off the coast of Alaska (BBC 2020).
- In November 2021, a coal mine disaster occurred at the Listvyazhnaya mine in Belovo, Russia, killing 51 miners and rescuers (RT 2021).
- On December 22, 2021, a landslide occurred at a jade mine in the township of Hpakant in Kachin State, Myanmar, killing a number of people. This incident followed earlier landslides in 2015, 2019, and 2020. Several hundred miners have been killed in these incidents (Wikipedia 2021).

In short, mining-associated accidents, loss of life, and environmental harm continue at a level that is not acceptable to society. Mining company performance has not always followed mining company aspiration. This is despite a myriad of policies, regulatory changes, and aspirational calls for action by investors, international organizations, indigenous peoples, government, churches, civil society organizations, and the mining industry itself.

There is a "values divide." Tension and a continuing trust deficit are created[14] (Owen and Kemp 2018, De Sa 2019; Oboni and Oboni 2020; Roche et al. 2017; Global Tailings Review 2020, Hopkins and Kemp 2021, Responsible Mining Foundation (2022).

Growing importance of metals

Mined materials are critical for supporting contemporary society in both developed and emerging nations across the world. With the urgent pursuit of a transition to a low-carbon global economy and practical application of circular economy concepts, mined materials will only increase in importance.

The challenge posed by uncertainties and risks

The nature of the positive and negative implications of mining ripples out across space and time—for people and ecosystems. While enhanced understanding has been achieved in the last 50 years, implications are not fully understood by researchers or practitioners, not fully addressed by government policy and regulation, not fully treated by company practices, and, most importantly, not fully captured in the market price of mined commodities. Significant inherent uncertainties and risks remain. While that is the case to a varying degree for most human activities, mining is more extreme: sites are often in wilderness locations, conditions are less controlled, and implications of failures are greater. With time, understanding increases and practices evolve. Given the inevitable growing need for mining as part of the transition to a low-carbon economy, a primary challenge is to strengthen environmental and social practices as much and as fast as possible through explicit programs of collaborative monitoring, adaptation, improvement, and open reporting.

Observations

1. Without concrete action, ongoing tension between mining and society will continue at a level that will discourage innovation and change. The incidents noted above and the attendant sense of concern about harm to people and the environment, inequity, and unfairness reflect an ongoing disconnect between societal values and those reflected in the performance of mining companies. Thus, the ongoing tension between mining and society is hardly surprising. A certain degree of tension will inevitably exist and is necessary in drawing attention to points of difference between interests. However, without concrete change and improvement of social and environmental performance across the industry, the tension will continue at levels that will discourage innovation and change.
2. The leadership, trickle-down change model is not adequate on its own. In sum, it appears that the leadership, trickle-down change model that was adopted in 2002 to bring improved environmental and social performance across the mining global industry has not delivered the overarching industry-wide change that many had hoped for. It certainly has brought change to some leadership companies, but not broadly across the industry. The leadership, trickle-down approach is helpful and even necessary but not sufficient.
3. Key questions remain that are unasked and unanswered. Today, with the benefit of hindsight, it is apparent that the following questions that are critical to bringing industry-wide change have been asked and answered: (1) what and who is the global mining industry? (2) what is the appetite and capacity for change within the mining industry? and, importantly, (3) what are the barriers to and functional incentives for change—the keys to achieving efficient and effective change—that are appropriate for all of the different parts of the industry profiled in Table 3, not just a few "leading" companies.
4. The individual corporate cultures and behaviors of a small number of big companies will not on its own drive change across the full industry. As pointed out in the "Additional

[14] The idea of a "trust deficit" between society and the mining industry was assessed by Lane and Muricy (2021) as the single biggest risk facing mining companies.

complexities" section, the largest 650 mining companies control in the order of three-quarters of the value of the world's mine production. However, these companies and their approaches do not provide the only set of inputs to performance. Not only is there a marked variation in size, ownership structure, values, objectives, geographic focus, and interest in and capacity to respond to change across the full spectrum of 14,000 companies that operate producing mines, but the global mining community also consists of many other interests that influence performance. It is simply not reasonable to assume or expect that in the absence of a deliberate set of strategies, the practices of the larger companies will effectively, efficiently, and automatically trickle out to the 25,000 mining companies across the world operating in some 140 countries.

5. Understanding mining's culture is key to bringing change across the global mining community. The culture of any community provides the foundation of its behavior. And changing that behavior starts with understanding and adjusting that culture. In mining, there is clearly significant variation in the cultures of the 25,000 mining companies that lie at its core. However, a common culture—with ancient roots—lies like a thin veil across the entire global mining community. Its principal features may be a desire for control coupled with financial gain while generating product and services needed by society. However, it also is likely the source of significant inertia that resists change and compels companies to stay close to the norm. If industry-wide change in the mining industry in terms of improved social and environmental performance is to be achieved, then the global mining community's culture—points of commonality and points of divergence—must be understood and used as the foundation for bringing change.
6. Fresh perspectives and enhanced research on environmental and social aspects of mining are needed. Our discussion may have raised more questions than it has answered. There is no doubt that work to date aimed at bringing change to the mining industry and improved environmental and social performance provides a strong basis for learning. However, fresh thinking and perspectives are required to develop the needed insights.

To that end, others have noted that while mining industry expenditures on research and development effort were sufficient to ensure supply met demand during most of the twentieth century (Doggett 2007, Jébrak 2012), a downward trend in mining company research and development expenditures began in the 1980s and has continued. Filippou and King (2011) point out that mining companies spend less than 1% of their revenues on research and development in support of innovation. With climate change and poverty reduction being faced as major issues across the world, the need for enhanced research and development effort is urgent (Hitzman 2002).

Next steps

There is a need for creative strategies to improve the environmental and social performance of the global mining industry. Doing so is only possible through dialog across all the interests that contribute to mining's complex, heterogeneous culture.

Such a call for action immediately raises a number of questions:

1. Participants. Who are the needed participants and what are the best mechanisms to bring them into the conversation?
2. Leadership. Who should or could lead such an exploration?
3. Process design. What is the best process design of such a review, one that would ensure input from all key interests while building trust for subsequent action both within and outside the industry?
4. Funding. What funding mechanisms can be harnessed?

These four questions are far from trivial. Early conversations have been initiated among individuals around the world to test the validity of the ideas presented in this paper, to discuss the four questions above, and develop an action plan for moving forward.

This proposal is motivated by two factors.

First is the urgent need to address climate change, much complicated by the evolving supply/demand turmoil sparked by events such as the Ukraine conflict. Unless the world experiences a dramatic population drop, these events will lead to a need for more, not less mining. The global mining community faces a choice in playing its part. Either it can choose a pathway that is marked by respect for and generates a positive contribution to people and ecosystems. In this choice, the trust deficit will decline. The other choice continues the current way for many in the industry. It is marked by a limited focus on generating shareholder value, an approach that will lead to continuing harm and maintenance of the trust deficit.

Second, the choice described above is not limited to mining. Rather, through its actions, the mining industry can demonstrate a powerful degree of leadership—across all industries—in the needed transition to a low-carbon economy and a future development direction that is characterized by greater equity and enhanced security, the essence of sustainable development.

Summary

This paper addresses the challenge of bringing improved social and environmental practices across the global mining community. That community includes:

Corporate core

The corporate core of the global mining community includes roughly 25,000 companies active in 140 countries. Of these, about 14,000 (56%) operate producing mines and 11,000 (44%) are non-producing explorers or investment juniors. The 14,000 producers include about 50 global giants (0.2%), 250 seniors (1%), 3200 intermediates (13%), and 10,500 production juniors (42%). Non-producers include some 8500 exploration juniors (34%) and 2500 investment juniors (10%). Companies vary significantly in size (as estimated by asset base, numbers of operations, numbers of employees); corporate objectives; risk tolerance; overall financial strength and means of financing; ownership model: public, private, state-owned, hybrid; geographic focus; commodity focus; technical challenges; extent of exposure to multiple operating environments; regulatory regimes they are operating under; and interest in and capacity for embracing change leading to improved social and environmental performance.

Around the core

Mining companies do not exist as an isolated industry. Surrounding the 25,000 core companies lies a complex array of service, supply, and support industries (financial, technical, social), industry associations, organized labor, host communities and land holders (indigenous and non-indigenous), research and teaching organizations, and civil society organizations.

Government

All these organizations operate within the policy, laws, regulation, and enforcement actions set by government. Governments serve on the one hand to incentivize greater mining activity and on the other to modify mining activity in favor of competing political, social, environmental, and economic pressures that reflect host-country policies. Across the world, government's interest in and capacity for effectively managing change vary greatly as does trust in government by industry and citizens alike.

In sum:

1. Social and environmental performance improvement across the mining industry has been too little and too slow; the gap between mining's performance and society's expectations remains as does the attendant trust deficit.
2. The leadership, trickle-down change model that has been depended on to bring change to mining practices over the past several decades is necessary but not sufficient.
3. Among mining companies, there are significant variations between individual company cultures. However, there is a "mining culture" that has ancient roots and is emergent from the global mining community that includes all of the above elements: the 25,000 core mining companies, the surrounding service and support companies, host communities and land-holders, research and teaching organizations, civil society organizations, and government. Each of these elements contributes to the mining culture and it follows that each of these has a role to play if improved social and environmental performance is to be achieved across the global mining community.
4. Cursory observations suggest that the dominant features of corporate mining's culture may be a desire for financial gain and a "control" management style while generating product and services needed by society. However, the global mining community's culture overall is also likely a source of significant inertia that resists change and compels companies to stay close to the norm.
5. Self-identified "leadership" companies play a key part but may not be the dominating force in defining the culture of the global mining community. Each part plays a significant role—large and small core mining companies, the surrounding maze of organizations, and government. Most importantly, it is this culture—and the related barriers and effective incentives for change—that needs to be understood and addressed as the foundation of any successful attempt to bring improved social and environmental improvement across the whole global mining industry.
6. Government's role is critical and greatly variable across the community of nations.
7. Fresh thinking and perspectives are needed from across the global mining community if mining and societal values are to be more synchronized and the trust deficit reduced.

The above reflections are preliminary. They and the needed strategies and action plans need careful vetting and development through dialog among all key interests from across the global mining community. We are calling for such a dialog. Without it, the mining's trust deficit will remain.

Questions of leadership, funding, process design, and participants require careful consideration and careful attention. To that end, early conversations have been initiated among individuals around the world to test the validity of the ideas presented in this paper and collaboratively build the needed approach.

Motivation for doing so comes from a sense that current conditions can serve as an opportunity for mining to demonstrate a powerful degree of leadership in facilitating the transition to a low-carbon economy and a future development pathway characterized by (1) fairness in the distribution of costs and risks, benefits, responsibilities, and accountabilities across the full project life cycle through post-closure; (2) social justice; and (3) care for the environment.

Appendix 1

Approach 1 Methodology

Step 1. Analysis of trading platforms

1.1 Accessed the International Organization for Standardization Standard 10,383 to compile a list of all the trading platforms worldwide (ISO 2016). For each trading platform, the following was compiled:

a. Location of business (country and city)
b. Trading platform name and business aliases (if applicable)
c. Market identifier code (MIC)
d. Company website
e. Whether the trading platform was active in 2016 (at year-end)

1.2 The information above was used to generated statistics relating to the amount of Trading Platforms in each geographical region. This number indicates the market structure and is useful for better understanding the public–private company relationship.

Step 2. Developed the master list of mining companies

2.1 Accessed the Mergent Online database and using mining codes of the standard industrial classification (North American) created a comprehensive list of mining companies, compiling:

a. Company name
b. Public or private classification
c. Country of business
d. Whether the company was active in 2016 (year-end)
e. Primary listed exchange
f. Ticker symbol

Step 3. Categorized "mining" companies using categories identified earlier by MacDonald (2002)

3.1 Accessed the World Federation of Exchanges (WFE) website to compile a list of trading platforms with strong disclosure requirements, wide-breadth of data availability, and timely disseminated information (World Federation of Exchanges 2017). To accomplish this:

3.2 From the WFE website obtained a list of the corporations which are registered WFE members.

3.3 From the individual corporation websites compiled a list of the equity trading platforms operated by each WFE members and the LME. Note some members such as the International Continental Exchange (ICE) have multiple trading platforms such as the New York Stock Exchange (NYSE) and the NYSE American. Also, the London Metal Exchange (LME) is a former member but is included within this list for the analysis.

3.4 For each of the above WFE member equity trading platforms, access their website to obtain a list of the mining companies trading on WEF member platforms. This list was then used to develop the approximate proportion of companies in each of the categories. We did this by:

a. For each of the above trading platforms, access their corporation website to obtain a list of the companies trading on the platform in 2016.
b. From the list of companies, determine which companies had mining activities based off corporate information from Annual Reports, and the Mergent Online database.
c. Combining the list of mining companies of each exchange together into a single list to ensure no double counting. In the model, dual or multiple listings are recognized by the presence of more than one ticker under the appropriate exchange column.

3.5 Accessed the Mergent Online Database (FTSE Russell 2016) and various annual reports to draw corporate information relevant to WFE-listed mining companies including:

a. Total assets
b. Ticker symbol
c. Listed exchange
d. Website link
e. Annual report
f. SIC code

3.6 Used the "Total Assets" of WFE members to classify mining companies into size categories.

a. All currencies were converted to USD using 2016 conversion rates from the World Bank.
b. These size bins are Global Giants, Seniors, Intermediates, Production Juniors, Exploration Juniors, and Investment Juniors.

c. The size threshold values for the bins are based off MacDonald's 2002 report, adjusted for inflation by using 2016 values obtained from the World Bank.

3.7 Accessed other websites to reconcile information which had a level of uncertainty or if the Mergent Online company profile had missing information.

a. Asian companies were the most likely to have information missing. Missing information was most commonly determined through Annual Reports. These Annual Reports had to be translated into English using Google Translate

Step 4. Compiled supplementary information

4.1 Using the US Central Intelligence Agency's World Factbook (Central Intelligence Agency 2016), we listed the various countries, territories, and islands making up the globe, and for each geographical region obtained the types of natural resources, industries, exports, GDP, and GDP per industry,

4.2 The information from the World Factbook was reconciled against the ICMM data tool (ICMM 2016) and values from the World Bank. Additional information was obtained from the ICMM data including country export contribution, and production value expressed as a percentage of GDP.

Step 5. Developed the summary

2.1 The language and database structures were standardized between each of the steps above.

2.2 For each geographical region (in this case groupings of countries) determined the amount of:

a. Trading Platforms (an indicator of whether the region has western style markets)
b. WFE Mining Companies (for determining be used to determine size classifications)
c. Public Mining Companies
d. Private Mining Companies
e. Total Mining Companies
f. Countries containing mineral resources
g. Countries exporting mining products
h. Countries with a significant mining presence

B. Created a summary statistics page using the geographical and total asset identifiers within the database. Further analysis on this data by experts is possible and encouraged.

Appendix 2

Approach 2 Methodology

Raw Materials Data (RMD) has been compiled over a 30-year period ending in 2015. It is based on company-level information drawn from annual company reports, country studies, government statistics, commodity reports, reports from industry associations, and any other available and reliable company and operation data. For copper, iron ore, and zinc as examples, around 95% of total global production as registered by national statistics was identified on a company-by-company basis. This compares to gold for which there is much more small scale production and the figure was 89%. Syntheses are compared to national/global statistics and when a variance is discovered (could be lower or higher), further analyses are undertaken through direct contact interviews and more public data as it becomes available. The data set misses most industrial minerals mines and does not fully capture many smaller mining companies, particularly coal, nor does it cover limestone, dimensional stone, and sand/gravel quarries.

Number of companies, various types in RMD	Number in database
Mining companies	6293
Energy companies, with coal mines	724
Steel companies with coal and/or iron ore mines	201
Holding companies, all of which are owners of mining companies	1483
"Major" mining companies, arbitrary definition	167
Family-owned mining companies (excluding ASM operations)	632
Total	9500

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