Review
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Challenges and Implications for the Mining Industry for Future Resources Extraction

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Epochs of human civilization are marked by the sources of materials used at the periods, namely: Stone Age, Bronze Age, Iron Age and Silicon Age. The materials used at these eras were mined and can be linked to the development of mining for the benefit of society. The same epochs are indications of advances in Materials Science and Engineering. We are now in the Smart or Intelligent Materials age. One of the key drivers of the Smart Materials era is sustainable development. To achieve sustainable development, the G8 countries agreed on the 3R Initiative at the Sea Island Summit in June 2004 that was launched at the Ministerial Conference in Tokyo in 2005. The 3Rs concept for sustainable development refers to Reduce, Reuse and Recycle and it is now extended to 4Rs to include "Recover". There is potential to further extend the 4Rs concept to 5Rs to include Reprocess. Achieving the objectives of 5Rs within the Sustainable Development Goals of the United Nations involves a critical look at how renewable energy and Smart or Intelligent materials are developed. A critical source of Smart materials and renewable energy resources is mining. Unfortunately, mining is now considered intolerable and antagonistic to sustainable development in the context of environmental friendliness and its contribution to fossil fuel use consequences. Intelligent mining ensures sustainable resource recovery and processing and will make critical materials availability for Smart materials and renewable energy development. Regrettably, mining currently faces aggressive challenges with a bleak future in accomplishing these objectives.

Keywords : Civilization, Mining and Smart materials, Renewable energy

1 INTRODUCTION

The stages of human civilization are marked by the sources of materials used in those periods, namely: Stone Age, Bronze Age, Iron Age and Silicon Age or Age of Information. The next Era of human civilization is the Smart or Intelligent Materials Age.

At the forefront of today's challenges to society is climate change. The impact of climate change is evidenced in several forms including: shrinking glaciers, ice breakups on rivers and lakes, shifting plant and animal ranges, early flowering of plants and the rise in the Earths average temperature. It is argued that if we do nothing to reverse the current trend of rising temperatures because of climate change, more catastrophic flooding, bush fires, extreme weather and destruction of species will occur beyond current levels [1].

Among the mitigation measures to save the planet at the Conference of the Parties (COP) meeting number 26 (COP26) held in Glasgow, Scotland from 31st October to 13th November 2021, one of the most aggressive actions often argued to be taken is to eliminate the use of fossil fuels, namely: energy from coal and oil and gas. Indeed, they argued coal mining is to stop. Germany took to lead to shut down its last coal mine in 2018 [2]. The notion that countries should move away from fossil fuels was strongly contested by developing countries at the COP26 resulting in the reframing of the clause on coal.

At the time of writing this review, climate and energy experts are suggesting hydrogen as the best energy source for its abundance. Unfortunately for these experts, currently, the most abundant hydrogen is "gray" hydrogen (hydrogen obtained from fossil fuels). Less than 1% of the world's hydrogen is "green" (i.e., is obtained from water). The argument for and against fossil fuels remain fluid, with the 27 countries of the European Union divided on the future role of fossil fuels in the climate saving fight.

The fight over the use of fossil fuels which is linked to coal mining and its replacement with renewable energy such as wind, solar, geothermal and hydrogen, and the general view that mining products could be replaced with Smart Materials portrays the spurious view that mining is unimportant today and destroys the environment. These negative views have adversely impacted university enrollments in mining engineering and petroleum engineering programs with dire consequences on the future development of humanity as will be explained in later sections of this paper.

The Society of Mining Engineers (SME) eloquently describes the vital role of mining for the existence and civilization of humanity [3]. As often said, "If it cannot be grown, it must be mined" [4]. A similar view is expressed by Clausen et al. [5] when they stated: "Mining is not everything, but everything is nothing without mining". Figure 1 shows how much mining has contributed to the development of humanity and continues to do: from home comfort to medicine, food, water, power, transportation, military, and to space exploration. This picture evidently confirms the positions

Figure 1 Contributions of mining to the development of humanity−civilization (photo taken at the El Teniente Mining Museum, 2013.

that if it cannot be grown it must be mined, and that mining is not everything, but everything is mining. To argue otherwise, as will be demonstrated in this review, implies how much education the public needs to understand that without mining there will not be civilization and we will not be enjoying the comfort we have today, cellphones, computers, airplanes, and the comfortable homes.

The theme of the Nineth International Conference on Materials Engineering for Resources (ICMR) is "Smart Materials for Resources". This theme suggests that we need Smart Materials for Resources Extraction, and leads to the popular connotation "Which is older, the chicken or the egg?" Similarly, do we need resources for Smart Materials OR Smart materials for resources extraction? This author believes in the former. This is explained further in the paper and forms the thrust of this review as many unknowingly believe that smart materials can replace mining products.

Material Science and Engineering is the study of the properties of solid materials and how those properties are determined by a material's composition and structure [6]. According to Rogers [7] Smart or Intelligent Materials are defined as materials that change their behavior in a systematic manner in response to specific stimuli such as alteration in a magnetic or electrical field or environmental factors.

The consequences of no mining are dire. Without mining some critical elements/metals required for Smart Materials and some critical technologies will not be available (Table 1).

Table 1 Examples of critical elements that are not available without mining

Critical element	Produced in?	Reasons for criticality	Example uses
Rare earth elements	China (90%)	• Single producing nation • No substitute • Difficult processing	• Magnets in electronics • Laser technology
Rhenium	Chile, USA	Only produced as a byproduct of molybdenum mining	Turbofan engines
Lithium	Australia, Chile	Australia, Chile	Battery technology for electronics

The most widely used sources of Smart Materials include thermoplastics. Typical thermoplastics used in the creation of Smart Materials are polylactic Acid (PLA) and acrylonitrile butadiene styrene (ABS). Some sources of Smart Materials are natural minerals. Examples of these natural minerals are listed by Sprynskyy [8] as opal, quartz, perovskite, garnets, boracite and rippite, chrysotile, imogolite, allophone, menezesite, stepanovite and montmorillonite. Smart materials can also be made from alloys of metals that are mining products. Such smart alloys include for example nickel-titanium, copper-zinc- aluminum, and copper-aluminum-nickel. Thus, it is evident that in the production of Smart or Intelligent material mining becomes a critical means of this technological era.

Wood Mackenzie [9] observed that globally the world would need more than 5.5 million tonnes of copper to build wind turbines alone over the next 10 years. As if this is not astonishing enough, when we consider the shift from fossil fuel cars to building electrical cars and all the metals involved (nickel, cobalt, lithium, rare-earths, and silver among them) coupled with the requirements for resources for solar panels, smart phones, computers and batteries, the amount of mining needed is astronomical. Indeed, the following statement by Clausen et al. [5] is indicative of the critical role of mining in achieving the COP26 goals:

> "…. topics of energy transition or electromobility, which are often discussed today, would be just as unfeasible, and unconceivable without raw materials as modern information and communication technology as a basis for industry 4.0."

The objective of this paper is to bring to fore the various misconceptions in society about mining in the context of the challenges of climate change, one of which is reflected in this conference themes "Smart materials for resources extraction". Other misconceptions about mining are the general misconceptions that smart materials can replace mining products and renewable energy, namely: wind, solar, geothermal and hydrogen can replace fossil fuel from coal and oil and gas. More strongly, it is societies believe that mining is destroying the environment and therefore should be stopped. These believes have posed significant challenges to mining engineering and implicitly the future development of humanity. This paper outlines the challenges facing the mining industry and the profession which have been the vital source of human civilization as a major resource of materials needed to meet the next era of civilization of mankind, the Smart Materials era, and the renewable energy drive to save the environment.

2 CHALLENGES TO THE MINING INDUSTRY AND THE MINING PROFESSION

The global community is facing the consequences of climate change and there is a strong agenda albeit willingly or unwillingly to reverse the trend. This effort includes active pro-environmentalism. Environmentalists see mining as man-made activity that is destroying the environment with total disregard for its role in the civilization of mankind and its continuing position in our future development.

The key challenges currently facing the mining industry and professions include:

- Low enrollments in mining engineering programs
- Opposition to start of new mines and strong agitations for the closure of existing mines
- Limitation and elimination of fossil fuels sources (coal, and oil and gas)

- Paradigm shift from surface mining to underground mining and mining at ultra-depths
    - Including extraction of remnant ores and coal

2.1 Low enrolments in mining engineering programs

Suorineni [10] observed that global trends in enrolments in mining engineering programs have shown a sharp decline. The global enrolment trends are reflected in the admissions and graduation historical records of UNSW Sydney then School of Mining Engineering (Figure 2). This trend is like that facing mining engineering programs in the United States of America.

In 2017, approximately only three students chose mining engineering as their first choice for admission into the School of Mining Engineering in UNSW Sydney. This persistent trend forced the university to merge two independent schools, namely: The School of Mining Engineering and the School of Petroleum Engineering, into one School now known as School of Minerals and Energy Resources Engineering. This trend became the fate of mining programs in Australia, merging with other schools or disappearing.

The problem of survival of mining engineering schools has become so critical that it was one of the panel discussion subjects in December 2021at the Future Mining Conference. Professor Canbulat revealed that in 2020 there were 110 Australian mining engineering graduates compared with more than 600 mining engineering related positions advertised. Professor Kecojevic of West Virginia University noted that mining enrolments in the US dropped from 1500 in 2015 to 750 in 2020. It is this shortage of mining engineering professionals that is threatening the survival of the mining industry and profession. Experience shows that awarding of scholarships does little to entice students into mining. To reverse the downward trend in mining education, mining programs in universities are taking the following measures:

- Changing their curriculums
- Merging mining programs with other departments/schools, and
- Working with industry to offer scholarships
- Change mining engineering program names
- Formation of mining regional mining engineering federation programs such as Federation of European Mineral Programs (FEMP)

In addition to the efforts by universities and industry listed above it is critical to educate the public on the importance of mining and to take advantage of the Generation Z intricate knowledge and use of current and emerging technologies. Mining has changed drastically over the years from being physical and manual to being data and technology driven.

Generation Z considers mining as labour intensive, dirty and environmentally destructive. Environmentalists have made the situation worst. This view and its consequences are the closure of many mining engineering programs and merger of others that obscure them globally even though the economies of many countries including for example Australia still depend on the mining industry.

The word “mining” now looks as a curse to those in the profession and mining engineering programs in universities no longer want to see this word in their title descriptions, as reflected in the new school’s name at UNSW Sydney. The School of Mining Engineering, now merged with the School of Petroleum Engineering is called the School of Minerals and Energy Resources Engineering. RWTH Aachen University Mining Engineering faculty changed its name to Georesources and Materials Engineering as a camouflage to increase enrolments into mining engineering [12].

The negative views of environmentalists have had the greatest adverse impact in mining education. During the 2018 International Mining and Resources Conference (IMARC) in Melbourne, Australia, the conference center was always blocked by environmentalists and the city had to call in riot control police to manage the situation (Figure 3).

This Author was confronted by two female protestors at the conference who asked for his support by not participating in the conference. I politely asked them if they knew the importance of mining in daily lives by referring to the cellphones, earrings, and other jewelry they were wearing. Their ignorance, agitated them on questioning, showing that they needed to be educated on the importance of mining.

Fundamentally, the current global low enrolments in mining engineering programs in universities is going to cause acute shortage in the needed skills required to meet the huge demand in mining products required to meet the Smart Materials and Renewable Energy drive as replacement for fossil fuels. FEMP was formed as a means of overcoming the acute labour shortage in mining in Europe [13]. These linkages of the role of mining in

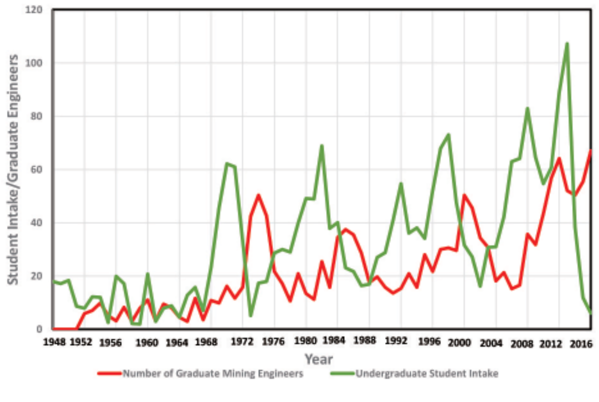


Figure 2 Enrollment trend in the School of Mining Engineering, UNSW Sydney [Modified from [11]].

Figure 3 Rio Police trying to control protestors surrounding the IMARC conference center in Melbourne

improving humanity and in meeting COP26 goals must be made through public education for the society to understand that the objectives of COP26 with the goal to manage climate change can only be achieved through the intelligent sustainable mining rather than eliminating mining.

2.2 Challenges in the development of new mines and mining at ultra-depths

It is now a big challenge to start new mines. Communities are aggressively against the opening of new mines in their backyards. Approval of leases for new mines can take ten years or more. In most cases, the community is against the project under the pretext that it will destroy the environment. If the projects are to proceed, the communities must be guaranteed of the benefits of the project to them under the theme of sustainability. These obstacles, although fair, are often borne out ignorance or misinformation.

2.2.1 Shift from surface to underground mining

There is paradigm shift from surface mining to underground mining and mining at ultra-depths. This is because there is a direct link between surface mining and environmental damage, not allowing for the fact that there is always a plan in place for rehabilitation of the said disturbed lands. Because of this reasoning, Rio Tinto made a strategic paradigm shift to have the bulk of their mining productivity coming from underground rather than from surface mining starting from 2014 (Figure 4).

One of the primary factors for the award of funding for the establishment of a new mining project is that the company must demonstrate that it has an acceptable procedure and funding in place to reclaim the land in the way that the company met it. Such oppositions are also often a result of the communities' ignorance about the benefits of mining. Public mining education is needed to mitigate these oppositions.

The consequences of the negative reactions to the establishment of new mines in mining communities are that the establishment of new mines now take more than ten years to be approved, of course at additional cost to the mining companies as a result of project overruns. In unstable political environments, these consequences could lead to project abandonment.

Major mining companies have shifted a major source of their ore production from open pit mining to underground mining. While other factors such as most surface orebodies being depleted over the years might have influenced this shift, other factors include pressure from environmentalists.

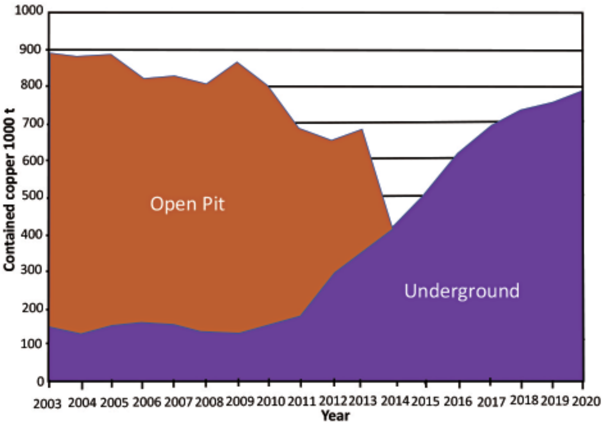


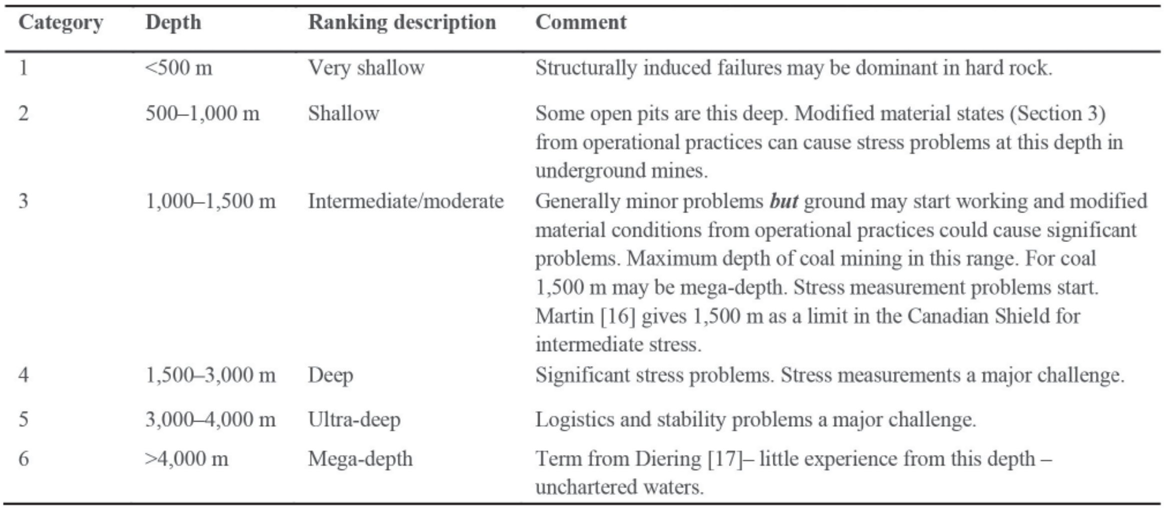
Figure 4 Rio Tinto strategic shift from surface mining to underground mining in the face of environmentalists' negative stance against mining [14]

2.2.2 Mining at ultra-depth

An alternative to opening new mines using underground mining systems instead of surface mining is to go deeper in existing underground mines. What is deep or ultra-deep are terms often vaguely used. Mining depth classifications depend on whether you are dealing with metalliferous mining or coal mining (soft rock mining). In coal mining a depth of 500 m is deep, and 1000 m would be considered ultra-deep. Depths of 500 m to 1000 m are shallow in metalliferous underground mines. Suorineni [15] suggested the following classifications of depth in metalliferous underground mines (Table 1). The strategic decision by most mining companies to go deeper is now often made to minimize the impact of environmentalist's resistance to mining-minimize the mining footprint.

It is also an attempt to proof that mining companies care about the environment in contradiction to the environmentalist's argument. A good example of mining companies going deeper instead of looking for new mines is the Mponeng Gold Mine of AngloGold Ashanti in South Africa, that is currently estimated to go beyond 4 km below surface.

Table 2 Depth classifications in metalliferous underground mining [15]



Category	Depth	Ranking description	Comment
1	<500 m	Very shallow	Structurally induced failures may be dominant in hard rock.
2	500–1,000 m	Shallow	Some open pits are this deep. Modified material states (Section 3) from operational practices can cause stress problems at this depth in underground mines.
3	1,000–1,500 m	Intermediate/moderate	Generally minor problems ***but*** ground may start working and modified material conditions from operational practices could cause significant problems. Maximum depth of coal mining in this range. For coal 1,500 m may be mega-depth. Stress measurement problems start. Martin [16] gives 1,500 m as a limit in the Canadian Shield for intermediate stress.
4	1,500–3,000 m	Deep	Significant stress problems. Stress measurements a major challenge.
5	3,000–4,000 m	Ultra-deep	Logistics and stability problems a major challenge.
6	>4,000 m	Mega-depth	Term from Diering [17]– little experience from this depth – unchartered waters.

The main challenges to going deeper include

- Availability of the appropriate technology against high temperatures and
- Stress at these depths.
- Seismicity and rockbursts.

Replacement of humans with robots is a plausible solution to mining at depth at high temperatures. Rio Tinto block caving mines in Oyu Tolgoi Mine in Mongolia and Arizona Resolution Copper in Arizona are at temperatures of about 80° C at approximately 2 km below surface. Replacement of humans with robots will eliminate the high cost of ventilation and risk of hazards from heat stroke and seismicity due to human exposure. Wagner [18] presents a summary of deep mining challenges.

High stresses and seismicity and rockbursts are the other sources of challenge facing mining at depth. At issue again is what constitutes high stress? High stress cannot be defined by just stress but is a function of the rock strength. The ratio of rock intact strength to the major in situ principal stress defines stress levels as noted by Swan et al. [19]. Figure 5 shows various mines at different depths related to their intact rock uniaxial compressive strengths. The figure shows that mines at shallow depth could be in high stress while mines at depths greater than 3 km could be at low stress, merely due to the uniaxial compressive strengths (σ_c) of their intact rocks.

Rockbursts remain a challenge in mining at depth. Salamon [20] stated:

> “A disconcerting feature of rockbursts is that they defy conventional explanation.”

This statement is still as true today as it was then. Trifu and Suorineni [21] noted as follows:

> “Current technology cannot predict when rockburst will occur, and the best we can achieve today is to identify areas of high rockburst potential using numerical models and/or experience.”

The key to mitigating rockburst hazards is motoring and using quality rockburst resistant ground support systems. The remaining challenge is how to predict the time of occurrence of a rockbursts, as a search for precursors to rockburst occurrence remain elusive. Pu et al. [22] conducted an extensive review of rockburst prediction approaches. It is clear from the review that there is confusion between predicting where rockburst could potentially occur and when that rockburst could occur. Predicting the location of a rockburst is not a challenge today, rather the challenge is in the timing. While some authors are claiming they can predict the time of occurrence of rockbursts, a lot remains to be done to justify such claims. A misconception in these claims is that these authors merely look at numbers without the important consideration leading to the events. It is this author’s view that the word “prediction” in the context of rockbursts is misused.

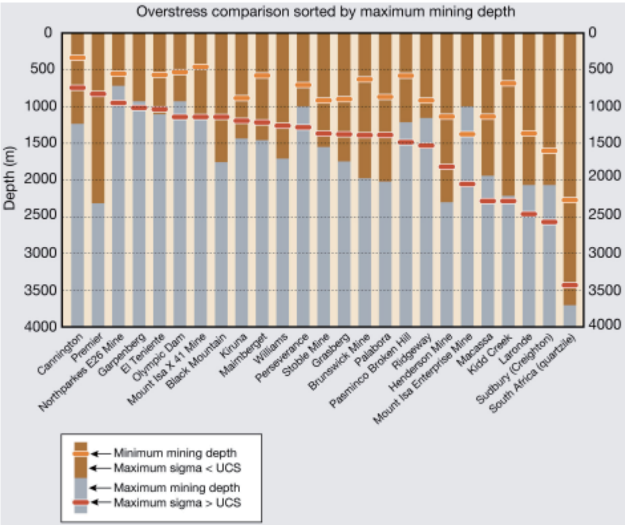


Figure 5 Significance of defining stress levels as function of intact rock uniaxial compressive strength [19]

At the present time with our current knowledge, monitoring remains key to rockburst mitigation. Seismic monitoring systems are well advanced for this purpose and can be used to identify potential locations of rockbursts. However, there remain a challenge in reliably predicting seismic source locations.

Accurate prediction of seismic source locations with seismic monitoring systems depends on the input seismic wave velocities. Input seismic wave velocities in algorithms in seismic monitoring systems are either constant or at best updated periodically to account for rockmass degradation and changes in the mine geometry. This approach can cause unintended errors in seismic source locations, recognizing that rockmass conditions and the mine geometry are constantly changing in mining environments. This implies that the input seismic wave velocity is constantly changing. To solve this problem, we need to be able to predict seismic wave velocity in real time in mining conditions to use as input in the algorithms used in seismic monitoring systems to predict seismic source locations. This is the current research focus of the primary author.

2.3 Elimination of fossil fuel resources and promotion of renewable energy

Fossil fuels are under attach. In 2018 Germany shut down its last coal mine, the Prosper-Haniel coal mine. Thermal and coking coals are used for heating and making of steel. Steel is a major source material for human comfort–housing, roads, transportation, etc. and cannot yet be produced commercially without coal even though laboratory scale prototypes are developed.

To eliminate coal, from the energy supply chain renewal energy including wind, solar and geothermal energy are energetically promoted. Unfortunately, what the promoters of the shift from fossil fuels to renewable energy overlook is that we need various materials to build the structure required to get the renewable energy, be it wind, solar or geothermal.

Mone et al. [23] provides state-of-the-art understanding of wind energy cost trends and drivers. Figure 6 provides insight of the materials required for the construction of wind turbines (Figure 7) and their impact on the power capacities of these structures.

As clearly shown in Figure 6, aluminum, glass, copper steel and iron are critical and major components of wind turbines. These materials are mining products. Additionally, the foundations of these wind turbines will also be made of concrete (cement and aggregates). Without mining, no wind turbines, and no wind energy.

Another source of renewable energy is solar energy. Solar panels or modules are made from silicon of various forms, crystalline or

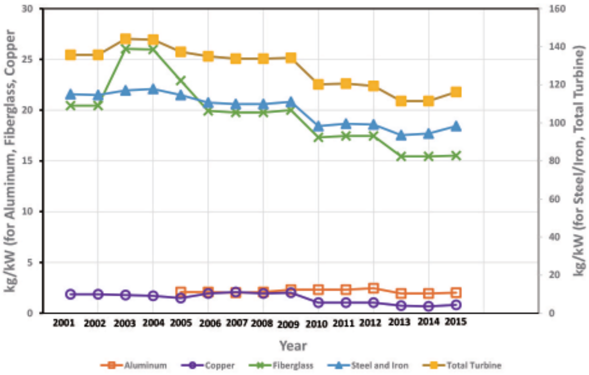


Figure 6 Mass intensity of mapped life cycle analysis (LCA) of 40 wind turbines showing raw materials used (Reproduced from [23])

Figure 7 Wind turbines in a wind energy farm [24]

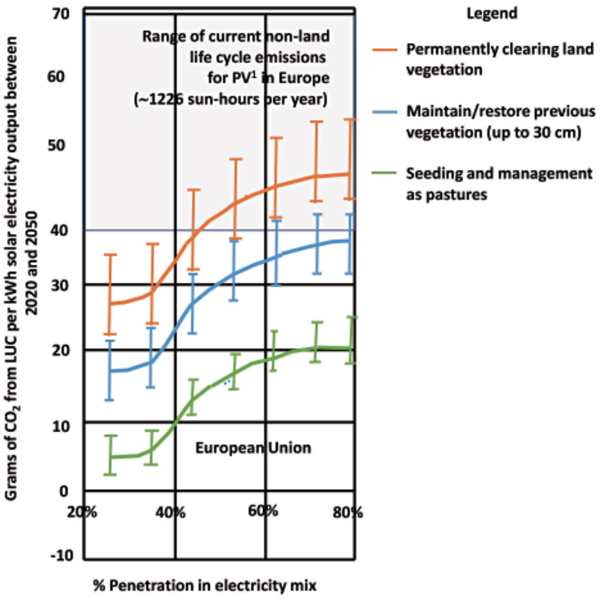


Figure 8 Land use change emissions related to land occupation per kWh of solar energy from 2020 to 2050, for the three solar land management regimes for Europe (i. permanently clearing land vegetation ii. Maintain, restore of previous vegetation (up to 30 cm) and iii. Seeding and management as pastures) modified after (Reproduced from [25])

amorphous. Silicon belongs to the 14th group of chemical elements on the Periodic table. It has powered the Information or Digital Age which is thus commonly referred to as the Silicon age. The oxide of silicon is silicon dioxide (SiO_2) commonly referred to as silica and ordinarily known as quartz. Quartz is a major component of most rocks and is resistant to weathering.

Without going into the details, solar panels consist of three key components, namely: silicon solar cells, metal frames from aluminum and glass. Once, again all these materials are mining products and without mining, there will be no solar energy.

Arguably, based on the Vattenfall's life cycle studies of electricity in 1999 solar energy tends to produce 50 g of CO_2 per kWh compared to the 975 g of CO_2 per kWh produced from coal, showing that solar panels are therefore at least 20x better kWh for kWh in terms of CO_2 footprint. What is ignored in the argument for solar energy is the size of the land footprint required for commercially viable supply of the solar energy panel. Admittedly, this is a rather complex subjected as revealed in van de Ven et al. [25]. However, Figure 8 is indicative of the implications of commercial solar panels on land use.

Based on Figure 8, van de Ven et al. [25] conclude that due to the lower irradiance and higher latitude of Europe, absolute land use of per unit of solar output will be higher compared to Japan and South Korea. This difference is expected to increase with higher solar energy penetration rate.

According to Smil [26] in a future powered by renewable energy, society might have to devote 100 or even 1000 times more land area to energy production than today. Figure 9 shows the land footprint of the various energy sources. Examination of Figure 9 shows that solar energy land footprint is about the same size of under and surface mining coal land footprints combined. Van de Ven [25] notes that the resulting land cover changes, including indirect effects, will likely cause a net release of carbon ranging from 0 to 50 g CO_2/kWh, depending on the region, scale of expansion, solar technology efficiency and land management practices in solar parks. This is in addition to the land lost to solar panels. The consequences of solar land use impact are its enormous negative impacts on agriculture, biodiversity, and environmental quality.

Like mining engineering, Cann [27] states that the arguments in favour of renewal energy and against fossil fuel use has resulted

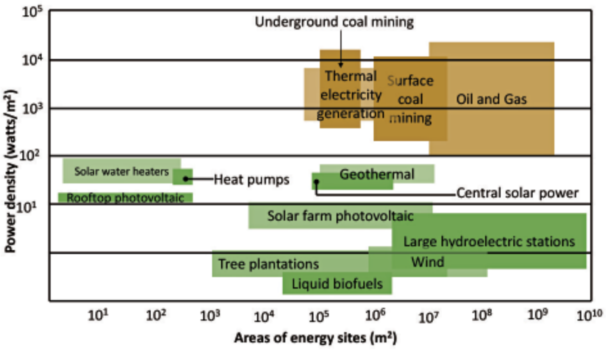


Figure 9 Power density versus land footprint size for various energy sources (Reproduced from [26])

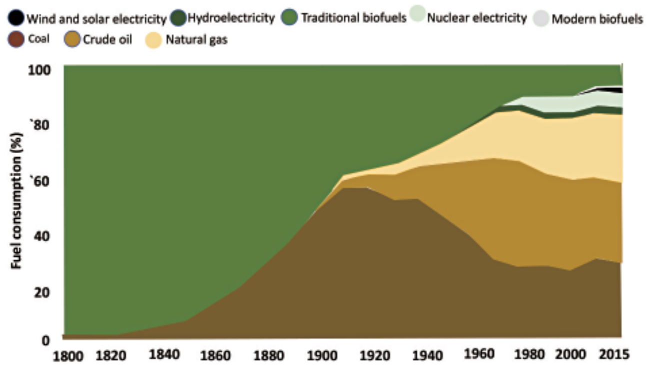


Figure 10 Periods of energy transitions (from [26])

in the collapse of Petroleum Engineering programs in universities. This is also bad news for the oil and gas industry, as they are going to face skill labour shortages in the industry while still meeting the global energy needs prior to the world having sufficient energy capacity to replace fossil fuel.

Historically, energy transitions are slow, painstaking, and hard to predict. As shown in Figure 10 the transition from wood ("traditional biofuels") to fossil fuels−first coal, then oil and natural gas took more than a century. Wind and solar energy emerged in the 1990 and will take a significant time to replace fossil fuels.

This makes the shortage of skill labour in the oil and gas industry in making energy available prior to full transition to renewable energy too early and counterproductive to the energy transition argument.

This discussion is incomplete without mentioning geothermal energy as a renewable energy source. The question to ask again is: Is geothermal energy feasible without mining? The US Energy Information Administration (US IEA) states that Geothermal power plants require high-temperature (149°C to 371°C) hydrothermal resources that come from either dry steam wells or from hot water wells and these resources are obtained by drilling wells into the earth and then piping steam or hot water to the surface. The hot water or steam powers a turbine that generates electricity. Some geothermal wells are as much as 3.2 km deep. The materials used in making the drilling equipment, pipes, and turbines come from mining products.

Strangely, the proponents and promoters of renewable energy ostensibly forget that they need mining products to get access to the geothermal energy and tap it for use, manufacture the solar panels and materials to store and distribute it, and need wind turbines and ancillary materials to produce, store and distribute it. All required materials come from mining.

3 SUMMARIES

The negative sentiments from the public are a threat to the mining industry and the profession and have a profound impact on the development of skills needed to meet the future production of materials required for the development of the Smart materials and renewable energy resources the world needs to combat climate change. This observation could not be more clearly expressed in the statement by Lind [28]:

“The talent pool for mining engineers is drying up in part because of the negative sentiment (destroying the environment) towards the industry, particularly in metropolitan areas, which is affecting students' ability to see a long-term future for themselves in mining.”

Historically, mining is the core for human civilization. Mining provides the raw materials for transportation, medicine, access to clean water, housing, space exploration, communication, and food. Developments of renewable energy and Smart Materials are not feasible without mining. To think that renewable energy and Smart materials will replace the need for mining is a tragic mistake.

What is critical is achieving a balance between maintaining the environment and mining. Sustainable mining is required to ensure a symbiotic relationship between mining and the environment. The public needs to be educated about the benefits of mining to society to reverse the current negative attitudes towards the industry and profession.

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