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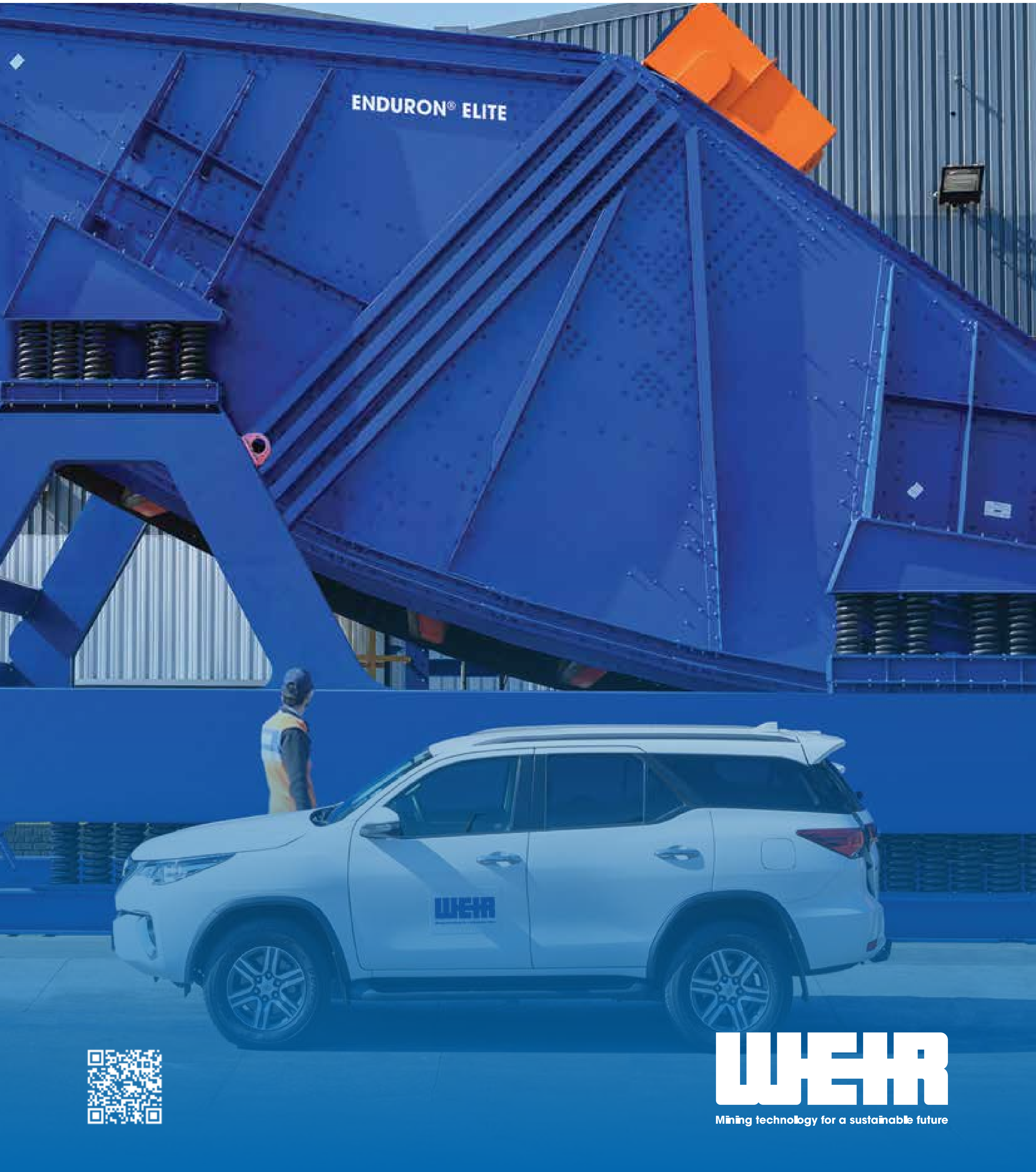
MINING & QUARRY WORLD



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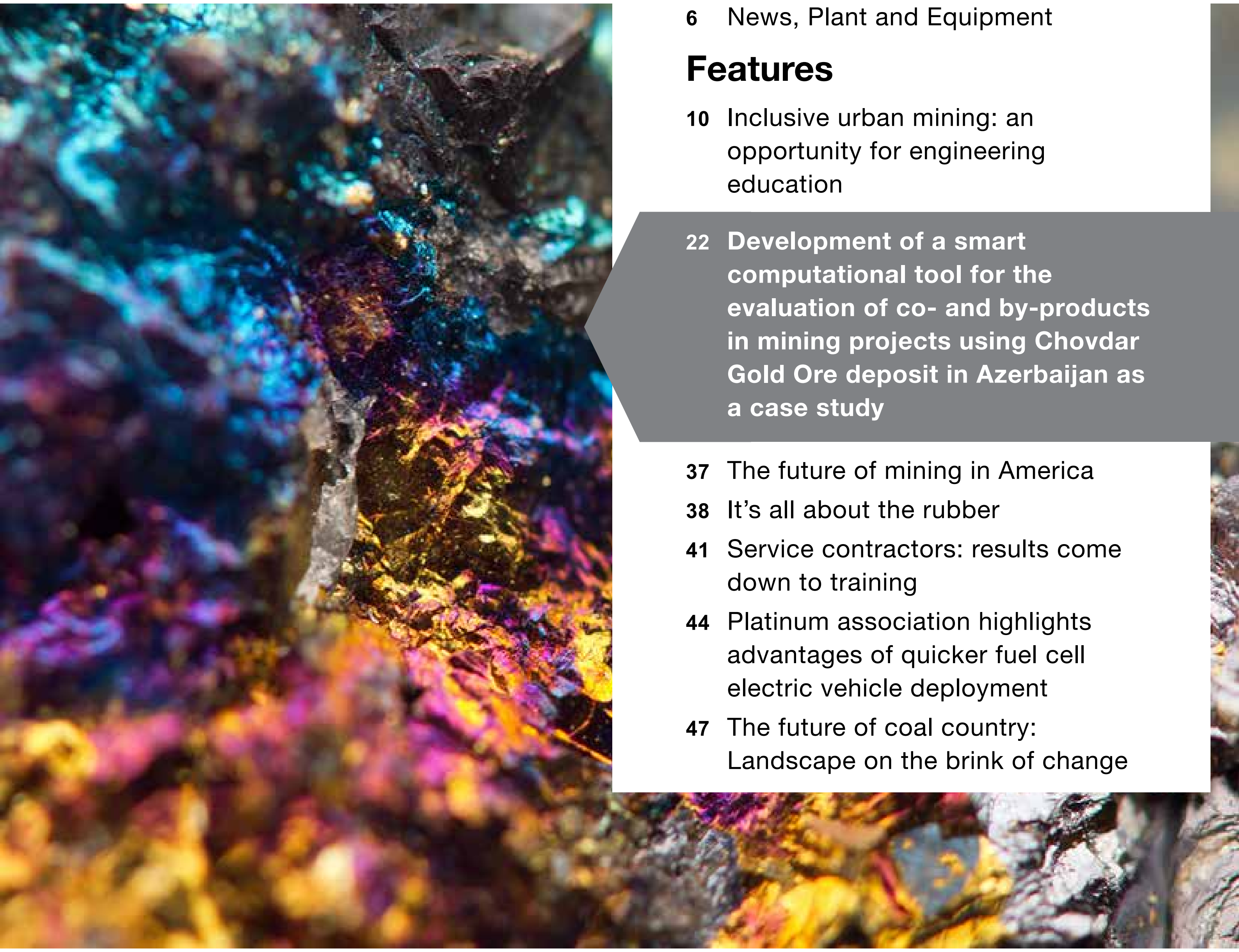

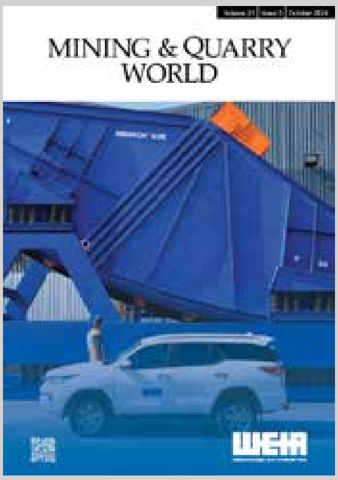

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Sandvik debuts innovative underground mining drill

Sandvik Mining and Rock Solutions has introduced its first intelligent i-series narrow vein drill, describing the machine as "the mining industry's most advanced narrow vein underground drill".

Sandvik DD212i is a compact single-boom jumbo equipped with a new carrier and updated design, ideal for mining development in narrow vein operations.

Optimal in narrow vein and medium-sized drifts, Sandvik DD212i ensures more tonnes per blast, maximum profitability and operational efficiency thanks to its precise electronic positioning and instrumentation for hole measurements.

Built with an intelligent control system – the Sandvik intelligent control system architecture – and various scalable automated functions, Sandvik DD212i offers higher drilling accuracy and pull out for higher drilling productivity.

"Sandvik DD212i was developed for mines looking for compact equipment with better connectivity and data collection capabilities," Sandvik Mining and Rock Solutions low profile and narrow vein product manager for underground drilling Jean-Christophe Goiffon said.

Sandvik DD212i has a hole length of 2.83m to 4.05m and a hole diameter of 43mm to 64mm.

"Despite its small size, Sandvik DD212i offers increased productivity and drilling accuracy in challenging operations with deeper and narrower orebodies," Goiffon said.

Other benefits and features of the Sandvik DD212i include having a SB20i instrumented boom with dual roll overs and one metre boom extension and compact telescopic drilling modules, a comprehensive drill plan design, various data reporting and analysing tools, Sandvik RDX5 rock drills, a safer ROPS (roll over protection system) and FOPS (falling object protective structure) cabin and canopy, and more versatility in its drilling applications data maximisation.

Sandvik said these combined features enable increased penetration rate and better advance and better pull-out results compared to predecessors in Sandvik's narrow vein offering.

"Many regions are experiencing reduced availability of skilled labour, and our customers are interested in easy and fast training solutions with automated functions that enable higher performance for new and low-skilled operators," Goiffon said.

Sandvik is implementing a new module in its digital driller training simulator for Sandvik DD212i so the machine can be smoothly integrated into operations.

The company is expected to introduce more optional extras for Sandvik DD212i in the next few months.

BHP awards $109 million Jimblebar contract

NRW Holdings has announced that its subsidiary, NRW Civil & Mining, has been awarded a development contract by BHP at the Jimblebar iron ore mine in Western Australia.

The contract, which is valued at around $109 million, includes various civil, building, mechanical, and electrical works aimed at supporting sustainable production at the mine.

The project scope includes bulk earthworks, the construction of permanent facilities, and the development of a new floodway.

Additionally, the contract involves the construction of a light vehicle access road, along with heavy and light vehicle standpipes and a washdown facility.

Further works include the realignment of a high-density polyethylene (HDPE) pipeline and the installation of a 33kV overhead powerline.

The project is expected to commence in November 2024, with completion scheduled for the second quarter of 2026.

It will employ a workforce of up to 120 personnel and require the use of 55 pieces of plant and equipment.

This contract marks a continuation of NRW's long-standing relationship with BHP, further expanding the company's involvement in the Pilbara region's mining infrastructure projects.

Jimblebar is one of BHP's key iron ore operations in Western Australia, contributing significantly to the company's iron ore output.

It has been in operation for just over 10 years and is located 40km east of Newman in the Pilbara region of WA. Jimblebar is an open-cut pit iron ore mine home to BHP's first fully autonomous truck operation.

BHP has been using data and technology such as automation and artificial intelligence to further unlock growth opportunities and enhance their operating performance at Jimblebar.

The company is using autonomous trucks at some of their sites across Western Australia and Queensland and is extending this to Spence and Escondida.

At Jimblebar and Newman, truck automation has resulted in a 90% reduction in heavy vehicle safety risks the company says.

Black Cat accelerates mining at Paulsens

Black Cat Syndicate is set to accelerate and extend mining at its Paulsens gold mine in Western Australia.

Underground operations at the site are continuing to progress and jumbo ground support is ongoing, with additional locations available for development and sampling.

"Based on the success of the high-grade stockpile strategy, available capacity in the processing facility and the rising gold price, planning has commenced to accelerate and extend gold production," Black Cat managing director Gareth Solly said.

"These plans include extending the high-grade selective mining strategy for the life of the mine plan and advancing the Belvedere underground to mine readiness. On the debt front, due diligence has been satisfactorily completed and the legal documentation is being finalised."

Planning has started to advance mining at the Belvedere deposit, located 6km from the processing facility.

Based on the success of the high-grade stockpile strategy, scheduled throughput of the processing facility and the rising gold price, planning has commenced to accelerate and extend gold production.

Development drives are continuing further than expected and more stopes are being exposed exposed, leading additional miners to commence in October, immediately accelerating the high-grade stockpile build ahead of commissioning in December 2024.

Project to study use of SMRs for bio-coal production

Swedish lead-cooled small modular reactor technology developer Blykalla said it is participating in a new project focused on integrating SMRs with thermochemical processes to produce renewable materials, like bio-coal and bio-oil, which can then be used to reduce carbon emissions and enhance energy efficiency in Sweden's steel and chemical industries.

The project is a collaborative effort between academia – RISE Research Institutes of Sweden (which is leading the project) and the KTH Royal Institute of Technology – and relevant industry actors steel producer SSAB, Blykalla and bio-coal producer Envigas. Funded by the Swedish Energy Agency, the project has received a substantial investment of over SEK10 million (USD967,000 million) and is set to start in December.

Blykalla said the project focuses on leveraging the heat generated by SMRs to power thermochemical processes such as pyrolysis and hydrothermal carbonisation. The objective is to produce renewable materials that can replace fossil-based products in the steel and chemical industries, thus significantly reducing carbon emissions and enhancing energy efficiency. By coupling SMRs with these processes, the project aims to maximise resource efficiency and contribute to Sweden's ambitious target of becoming fossil-free by 2045.

"This effort is expected to support the broader industrial transition to fossil-free processes, particularly in sectors that are traditionally heavy carbon emitters, like steel production," it added. "The results are anticipated to have far-reaching implications, providing a model for other countries and industries looking to reduce their carbon emissions and enhance energy efficiency."

Blykalla – formerly called LeadCold – is a spin-off from KTH in Stockholm, where lead-cooled reactor systems have been under development since 1996. The company – founded in 2013 as a joint stock company – is developing the SEALER (Swedish Advanced Lead Reactor. A demonstration SEALER (SEALER-D) is planned to have a thermal output of 80 MW. As in future commercial reactors from Blykalla, the fuel rods will be cooled by 800 tonnes of liquid lead. The reactor will have a height and diameter of about 5 metres.

Blykalla's goal is for its first 140 MWt SEALER-55 commercial reactor to be ready for operation by 2030.

American Lithium prepares for market recovery

American Lithium is strategically positioning itself for an anticipated recovery in the lithium market, despite facing significant challenges owing to a steep drop in lithium prices.

In a shareholder letter, newly appointed interim CEO Alex Tsakumis stressed the company's commitment to advancing its projects and adapting to the current market landscape, which has seen lithium prices plummet from a peak of $85 000/t to about $10 000/t.

In light of these market conditions, American Lithium has implemented proactive measures including cost-cutting strategies and management changes, ensuring the preservation of its treasury while advancing its large-scale "green metals" deposits toward prefeasibility study.

"These actions are designed to prepare us for when market conditions improve. Our top priority remains ensuring the advancement of all ongoing projects," Tsakumis stated, underlining the company's commitment to maintaining strong relationships with local communities.

Tsakumis took over from Simon Clarke, who resigned on September 1.

Looking ahead, the company is optimistic about the potential for a market rebound, particularly with emerging premium pricing for lithium carbonate supplies.

Further, American Lithium is poised to benefit from geopolitical developments, including Peru's initiative to develop its own nuclear energy capabilities, which could enhance the value of the company's Macusani uranium project.

Besides Macusani, American Lithium owns the Falchani lithium project in Peru and the TLC lithium project, in the Esmeralda district of Nevada.

Tsakumis said the company was continuing to expand its resource base at TLC and Falchani, and that it remained committed to contributing to the domestic critical metals supply chain.

He noted that an operational update was slated for release this month, where American Lithium would provide further insights into its strategic vision and project advancements.

US Energy Dept finalises $2.26bn loan for Lithium Americas' Nevada mine

The US Department of Energy finalised a $2.26-billion loan for Lithium Americas to build Nevada's Thacker Pass lithium mine, one of Washington's largest mining industry investments and part of a broader push to boost critical minerals production.

The loan, provisionally approved in March, is a key part of US President Joe Biden's efforts to reduce dependence on lithium supplies from China, the world's largest processor of the electric vehicle battery metal. Biden officials permitted a similar lithium project under development recently.

The Thacker Pass project is slated to open later this decade and be a key supplier to General Motors, which earlier this month boosted its investment in the mine to nearly $1-billion.

"The Biden-Harris Administration recognises mineral security is essential to winning the global clean energy race," said Ali Zaidi, the White House national climate advisor.

Former President Donald Trump had permitted the mine just before leaving office. Initial construction at the site, just south of Nevada's border with Oregon, started last year after the company won a long-running and complex court case brought by conservationists, ranchers and Indigenous communities.

With the loan now closed, Vancouver-based Lithium Americas plans to start major construction, a process that could take three years or longer. The mine's first phase is expected to produce 40 000 metric tons of battery-quality lithium carbonate per year, enough for up to 800 000 EVs.

The project is expected to employ about 1 800 people during construction, and provide 360 full-time jobs once the mine is operational. The loan will have a 24-year term, with interest rates based on the US Treasury rate as each tranche is drawn.

"This essential loan helps us reduce dependence on foreign suppliers and secure America's energy future," said Lithium Americas CEO Jon Evans.

The mine's cost had been increased from a previous estimate of $2.27-billion to nearly $2.93-billion due to higher engineering costs, an agreement to use union labour, and the company's decision to build a housing facility for workers and their families in the remote region.

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Today, our ground support experts provide simulator-based remote training and certification programs that are increasingly part of the daily business. Our VR solutions enable cost reduction, quality improvement and safety enhancement in mining and tunneling.

Enabeling innovation.

BHP strives to decarbonise India's steel

BHP has taken the first step in its partnership with one of India's largest private steel companies, JSW Steel, and carbon capture solutions provider Carbon Clean.

The parties are collaborating to accelerate deployment of carbon capture technology for steelmaking decarbonisation, following the recent signing of a joint study agreement.

Under this agreement, the parties will commence joint studies to explore the feasibility of Carbon Clean's CycloneCC modular technology to capture up to 100,000 tonnes per year of CO2 emissions – the largest scale CycloneCC deployment to date in steelmaking.

India's steel production is set to double by 2030, and will likely have a critical role in achieving India's target of net-zero by 2070.

With the increasing commissioning of blast furnaces in India with decades of life ahead of them, supporting longer term near-zero decarbonisation routes is essential.

There are several challenges with the adoption of carbon capture technology in the steel industry, including capital expenditure and ongoing operating costs, as well as the integration of new equipment into an existing operations site with space limitations.

The CycloneCC rotating packed bed technology in combination with Carbon Clean's proprietary APBS-CDRMax solvent aims to address these challenges through reducing total installed cost and the unit footprint by up to 50%.

It is anticipated that these joint studies will be completed during 2026, at which time the parties will consider installing CycloneCC at JSW Steel's Vijayanagar site in India's southern state of Karnataka.

"We are actively studying multiple pathways for steel decarbonisation, including through use of hydrogen and renewable power, but we recognise that the blast furnace route will likely remain a pathway for the production of steel, particularly within India," BHP chief commercial officer Rag Udd said.

"Partnerships and collaboration to accelerate the development and deployment of these technologies is essential, and we are pleased to be working with JSW Steel and Carbon Clean in tackling the challenge of decarbonising steelmaking."

BHP also announced earlier this week that it is collaborating with India's largest government-owned steel producer, the Steel Authority of India Limited (SAIL), towards lower carbon steelmaking technology pathways for the country's blast furnace route.

Rio to acquire Arcadium in $10b deal

Rio Tinto has confirmed it will acquire Arcadium Lithium in a $US6.7 billion ($9.97 billion) deal that will establish Rio as the world's third-largest lithium miner.

The deal has been struck through a definitive transaction agreement, under which Rio Tinto will acquire Arcadium in an all-cash transaction for $US5.85 ($8.71) per share.

This is a 90% premium on Arcadium's October 4 closing price of $US3.08 ($4.59) per share.

"Acquiring Arcadium Lithium is a significant step forward in Rio Tinto's long-term strategy, creating a world-class lithium business alongside our leading aluminium and copper operations to supply materials needed for the energy transition," Rio Tinto chief executive officer Jakob Stausholm said.

"Arcadium Lithium is an outstanding business today and we will bring our scale, development capabilities and financial strength to realise the full potential of its Tier 1 portfolio.

"This is a counter-cyclical expansion aligned with our disciplined capital allocation framework, increasing our exposure to a high-growth, attractive market at the right point in the cycle."

Arcadium Lithium chief executive officer Paul Graves said he is confident the deal is more than fair to shareholders.

"This agreement with Rio Tinto demonstrates the value in what we have built over many years at Arcadium Lithium and its predecessor companies, and we are excited that this transaction will give us the opportunity to accelerate and expand our strategy, for the benefit of our customers, our employees, and the communities in which we operate," Graves said.

Since Alkem and Livent officially merged at the start of 2024 to become Arcadium Lithium, the company has ramped up its production capacity to 75,000 tonnes of lithium carbonate per year, with expansion plans in place to more than double capacity by the end of 2028.

Arcadium chair Peter Coleman addressed shareholders with a letter supporting the transaction, emphasising the transaction is in their 'best interests' given the recent volatility in lithium prices.

"The immediate and substantial cash offer provides shareholders with certainty and liquidity, allowing shareholders to realise the full value of our investment without the ongoing risks associated with potential future market fluctuations," Coleman said.

"By accepting this proposed transaction from a larger, more diversified player, shareholders can avoid these risks as well as potential delays or setbacks in project execution, in exchange for immediate returns."

Mali accuses Barrick Gold of breaching agreement

Mali has accused Barrick Gold of failing to abide by commitments made in a recent agreement, charges the Canadian miner denied recently, saying it did not accept any claims of wrongdoing.

Barrick, the world's second-largest gold miner, announced on Sept. 30 it had agreed with the government to resolve disputes over the Loulo and Gounkoto gold mines, days after Malian authorities briefly detained four Malian staff working for the company.

But in a joint statement dated Oct. 23, Mali's economy and mines ministries said Barrick had "not honoured the commitments to which it subscribed in the agreement."

Without sharing further details, the ministries said the breaches included those relating to environmental and corporate social responsibility and foreign exchange rules.

They said there were "serious risks to the group's continued operations in Mali, one of whose operating licenses expires at the beginning of 2026."

"The Malian government has decided to draw all legal consequences arising from the actions taken by Barrick Gold," they said.

In response, Barrick denied the allegations and said since Sept. 30 it had been actively engaged with the government to reach a settlement that would include an increase in the state's share of economic benefits from the Loulo-Gounkoto complex.

"While Barrick does not accept any claims of wrongdoing, it has chosen to act in good faith as a long-standing partner of Mali," it said in a statement, adding that the company had paid the government $85 million in early October in the context of ongoing negotiations.

Earlier this month, three sources told Reuters that Mali's military government was seeking at least 300-billion CFA francs ($512 million) in outstanding taxes and dividends from Barrick.

Asked to comment at the time, a Barrick spokesperson said the company was still in the process of negotiation.

The demands on Barrick follow an audit of mining contracts last year and a subsequent push by the junta to renegotiate existing agreements with foreign mining firms aimed at channelling a greater share of revenues into state coffers through a new mining code.

Australians back mining for much-needed minerals

A new report from CSIRO has revealed Australians have increased trust in the mining industry but expect the sector to continue to maintain high environmental, social and governance (ESG) standards.

Authors of the report surveyed 6400 participants, focusing on critical and energy transition metals to measure community sentiment toward mining's role in renewable energy efforts.

Conducted in collaboration with Voconiq, the survey marks the third instalment in a decade-long program of research, providing an update to the national surveys conducted in 2014 and 2017.

"These insights are crucial for policymakers, industry leaders, and communities as they navigate the evolving social licence for mining operations, particularly in the context of the energy transition," CSIRO Mineral Resources science and deputy director Dr Louise Fisher said.

A total of 73% of respondents acknowledge that access to critical minerals is essential for achieving net-zero emissions, while 71% agree that mining is important to the Australian way of life.

Key findings from the survey included:

- increased trust: public trust in the mining industry to act responsibly has significantly improved over the past ten years
- evolving sentiments: while there is greater acceptance of mining, acceptance is contingent on the industry to continue addressing environmental concerns, engaging transparently with communities, and ensuring a fair distribution of economic benefits
- awareness of ESG: the survey underscores Australia's commitment to maintaining a high ESG standard, which resonates with the values of everyday Australians
- concerns persist issues such as dust, water quality, and community health remain significant concerns, highlighting the need for strong regulation and community collaboration.

"As Australia progresses towards net-zero emissions targets, the data indicate that while mining is recognised as necessary, community apprehensions about its impact must be addressed," Voconiq chief executive officer and co-founder Dr Kieren Moffat said.

"This research will help inform ongoing discussions about the future of mining in Australia, emphasising the importance of collaboration among the mining industry, regulators, and communities."

Inclusive urban mining: an opportunity for engineering education

With the understanding that the mining industry is an important and necessary part of the production chain, we argue that the future of mining must be sustainable and responsible when responding to the increasing material demands of the current and next generations. In this paper, we illustrate how concepts, such as inclusiveness and the circular economy, can come together in new forms of mining – what we call inclusive urban mining – that could be beneficial for not only the mining industry, but for the environmental and social justice efforts as well. Based on case studies in the construction and demolition waste and WEEE (or e-waste) sectors in Colombia and Argentina, we demonstrate that inclusive urban mining could present an opportunity to benefit society across multiple echelons, including empowering vulnerable communities and decreasing environmental degradation associated with extractive mining and improper waste management. Then, recognising that most engineering curricula in this field do not include urban mining, especially from a community-based perspective, we show examples of the integration of this form of mining in engineering education in first-, third- and fourth-year design courses. We conclude by providing recommendations on how to make inclusive urban mining visible and relevant to engineering education.

The first reference to urban mining is claimed to be in The Economy of Cities by the Urban Theorist Jane Jacobs in 1969[1]. In her piece, the author described future cities as mines with huge, rich, and diverse raw materials[1,2]. However, the origins of this concept are still under discussion[3], and differences in definitions arise based on the contrasting ideologies and priorities of stakeholders yielding the term.

In general, an "urban mine" is understood as the urban accumulation of anthropogenic materials aboveground[2,4], and "urban mining" could be interpreted as the activity that converts "wastes" into resources[5]. Aldebei *et al.*[2] understand urban mining as a metaphor for describing the same activities of prospecting, exploration, development, and exploitation as traditional mining. For the purpose of this article, we will utilise the following definition proposed by Cossu and Williams, "Urban Mining extends landfill mining to the process of reclaiming compounds and elements from any kind of anthropogenic stocks, including buildings, infrastructure, industries, products (in and out of use), environmental media receiving anthropogenic emissions, etc."[6]

The term “urban mining" is assumed to be applicable to many kinds of waste[5]. However, this work is based on two specific streams, namely construction and demolition waste (C&DW) and waste of electrical and electronic equipment (widely known as WEEE or e-waste). These are two of the most relevant anthropogenic sources in terms of quantity and economic incentive[7]. E-waste mainly motivates research and practice because of its high concentration of rare earth minerals, and buildings and infrastructure waste are the largest anthropogenic stock worldwide. In other words, C&DW is “the largest urban mine"[2].

As a direct consequence of the population growth, urbanisation, and excessive con sumption that characterse the last century, the exploitation of natural resources and the generation of waste have increased radically[5]. Under these circumstances, the concept of urban mining of anthropogenic wastes has been introduced for almost four decades as an alternative to the conventional way of extracting raw materials, which is particularly important to decrease their depletion and lower the mining footprint[8]. For example, managing electrical and electronic equipment under the circular economy approach can reduce the use of raw materials to produce new devices by up to 80%[7].

Urban mining also serves as an approach to sustainable waste management in cities and can be a source of new job opportunities for young people and/or immigrants[7]. As an anthropologist studying informal e-waste management in Tanzania observed, “(. . .) recycling offers a skilled vocation, with a sense of stepped progression, secure revenue and entrance into a social support network that sustains and enhances local lives"[9]. Therefore, urban mining also has the potential to become inclusive by contributing to the production of goods and offering services while simultaneously pursuing social objectives to enhance the quality of life of vulnerable communities.

Although it is promising as an economic, social, and environmental activity, urban mining still has its limitations. The recent efforts in legislation to promote urban mining that have been implemented in Europe and other regions, for example, the WEEE Directive (2012/19/EU) and its recent amendments that have become international models for e-waste management[10-12], are not enough to deal with the 82% of electrical and electronic equipment that is not treated in a sound environmental manner[7,12] and the 35% of C&DW that still ends up in landfills globally[13]. The causes of these figures include low recovery efficiency rates as a consequence of inefficient product design, lack of development and effective implementation of regulations and certifications to promote the use of reused materials, negative perceptions about second-hand materials and products, lack of awareness about the benefits of urban mining and the impacts of e-waste and C&DW, space scarcity in urban centers to store materials, high costs of best-quality recycling processes that make it difficult to afford for small and medium-sized enterprises (SMEs), and high competitiveness of landfilling associated with immature local markets and poor economic incentives for the circular economy[7,14].

In Latin America, despite advances in this field, much work still needs to be undertaken to improve the low e-waste recovery rate below 2%[12] and C&DW recovery rate below 10%[15]. As a result, a significant part of the waste with economic potential is abandoned in open spaces[2] or exported, resulting in lower efficiency of the waste management systems[16]. Furthermore, this situation limits green job opportunities in the region, especially for informal waste pickers and recyclers, who currently play a key role in the circular economy[17,18].

In the last decade, many international organisations have focused on this issue, and financial resources have been allocated in this field, eg, the 2018-2022 UNIDO-GEF PREAL project for the Environmentally Sound Management of POPs in Waste of Electronic or Electrical Equipment[19]. However, projects and research are, in general, led by stakeholders interested in industrial ecology, waste management, environmental health, and the circular economy rather than academics and researchers from the mining sector with an interest in the potential of urban mining as an alternative economic activity of material extraction and social empowerment[18].

While the traditional training of mining, metallurgical, and materials engineers might not focus on urban mining[18], we agree that “shortly, our society is undergoing an accelerating transition from virgin mining of linear economy to urban mining of circular economy"[20], and we suggest these groups should be part of this transition. Johansson *et al*.[18] claim that, as was the case for traditional and deep-sea mining, the development of technology could make urban mining attractive as an economic activity. They also highlight that even if the nature of mining changes, as with any mining activity, engineers and researchers specialised in materials composition, collection, extraction, separation, and recovery are crucial to overcoming current technological challenges for implementation.

In light of the need for further research and initiatives, there is a potential for science and engineering education to contribute to these global challenges. Some scholars reported a constant declining interest in mining studies worldwide[21] and proposed a focus on sustainable development to generate new competencies and subjects and promote inno vative solutions and technologies by emphasising environmental and social aspects[21]. Literature has reported the positive impacts of incorporating non-traditional mining areas into traditional engineering programs, for example, the case of incorporating artisanal and small-scale gold mining (ASGM) into the curriculum of an engineering college in the US[22,23], an approach that was also recommended by organisations, such as USAID and UNITAR as a crucial step towards formalisation of the activity[24,25]. In this context, urban mining could also be proposed as an alternative to attract more students into the mining sector.

OBJECTIVES

Understanding that the mining industry is an important and necessary part of the production chain that should be aligned with international environmental agreements and goals, eg, the United Nations 2030 Agenda and the Sustainable Development Goals, the future of mining must be sustainable and responsible when responding to the increasing material demands of the current and next generations. With this in mind, in this paper, we illustrate how concepts, such as inclusiveness and the circular economy, can come together in new forms of mining – what we call inclusive urban mining – that could be beneficial not only in mining engineering curricula and the mining industry but also for environmental and social justice efforts aimed at empowering vulnerable groups in regions, such as Latin America.

Population movement from rural areas to urban centers has created increasing demands for employment, often for individuals with low levels of education and literacy[26-28]. In this context, cities play a role in offering stable, secure, formal, economically sufficient, and dignified green jobs, including in the waste management sector[7]. Taking this into account, we begin by demonstrating how, if recognised, inclusive urban mining could present an opportunity to benefit society across multiple echelons, including empowering vulnerable communities and decreasing environmental degradation associated with extractive mining and improper waste management. To do so, we use our research experiences in the C&DW and e-waste sectors in Colombia and Argentina to show how present and future urban miners are or can be empowered to build livelihoods out of treating what is traditionally seen as waste and how their path could be extended to prospective miners. Then, recognising that most engineering curricula in this field (eg, mining, environmental, and materials engineering) do not include urban mining, especially from a community-based perspective, we show examples of the integration of this form of mining in engineering education in first-, third- and fourth-year design courses. Finally, we conclude by providing recommendations for how to make inclusive urban mining visible and relevant to engineering education in different institutional contexts.

Given the few works found in the literature that introduce these ideas and perspectives, we challenge the status quo by proposing a conversation on a new paradigm that completely changes how we understand and treat material stocks. In this regard, we understand that the novelty of this study should be highlighted.

DESCRIPTION OF STUDY SITES

C&WD in Colombia

In the past decade, there has been a rise in research and literature on C&DW management issues[29], and several countries, such as Germany, Spain, and Belgium are adopting strategies to treat and handle this type of waste[30]. However, Latin America lags in this area, and some countries, such as Colombia, despite generating vast amounts of C&DW, have not made noteworthy progress in managing it[31]. An estimated 35% of C&DW is disposed of in landfills without further treatment[32]. In their article, Colorado et al. attempt to obtain the first quantified values of C&DW in Colombia[13]. However, information on the management of C&DW in Colombia is very scarce, and Colorado et al. concluded that no reliable data depicting the amount of C&DW generated annually in Colombia exists. Similarly, most countries in Latin America do not collect data on the generation and quantification of C&DW[13].

Nevertheless, within a thesis project from 2003, author García Botero detailed C&DW in Bogotá, Colombia and examined if the sustainable development needs of the city are being met[33]. He concluded that approximately 99% of C&DW in the context of Bogotá is "useable", and a majority of this C&DW is made up of concrete, asphalt, brick, blocks, sand, gravel, earth, and mud. Furthermore, Méndez-Fajardo's article argues that recycling and reusing C&DW can produce significant positive impacts for citizens; however, these potential values are often overlooked[34]. These positive impacts can be seen at multiple echelons, including the environmental, social, cultural, economic, and even political level.

To study how to promote and support inclusive C&DW management in Colombia for the empowerment of low-income communities, we worked with Community A, a small, low-income community located just outside Girardot in the department of Cundinamarca. Girardot is a popular vacation spot and houses many recreational activities due to its warmer, tropical climate and proximity to Bogotá, the capital of Colombia which is home to over seven million people.

Unfortunately, not much is officially known about Community A. Based on our estimates, about 200 families live in the community, many of which do not have access to sewage systems. This site was considered relevant for our study because of their desire to take part in the project as well as the occupational profile of the inhabitants. While many of the men in the community work in construction practices, most of the women work in the informal sector (selling products, such as soda, avocados, and arepas from their homes or on carts either in the city or on the surrounding roads) or are unemployed. Furthermore, despite their occupational status, all the women in Community A are caretakers in their homes as well, for their children, parents, pets, and households. The local knowledge and the gender-related disparity in terms of job opportunities made Community A an interesting sample to study inclusive urban mining. The members in the community we spoke with wanted to learn how to extract value from C&DW and how they could make it profitable for themselves and their families. Thus, the goals of this project were refined with the guidance of the community, to increase education about C&DW and find a way to make this effort profitable.

E-Waste in Argentina

Despite the fact that Argentina had the highest generation of e-waste in 2019 (328 kt) out of the 13 countries studied by Wagner *et al.*[35], the management of this waste stream in Argentina is considered to be at a nascent stage, and little is known about it. Recent reports developed by national authorities confirmed a data gap[36], and the lack of regulations reveal that electronic waste management is a pending issue in the country. However, there are communities whose income depends on these materials. Some sources estimate that in 2017, nationally there were 600 people working in the informal e-waste recycling sector, and the number grew to around 2000 workers in 2019[37]. A different source indicated that there were 2800 workers in 2019 in only 14 municipalities in the province of Buenos Aires[37].

The province of Buenos Aires and the City of Buenos Aires were selected as study sites in Argentina because they agglomerate the largest population and contain the enterprises and cooperatives that process the highest amount of e-waste[35,37]. In order to address the topic of inclusive urban mining, four cooperatives were studied. Cooperatives are "autonomous associations of persons united voluntarily to meet their common economic, social and cultural needs and aspirations through a jointly owned and democratically controlled enterprise"[38]. Three of the cooperatives under study are exclusively dedicated to e-waste, and one is a cooperative dedicated to solid waste but brings together workers who individually recover e-waste materials. Additionally, we included one university extension program currently offering e-waste management services in the province. The names and specific details of these facilities are protected, so they cannot be easily recognised.

- Facility A (cooperative): It started in 2018 as a solid waste cooperative, and since 2022, its members have decided to explore e-waste processing as an additional source of income. The e-waste sector now has five workers and one coordinator. They are in the process of formalising their activity in relation to e-waste management.
- Facility B (cooperative): It is a solid waste cooperative that started almost ten years ago. They have more than 150 members, and almost half of them individually recover e-waste material from the streets. This cooperative is interested in e-waste, but its members do not yet have experience with this waste stream.
- Facility C (cooperative): With almost 20 workers, this cooperative is one of the province's most advanced small social businesses. They have already obtained legal permission to manage e-waste, their main activity.
- Facility D (cooperative): It has over 20 years of experience in the business and employs more than 25 workers. The cooperative is recognised as a formal e-waste operator and treats almost 1,400 tons of waste per year.
- Facility E (University extension program): It began as an academic extension program and now is one of the few e-waste operators in the province. Since 2009, they have trained 1168 students and treated 217 tons of e-waste.

METHODS

Methodological Framework and Ethical Considerations

As the local knowledge of communities is crucial for developing sustainable and just solutions[39], our research methods were participatory and we took a qualitative approach to understand the neglected knowledge, expertise, and values of the communities we worked with, as well as the complex systems that shape their lives. Qualitative methodologies, such as semi-structured interviews, participant observation, focus groups as well as workshops, were utilised to build this understanding. **Figure 1** summarises the logical items of this study.

Both projects were approved by the Colorado School of Mines Human Subjects Research Team and exempted from the Institutional Review Board (IRB) process requirements. The research in Colombia was developed in partnership with a Colombian university, Corporación Universitaria Minuto de Dios or Uniminuto. The groups specifically working on this project were the Parque Científico de Innovación Social (PCIS)/the Social Innovation Science Park, a research group led by Civil Engineering and Occupational Health and Safety Professors with social justice aims entitled Ingeniero a tu Barrio, the international studies group in Uniminuto-Girardot, as well as communication specialists including Professor Martha Liliana Herrera Gutiérrez, who was responsible for translation, facilitation, and communication. Together we worked directly with a low-income community in Colombia, Community A, to study how recycling C&DW, specifically concrete, could empower them. Approval for this research was also obtained from local Colombian authorities, including Uniminuto's PCIS as well as their research ethics committee. Additionally, the research in Colombia adheres to Uniminuto's Social Innovation Route Framework[40], a five-phase community engagement framework developed by PCIS.

Semi-Structured Interviews

Throughout the six weeks of fieldwork on C&DW completed in Colombia during June and July 2022, we interviewed 17

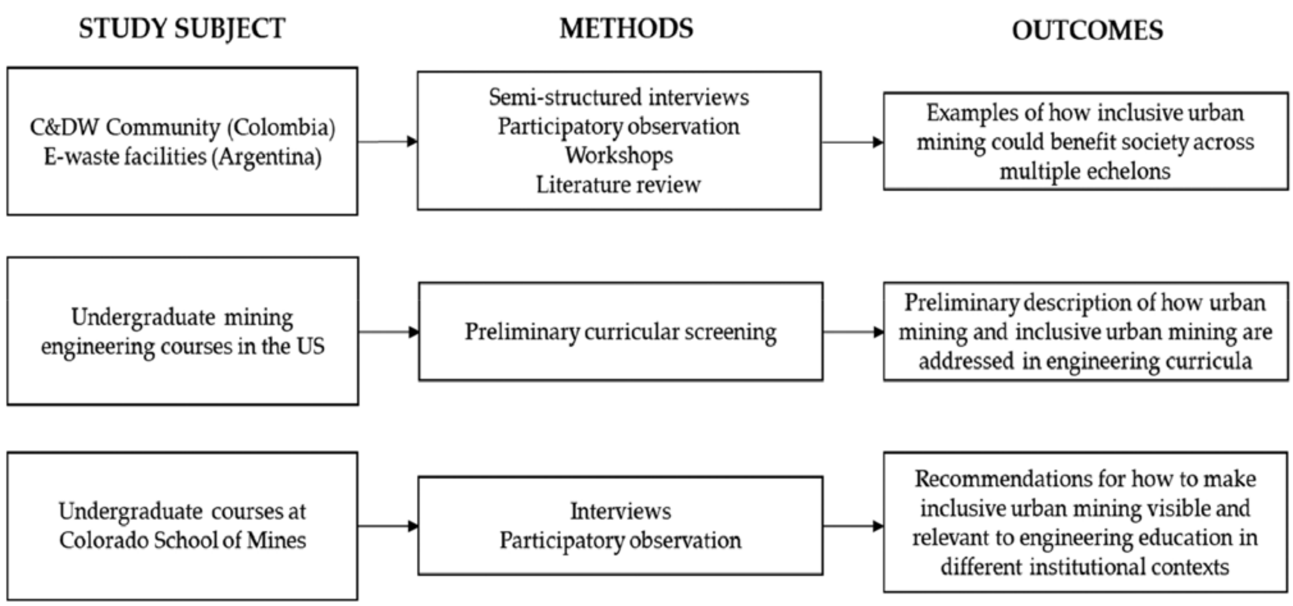

Figure 1: Schematic representation of the logical items of this study.

women and 12 men from differing backgrounds, including low-income community members, community leaders, engineers, academics, students, waste management experts, and government officials. During each interview, translation services were provided by professors from Uniminuto. Within these interviews, we asked our interlocutors to describe their backgrounds, knowledge of concrete and C&DW, risks and barriers they believed could prevent recycling C&DW in low-income communities, and if any groups could be disproportionately affected by these risks. Additionally, as this project had specific social justice goals to contribute to women's empowerment in low-income communities, our focus was to speak mostly with women in the community to understand their interpretations of women's empowerment and define how they specifically wanted this project to empower them.

A series of exploratory interviews were conducted during June and July 2022 for the research on e-waste. A total of 15 government representatives, researchers, and members of e-waste cooperatives and programs were interviewed. The meetings, each lasting approximately one and a half hours, were held virtually. The interviews aimed to obtain preliminary information on the current situation of e-waste management in Argentina, with a particular focus on the province and the city of Buenos Aires. Participants were asked to describe their workplaces, e-waste-related practices and dynamics, the challenges the sector faces, and their opinions on past and current waste management strategies. Additional unrecorded interviews with e-waste workers and government officials were also conducted during the participatory observation visits described in the next section.

Participatory Observation

Upon beginning our fieldwork session in Colombia, the Uniminuto team immediately began facilitating meetings with Community A. As the Uniminuto team had already collaborated with this community in the past, many community members already knew most people on our team. However, building rapport with the community during these meetings was essential for the group members who had not previously worked with Community A. Thus, time was spent introducing ourselves and our goals and conversing with the community members. To understand the community's goals for this project, it was essential to understand the context of the community, their values, beliefs, journeys, destinations, language, knowledge, and more through participant observations. We spent a lot of time trying to understand the knowledge community members had about C&DW and recycling. We learned the community was already utilising C&DW in their homes and on shared roads but in unsustainable ways. While there is a Junta de Acción Comunal for the community (a legally protected organised civil structure made up of members of the community), there are also natural leadership structures and leaders as well. Despite this divide in power structures, both groups wanted to find a way to make recycling C&DW profitable and beneficial for the community. The understanding of these relationships contributed to the understanding of urban mining potential in the community.

In Buenos Aires, jointly with the representatives of two local government agencies, three visits to e-waste facility A and two to facility B were conducted in August 2022. In facility A, the researcher was accompanied by a team consisting of one toxicologist and three social workers, and in facility B an environmental professional led the visit. Three other e-waste facilities in the province of Buenos Aires were visited by the researcher. During these encounters, neither video nor audio recordings were made. Photographs of the workspace, machinery, devices, and waste were taken with the previous authorisation of participants. The objective of this observation was to understand the different contexts of e-waste workers, their work dynamics, power distributions, needs, concerns, and desires. These interactions helped identify new actors and refine data on materials and equipment, collection and treatment practices, and the value chain characteristics.

WORKSHOPS

Through the preliminary analysis of the data gathered on C&DW and Community A during interviews and participant observations, we formulated a common theme, which was the desire to bring educational opportunities to the community and conduct workshops to give community members, especially women, skills to generate income. To follow our commitment to a community-centered research approach, we developed a participatory workshop with Community A that took place in March 2023. This workshop presented an opportunity for women and low-income community members in Colombia, specifically targeted towards Community A in this approach, to engage one another in the process of learning about recycling concrete from C&DW and develop a plan for how this can become actionable in their community. The workshop had five key sections: C&DW Composition and Values, Environmental Aspects, and Necessary Permits; C&D Recycling Processes and Technologies; Occupational Health, and Safety; Applications and Entrepreneurism; and Pathways Forward. We worked with community members through virtual communications and surveys to ensure that the included components were necessary and relevant. Additionally, to centralise local knowledge and build local capacity we invited Colombian subject matter experts to lead each of the key sections.

For e-waste communities, two workshops were held with each group of workers from facilities A and B. The main objective of the workshops was to analyze workers' perceptions regarding the chemical risks related to their activity, train them in basic concepts of risk prevention and management, and collect their opinions on a proposed intervention to prevent the open burning of cables. All the e-waste workers at facility A (five males) participated in the workshop with their coordinator (one male). At site B, since the cooperative is not formally working with e-waste, the associated urban recyclers with e-waste experience were invited to participate. In total, 37 (17 females, and 20 males) and their coordinator (1 male) participated in the workshop. The activities were conducted in two hours and included: (1) Initial general risk identification activity, (2) E-waste risk perceptions activity, (3) Discussion about a cable stripper prototype, and (4) Community mapping of burning sites, metal buyers, and collection points (only at site A). Audio recordings were taken with the prior permission of the participants.

Research Extension with the Undergraduate Students of the Colorado School of Mines

Following the teaching philosophy of the Colorado School of Mines (CSM) Humanitarian Engineering and Science program[41], three graduate–undergraduate research extension activities were carried out with CSM undergraduate students. First, the topic "Empowering People: Extracting

Value from Waste Through Urban Mining" was proposed as project motivation in the "Design I" course in Fall 2022, aimed at more than 600 first-year engineering students. Second, for a senior design course, specific sociotechnical challenges related to C&DW and e-waste were proposed to the students. Third, a new version of the "Engineering and Sustainable Community Development" course was delivered to 24 undergraduate students in Spring 2023, based on three e-waste technical challenges defined by a community of recyclers in Bogotá, Colombia.

Preliminary Review of the Mining Engineering Curricula

To describe the approach of urban mining and inclusive urban mining as topics in the engineering curricula, we conducted preliminary research on curricular databases from universities in the United States. We selected the top universities in mining engineering, as listed on the National Mining Association website[42], and then we examined each university's website and online course catalog individually, solely looking at their minimum requirements for obtaining a Mining Engineering Bachelor of Science in the 2022-2023 academic year. University, general education, and B.S. course requirements were not included. When examining each catalog, we searched each course description to determine if urban mining concepts and sociotechnical approaches were explicitly stated as learning goals in required courses. To search for urban mining concepts, we utilised the following search terms: "urban mining", "construction and demolition waste", "C&DW", "electronic waste", and "e-waste". We also searched for sociotechnical learning approaches by searching for the terms "community", "sociotechnical", "social", "societal", or "human". Acknowledging the limitations of this approach because of its subjectivity related to the lack of detailed information describing the material reviewed within the required courses as well as the research projects being conducted within these universities external to course curricula, we incorporated our findings as a preliminary set of data that could be further analysed in future works.

INCLUSIVE URBAN MINING IN LATIN AMERICA

Currently, in most Latin American countries, the "resource recoverers"[43] or, as we refer to them in this paper, "urban miners", are not yet integrated into the regulatory framework. Their working conditions are often precarious, exposing them to hazardous chemicals, including heavy metals and halogenated compounds[44]. Although they provide a critical environmental service, waste workers have historically been stigmatised and excluded within society[43].

With growing interest, but still nominal in comparison with traditional mining, some countries in the region are facing the challenge of regulating the activity of urban mining, integrating informal workers, and promoting improvements in processes and technologies to increase productivity and promote sustainable local economic development[35,36].

To help overcome the challenges and barriers enumerated, we present below the current and potential benefits of urban mining for communities and the environment with a special focus on Latin America. We support our claims by providing evidence from our literature research and experiences with communities in Argentina and Colombia interested in treating waste not only as a source of income but also as a way of empowerment. We introduce inclusive urban mining as a concept that has its roots in inclusive solid waste management, an activity with a long history in these two countries[45,46].

Why Should Urban Mining Be Inclusive? Some Examples of Its Social Benefits

Women's Empowerment: Through Recycling C&DW

When asked about their role in their community, household, and workplace, many of the women in Community A in the Colombia research claimed to be a leader of some kind. They either defined that as having a position of power and knowing they could tell others what to do, or being a mentor or a friend to people when they needed something. Some also cited their age when asked about their role, stating that because they are older, they are wiser and therefore better leaders. When asked about the problems women face in their community, problems with children were often cited, such as children being left alone or turning to illegal activities to make money. Another problem that often arose was unemployment, sometimes due to the lack of transportation or job opportunities. Finally, when asked about solutions to these problems and how the term women's empowerment was understood, people often brought up workshops that had been conducted in the community in the past. These workshops often focused on cosmetology, such as doing hair and nails, art practices, baking, or cooking. Many people mentioned education and the importance of learning, and some brought up making money and having the ability to secure and spend money for themselves or their family while in the confines of their own homes. When asked about women's empowerment, one leader in the community stated, "[Women's empowerment] is the idea that women can work on their own with their own capacities". She also discussed the importance of bringing opportunities to the community and doing workshops to give women tools to find jobs.

As illustrated in the semi-structured interviews conducted with women in Community A, in this context, it was found that urban mining can best empower them helping them generate more income and advance their education to gain additional skill sets. While financial and economic decision-making power is a common dimension of women's empowerment, the details of how exactly this pursuit could be more beneficial and empowering to women in Community A were developed through a dialogue and an understanding of the community context. For example, the women demonstrated the need for the time and capacity to care for their families alongside these pursuits, thus making this a homebound endeavor.

While urban mining shows promise to contribute to empowerment opportunities for multiple vulnerable groups, including women, it must be acknowledged that these contributions can be maximised through a contextual understanding of the complex systems that shape the lives of these groups. As such, there is a need for academic institutions, especially those related to engineering and design, to work alongside communities to understand how pursuits, such as urban mining, can empower them. Moreover, to ensure relevant empowerment to vulnerable groups, it is essential to take an interdisciplinary approach, as empowerment is contextually situated; thus, different ideas of empowerment exist within different contexts and are reflective of their own specific communities and cultures.

Social Transformation and Digital Inclusion in the E-Waste Sector

In our visits to e-waste facilities, we observed the pride of workers regarding their role as green actors in a context where circular economy policies and regulations, although necessary, are still pending. This role is one of their motivations when facing the many obstacles presented to them. To name a few, they have little bargaining power vis à vis buyers – mostly intermediaries – and limited access to information and technologies to maximise waste recovery. Even with all the challenges, these groups of workers, mostly born and raised in vulnerable conditions, go through a collective process of what they call "subsistence, resistance, and transformation". Some are young adults who have never kept a job for more than a couple of months, but in their cooperatives, they become resilient and learn not only specific knowledge relevant to their business, but also the general rules of the labor industry, such as complying with the schedule and attendance. Hence, as an interlocutor told us once, "We [the cooperative] not only recycle materials, but people". Therefore, it is not arbitrary that some cooperatives have included words, such as "dignity" or "justice" in their names. We see, then, that the feeling of belongingness that the activity generates in workers has the potential to contribute to the education on labor conduct, becoming a transforming process for specific groups, including young recyclers.

For workers in general, as in any other labor space, learning new skills and developing new knowledge are essential, and urban miners are not exempted from this process. They learn to repair and disassemble e-waste by gaining specific knowledge about electronics, IT, mechanics, and sometimes material composition and chemistry. However, particularly for this sector and especially in the Latin American context, learning these disciplines goes beyond training workers in their roles. This learning process also means a step towards their insertion in an increasingly demanding digital society. This is an additional benefit of urban mining, illustrated by the case of a worker who, during a workshop, told us, "Since they [the cooperative] gave me a computer, I was able to use one for the first time in 60 years". This worker's access to technology, although based on the objective of training him on electronics repairing, ended up meaning his access to a digital world that is often hampered for people his age.

In urban mining cooperatives, we have observed how not only materials but also people are transformed. Understanding this opens the way to many study areas that are scarcely explored today by the academic community. We question what other social benefits do urban mining cooperatives bring? Could the social benefits be externalities that account for the comparison between urban and traditional mining? We wonder, in particular, for the e-waste management sector, how could actors dedicated to digital inclusion and actors dedicated to e-waste management interact? What impacts would a more inclusive digital society have on the use, disposal, and management of electrical and electronic devices? Could the circular economy based on e-waste become a mechanism for digital inclusion?

The Value of Local Knowledge for the Global Development of Urban Mining: Examples from the E-Waste Sector

Although many of the e-waste recoverers did not perceive themselves as producers of knowledge or technology, as a result of our visits and workshops, we learned that the knowledge of these workers is as important as any other certified by an academic degree. For example, some workers can quickly identify components and materials with high efficiency, and some apply craft and ingenious low-cost plastic identification methods (eg, by their texture, smell, or color). Others have perfected techniques, such as manual disassembly or burning, to improve the quality of the metals they obtain, even in conditions that create major health problems for them and their communities because of their exposure to hazardous chemicals[44]. Likewise, some workers with more than a decade of experience in the sector have undertaken the important task of sharing their knowledge with less experienced peers, providing in-person training and written material. The information is exchanged between the workers themselves. They themselves are the referents of the activity and share their knowledge. A good example is the free and public guidance document "Cooperación y reciclado para un mundo sustentable" ("Cooperation and recycling for a sustainable world") edited by Salcedo et al. in 2019[47].

In the literature, waste workers are usually pigeonholed into informality[48], and under a global gaze that proposes external strategies to deal with local problems. We believe that to avoid the traditional labels of "lacking" or "informal," and put an end to the historical marginalisation of the recyclers, waste pickers, and waste workers in general, it is necessary to study their resilient learning, improvement, and knowledge-transfer processes. Johansson *et al.*[18] claim that "the informal sector can nevertheless teach us how to change our perception of technospheric stocks and view them not as a problem but as a resource". We thus wonder how their voices could be amplified so that larger audiences know how their inventiveness and persistence can overcome the barriers of the context in which they work and how these skills and knowledges can help alleviate the global challenge of e-waste, C&DW, and other relevant waste streams. We then ask what can Latin American urban miners contribute to the global conversation on waste management? How can local knowledge improve foreign technological processes? These proposals are not in opposition, but on the contrary, they seek to promote a synergistic interaction between the development of knowledge and technologies in Latin American countries and countries of other regions.

Environmental Benefits of Urban Mining

Present-day demand for material resources combined with concerns about the sustainability of extraction practices and the effects of waste have increased the interest of both practitioners and scholars in the concept of the circular economy. In this context, urban mining is gaining momentum from various perspectives[49]. First, this practice rejects linear approaches to production, replacing the "end-of-life" stage of traditional waste management with reusing, recovering, and recycling processes throughout a product's life[50]. Second, many scholars agree that urban mining improves resource fulfillment by advancing the circular economy and minimising environmental burdens[51]. Obtaining materials from discarded items can also contribute to climate change mitigation since metal recovery consumes less energy than the extraction of primary raw materials[51]. For instance, the energy needed for the manufacturing and transportation of building materials could be reduced

Table 1: Preliminary review of Mining Engineering Curricula related to urban mining and sociotechnical learning approaches* in the US.

	Mining Engineering University												
Number of Required Courses	1	2	3	4	5	6	7	8	9	10	11	12	13
Urban Mining Concepts	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociotechnical Concepts	0	2	0	1	0	1	0	4	3	1	0	0	0
Number of Non-Required Courses	1	2	3	4	5	6	7	8	9	10	11	12	13
Urban Mining Concepts	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociotechnical Concepts	1	3	3	2	0	2	0	4	3	1	0	0	1

* Search terms: “urban mining", “construction and demolition waste", “C&DW", “electronic waste", “e-waste", “community", "sociotechnical", “social", “societal", “human".

by about 29% if these materials are recycled[7,52,53]. Third, urban mining provides a solution for uncontrolled waste management, which remains a significant global challenge[14] due to factors, such as the exposure of the environment and humans to hazardous substances and biological vectors. The accelerated growth of waste on a global scale results in valuable aboveground stocks in quantities that are often comparable to or exceed natural stocks[6]. For example, Grant *et al.*[3] indicate that “thirty smartphones contain as much gold as one ton of mine rock from a traditional gold mine". Thus, these resources have become attractive to those that acknowledge the gradual depletion of economically minable resources[49].

Environmental Benefits of Recycling C&DW in Colombia and E-Waste in Argentina

The construction industry is a main contributor to carbon dioxide emissions across the globe due to it containing many elements with high carbon footprints, such as cement and concrete production, transportation, and C&DW generation[54]. In 2020, the United Nations Environment Program (UNEP) stated that the buildings and construction sector accounted for 38% of the total global energy-related CO_2 emissions in 2019[55]. The cement industry alone contributes to about 8% of the global CO_2 emissions[56]. Effectively managing C&DW is a critical component of preserving our environment, natural resources, economy, and society[57]. Despite this, C&DW mismanagement is a widespread issue.

Around the world, the problem of C&DW is worsening, thereby exacerbating environmental and social issues [58]. In Colombia, the expansion of the construction industry is aggravating these issues through the disposal of C&DW in an insufficient and unregulated manner and the increased illegal extraction of aggregate materials[59]. These increasing environmental and social issues are gaining national recognition in Colombia, as seen in Resolution 472, which outlines the management of C&DW in Colombia in light of the inadequate disposal and increased generation of C&DW in cities across the country, including Bogotá, Medellín, Santiago de Cali, Manizales, Cartagena, Pereira, Ibagué, Pasto, Barranquilla, Neiva, Valledupar and San Andrés[60] as well as other legislation released over the past couple years[61-63]. Recycling C&DW could contribute to reducing the inadequate and unregulated disposal of C&DW and decrease the illegal extraction of aggregate materials.

Regarding e-waste in Argentina, a national report estimates that 465,000 tons of this waste stream are generated per year[36] and only 4% is managed in an environmentally sound manner[35]. Roughly, following the methodology in Forti *et al.*[12], we calculated that this low percentage contributed to a net saving of 8 kt of CO_2, equivalent to emissions from the recycling of secondary raw materials substituted to virgin materials. If this percentage increases up to the goal of 30% under Target 3.2 of the ITU Connect 2030 Agenda[64], it might help save up to 60 kt of CO_2 equivalent emissions.

INCLUSIVE URBAN MINING IN US ENGINEERING CURRICULA

Preliminary Screening of Urban Mining Content in the US Engineering Programs

Table 1 summarises the preliminary research findings on curricular databases from the universities in the United States with Mining Engineering Bachelor of Science programs.

There are 13 universities in the United States with Mining Engineering programs. Within these programs, urban mining was not explicitly listed as a learning goal in any course descriptions found within the universities’ websites or online course catalogs depicting the minimum course requirements for obtaining a Mining Engineering Bachelor of Science in the 2022-2023 academic year. The programs include courses with sociotechnical approaches, or at least discuss human-based concepts to a certain extent; however, these approaches were found more often within the non-required courses.

To reiterate, our findings should be viewed as a preliminary set of data that could be further analyzed in future works due to the limitations of this approach, including its subjectivity related to the lack of detailed information describing the material reviewed within the required courses in course descriptions found on university websites. Additionally, this screening did not include research projects being conducted within these universities external to course curricula.

It is not the intention of this work to only focus on the US curricula but to call on global engineering and technology academic institutions to involve current waste management challenges in their programs as motivators for technological innovation projects. Through the examples described below, we want to emphasise that urban mining could be a significant research subject and an excellent educational opportunity for organisations specialising in traditional mining, as these organisations could take advantage of their existing technical knowledge in material extraction and processing.

Approaches to Include Urban Mining in the US Engineering Curricula

Introducing Urban Mining to First-Year Engineering Design Courses

The faculty in the design 1 and 2 courses at CSM are diverse in terms of academic and professional backgrounds. They mostly have STEM majors, such as design, civil engineering, electrical engineering, and other traditional engineering disciplines. Some have experience in the industry, and some others are senior researchers. This diversity gives the students exposure to different industries and "real-world problem-solving and design experiences", as our interviewee claimed. In total, they teach 25 groups of 25 first-year engineering students by applying an ambitious but enriching approach involving problem formulation, design thinking, and stakeholder engagement.

The purpose of their teaching approach is to expose students to stakeholders and communities they did not know about and to make them reflect on how engineering projects might affect those communities. Its purpose is also to broaden students' perspectives in ways they might never find out on the news or social media. This approach is not exempt from resistance, either from the faculty or students. According to the instructor, many students tend to separate the technical and the social and only focus on the technical challenge because, in the end, "the majority is going to end up in traditional engineering jobs one day, and that is just the path they want". Some other students understand the complex issues that low-income communities are facing, but they just do not want to get involved. In this context, the instructors try to emphasise the importance of integrating knowledge. They explain to students that engaging with stakeholders and considering the specific contexts, geographies, cultures, and expectations are key stages in the design process. "You cannot do technical in a vacuum", our interviewee claimed. As an example, he asks students, "Could you design a technical solution without considering government regulations"?

The efforts of going beyond the boundaries of traditional engineering are huge for the faculty, and despite some room for improvement in terms of genuine stakeholder engagement, those instructors with traditional engineering backgrounds are proud of what they are doing in this class. They are aware that even if it is an introductory course, they provide additional techniques that are not usually offered in the first year in other programs in the US.

At CSM, students receive a "call for proposal" (CFP) broad enough so they can elaborate on the problem after a series of research stages that can involve literature research and consultation with subject experts, potential users, and other stakeholders. In 2022, for the very first time, the CFP was developed in collaboration with two graduate students from the Humanitarian Engineering and Science program, who are the authors of this paper. The topic, "Empowering People: Extracting Value from Waste Through Urban Mining" was innovative since it introduced urban mining, life cycle, and waste management as motivations for design. The students received a brief description of the general situation of waste management systems in low-income communities and the specific challenges and opportunities in the study sites that we present in this paper.

The way the CFP was developed allowed students to set the boundaries of the problems by themselves, encouraging them to think creatively and "out of the box", to look at things outside their own immediate context, and to familiarise with the processes that happened after "the magic truck comes by and picks up the purple bin".

From a total of approximately 625 students, 110 students grouped in 25 teams achieved the 20% best-scored projects. Among the winning teams, the distribution of themes was Food/organic waste (5), E-waste (4), Plastic/packaging waste (4), Household effluents (2), Medical waste (2), Textile waste (2), and Others/Out of scope (6). The CFP motivated students to reflect further down the line at the end of product life. For example, some students worked on recycling technologies to be applied locally. Others looked at extending the life cycle by redesigning products or tried to look for upcycling opportunities at the source. A number of students preferred to address the specific challenges related to the settings and contexts that we have presented. They usually choose their path according to what they are exposed to and tend to lean towards stakeholders that they already know. The groups interacted with recycling, electronics, processing companies, big warehouses, consumers, and professional users.

Although the experience was enriching for both students and professors, introducing a new way of mining provoked tensions in a school well-known for its mining tradition. Some mining professionals asked, "Why are they calling this mining"? and claimed, "This is not our definition of mining. This is not what mining engineering is". We wonder, then, what does it take for the traditional disciplines to extend their boundaries? In the end, changes in the curricula that in the past seemed far off, such as the inclusion of the social aspects in a first-year engineering design course, became a reality seven years ago. We wonder, what is urban mining lacking to be considered as a topic of relevance by the traditional mining sector? What are the differences? What are the convergence points?

Introducing Urban Mining in Elective Courses: The Case in an Engineering and Sustainable Community Development course

For the very first time, in Spring 2023, the course Engineering and Sustainable Community Development (ESCD) was taught in a project-based format, involving direct interaction with communities. This course gathered twenty-five third-year and graduate students to work collaboratively with a Colombian recycling association to improve three processes: e-waste plastic identification, copper separation from cables, and precious metals separation from circuit plastic boards. From the instructor's perspective, urban mining is not the initial motivation of students that join this course. These students care about community-based projects in general, and even if they have education in specific disciplines (Environmental Engineering, Civil Engineering, Mechanical Engineering, Chemical Engineering, and Design Engineering), they are curious about the different ESCD opportunities for practice. Addressing a waste-related topic and how other communities interact with it stimulates students to think in ways they never have.

According to the instructor, urban mining could be framed as the future of mining. He thinks it has the potential to convene students, researchers, and industry professionals who are not usually involved in traditional mining (for example, electrical and civil engineers) that would be able to apply their knowledge and skills to transform anthropogenic waste stocks into valuable materials. In this sense, traditional mining institutions could see urban mining as a way to expand their curricula, staff, and areas of expertise. The expansion, however, will not be easy for those that have a traditional mining background, he said. It will require not only their willingness but the comprehension of new knowledge to deal with mines not located in the mountains but in the cities. Therefore, the challenge ahead will be to deal with the technical differences as well as the intricate relationship between material extraction and urban systems.

When we asked him how to make urban mining visible and relevant, the instructor did not hesitate to claim that extending graduate research into first and third-year design courses is an important grassroots step that could eventually position the topic as an institutional priority from the top-down. He explained that improving urban mining not only contributes to the circular economy but also provides employment opportunities for marginalised groups of people, such as those displaced by violence, poverty, or climate change. In this sense, applying a community-based approach in the engineering curricula gains more significance when urban mining is seen as an employment solution. He acknowledged that engineers could address urban mining from an industrial, automated, and large-scale perspective, but in doing so, they might be ignoring and neglecting the current labor problems that cities are facing and the minor waste streams that are managed in small neighborhoods. “All those stocks of waste are always going to exist, and all those people needing employment are always going to exist irrespective of the big machinery that you put in place". Hence, he emphasises the need for more engineers and engineering students to be trained to co-work with marginalised communities with the aim of improving their processes, products, and labor conditions.

The instructor also pointed out some important parallels between artisanal small-scale gold mining (ASGM) and urban mining. Less than a decade ago, the Minamata Convention forced countries to focus on reducing and, when feasible, eliminating the use of mercury. ASGM became a major area of interest for many institutions, including well-known traditional mining schools and research centers in the Global North. This new area of interest opened opportunities for research and practice in fields, such as engineering and social sciences. The recurrent presence of informality and the way in which communities engage in these activities, sometimes ending up exposing them and their families to hazardous chemicals, are other points of commonality between ASGM and urban mining. Furthermore, ASGM and urban miners both “are for the most part invisible to mainstream society", the professor said. Taking this into account, we wonder if similar drivers, such as the global concern about scarce materials, including rare earth elements, metals, and minerals, might have the same result for urban mining. Will inclusive urban mining become a field of research and practice in the way that artisanal scale gold mining did, even with the tensions and resistance that it generates?

Introducing Urban Mining Projects in Third and Fourth-Year Project-Based Design Courses

In an effort to offer the upper-level engineering students opportunities to learn more about human-centered design and humanitarian engineering challenges, CSM offers a three-semester hour project-based design course targeted towards junior- and senior-level students. Within the Fall 2022 semester, multiple graduate students from the Humanitarian Engineering and Science program – including the authors of this paper – were able to work with project teams in this course on specific real problems affecting real people. Overall, of the 23 students registered for this course in the Fall 2022 semester, 10 students worked on urban mining-related projects. One group of four students worked on a C&DW-related project, while two groups of three students were devoted to e-waste-related projects.

The faculty member responsible for facilitating the course in the Fall 2022 semester described urban mining as an opportunity, not only to “emphasise reclamation of precious materials in environmentally friendly ways that are also economically beneficial to disadvantaged populations" but to push back on the negative connotation associated with the term “mine" due to the often-harmful activities, practices, and ramifications of the industry. The professor believes urban mining is a way to “reclaim the word ‘mine’ for positive applications", and institutions responsible for the progression of the often damaging activities, practices, and ramifications of traditional mining processes, such as universities including CSM, should be at the forefront of developing “more environmentally friendly and socially equitable ways of mining and engineering", such as urban mining. The inclusion of urban mining in the curricula to atone for the negative externalities involved in traditional mining can also be an opportunity to enhance mining engineering education by facilitating understandings of concepts, such as life cycle analysis.

In addition, the professor stressed the importance of understanding the local context of projects, such as the cultural, socioeconomic, and environmental dimensions of the cities with which they work, and utilising approaches from the social sciences and environmental sciences to develop solutions that are “most appropriate to their target population and do the least harm to the same population as well as their environment". He stated that this utilisation and understanding was even more essential than technical foundations, such as the engineering mindset, to arrive at a point where the technical solutions were appropriate. Furthermore, to develop the best solutions possible, the professor argued that stakeholder engagement, particularly empathetic stakeholder engagement (“which is culturally sensitive, appropriate for local contexts, aware of potential unintended consequences, and ultimately in search of the greatest number of ‘win-win’ situations as possible, where the environment is also a key stakeholder"), is essential. We the question how critical social and environmental science approaches can have a space in engineering curricula, as these topics (particularly the social sciences), despite their importance, are traditionally shunned in engineering education.

LIMITATIONS OF THIS STUDY

There are two major limitations in this study that could be addressed in future research. The first limitation is related to the number and selection of participants included in our interviews and workshops, which were relevant in terms of the qualitative analysis of the C&DW and e-waste contexts in Colombia and Argentina presented but not statistically representative for a quantitative analysis. The second limitation is related to the reduced scope of our curricular review, since courses in departments other than Mining Engineering should be explored, including Chemical Engineering, Environmental Engineering, Resources Engineering, and Materials Engineering, among others.

CONCLUSIONS

As illustrated above, urban mining has a leading role in the circular economy that is currently developing. However, in particular contexts, such as in Latin American countries, this activity poses additional benefits that can be maximised if they are understood and studied. We state that the study of urban mining from an interdisciplinary approach could contribute to this field in order to achieve a much more inclusive and sustainable activity. For urban mining, cities are the locations where the extraction, circulation, and accumulation of materials take place. Hence, to favor inclusive urban mining it is not only necessary to understand collection and extraction processes but also to understand cities and their context. Contextualising this activity means analysing local legal frameworks, stakeholders involved, their history, ideologies, culture, alliances and power differentials, the flow of materials, current technologies, and processes. In light of our findings, we argue that the future challenges associated with inclusive urban mining are sociotechnical in nature. Thus, we highlight the importance of promoting community-based research methods and concepts from the Engineering and Sustainable Community Development practices[65] to be included in mining, materials, metallurgical science, and engineering academic programs as a way to address these challenges.

It is not without reason that we have argued the case for working alongside communities to solve problems in a participatory way, as the knowledge of the local community members is crucial for developing sustainable and just solutions. However, this effort makes it necessary to promote knowledge sharing throughout the entire problem-solving process within and between multiple fields, disciplines, and communities and it also exemplifies the importance of fostering sustainable networking pathways. Productive interactions between groups are fundamental to maximising the capacity to collaboratively find a viable, just, and long-term solution to community problems. To understand effective knowledge sharing, we argue that studying groups that are already doing this successfully is essential. Uniminuto, a Colombian University, is a prime example of an academic institution striving to create a positive social impact and uplift the vulnerable communities. Through knowledge and experience gained in PCIS projects, they have developed the "Social Innovation Route Framework"[40], a five-stage framework outlining community engagement projects, which is a powerful tool that academic institutions, especially those related to engineering and design, can utilise to take a proactive role in (1) working with vulnerable groups to improve their labor and environmental conditions and (2) understanding the sociotechnical dimensions of their projects.

Our observations also reflect the benefits of educational proposals that combine engineering knowledge with concepts from the sustainable community development framework, which is based on the social sciences. Thus, the interdisciplinary approaches that motivate students to make a contextual analysis of their projects, including history, politics, ideology, ethics, and culture, influence the way in which they develop their inventions. These approaches could also bring them closer to the Latin American context without falling into methodologies of the North-South dominance.

To answer the questions that were raised in this work, we propose some additional areas for future research. First, there is a need for a deeper analysis of the US and Latin American science engineering curricula to understand the lack of urban mining content and identify synergistic opportunities with overseas academic entities. Second, further work needs to be undertaken to screen current educational programs in the US since our study is limited. Third, future efforts within the engineering education field should be focused on developing an outline of an Inclusive Urban Mining course with the insights from this research that could be then included in the US engineering programs. Fourth, additional topics that should supplement the study of inclusive urban mining should be identified. Some topics that we believe could be beneficial to include are understanding the material politics of what is traditionally viewed as "waste" as well as learning social science approaches, such as contextual and empathetic stakeholder engagement strategies, to properly understand cities and their context.

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Development of a smart computational tool for the evaluation of co- and by-products in mining projects using Chovdar Gold Ore deposit in Azerbaijan as a case study

Despite their significance in numerous applications, many critical minerals and metals are still considered minor. Since most of them are not found alone in mineral deposits, their co- or by-production depends on the production of base metals and other major commodities. In many cases, the concentration of the minor metals is low enough not to be considered part of the production. Hence, their supply is not always secured, their availability decreases, and their criticality increases. Many researchers have addressed this issue, but no one has set actual impact factors other than economic ones that should determine the production of these minor commodities. This study identified several parameters, the number and diversity of which gave birth to developing a computational tool using a multi-criteria-decision analysis model based on the Analytical Hierarchical Process (AHP) and Python. This unprecedented methodology was applied to evaluate the production status of different commodities in a polymetallic deposit located in Chovdar, Azerbaijan. The evaluation outcomes indicated in quantifiable terms the production potentials for several commodities in the deposit and justified the great perspectives of this tool to evaluate all kinds of polymetallic deposits concerning the co- and by-production of several minor critical raw materials.

From the Ages of Antiquity to the present day, humanity has exploited minerals and metals found on the Earth's crust. Prehistoric man is known to have used only a handful of metals including copper, iron, gold, silver, tin, and lead. Thousands of years later, the Industrial Revolution heralded an unprecedented age of rapid industrial and economic growth that was substantially driven by the exploitation of many more minerals and metals. Undoubtedly, the evolution of the modern world has played a significant role in the constantly increasing production of many more minerals and metals used to perform specialised functions or have found applicability in several new applications[1,2].

However, only few metals such as copper, tin, lead, and iron can be found in relatively high concentrations worldwide and are produced in relatively high volumes[3]. From a geological point of view, these metals can either be found alone or mostly as hosts in polymetallic geological formations. Unlike these "major" metals, there are "minor" metals occurring in polymetallic deposits in concentrations sometimes low enough not to be considered feasibly exploitable on their own[2,4]. These metals are deeply embedded in our high-tech products and despite their increasing demand, they are produced in relatively low volumes. In fact, several of these critical metals are recovered only as by-products from a limited number of geographically concentrated ore deposits, thus making their markets dependent on geopolitical strategies and raising concerns regarding their supply[2].

Several researchers have investigated this matter in detail. In 1979, Skinner[4] was one of the first to talk about the sustainable supply of minor metals and referred to possible resource limitations in the future. A few years later, Campbell[5] presented short-run supply curves for primary and secondary metals, indicating the individual behavior and the interconnection between primary, co-, and by-products in terms of their connected supply and the impact this has on their prices. Wellmer *et al*.[6] justified Campbell's theory and mentioned that many metals are produced exclusively as by-products of other minerals and metals, meaning that their production is strictly limited by the production of the "host" materials to which they are associated.

In recent years, research has intensified, given that new uses and applications for many more minerals and metals have been developed. Verhoef *et al*.[7] introduced a system of linked cycles in the form of a metals' wheel, showing metal linkages in natural resource processing while illustrating the capacity of available metallurgical processes dealing with impurities in their primary or secondary feed. Reuter *et al*.[8] introduced a different metal wheel showing the complex interactions between different metals and the economic and thermodynamic recoverability of (co-) elements. Buchert *et al*.[9] introduced a group of "green minor metals", emphasising their significant applicability in renewable energy resourcing, and how some minor critical metals are dependent on the mining development of major metals. Willis *et al*.[10] conducted research on critical by-products of copper, lead, zinc, and nickel with relatively small volumes of production.

Wellmer and Hagelüken[11] published their work related to the security of supply of secondary resources under conditions of economic viability and environmental sustain- ability. They introduced a feedback control cycle of mineral supply. Their "metal wheel" summarises the standard technologies for the metallurgical treatment of metal associations involving major and minor metals. The concentric rings of the wheel demonstrate the interconnectivity between the main metals as carrier metals and the co- and by-product metals. Inspired by Reuter *et al*. [8], Nassar *et al*.[2] introduced a periodic table of compan- ionability and their metal wheel version (**Figure 1**). In this wheel, the principal host metals form the inner circle, while companion elements appear on the outer circle at distances proportional to the percentage of their primary production.

Efforts have also been made to quantify the recoverable sources of by-product metals, in the case of cobalt[12] or the case of gallium, germanium, and indium[13,14]. It is worth mentioning that a Minor Metals Trade Association was founded in 1973, when by-product metals were starting to be used in growing mass applications. The Association was formed to guide those involved in the nascent minor metals industry and currently comprises companies from across the globe engaged in all aspects of minor metals activity.

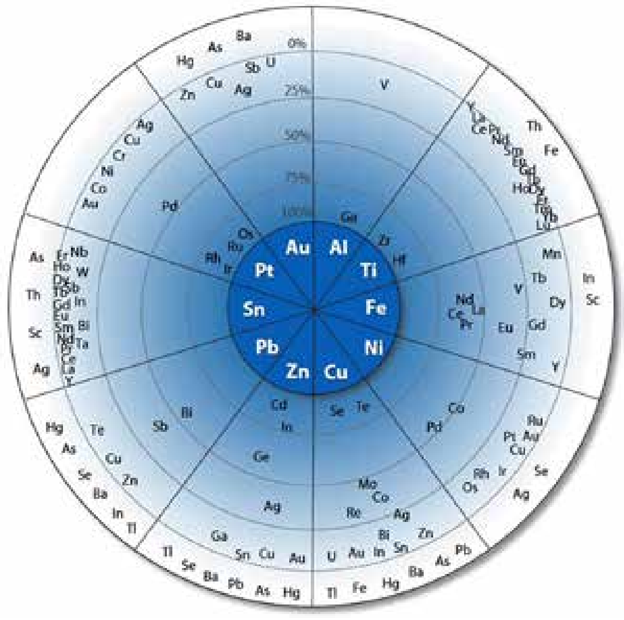


Figure 1: The wheel of metal companionability[2].

The interconnection of major and minor metals is undeniable, but so is the criticality of several minor metals. However, the concerns about the sustainable supply of critical metals are rarely considered. The selling prices, the additional product extraction costs, and the primary commodity market conditions determine the policies regarding co- and by- products in mining projects. Van Schaik and Reuter[15] tried to associate the sustainability of companion products by linking three core domains: the resource cycle (materials and energy), the natural cycle (society and environment), and the technology cycle (engineering and science). Although this work is mainly related to the recyclability of materials, it is the first effort made to connect the metal wheel with the other cycles. To quantify the recoverable resources of by-product metals, and specifically cobalt, Mudd *et al*.[12] mentioned a few key parameters to make a realistic estimate of anticipated companion metal availability. The authors focused not only on the economic aspects but also discussed the recovery efficiencies for the minor metals and the benefits of companion metal recovery. Frenzel *et al*.[13,14] also mentioned the impact of new processing technologies on the by- product production of gallium, germanium, and indium. In other studies, the development of technology has been mentioned to increase by-product recovery efficiency or even reuse waste tailings to recover metals such as rare earth elements[16-18].

Valero *et al*.[19] adopted the concept presented by Mudd *et al*.[12] and mentioned that even a single metal may be treated differently within a mining project based on differing grades and quantities. However, their focus was mainly on factors such as the tonnage and commercial prices of commodities. Finally, Renner and Wellmer[20] discussed the impact of volatility drivers on the metal market of both major and minor metals across the globe. According to this study, volatility can result from the fluctuation of commodity prices and political instability, market speculation, and policy responses. Hitch *et al*.[21] mentioned that the treatment of wastes is not only a matter of new technologies for the feasible recovery of metals but also because of their reactivity characteristics that raise environmental concerns. Thus, waste may turn into a valuable by-product or material for alternative use, while, at the same time, environmental pollution can be prevented.

A series of global supply and demand changes lie at the heart of current developments. Research has shown that the supply of by-product elements is potentially riskier than that of primary elements because the economic health of their associated primary commodity market depends on their recovery[2,22,23]. These changes have led to increased calls for policy responses during the co- and by-production of such products, particularly the most critical ones. For instance, the use of several methods in waste management and the extraction of metals from waste has been expanded in the concept of the circular economy and zero waste production[24,25].

Several mining projects are discussed hereinafter in this study, in which the status of co- and by-products changed during mining operations and production due to several factors. Hence, in addition to costs and revenues, other parameters can also impact the co- and by-production decision before, during, or even after mining operations. However, there is no existing literature that deals directly with this issue. Hence, this work intends to cover this research gap by identifying all possible parameters that can impact the decisions regarding co- and by-product production. In addition to identifying, for the first time, all the impact factors, another objective was to evaluate them in an unprecedented quantitative way overall. This is because the conditions in any mining project vary, and so does the significance of the different parameters. For this reason, a multi-criteria decision analysis technique (MCDA), namely the Analytical Hierarchical Process (AHP)[26], was implemented in the developed methodology, to evaluate all the criteria simultaneously.

Initially, the AHP calculations were undertaken using Microsoft Excel. Nevertheless, the vast number of identified factors and the complexity of the co- and by-production assessment stimulated the development of a new computational tool using Python. The computational power makes this novel tool easier and faster to use while increasing its flexibility by allowing the user to adjust the number of evaluation parameters according to the conditions of any mining project. The final objective of this work was to apply these parameters and their evaluation to a mining case study in Chovdar, Azerbaijan, where a polymetallic deposit based on gold production is exploited. The justification of the methodology through the specific case study denotes the significance of this work.

The purpose of this paper is to present an innovative easy-to-use computational tool that can be applied to any polymetallic project, assist stakeholders to make proper decisions regarding co- and by-production, and thus contribute toward a more secure supply of several critical minor metals and a more sustainable mining industry.

LITERATURE REVIEW

A thorough literature review was conducted, regarding the status of primary and companion products, including of waste and tailings in many mining projects that had changed due to various reasons other than economic ones, thus impacting mining plans and production strategies.

Scandium Production from Red Mud

When the limited availability of a metal is combined with a sudden increase in demand and market volatility, there are several new reasons to proceed with production. This is the case with rare earth elements (REEs) and the extensive publicity they received after the REE crisis of 2011 when fears of supply disruption drove prices up nearly tenfold[27]. The crisis was short-lived, and the prices declined rapidly, but the criticality of REEs remained and, thus, new REE deposits were explored around the world. Parallel to this, several ongoing mining projects, in which rare earths already existed but in small concentrations and were characterised as waste, started investigating their possible production as co- or by-products, including from the waste rock and tailings. For example, rare earth elements, particularly scandium, are occasionally found in bauxite residues, also known as red mud[28,29]. The concentration of rare earths in bauxite residue may vary between 500 and 1700 mg/kg[30]. The increasing importance and the newest developments in processing technology made some mining companies rethink producing REE from waste. For example, a pilot plant is under construction in Greece to investigate the efficiency of leaching and ion exchange on an acid basis to recover scandium from red mud[31,32]. Similar research is being conducted in China[33].

Borates and Lithium Mining

Similarly, the demand for lithium has increased since its application in batteries has proved highly efficient[34-36]. The exploration boom for battery raw materials included investigations of tailings. Rio Tinto has mined borates in California, US, since 1927 and has recently commenced the production of battery-grade lithium from waste rock at a lithium demonstration plant, being the first top diversified miner to add lithium output to its portfolio, and enhancing the idea of re-evaluating waste rock and tailings[37]. Given the dynamic market of several minor metals, the advanced developments in processing technologies and the need for less waste production, even more producers are reconsidering the possibility of treasures hiding in their tailings. Even tailings from mines having seized operations could also be exploited to recover precious metals, treat the tailings, and mitigate further environmental pollution caused by acid mine drainage. Projects are working toward this direction, such as the Penouta mining project in which tailings are being investigated to recover tantalum and niobium[38], or the Tiouit gold-silver-copper mine in Morocco, where the desulfurisation of the old tailings has been investigated[39].

Mercury Extraction

In modern mining, preserving the environment is considered a top priority. Thus, in addition to the treatment of tailings, dangerous elements such as naturally occurring radioactive materials (NORMs) and toxic elements also receive special treatment. Some of these, such as uranium, thorium, and mercury, are extracted from the waste and treated as by-products even in low non-profitable concentrations. In 1997, Garcia-Guinea and Harffy published a paper in the journal Nature with a questioning title about whether

Table 1: Potash and salt production history in German mines.

Mine	Potash (KCl)	Potash ($MgSO_4$)	Rock Salt
Sondershausen	1893-1991		2004-today
Sigmundshall	1898-2018	2001-2018	
Bernburg	1900s-1973		1939-today

mercury mining is undertaken at a profit or a loss[40]. The paper argued how mercury prices have dropped since the 1960s due to many environmental and health problems caused not only by its mining but also by the metal itself. Several publications about mercury pollution[41-43] have built a legacy about how dangerous this element is. Mercury is found mainly in China, Spain, and California, US. The mining district in Almaden, Spain, used to be responsible for 25% of the world's production until operations stopped in 2001 due to the prohibition of mercury mining in Europe[43]. By-product mercury production is expected to continue from large-scale gold–silver mining and processing. There are also reports of small-scale, artisanal mining of mercury in China, Russia (Siberia), Outer Mongolia, Peru, and Mexico[44].

Marble Quarrying

Primary, co-, and by-products can also be produced from the same commodity but with different quality standards, and different selling prices for different applications. A typical example is steel slag, a by-product of steel making produced during the separation of the molten steel from impurities in steel-making furnaces. Generally, this may not be the case for many metals, but it can be a significant parameter for several industrial minerals, and construction materials in different shapes, sizes, textures, and weights. Marble, for example, is a dimension stone that is either sold as a whole block or cut into tablets. The size of the block or tablet and the purity of marble are quality standards that affect the price of the final product. Blocks that do not meet the quality standards are crushed, milled, and roasted to become dry pulverised products in different grain sizes. These marble dust and calcium carbonate powders (fillers) are sold for different industrial applications. Dionyssomarble in Attica, Greece, has a long history of exploiting white marble deposits[45]. However, not all products were produced from the beginning. Since 1975, the company has expanded its processing facilities and produced exceptionally clean, aggregate crystalline calcium carbonate powder filler in controlled granular sizes.

Salt and Potash Rotating Production

Production of some metals such as iron, and some industrial minerals such as salt and potash, can be determined by local demand and supply conditions. Layers of salt and potash follow in geological formations such as bedding planes[46] and can be mined either together or successively. Their co-production flourished in Germany during the 1950s, in the aftermath of World War II, when the reconstruction of the country was at a peak. The German car industry was booming, and the national road network increasingly comprised paved roads. However, the newly paved roads were icy during winter, making driving dangerous. Authorities applied an effective de-icing procedure using salt to clean the roads[47,48].

Production of salt and potash in Germany has focused either on the one commodity or the other, depending on a series of factors that can alter their priority and, in turn, the classification of the two commodities as primary, co-, or by-products. In Sondershausen, Germany, potash production (KCl) started in 1893 and stopped in 1991 (**Table 1**) due to economic and political reasons (German reunion). However, salt production for de-icing started in the mine in 2004 and continues today[49]. At the Sigmundshall mine, potash production started in 1898, and after 2001, additional production of "Special" potash (MgSO4) took place and expanded the life of the mine (**Table 1**). The recoverable reserves were depleted in 2018 and the mine finally closed[50]. Furthermore, the Bernburg mine started producing potash in the 1900s and, from 1939, started also producing rock salt. In 1973, the mine stopped producing potash and focused only on salt because a neighboring mine in Zielitz had started potash production in 1969[51].

Production History of a Silver-Based Polymetallic Deposit

Moving to the eastern part of Germany, we discuss the exploitation of the polymetallic deposit in Freiberg and how different parameters have affected the change in co- and by-products through time. The lead-zinc deposit in Freiberg was discovered in 1168, and it initially attracted interest for

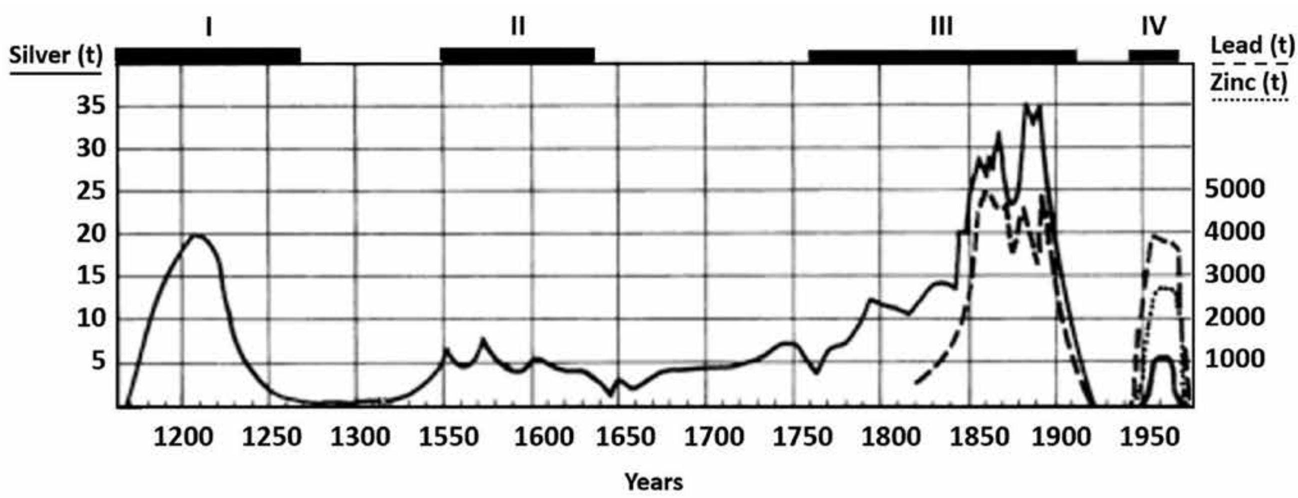


Figure 2: The history of production in Freiberg (modified after Bayer[53]).

its mineralisation-bearing silver. Silver was the only mining product until the 18th century. In 1710, the General Melting Administration was founded. Since then, the revenues have also been based on the content of copper and lead[52]. The latter, and the further development of the metallurgical technology, resulted in commencement of the production of lead officially as a by-product in approximately 1820 (**Figure 2**).

The decline of Freiberg's silver mining began with the introduction of gold currency (Goldmark) in the German Empire by law in 1873. The price of silver decreased by half from 1880 to 1898 due to silver deliveries from South America. The prices of by- products lead and zinc decreased massively due to overproduction worldwide. Hence, from 1903-1913 it was decided to shut down all mines[53]. However, due to the preparations in Germany for World War II, there was an increased demand for non-ferrous metals from 1933 onwards. Therefore, from 1935, Freiberg mining resumed. Lead and zinc became the primary commodities for geostrategic reasons, while silver was mined as a by-product. After the end of the war, the mining and metallurgical plants were nationalised in 1961 and closed for economic reasons in 1969[53].

Coal and Uranium Rotating Production

Not far from Freiberg, in the Döhlen Basin, coal (initially) and uranium (afterwards) were produced from the same mine site. Mining for hard coal in the area is known to have taken place since the 15th century with rural extraction[54]. Until 1930, small mining companies exploited the area for coal. In 1947, however, SAG/SDAG Wismut started mining uranium bound to hard coal for nuclear armament purposes of the former Soviet Union. Mine ownership alternated between Wismut and the local hard coal mining companies several times. The mining of hard coal for energy purposes stopped in 1967. In 1968 the mine was transferred for one last time to SDAG Wismut. From that time on, until 1989, coal was only mined for its uranium content[54].

MATERIALS AND METHODS

The research methodology developed in this work was initially based on collecting and analyzing information and data from a substantial quantity of literature sources and actual mining projects, some of which have been discussed in the previous sections. What is specific about these mining projects is that, through the years of mining operations and production, the status of their co- and by-products changed due to several factors. These data sets were then used to identify and classify all possible factors that can impact the determination of primary, co-, and by-products in a mining project.

The substantial number and diversity of criteria led to using a multi-criteria-decision- analysis (MCDA) process such as the Analytical Hierarchical Process (AHP) to simultaneously evaluate all the parameters. This MCDA technique has been used in making decisions based on multiple criteria in numerous case studies from a wide range of disciplines.

Depending on the different conditions of any given mining project, these parameters have different levels of importance each time. Therefore, AHP compares the factors and applies weights to them. Accordingly, the multiple final options for each product can also exist. Thus, AHP was further applied to prioritise the final decisions, calculate percentages, and indicate which are preferable on every occasion. As a result, an MCDA tool was developed that can be applied in the evaluation of any polymetallic mining project to determine the main, co-, and by-products. The developed algorithm was computed with the help of Python to create a smart computational tool that will help run the calculations faster and more efficiently.

Data and information from a polymetallic mining project were implemented in the newly developed MCDA tool to test its efficiency. The case study is a gold mining project in Chovdar, Azerbaijan, where gold is the main product, and silver and mercury are produced as by-products. Azergold is the mining company that runs the Chovdar open-pit mining project. The ongoing exploration has revealed additional resources that extend to a substantial depth. For this reason, the company is investigating the possibility of soon transiting to underground mining. Interestingly, in the additional discovered resources, there are a series of other minerals and metals in lower concentrations than those of gold and silver. Accordingly, the developed computational tool was used to determine whether these minerals and metals can be defined as co- or by-products.

SETTING THE EVALUATION PARAMETERS

Based on the existing literature, the ore grade and the prices, costs, and reserves determine the revenues of a commodity in a mining project. In some mining projects, when additional resources are found, and the concentrations of some minor elements are significantly increased, this indicates that such elements' status may change from waste to by-product or from by-product to co-product. Parameters other than the price that can interact with the ore grade are the recovery rate during the processing of the ore and the environmental effects if the commodity with the high ore grade happens to be a toxic or radioactive element.

Hence, market, technological, environmental, and socio-political factors were identi- fied, in addition to the apparent economic parameters. The availability of a commodity is an important parameter directly associated with the supply of the commodity in the market, especially for minor metals, and depends on the mining production and processing of the primary commodities. The imbalances between metal supply and demand, actual or anticipated, have inspired the concept of metal criticality[55]. However, the criticality of a commodity is not only dependent on this one parameter. A detailed criticality evaluation includes data from widely varying fields and sources of information, including geology, mineability, technology, the environment, human behavior, the assessment of experts, and many more. Thus, environmental implications, lack of efficient processing techniques and capacity, vulnerability to supply restrictions, and geopolitical issues are some of the most critical factors affecting certain commodities' criticality.

Like the two parameters mentioned above, the market volatility of a commodity is another equally significant factor that can determine the production status of metals. When the limited availability of a commodity is combined with market volatility and a sudden increase in demand, then it seems that there are several new reasons to produce this metal. Finally, another market parameter that needs to be considered is the local demand for commodities and how this can affect their production status.

The local demand is not a factor that applies to most metals traded worldwide. How- ever, it would undoubtedly affect

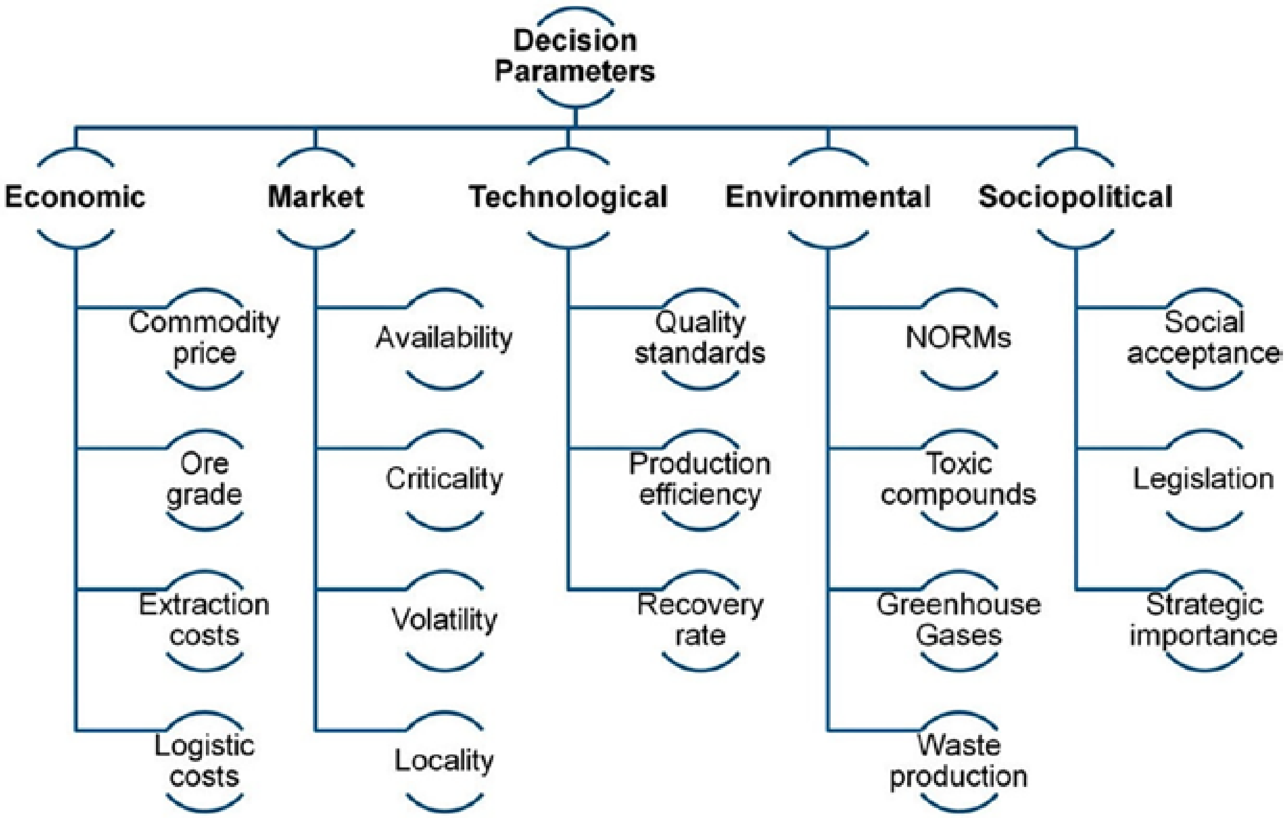


Figure 3: Classification of the parameters for the of co- and by-products production.

minor minerals and metals that could be produced as by-products, contribute to the revenues, lower the waste production and disposal, and finally meet the demands of local societies. The locality of a mining product is directly related to the extraction and logistic costs, prices, and socio-political factors.

Through technology, the mining industry has overcome many obstacles. New options for increasing productivity are being generated by the evolving technology of the mining industry[56]. A significant technological factor regards the quality standards that a product shall meet to be determined as a primary, co-, or by-product, or waste. It may seem this parameter does not apply to many metals but only to some industrial minerals and dimen- sion stones, as shown in the literature review. However, even regarding the processing and refinement of metal alloys, if the end products do not meet the quality standards of the market or a specific customer, then their value is depreciated, and their feasible production may well be at risk. Low production efficiency can affect extraction costs, not to mention the quality standards. High production efficiency can boost the feasible production of minor and low concentration elements in a deposit and determine them as potential by-products. Most importantly, increased production efficiency offsets declining ore grades and mining cost inflation that threaten the mining industry. In addition, the metal recovery rate, also known as the mineral recovery percentage, indicates the percentage at which valuable metals are expected to be available for sale after the refining process has taken place.

Mining will always impact people and the environment, either positively or negatively. The presence and content of NORMs and other toxic compounds can entail high environ- mental risks and may require particular attention and close monitoring[57]. Such metals require special treatment either as products or waste, and, even though they are usually found in small concentrations, it is often cheaper to process them as by-products rather than treat them as waste. Another group of potential contaminators is that of the greenhouse gases responsible for the greenhouse effect primarily associated with coal mining[58,59]. An additional factor interconnecting with the presence of NORMs and toxic compounds from the extraction of minerals and metals regards the treatment and disposal of wastes and tailings[60].

Evaluation is also needed of the “mining friendliness” of the commodities produced in a mine. Not all commodities are easy and environmentally friendly to extract. Some elements have gained a reputation for being extremely hazardous when mined. Even when the actual risk of contamination is low due to insignificant concentrations or when the actual contamination is minimised due to sufficient safety measures, opposition to mining-specific commodities can be substantial. In fact, the mining industry considers the Social License to Operate as the most important business risk to be revoked by local communities if unsatisfactory conditions occur[61,62].

Therefore, the social acceptance of extracting specific commodities in a mine is an essential factor. It is also significant to evaluate the legislation status that governs the mining industry in a country and the specific legislation acts that may support or prohibit the production of specific commodities. Finally, the strategic importance of specific commodities is an important factor that should never be neglected. The classification of a metal as strategic and critical not only for economic but also for political and strategic reasons may influence its production status from waste to a by-product or even co-product. The strategic importance of a commodity can affect the criticality, availability, and volatility of its market, not to mention its price. It can also affect the social acceptance and amendment of legislation related to its production.

Accordingly, 18 qualitative and quantitative parameters were determined and classi- fied into five categories according to the relevance of the criteria in the respective categories (**Figure 3**). Many of these parameters have never been considered before, and no similar classification has been introduced in the literature. Some of the parameters may overlap with others. At the same time, factors can be attributed to more than one of the main categories in which they are classified in their simultaneous evaluation. The clustered criteria are structured in such a way that, in each category, they do not exceed the number of 7 ± 2 because of the general limitations of the human mind, which is capable of handling only so many conceptual objects and discrete figures at a time[63,64]. Hence, criteria belonging to the same category can be easily evaluated and compared on a pair-wise basis.

The overall classification is hierarchical so that all criteria are rightfully prioritised. Nevertheless, depending on the deposit properties and the conditions of the examined mining project, not all criteria need to be evaluated in every case study. When a specific parameter is neutral or does not affect the product status determination, it can be excluded from the evaluation.

DEVELOPMENT OF THE DECISION TOOL

Whether a mining product is characterised as primary, secondary, or waste based on so many factors is a sophisticated process. Such a complicated problem needs to be decomposed into simple assessments without neglecting that some elements have a more significant impact on the decision making than others.

Decision making, in general, is explained as a selection process in which the best alternative is chosen from alternative sets to reach an aim or multiple aims. The process alone is not concerned with defining the objectives, designing specific alternatives, or evaluating consequences; decision making offers simple techniques and procedures to reveal preferences and choices in multivariable problems. Such techniques are described as multi-criteria decision analysis (MCDA) or multiple-attribute decision making (MADM). These techniques solve problems in which discrete alternatives can be selected from a finite set[65,66]. Existing MCDA methods include value measurement models, such as the Analytical Hierarchical Process (AHP) and Multiple-Attribute-Utility Technique (MAUT); goal-, aspiration-, or reference-level models, such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS); and outranking models, such as the Elimination and Choice Translating the Reality (ELECTRE) and Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) methods [65]. Each method has its strengths and weaknesses in different areas, and it is difficult to say one is better than another; ultimately, it depends on the specific problem that needs to be solved.

Considering the nature of the decision-making problem in this work, AHP was se- lected over the other MCDA methods. This technique is preferred for its ability to rank alternatives in order of their effectiveness when conflicting objectives or criteria must be satisfied[67,68]. Furthermore, AHP can detect inconsistent judgements and estimate their degree of inconsistency[67]. Moreover, the parameters

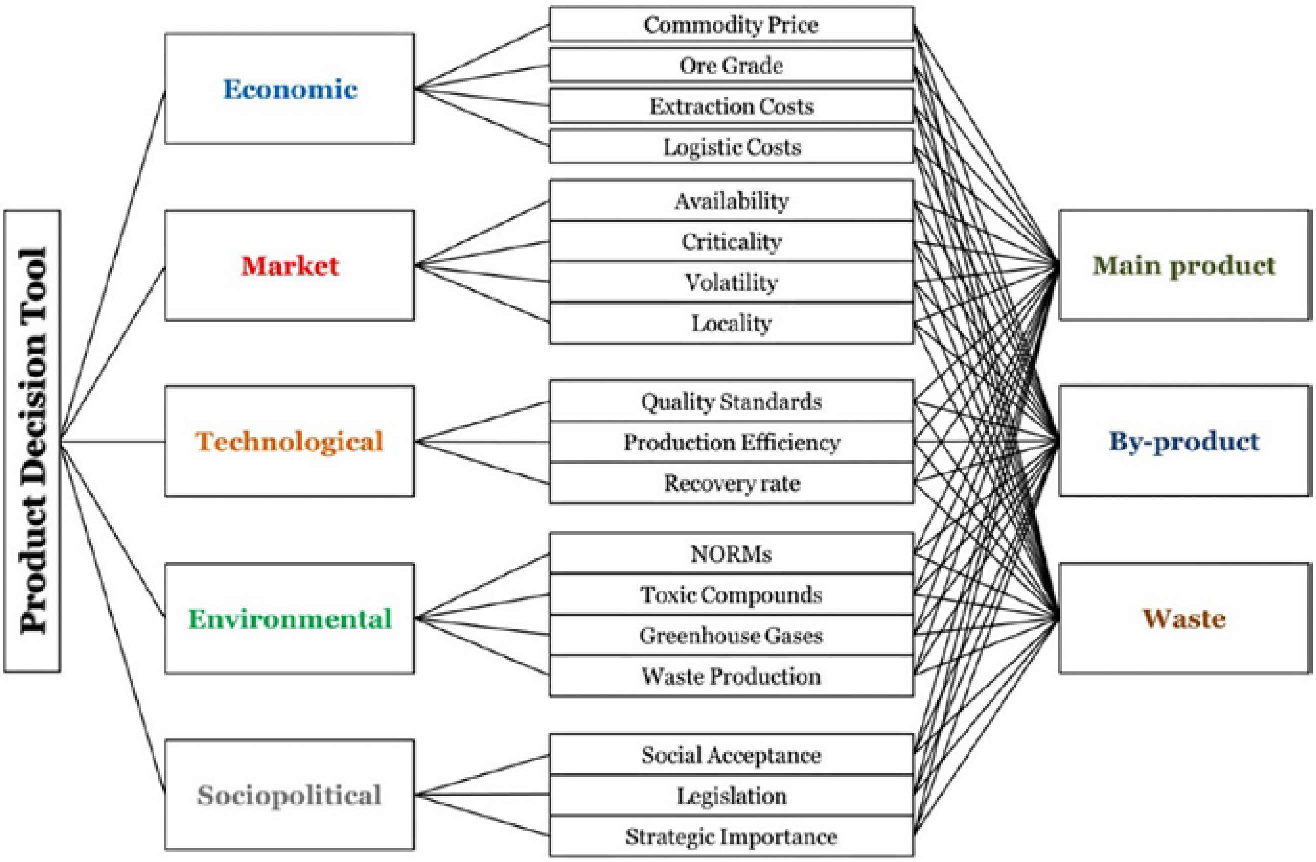


Figure 4: Hierarchy structure of the Product Decision Tool.

Table 2: Category names and codes.

Codes	Categories
ECO	Economic
MAR	Market
TEC	Technological
ENV	Environmental
SOC	Sociopolitical

Table 3: Criteria names and codes.

Codes	Criteria
C1	Commodity price
C2	Ore grade
C3	Extraction costs
C4	Logistic costs
C5	Availability
C6	Criticality
C7	Volatility
C8	Locality
C9	Quality standards
C10	Production efficiency
C11	Recovery rate
C12	NORMs
C13	Toxic compounds
C14	Greenhouse gasses
C15	Waste production
C16	Social acceptance
C17	Legislation
C18	Strategic importance

Table 4: Codes for the product options.

Codes	Categories
PRPRO	Primary product
BYPRO	By-product
WASTE	Waste

determined in the previous section are classified into separate categories, making AHP the ideal decision-making method to decompose the problem and build hierarchies of the individual criteria. Finally, the AHP preferences and pair comparisons can be easily computed.

Initially, the algorithm was developed in Microsoft Excel and later in the form of a Python computational tool to make the calculations faster and more efficient. The following sections discuss the development of the algorithm and the computational tool.

Development of the Product Decision Tool

The decision-making algorithm is mapped into a generic AHP hierarchy (**Figure 4**), in the order of the five categories, the 18 criteria, and the three product options. To facilitate easier data manipulation in the evaluation process, the categories, criteria, and options were coded (**Tables 2-4**).

The purpose of AHP is to assist decision makers in organising their judgements to make more effective product decisions by bringing the evaluation to the level of pair- wise comparisons of components with respect to attributes and alternatives. The AHP method uses both qualitative and quantitative variables, and it is not only useful for making decisions, but also for prioritising tangible and intangible criteria by setting weight factors on them. To make these comparisons, a fundamental scale introduced by Saaty[26] is used to indicate how many times more important one element is over another (**Table 5**). The result of the pairwise comparisons over n criteria is summarised in a $n \times n$ reciprocal matrix (**Table 6**), where elements represent the pair-wise comparisons. Each entry of the matrix represents the importance of one criterion relative to the other.

The next step is to compute the vector of weights based on the theory of eigenvector procedure in two steps. First, the matrix is normalised, and the criteria weight vector is then built. The sum of all elements in the weight vector is equal to 1 and shows the relative weights among the compared criteria. Since the comparison is based on subjective evaluations, the consistency of the comparisons is checked using a consistency index. If the degree of inconsistency in judgements is acceptable, the efficiencies

Table 5: The fundamental scale of AHP [26].

Relative Intensity	Definition	Explanation
1	Of equal value	Two elements are of equal value
3	Slightly more value	Experience slightly favors one element over another
5	Essential or strong value	Experience strongly favors one element over another
7	Very strong value	An element is strongly favored, and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another of the highest order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

Table 6: Pair-wise comparison matrix of the main categories.

	ECO	MAR	TEC	ENV	SOC	Weights
ECO	1	aeco,mar	aeco,tec	aeco,env	aeco,soc	weco
MAR	1/aeco,mar	1	amar,tec	amar,env	amar,soc	wmar
TEC	1/aeco,tec	1/amar,tec	1	atec,env	atec,soc	wtec
ENV	1/aeco,env	1/amar,env	1/atec,env	1	aenv,soc	wenv
SOC	1/aeco,soc	1/amar,soc	1/atec,soc	1/aenv,soc	1	wsoc

of all alternatives on a criterion are normalised to eliminate the effect of different units of measure. The matrix of the normalised efficiency outcomes is finally multiplied by the eigenvector to obtain the aggregated AHP priority score. The decision is then made based on the logic that the higher the AHP priority score for an alternative, the more preferable this alternative.

To ease the assessment process, pair-wise comparisons of the criteria are separately undertaken for each category. A pair-wise comparison of the categories is also undertaken to show their respective relevant importance. Hence, six matrices are generated but, for the sake of space, only the pair-wise comparison of the categories is illustrated in **Table 6**. This process applies weight factors to all categories and criteria.

Like probabilities, weights are absolute dimensionless numbers between zero and one. Depending on the problem, "weight" can refer to importance, preference, and likelihood, or the decision makers can consider another relevant parameter. Weights are distributed in a hierarchy according to their architecture, and their values depend on the information entered by users of the process[26]. The criteria weights and options are intimately related but need to be considered separately. The priority of the goal and the alternatives always add up to 1 (or 100%). This can become complicated with multiple criteria levels but, if there is only one level, their priorities also add to 1.

Two additional concepts apply when a hierarchy has more than one level of elements, like in this case where we have the categories and the involved parameters: local and global priorities. The local weights here (wi) represent the relative weights of the nodes within each closed group of siblings (criteria) concerning their parent (category). These local priorities of each group of criteria add up to 1.000 or 100% (**Equations 1** and **2**). The global weights (gwi) are then obtained by multiplying the local weights of the siblings (criteria) by their parent's (category) global priority (**Equation 3**). Hence, the global weights for all parameters in the level add up to 1 or 100% (**Equation 4**).

Equations 1

$$w_{eco} + w_{mar} + w_{tec} + w_{env} + w_{soc} = 1$$

Equations 2

$$w_i + w_{i+1} + \ldots + w_n = 1$$

Equations 3

$$gw_i = w_{zzz} \times w_i$$

Equations 4

$$gw_i + gw_{i+1} + \ldots + gw_t = 1$$

where:
n is the number of parameters in each category;
zzz represents each of the five categories (ECO, MAR, TEC, ENV, and SOC); t is the total number of criteria (in this case t = 18).

The next step is to compare all three options (primary or co-product, by-product, and waste) per criterion. This process will generate 18 3 × 3 matrices, the general version of which is illustrated in **Table 7**. The priorities (w_{yCi}) for the (y = 3) options are calculated with the same procedure as for the categories and criteria. Consequently, the weights in each matrix calculation add to 1.

Table 7: Pair-wise comparison matrix of the options with respect to criterion Ci.

	PRPRO	BYPRO	WASTE	Weights
PRPRO	1	$a_{prpro,bypro}$	$a_{prpro,waste}$	w_{1Ci}
BYPRO	$1/a_{prpro,bypro}$	1	$a_{bypro,waste}$	w_{2Ci}
WASTE	$1/a_{prpro,waste}$	$1/a_{bypro,waste}$	1	w_{3Ci}

Each weight (w_{yCi}) is multiplied by the global weight (gw_i) of the respective criterion and summed to the score for each option (**Equation 5**).

Equations 5

$$OPTION_y = (gw_i \times w_{yCi}) + (gw_{i+1} \times w_{yCi+1}) + \ldots + (gw_t \times w_{yCt}) = 1$$

The outcome for all preferences indicates which product option is the most suitable. The sum of all options is equal to 1 or 100%. The stronger an option, the more apparent the decision that needs to be made. However, when two options are close to each other, more detailed evaluations may need to be made.

The procedure is separately conducted for each mineral or metal. It needs to be individually repeated for all minerals and metals, indicating whether each should be considered a primary product, co-product, or by-product, or be treated as waste. The criteria and the options are evaluated (comparing pairs) without neglecting the priority and importance of any categories or parameters. The classification is done according to the relevance of the criteria in the respective categories, even though some parameters could be included in other categories, and several criteria are interconnected. Depending on the properties of the element under evaluation and the conditions of the examined mining project, not all criteria need to be evaluated. When a specific parameter is neutral or does not affect the product selection, it can be excluded from the evaluation.

This was an issue during the initial development of the algorithm in Microsoft Excel. Changing the tool's structure by adding or excluding criteria to meet the conditions of each element or project under examination required time and effort. This problem was solved with the development of the Python computational tool, which will be discussed in the following sections. Another solution was to modify Saaty's fundamental scale (**Table 4**). While keeping the general structure of the scale the same, the assigned relative densities of unusable parameters can be rearranged to acquire the lowest possible weights. The same adjustments can be made during the evaluation of the options. The consistency of the calculations can be checked again after the rearrangements.

Development of the Computational Tool

The next step was to convert the developed algorithm to Python Code and use Tkinter, which is the standard graphical user interface (GUI) library for Python, to build an easy- to-use and fast-calculating computational tool. The developed tool uses three types of input data: general input data, data based on the number of categories and criteria, and data based on the number of options. The categories and options numbers are the primary input values (**Figure 5**); other input variables, including the names of categories, number of criteria, and names of options, are dependent on the primary input values (**Figure 6a,b**). Next is the comparison of the categories and criteria in pairs in the generated n × n matrices. The reciprocity of the matrices allows for the automatic generation

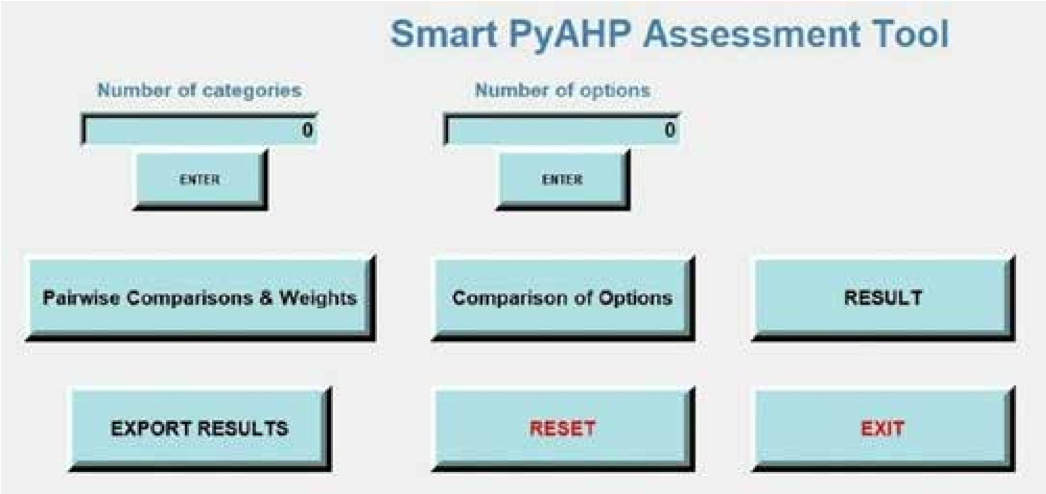
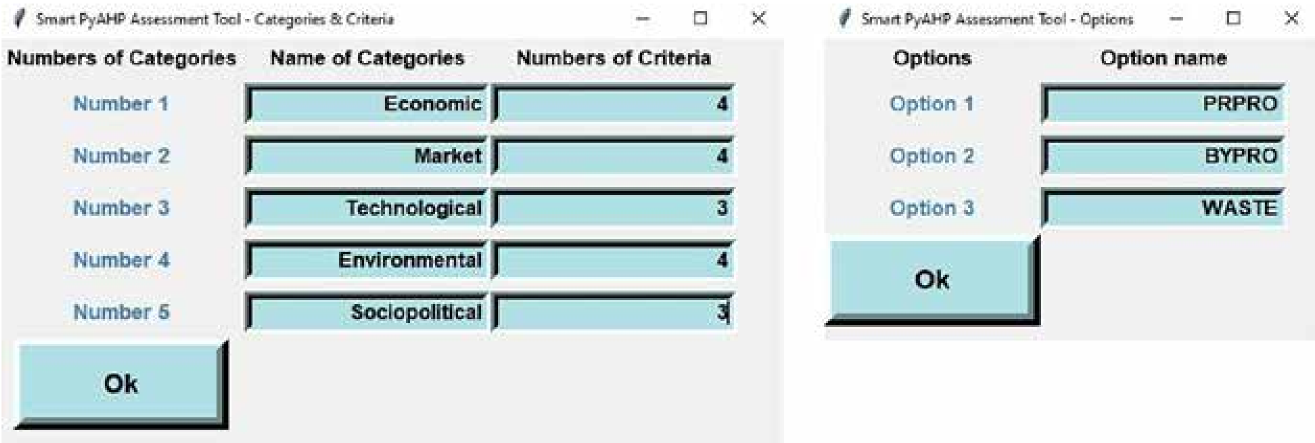


Figure 5: Main window of the computational tool.



(a) (b)

Figure 6: Insertion of: (a) the names of categories and numbers of criteria; (b) the names of options.

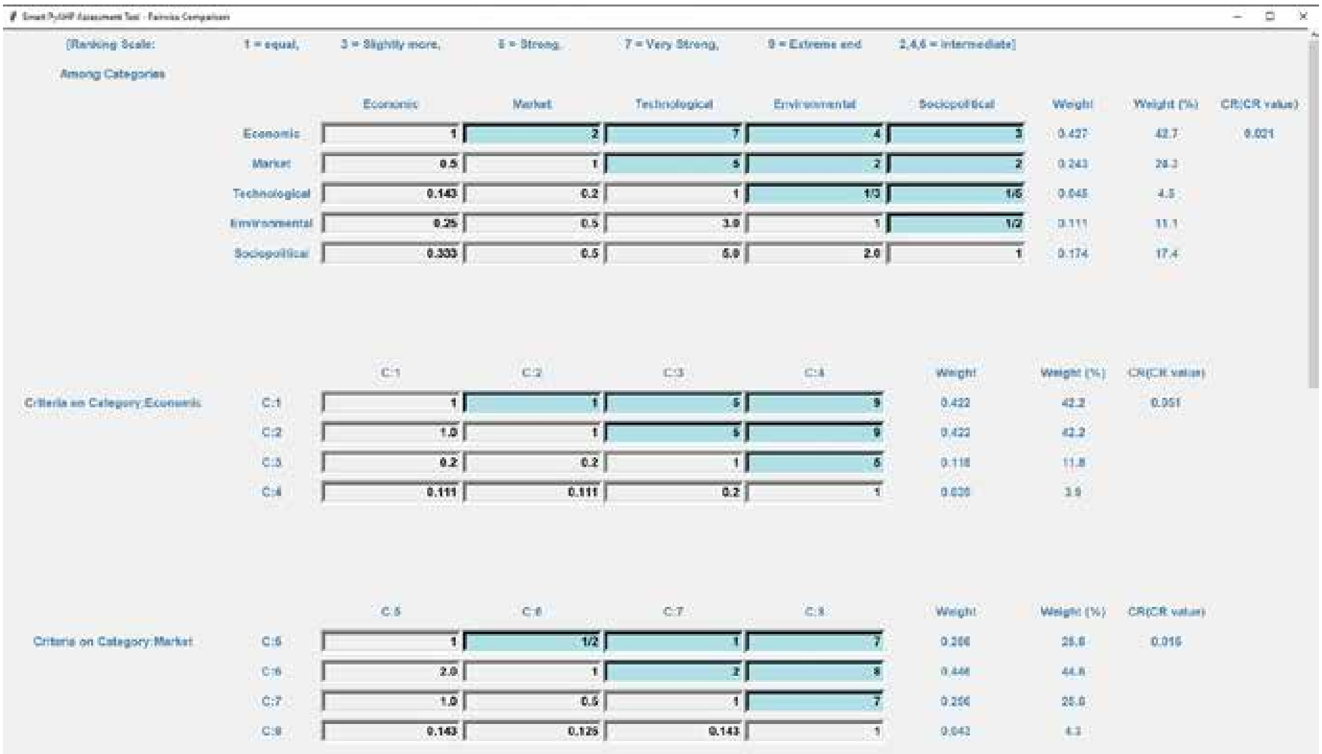
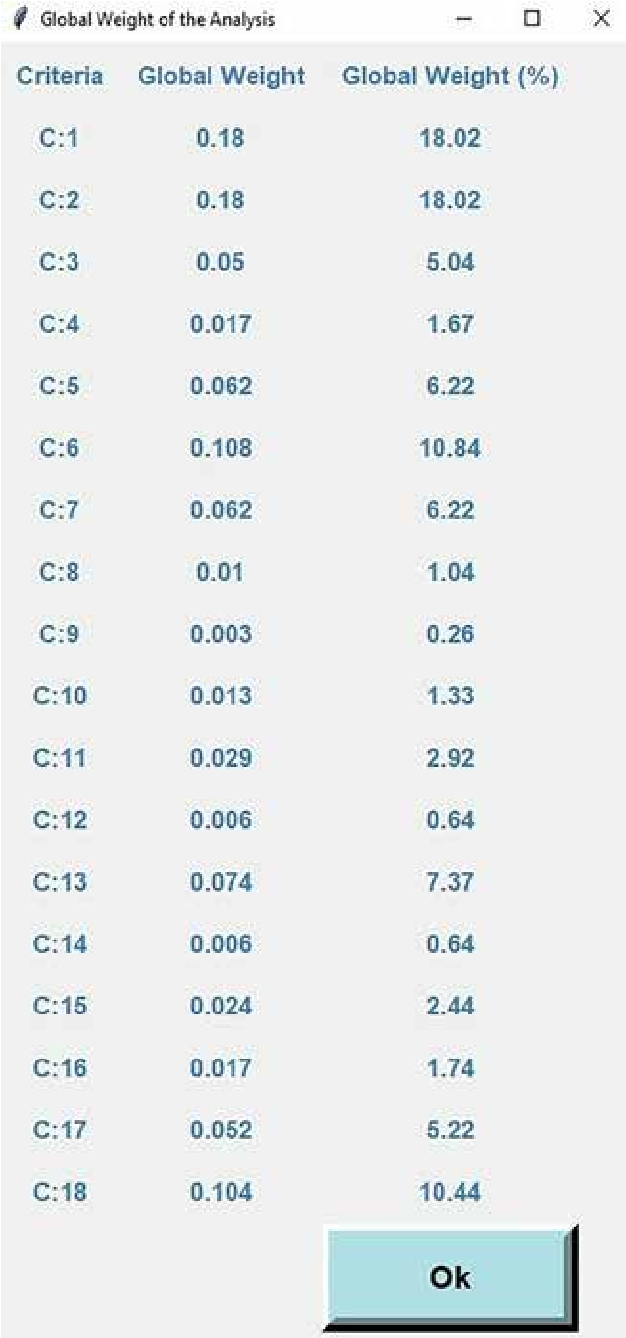


Figure 7: Pair-wise comparisons inserted in the generated matrices.



Global Weight of the Analysis

Criteria	Global Weight	Global Weight (%)
C:1	0.18	18.02
C:2	0.18	18.02
C:3	0.05	5.04
C:4	0.017	1.67
C:5	0.062	6.22
C:6	0.108	10.84
C:7	0.062	6.22
C:8	0.01	1.04
C:9	0.003	0.26
C:10	0.013	1.33
C:11	0.029	2.92
C:12	0.006	0.64
C:13	0.074	7.37
C:14	0.006	0.64
C:15	0.024	2.44
C:16	0.017	1.74
C:17	0.052	5.22
C:18	0.104	10.44

Ok

Figure 8: Generation of the global weights for all criteria.

Smart PyAHP Assessment Tool - Final Result

Option Name	Final Result	Final Result(%)
PRPRO	0.699	69.9
BYPRO	0.231	23.1
WASTE	0.07	7.0

Ok

Figure 9: Generation of the references for all three options.

of half the inputs. In addition, the user can insert fractions when the comparisons favor the second parameter over the first (**Figure 7**). In AHP, pairwise comparisons can be made by more than one decision maker, and a geometric mean can be used to consider all the options.

The tool generates the local and global weights for all criteria (**Figure 8**) and checks the consistency of the comparisons. Separate calculations are made to evaluate the three options for each weighted criterion. The overall process output is given in percentages of preference for each of the three options (**Figure 9**). Hence, the user can identify the preferences for the mineral or metal under investigation as a potential primary, co-product, or by-product, or if it shall be treated as waste.

The computation of an AHP algorithm in Python is a sophisticated process carried out under various functions' directions (**Figure 10a**). Several lists and dictionaries were required to overcome the calculations' complexity, considering that local and global weights had to be generated and consistency had to be checked (**Figure 10b**).

The outcomes of all calculations can be exported in CSV files and further processed in Microsoft Excel. The next step toward optimising the developed tool is to allow the user to insert data from CSV or ASCII files.

RESULTS AND DISCUSSION

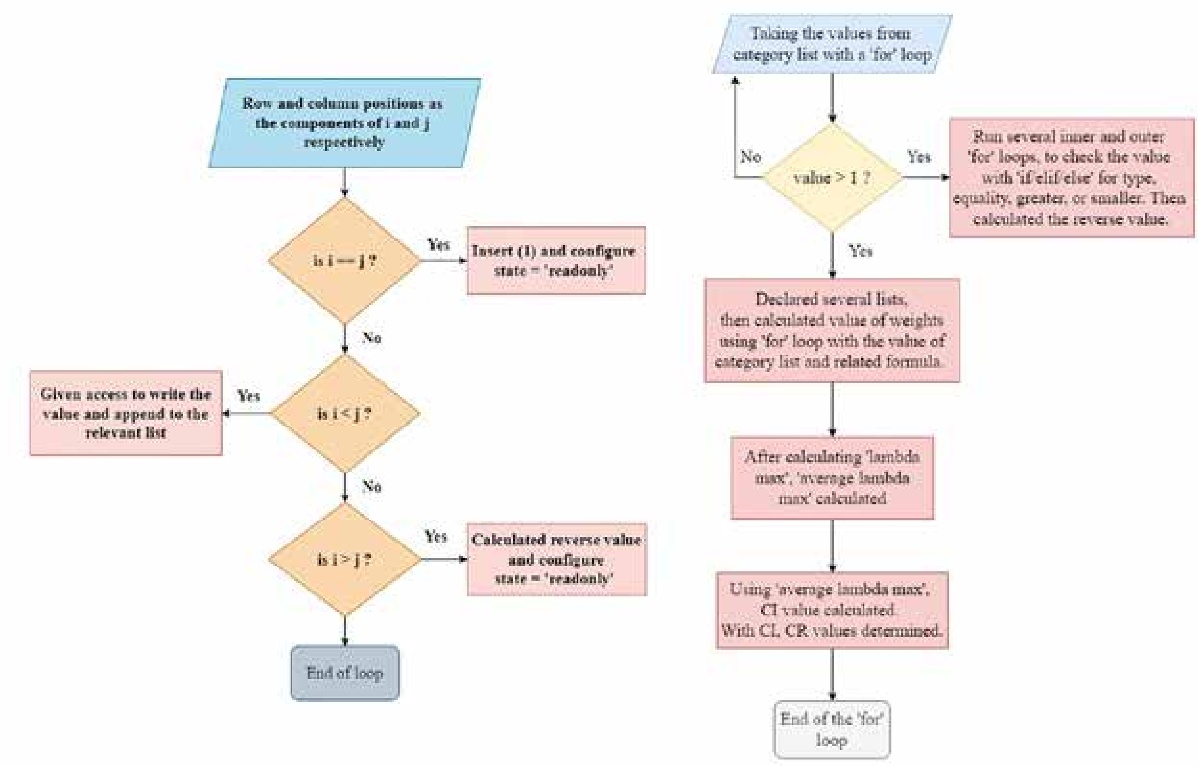
Following the theoretical development of the AHP decision tool, the assessment of one case study is described in this work. The Chovdar gold mining project in Azerbaijan was selected for the application of the computational tool. Gold is the main product of this mine, and silver is a by-product. However, detailed exploration activities have revealed the presence of other minerals and metals in smaller concentrations.

The exploitation is scheduled in two phases; the first phase has already started, and surface mining is applied, while a feasibility study is also being prepared for the second phase, in which exploitation will transition to underground mining operations. The concentrations of all metals other than gold and silver are insignificant during the first phase. However, in the second phase, the resources to be mined include higher concentrations of metals such as copper, iron, and bauxite. It has not been clarified whether the mining company – Azergold – will exploit these additional elements as co- or by-products. Hence, applying the developed tool in this case study may significantly contribute to the actual decision making.

All authors' calculations and assessments were made together and are based on publicly available data and information provided by the managers, engineers, and personnel of Azergold during a three-month internship (September–November 2019) of the first author at the mine site in Chovdar, Azerbaijan. Feasibility Study and Environmental Impact Assessment reports for the deposit are pending and, thus, not enough technical and economic data are available for a more precise assessment of the potential products. Nevertheless, existing data can yield a first good estimation for all commodities.

The Chovdar Polymetallic Deposit in Azerbaijan

Chovdar is known as a sizeable gold-sulfide deposit discovered relatively recently (in 1998) and run by zgr/tonne of gold. The exploration results resulted in exploiting the mineralisation in two phases. Phase One is toz ezploit the oxidised mineral reserves from an optimised open pit, and Phase Two is to



(a) (b)

Figure 10: Flowcharts for: (a) generating matrices to input and collect values; (b) the calculation of weights and consistency indexes.

develop an underground mine to subsequently exploit the remaining oxidised mineralisation and sulfide mineralisation[69].

The Chovdar process plant is located approximately one kilometer south of the open pit. It comprises the entire treatment process from ore size reduction, beneficiation, heap leaching, carbon processing, electro-winning, refining, cyanide recovery, copper recovery, and, finally, cyanide destruction before tailings discharge[69]. The end-product is in the form of gold-silver alloys, shipped to Switzerland for further processing[71]. Although present in low concentrations, mercury cannot be disposed of as waste on-site; thus, it is also shipped off-site. Further mercury data are unavailable due to confidentiality restrictions of the company.

Exploration continues through the strategic phases of thorough assessment and evaluation during the life of a mine. Azergold has started geophysical and drilling operations to increase the reserves on the near and far flanks of the deposit. An interesting piece of information to note while transitioning from the oxide to the sulfide phase is the changing of concentration percentages in several metals found in the mineralisation of Chovdar. Gold is the main product, silver is mined as a by-product, and mercury is extracted as waste. Various metals such as copper, iron, zinc, and aluminum, among others, are found in relatively low and uneconomic concentrations[69,71].

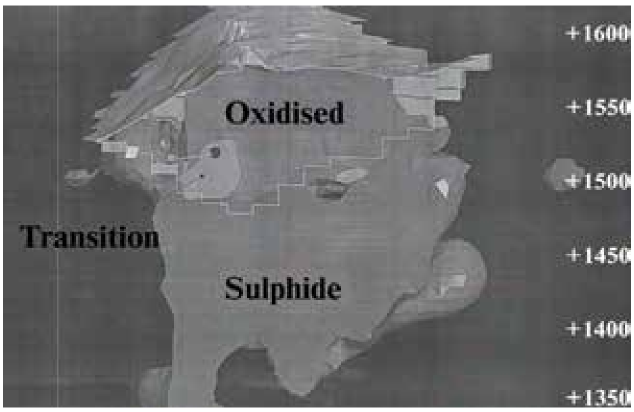


Figure 11: Scheme of oxidised primary sulfide and mixed ores' location of Chovdar field[70].

However, in the sulfide phase, the concentration of some minor metals is increasing to be significant enough, and should attract the attention of the project managers and make them reconsider their production. A detailed analysis was carried out for the chemical composition of the elements based on samples. The gold content ranges from 0.65 to 3.85 ppm, and is the leading commercially valuable component in all considered samples. Silver, having content ranging from 2.5 to 23.2 ppm, is particularly interesting for the following extraction. Moreover, a relatively high content of copper (0.825%) has been revealed in some samples. This suggests the possibility of the subsequent efficient extraction of the metal from the primary-sulfide ore types of the deposit[70]. Similarly, increased grades of iron and aluminum indicate that further techno-economic analysis should be undertaken for the potential production of these elements. Raising iron and aluminum ore grades may not be as economically attractive as for copper, but it certainly should attract the interest of the project managers.

The transition from the oxide to sulfide phase will probably require a significant change in the processing method. Gold particles in the sulfide phase are mostly encapsulated in pyrite and, thus, are not amenable to cyanidation. Pre-oxidation of the pyrite was necessary to liberate gold particles or provide a path for cyanide to contact the gold. This will probably require the process plant to be modified before sulfide exploitation.

Evaluation of Products in the Chovdar Mining Project

Six potential products were individually evaluated: gold, silver, copper, iron, alu- minum, and mercury. Based on the history of production during the oxidised phase, gold was the first commodity to be evaluated, followed by silver. Assessments of copper, iron, aluminum, and mercury were then conducted. Once each metal was evaluated, the results were also considered for the following commodities' assessment.

In each evaluation, the first action is to prioritise the categories between them and then separately make cross-comparisons of the criteria in each category. Hence the global weights are generated for all parameters. Then, the three options for each commodity (primary product, by-product, waste) are evaluated for suitability to the respective metal concerning every parameter. Finally, options preferences (in %) are calculated for each commodity. **Table 8** discusses the global weights calculated for all potential products.

The evaluation of gold indicates that the economic parameters are considered with the highest priority, and the market and sociopolitical factors follow in percentages. The environmental criteria are relatively less important, and the technological parameters are ranked last. The price and grade of gold in the deposit are the most significant factors, followed by its criticality and strategic importance. The toxic compounds used in the processing (cyanide) also seem to have a remarkable impact on the evaluation.

These results seem logical since the ore grade of gold in Chovdar (2.39 gr/tonne) can be characterised as high for an open-pit mining operation and the average grade for an underground mining operation. The criticality of gold is prioritised to be high enough; its value as a metal makes it always a critical commodity of great strategic importance. It is interesting to note that the technological parameters are low. This can be explained by the fact that the recovery rate is already high enough, and the metallurgical tests and evaluations for the extended processing plant show excellent results.

Data and information derived from the evaluation of gold were also considered for the assessment of silver. This kind of information includes the facts that gold will most probably remain the main product at Chovdar, all costs will be covered by gold production, and silver will continue being shipped together with gold for refinement to Switzerland. Like gold, silver's price and ore grade are essential parameters to its criticality. The latter is higher than that of gold because of silver's by-production dependence on gold. Nevertheless, the grade is high enough to make silver production efficient and is combined with the commodity's importance. Silver may not be as powerful as gold, but it is also considered a strategic metal. The existence of toxic compounds during processing is also of notable priority.

Copper was the next metal to be evaluated as a potential product at Chovdar, considering the evaluation results of both gold and silver. Importance is given to the increased concentration of copper in the sulfide phase of the deposit and the fact that there is a high copper zone present in this phase.

In the oxidised phase of production, copper has been characterised as waste, rather than as a product. Hence, the economic parameters seem to be the most important, and the ore grade of the commodity is the most significant parameter by far. The price of copper will also play a role in the evaluation, whereas the extraction costs are mainly covered by the main product (gold) and are of less importance. The technological factors, and particularly the recovery rate, also have a significant weight. This makes sense since the higher the recovery of copper, the greater its chances of creating profit for the company.

Judging by the weights attributed to the parameters, it is evident that copper will be treated differently than gold

Table 8: Calculated global criteria for all potential products in the Chovdar deposit.

Criteria	Gold (%)	Silver (%)	Copper (%)	Iron (%)	Aluminum (%)	Mercury (%)
Commodity price	19.3	16.2	12	13.8	13.9	0.5
Ore grade	19.3	16.2	33.8	31.1	31.5	0.5
Extraction costs	4	1.8	5.5	5.7	5.8	2.7
Logistic costs	2.1	1.8	2.6	2.5	2.6	0.5
Availability	5.6	8.7	3.1	3.6	3	1.2
Criticality	10.8	17.3	3.1	3.6	3	1.2
Volatility	5.6	8.7	3.1	3.6	3	1.2
Locality	0.8	1.2	3.1	7.1	6	1.2
Quality standards	0.4	0.4	1.2	1.6	1.7	1.1
Production efficiency	2.4	3	7.5	2.9	3.1	10
Recovery rate	3.4	3.8	11.2	5.2	5.6	10
NORMs	0.7	0.6	0.5	1.9	2.1	2.4
Toxic compounds	6.6	5.2	2	1.9	2.1	21.6
Greenhouse gasses	0.7	0.6	0.5	1.9	2.1	2.4
Waste production	3.5	2.7	3.8	3.9	4.1	14.4
Social acceptance	1.5	1.2	2.3	3.2	3.5	9.3
Legislation	4.5	6	2.3	3.2	3.5	18.8
Strategic importance	8.9	4.8	2.3	3.2	3.5	1
Total (%)	100	100	100	100	100	100

and silver. Copper has low criticality and high availability as a metal worldwide, and its economic balance is the determining factor when deciding its production. The increase in concentration cannot go unnoticed, and is highlighted in the prioritisation of the parameters.

The next metal, the concentration of which is increasing in the sulfide phase of the deposit, is iron. In this case, the ore grade elevation may not be as high as it is for copper, and there no high iron zone is identified. Nonetheless, the concentration is also high enough to attract interest and proceed with evaluating this commodity. The same procedure is followed for assessing iron, considering the boundary conditions at Chovdar, the market prices for iron, its importance and availability as a metal, and the potential environmental concerns that its production might raise.

Similarly, the most critical parameters for iron, as for copper, are the economic criteria, followed by the market criteria. The ore grade is the most significant factor, and the price of iron is ranked second. However, the third most crucial parameter is the impact that iron production is expected to have in the local markets.

This result is due to the wide variety and diversity of applications that iron has in daily products and services in local societies. The metallurgical process of iron is well known and can be applied near a mine site; thus, the produced iron could be channeled to the local markets, thus reducing the logistic costs. Nevertheless, the price and ore grade of iron combined with the additional extraction costs will be the main determining factors for its classification as a by-product or waste in this project.

Aluminum was assessed next. The resemblance to the properties of iron both as a commodity in general and as a potential product at Chovdar is remarkable, and so are the evaluation results. The increase in concentration for aluminum seems to be greater than that for iron, yet not significantly different.

Once again, the economic parameters seem to play a significant role when deciding whether to produce aluminum. The market conditions follow in percentage terms, and the remaining three categories (technological, environmental, and socio-political parameters) are of equally lower importance in this case. Following the same pattern, the essential parameters are the ore grade of aluminum and its price in global markets. The locality is also evaluated as a crucial parameter, followed by the additional extraction costs and the recovery rate of aluminum.

Generally, aluminum has a much higher price as a commodity than iron. In addition, the ore grade of aluminum at Chovdar is also higher than that of iron. Consequently, even though the evaluation parameters have the same weights, the evaluation of the options with respect to the parameters led to slightly different preference results.

Mercury was the last of the commodities to be evaluated in this case study using the multi-criteria decision tool. Unlike the previous metals discussed, mercury has a different treatment and production evaluation. The same group of parameters is implemented in the tool, to be evaluated concerning the properties of mercury in the Chovdar mining project, in addition to the general conditions that govern the treatment of this metal globally.

Contrary to the evaluation results in the previous paragraphs, the most important parameters, in this case, are the environmental parameters, followed by the sociopolitical parameters. The technological factors have an observable percentage. More specifically, the most significant parameters overall are the presence of toxic compounds, the production of waste, the legislation status that governs the production and treatment of mercury and, of course, the social acceptance of having it as a product or treating it as a waste.

These results are different from those discussed above regarding the other commodities. For example, the price of mercury and its marketability are not as important. The recovery rate is an essential factor, but not in terms of yielding more profit. In this scenario, the higher the recovery of mercury from the ore and tailings, the less the risk of environ- mental contamination. As already discussed in this work, mercury must be produced as a by-product to preserve the surrounding ecosystem, follow the rules, and meet the social requirements. In addition, when extracted and shipped off-site, the costs needed to treat mercury as waste in the tailings are eliminated, and thus can be considered an indirect profit.

Comparative Analysis of the Results

Overall, six commodities were evaluated individually but under the same circum- stances and considering the same conditions of the Chovdar project. The results are rational and detailed enough, given the difficulties of deriving data when no actual economic assessments have been conducted to date for the second phase of exploitation at Chovdar.

Gold remains the leading product of the mine (**Table 9**), since no other commodity is classified as a co-product or will cover all the extraction costs. The transition to underground mining operations will increase the operating costs; however, gold production is expected to yield a significant profit for the company. Its strategic importance is essential not only for the relatively remote area, but also for the state of Azerbaijan. Hence, the mining project enjoys the government's trust and the society's acceptance.

Silver will be produced again as a by-product and significantly contribute to the project's revenues. Most likely, copper will be the second by-product after silver. Although the by-product option has the highest percentage, it does not have an absolute majority, indicating that a more detailed and careful evaluation must be made to decide whether copper can be feasibly extracted. Contrary to the results for copper, iron is preferably classified as waste. Nevertheless, a more detailed economic analysis is also needed for this commodity and market analysis should be undertaken to investigate the product sales prospects in the local markets. Aluminum is also not classified as a by-product or waste, although there is a slightly higher preference for it being produced as a by-product than iron. Accordingly, detailed economic and market analyses also need to be conducted for this potential product. Finally, mercury is treated differently, and the respective results justify its classification as a by-product, with a far more preferable 52%.

This last result justifies the scope for developing this production decision tool and the attempt to determine

Table 9: Comparative analysis of production results.

Commodities	Primary Product	Co-Product	By-Product	Waste
Gold	79.6%	–	15.5%	4.9%
Silver	–	34.4%	61.6%	4.0%
Copper	–	12.6%	49.1%	38.3%
Iron	–	13.5%	40.6%	45.9%
Aluminum	–	13.9%	43.5%	42.6%
Mercury	–	8.4%	51.9%	39.7%

all the potential parameters, in addition to the economic parameters, that can affect the production of a commodity. The percentages of 4.9% in the preferences for gold as waste or 8.4% for mercury as a co-product are worth mentioning. These can be attributed to two reasons: the first is the using of all parameters, even the less relevant ones, in this evaluation. In these assessments, the options of co-product, by-product, or waste were equally important. Although these parameters have very low weights, their overall sum yields a higher-than-expected percentage for the option. The second reason is the lack of accurate data and information that would allow decision makers to make more precise cross-comparisons.

Compared to the Excel workbook outcomes, the results derived from the computa- tional tool were very similar, if not identical. The insignificant differences may be attributed to the number of decimal places applied in the calculations. Nevertheless, the similarity of results justifies the efficiency of the computational tool. Python has gained traction over recent years and the quote that "Python is the new Excel" is becoming more frequent.

CONCLUSIONS

This work managed a large amount of information and data sets to identify and classify 18 parameters that can impact the determination of co- and by-products in a mining project. This list is not exhaustive; criteria can be added or removed, given the conditions governing each project under examination.

Using Python and a GUI, an evaluation tool was developed based on a multi-criteria- decision analysis model to assess the production perspectives in polymetallic projects. The tool allows for fast and efficient calculations, and the variation in the parameters is not an impediment. An advantage of the developed tool is that it considers more diverse parameters and yields detailed results, not only for the final options, but also for the importance of all parameters and those having the highest impact when evaluating each commodity.

To reduce subjectivity in decision making, a careful assessment needs to be made each time the tool is used concerning the boundary conditions of each project and the precision of the data and information provided for the evaluations.

The tool's efficiency was tested by implementing data from a polymetallic deposit in Chovdar, Azerbaijan. In this project, operations are transitioning from surface to under- ground, in which the mineralogy is also changing. Hence, a re-evaluation of the perspec- tives of the included metals aiming at their production feasibility was deemed necessary.

Overall, the evaluation results from the tool justified the production of gold, silver, and mercury that is already taking place in Chovdar, indicating that the tool works efficiently and can be used accordingly for the other commodities. Therefore, the results for the remaining potential products indicate the approach for the company to investigate whether any of these metals can become by-products of the project.

Mining companies, industry consultants, academics, and other stakeholders could use the developed tool in the assessments of several polymetallic projects. In this manner, the tool can be further tested and optimised, and the use of additional parameters can be deter- mined. Consequently, the necessity of producing minor metals will be further highlighted, not only with words but with the demonstration of detailed results and percentages.

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The future of mining in America

The rapid buildout of a clean energy economy is fuelling a significant increase in demand for responsibly sourced critical minerals that power everything from consumer electronics to electric vehicle batteries. No one knows that better than Nevada, where there is tremendous investments in the entire "cradle-to-cradle" lithium cycle, from mining to processing to recycling. As leaders at the Department of the Interior, we are focused on supporting a mining industry that is sustainable, responsible and efficient in order to confront the climate crisis with the resources its solutions demand. To do that, we must focus on a more inclusive, productive approach – one that prioritises engagement with Tribal Nations and local communities in Nevada and across the nation.

In 2023, President Biden's Interagency Working Group on Mining Regulations, Laws, and Permitting convened federal agencies, industry representatives, interest groups, labour unions, Tribes and others to develop permitting recommendations to reform and improve the way mining is conducted on U.S. public lands. The final recommendations, issued in September 2023, will ensure a more sustainable and responsibly sourced domestic supply of minerals, which are key to meeting the nation's climate, infrastructure and global competitiveness goals.

The work to redesign mining in the United States for a sustainable, liveable future benefits each of us. While Congress considers the report's recommendations, the Department is working to enhance how we bring the communities most affected by mining projects to the decision-making table.

One of the most promising avenues for improving permitting times and reducing conflict is through better community engagement. This is where change is needed most – not just in policy, but in practice. Mining projects often face delays due to opposition from communities that feel left out of the decision-making process and the economic benefits that flow from those projects. These are the same communities that have faced longstanding harm and inequities due to mining development.

Many Tribal communities, for example, still suffer from the health and environmental repercussions created by mining pollution from projects for which they were evicted from their lands or were not asked to engage, and from which they did not benefit. Consulting with Tribes early, and throughout the process, can prove invaluable. But Tribal consultation must be an ongoing, respectful dialogue that seeks to understand and incorporate Tribal perspectives, concerns and expertise as well as the recognition of the cultural, spiritual and historical significance these lands hold for Indigenous peoples.

Recommendations from the Interagency Working Group emphasised the need to prioritise community and Tribal engagement. This is a practical solution that can streamline the permitting process in Nevada and across the nation by fostering cooperation rather than conflict. When communities feel heard and respected, they are far more likely to engage in constructive discussions.

But engagement must go beyond just mitigating conflict. We must ensure that the economic benefits of mining projects are shared with the communities most affected by them. Too often, wealth generated by mining flows out of local areas and into the coffers of corporations, leaving behind environmental damage and economic disenfranchisement. This is particularly true for Tribes, which have long been excluded from the economic benefits of resources extracted from their ancestral homelands.

Tribes and other local communities deserve a seat at the table – not just as stakeholders to consult, but as partners who share in the economic rewards. This could take the form of revenue-sharing agreements, job creation or training programs, or other mechanisms that ensure mining projects contribute to the long-term prosperity of the communities where they operate.

Moving the U.S. mining industry forward will require a shift in mindset – a recognition that communities are not obstacles to be overcome, but partners to be engaged. By focusing on meaningful Tribal consultation and shared economic benefit, we can reduce conflict and shorten permitting timelines and build a mining system that works for everyone.

The path to a more efficient and just mining industry lies in partnership. Federal, state, Tribal and local governments and industry must work together if we are to build a future where mining projects respect the land, honor Tribal sovereignty, and contribute to the long-term prosperity for Nevadans and our entire country.

This opinion column was submitted by Secretary of the Interior Deb Haaland and Principal Deputy Assistant Secretary for Land and Minerals Management Dr. Steve Feldgus.

It's all about the rubber

Conveyor belt specialist Leslie David looks at how Netherlands-based Fenner Dunlop Conveyor Belting make their own rubber and why they are investing some €2.4 million in much more advanced rubber mixing equipment.

Rubber represents the biggest single influence on the performance and longevity of a conveyor belt. It also represents some 70% of the mass and up to 50% or more of the cost of making a belt. Consequently, in these times of ever-increasing price competition, led and dominated by manufacturers in Southeast Asia, primarily China, rubber is also the biggest opportunity for savings. Cost-cutting practices include the use of unregulated, low-grade raw materials, the use of bulking agents such as chalk, increasingly larger proportions of recycled scrap rubber of highly questionable origin and the substitution of essential polymers such as carbon black with low-grade versions created by burning scrap vehicle tyres. Another method is reduced quantities and often the total omission of key ingredients such as the antioxidants that all good quality rubber needs to resist the premature degradation caused by exposure to ozone and ultraviolet light.

Such practices allow unscrupulous manufacturers to massively undercut the prices of the few remaining manufacturers at the quality end of the market, such as the Fenner Dunlop's of this world. Despite such competition, Fenner not only refuses to change direction, they are even more committed than ever to further widen the quality and value gap.

A SCIENCE IN ITSELF

Because of its adaptability, most conveyor belt rubber is synthetic or only contains a relatively small amount of natural rubber. The creation of rubber compounds (rubber compounding) is the process where a range of 'specific task' chemicals, reinforcements, antioxidants and anti-degradants are mixed together with rubber polymers.

Creating rubber compounds is a highly complex process.

The most common polymers used in conveyor belts are Styrene- Butadiene rubber (SBR) and Nitrile rubber (NBR). The chemical agents form chains of polymers to form rubber compounds that will ultimately bze vulcanised. Vulcanisation is the process in which the compounds are chemically converted into a more durable final product by using heat and what are termed as 'cross-linking agents' such as sulphur and accelerators. It is a highly scientific process and even more complex when you begin to consider the multitude of physical properties and characteristics that the rubber used in conveyor belts need to possess.

MEETING EVERY NEED

Every type of rubber used on conveyor belts has to meet a long list of demands, so each has to be made according to a very specific recipe. The most basic ability is to resist abrasive wear along with the need to meet specific minimum requirements in terms of tensile strength, elongation (stretch), hardness, and resistance against tearing. Every rubber compound must be able to endure temperatures of at least minus 20 or 30 °C and, at the other end of the scale, withstand continuous material temperatures as high as 80 °C. Then of course, there is the ability of the rubber to resist the seriously damaging effects of ground level ozone and ultra violet light (both sunlight and fluorescent light). Both of these last two properties require special additives to be part of the rubber compound 'recipe'.

These are just the basic requirements. There is also a need for 'specialist' rubber covers such as resistance against the effects of oil, chemicals, fire, extreme heat (up to 400 °C), extreme cold (as low as minus 60 °C), high impact, ripping & tearing and the numerous combinations of those qualities for multi-purpose belts such as oil and fire resistant for example. Last but not least, the rubber needs to be able to form strong, reliable splice joints. Being able to consistently achieve all these requirements during the mixing process so that every individual batch of rubber compound is exactly the same is unbelievably challenging.

THE MIXING PROCESS

There are literally dozens of chemicals and ingredients used to make the huge variety of rubber compounds that different conveyor applications demand. The mixing process is where all of the polymers, chemical additives, carbon black and zinc oxide are mixed together according to the specific recipe for the required rubber type. For accuracy and consistency, Fenner Dunlop use a highly advanced computerised, automated mixing carousel that places very precise measurements of each ingredient into polymer-based bags. One technician I spoke to likened it to "making cakes that have to taste precisely the same every time".

Precise measurements of each ingredient in polymer-based bags are mixed and blended together

The ingredients are then placed into a 'coarse mixer' as the first step towards blending everything into one. The total mix is then transferred into a mill, which blends the rubber until it reaches an evenly distributed consistency. Different ingredients react differently and may be sensitive to permanent damage unless the machine settings and especially the temperatures during mixing, are exactly right. For example, additives used to create the all-important self-extinguishing properties in fire resistant belts can become almost totally ineffective if not mixed in the right way.

For this reason, some compounds need to start the mixing process as separate batches of ingredients. For example, Batch A may contain 90% of all the ingredients and in a second step the remaining 10% are mixed under slightly different conditions. In all cases, regardless of type, not only must the rubber compound possess all of the requisite physical properties and characteristics, it must also be able to undergo the further processes involved in making a conveyor belt, such as calendering and vulcanisation.

The calendering process.

The calendering process is where the rubber compound material, which has been pre-softened by heat, is placed into the center of counter-rotating rollers. The rollers compact the rubber into a sheet as it passes through them. The thickness of the resulting product is determined by the gap between the cylinders, called the nip region. The rubber sheet can then be joined with a carcass fabric layer. After the sheet passes over cooling rollers it is then spooled into a roll with special anti-stick fabric placed in between to stop the surfaces sticking to one another. These huge rolls of unvulcanised rubber are then ready to be made into conveyor belts.

HOMEMADE

Speaking to people in their impressive production facility in Drachten, it is clear that everyone is fiercely proud of the fact that they are the only remaining European belt manufacturer that continues to make all of its own products using its own production facilities. This includes the rubber, which even fewer of their competitors now make themselves due to a growing trend to outsource the manufacturing of their rubber compounds, mostly Southeast Asia, rather than produce them in-house.

The advantage is that specialist rubber compound manufacturers are able to minimise production costs by mass-producing rubber compounds in extremely large quantities. The downsides, however, outweigh the benefits. Firstly, outsourcing makes it almost impossible to apply the quality control disciplines needed to ensure the consistency of properties between batches of rubber produced at different times. Another downside is that some compounds have a 'best before' shelf life, so they need to be vulcanised before some important characteristics start to diminish.

Controlling the quality and the consistency –all Fenner Dunlop rubber is 'homemade'.

According to Fenner Dunlop's Innovation & Sustainability Director, Dr. Michiel Eijpe, outsourcing rubber production is not an option. "It is essential that we have total control from beginning to end, not only to consistently achieve identical high qualities and properties but also to comply with environmental regulation, which is extremely important for all concerned"

SAFE TO HANDLE, SAFE FOR THE ENVIRONMENT

It is an inescapable fact of life that to make some rubber compounds it is necessary to use chemicals that are hazardous in their own right. Fortunately, at least as far as Europe is concerned, there are very strong regulations in place to protect humans and the environment such as REACH (Registration, Evaluation and Authorisation of Chemical substances) regulation EC 1907/2006 and EU Regulation No. 2019/1021 concerning the use of persistent organic pollutants (POP's).

Sadly, most European belt suppliers continue to ignore these regulations, either completely or at least partially because doing so creates an extremely significant price advantage. Of even greater concern are manufacturers located outside of EU/EEA member states because they are not subject to REACH and POP's regulations. This provides them with an open door because they are free to use unregulated raw materials, which cost much less compared to their regulated counterparts, even though those same materials may be entirely prohibited or at least have strict usage limitations within the European community.

INVESTING IN THE FUTURE

Fenner Dunlop are certainly committed to their policy of making everything themselves. So much so that they have recently invested some €2.4 million in new machinery in their mixing department. Installation is complete and has entered the testing phase. They have also purchased an additional mill that will be installed at a later stage. "The primary reasons why such investment was needed revolves around three key factors", explains Dr. Eijpe. "Quality, safety and the environment". "Firstly, we needed better control over the processing of the more difficult materials we are now having to use. This is a result of the need to find alternatives to materials that we can no longer source from previous suppliers, for example due to the Russia – Ukraine conflict. It is, of course, essential that these alternatives have the same or higher quality properties as we have used before".

Dr. Michiel Eijpe.
Fenner Dunlop's Innovation & Sustainability Director.

"As a result of REACH and POP's regulation compliance, we also need to find alternative processing solutions for the substitute chemicals that replace those that become banned or have usage limitations placed upon them. Last but not least, there is the highly important question of safety. New ISO standards relating to operational safety of machinery are being introduced and although currently still in the draft stage, when they are implemented, our new mixing machines will instantly be compliant".

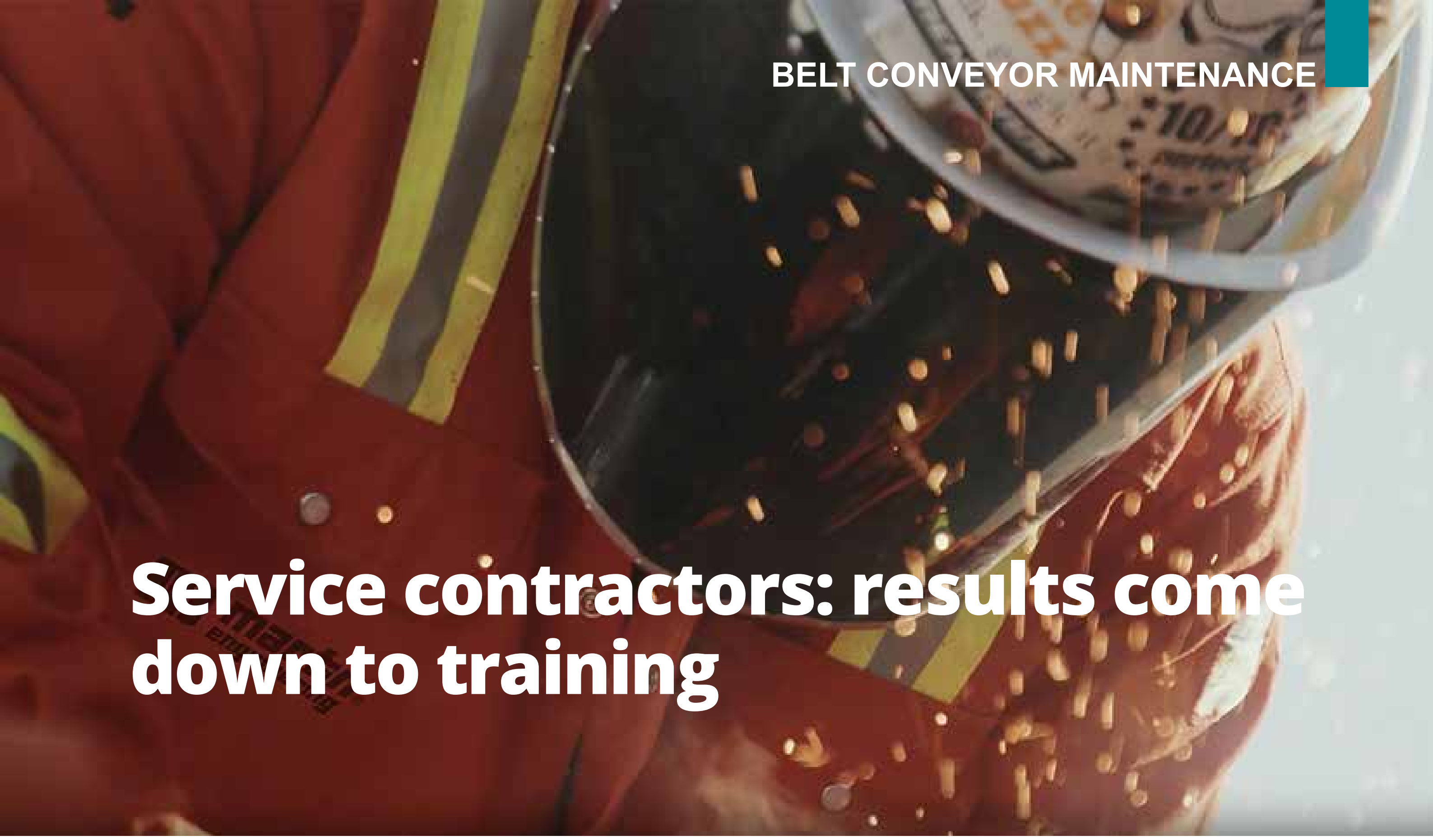
CONCLUSION

There can be no argument that the quality of the rubber has the biggest part to play in terms of performance, longevity and human and environmental safety. At the same time, it provides the greatest temptation for manufacturers to sacrifice those qualities in order to create a price-competitive edge. From what I have seen, Fenner Dunlop certainly have no intention of making such sacrifices, even in the face of such fierce competition from Asia. By surviving the onslaught, they are at least providing the end-user market with a choice. Long may that continue.

AUTHOR

Leslie David

After spending 23 years in logistics management, Leslie David has specialised in conveyor belting for over 17 years. During that time, he has become one of the most published authors on conveyor belt technology in the world.



Service contractors: results come down to training

Retrofitted installation by a professional who is familiar with the new equipment has the fastest and best result.

High-volume belt conveyor systems are among the most hazardous pieces of equipment in any bulk handling operation. Maintaining the delicate balance between production demands and efficiency can be a challenge for any internal maintenance team. To control labor costs and improve safety, operators often enter servicing agreements with outside contractors to perform routine maintenance or to retrofit new equipment during a shutdown.

Although outside contractors may be experienced, they often lack the proper training and specific knowledge needed to offer adequate servicing and installation of modern equipment designs. Moreover, this gap in expertise might limit what recommendations to common problems they offer, causing them to default to antiquated equipment or debunked solutions. This is why it is so crucial for contractors to have ongoing training that ensures they use modern techniques, install the latest equipment and operate to workplace safety best practices.

MODERN EQUIPMENT & TECHNIQUES TRAINING

As the global leader in belt conveyor accessories and material flow technology, Martin Engineering technicians are often invited to offer solutions to serious conveyor issues. For example, a common complaint from customers is that the belt cleaners currently installed on the belts are ineffective. The perception of the operator is that the product is defective or just plain “garbage”. Upon inspection, the technicians often find the equipment was simply, (1) not installed properly, (2) not adequately maintained (improper intervals, over-tensioned, etc.) and/or, (3) inappropriately specified to match the application requirements. All these issues can be addressed through proper training.

Some contractors only address the effects of conveyor inefficiency, while others offer solutions to remedy the root causes of inefficiency.

That’s why Martin Engineering ensures its team of Martin Service Technicians (MSTs) are up to date on the latest techniques and bulk handling technologies by conducting regular, intensive weeklong 28-hour training sessions like the most recent one in the spring of 2024. MSTs who have been with the company for a few months to a few decades regularly receive refreshers on their existing knowledge and to learn about new products and practices.

MSTs gather near a heavy-duty conveyor specifically set up for training purposes, ready to properly install new equipment.

From deep mines to large cement plants, the goal of the training is to ensure Martin's customers experience maximum efficiency and productivity in their bulk handling systems and are provided with the highest standard of service that complies with safe workplace best practices at every step.

"As factory-trained MSTs, it's not just our experience but also our knowledge that allows us to provide a solution for our customers," said Blayne Anderton, Martin Service Technician. "For an expert contractor to come in and do the job professionally and safely is one less stress the customer needs to worry about."

CONSIDERATIONS WHEN ENTERING A SERVICE CONTRACT

A service contract can reduce labor costs and ensure conveyor systems run efficiently. This has proven to reduce unscheduled downtime, improve system safety and lower the cost of operation. To improve project outcomes for every visit, service technicians should:

1) Walk the Belt™ to identify safety issues and obstacles to system efficiency.
2) Carry the correct certifications to provide the service safely.
3) Have the training required to properly complete maintenance and installation tasks.
4) Observe workplace safety best practices for every project including lockout/tagout/tryout and assistance-required procedures.
5) Possess the knowledge and experience to identify/offer economical solutions.

Confined space entry requires specific training since it is one of the most dangerous activities in bulk handling.

Innovative equipment like the CleanScrape have redefined what belt cleaner installation and tensioning looks like.

6) Provide a Walk the Belt™ report with photos tracking the project and any recommendations.

Martin Engineering's MST training hours are not just in the classroom but also hands on, working with operational life-sized equipment specifically designed to simulate real world environments. The most recent training week featured product training (install and maintenance), safety training (confined space entry, energy isolation, manlift, first aid and CPR), and skills training (welding). With a focus on the details, MSTs were taught the most efficient methods of installing Martin's newest products from the innovative CleanScrape® Primary Cleaner to the labor-saving Modular Transfer Point Kit.

"Martin is uniquely positioned because while we're on the site we're walking the belts and creating detailed reports with pictures," Jesse Beasley, Martin Service Technician, pointed out. "We offer ongoing knowledgeable support, not just installing our equipment and leaving."

TRAINING RESOURCES

Martin Engineering has long been recognised as having the most comprehensive onsite and on-line conveyor training programs in the world. The training textbooks, *Foundations, The Practical Resource for Cleaner, Safer, More Productive Dust & Material Control* and *Foundations for Conveyor Safety*, written by established industry experts, have become standard in several vocational programs with 22,000 copies currently in circulation worldwide.

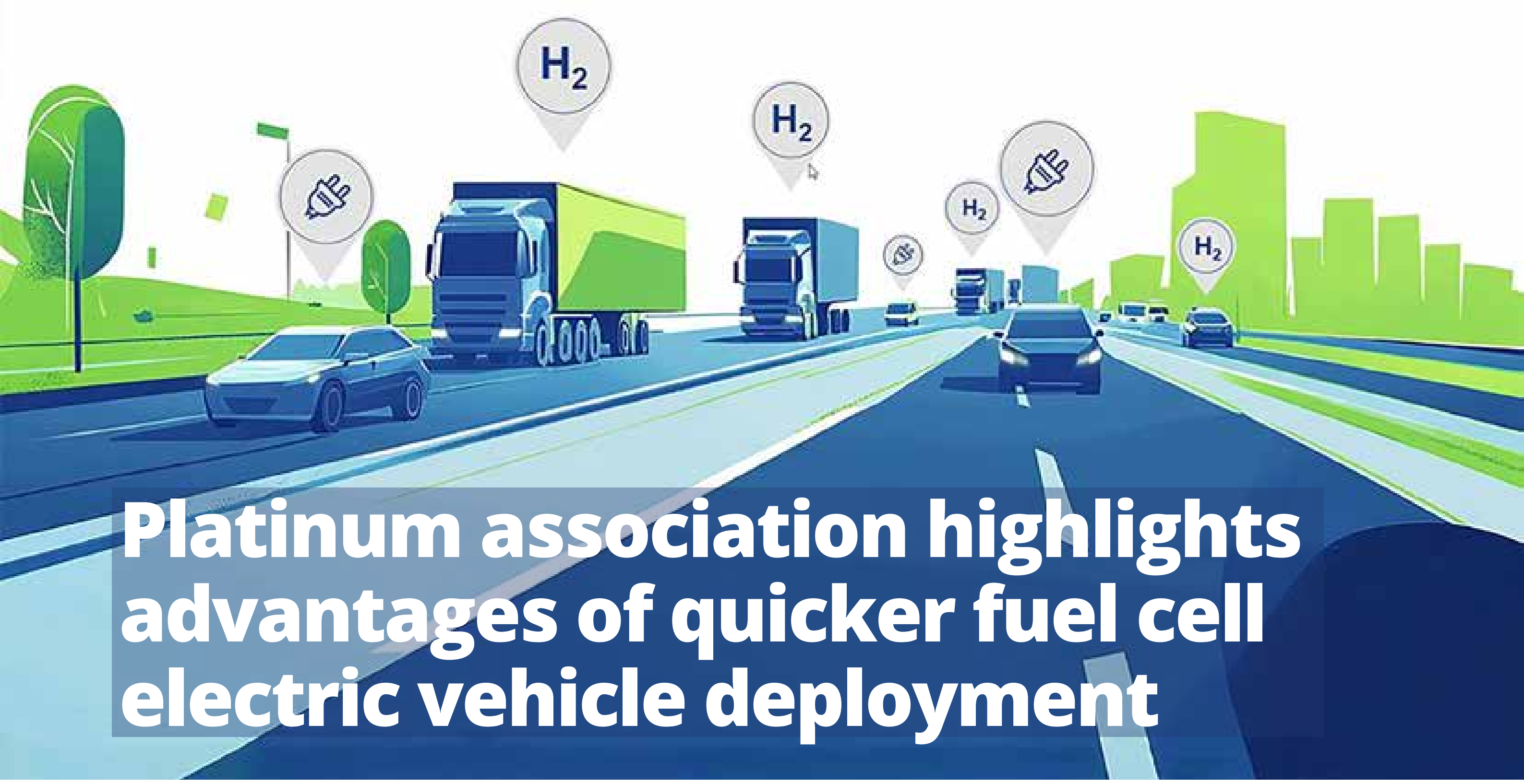
The company also has the largest free online archive of training resources in the *Foundations Learning Center* presented by knowledgeable and engaging trainers. The Learning Center uses a mix of text, graphics, videos, webinars, online events, and live experts available to answer questions. These free resources have democratised conveyor safety training globally, allowing for refreshers amongst both internal staff and contractors if questions about conveyor maintenance arise.

MANAGING RISK FOR BETTER PRODUCTION

Operation managers and safety managers alike are encouraged to go over reports created by MSTs and consider their recommendations. The internal Martin Engineering training program has ensured that suggestions offered in Walk the Belt reports are informed observations that can help improve production and safety, as well as forecast any issues that might result in unscheduled downtime or equipment damage. This allows operators to plan future improvements and better control costs.

"Our service technicians are basically the face of Martin; they're the front line," concluded Mike Moody, Business Development Manager for Martin Engineering. "Our MSTs are factory-trained service professionals who are fully aware of everything that needs to be looked at to make sure systems are safe and working best for our customers."

Martin Engineering has been a global innovator in the bulk material handling industry for more than 80 years, developing new solutions to common problems and participating in industry organisations to improve safety and productivity. The company's series of Foundations books is an internationally-recognised resource for safety, maintenance and operations training – with more than 22,000 print copies in circulation around the world. The 500+ page reference books are available in several languages and have been downloaded thousands of times as free PDFs from the Martin website. Martin Engineering products, sales, service and training are available from 17 factory-owned facilities worldwide, with wholly-owned business units in Australia, Brazil, China, Colombia, France, Germany, India, Indonesia, Italy, Malaysia, Mexico, Peru, Spain, South Africa, Turkey, the USA and UK. The firm employs more than 1,000 people, approximately 400 of whom hold advanced degrees. For more information, contact info@martin-eng.com, visit www.martin-eng.com, or call (800) 544-2947.



Platinum association highlights advantages of quicker fuel cell electric vehicle deployment

International Platinum Group Metals Association (IPA) is calling on policymakers to urgently drive forward the deployment of fuel cell electric vehicles (FCEVs), alongside battery electric vehicles (BEVs), before 2030 to boost European competitiveness.

The call embraces reducing dependency on critical raw materials by balancing the role of FCEVs alongside BEVs, maintaining Europe's competitive advantage in hydrogen technology as competitors rapidly catch up, and ensuring iridium supply for hydrogen production and clean transport.

Together with Heraeus Precious Metals and Johnson Matthey, two of the leading companies in the precious metals industry, IPA published its position paper 'Fuel Cell Vehicles to Boost European Competitiveness and the Green Deal'.

These platinum group metals (PGMs) experts outline where support is required to secure Europe's competitive position in FCEVs, meet Europe's 2030 zero-emission vehicle goals, and ensure a more achievable, resilient, and sustainable path to zero-emission mobility by 2050.

"PGMs are indispensable in the energy transition. To secure the scale-up of green hydrogen, we need a stable supply of PGMs which requires management measures for the PGM supply chain," Heraeus Precious Metals executive VP business line hydrogen systems Philipp Walter explained.

The European Green Deal and Sustainable Mobility Strategy sets ambitious targets for transport emissions reduction. While it calls for the deployment of zero-emission road vehicles, the reality is that deployments are heavily skewed towards BEVs, with FCEVs only seen as a longer-term necessity, particularly in the passenger vehicle segment.

In its paper, the association outlines three key reasons why the timely development of the FCEV market is required:

- Focusing support solely on BEVs imposes a high risk of supply chain bottlenecks. This is particularly true for critical metals such as copper, nickel and lithium.

- By investing in the development of its FCEV market, Europe would capitalise on existing, home-grown technology and supply chains, create more local jobs and prevent other countries from outcompeting Europe.

- Developing FCEVs would secure the continued supply of iridium, a by-product of platinum mining. Platinum is currently in high demand for use in catalytic converters but needs a replacement market for the future.

"Platinum Group Metals have a crucial role in the energy transition, and we need the correct policies in place to make optimum use of these finite resources. Supporting the growth of both FCEVs and BEVs will allow for the sustainable development of clean hydrogen technologies and provide the necessary confidence in the market to continue investment in PGM mining," Johnson Matthey PGM services CE Alastair Judge stated in the release to *Mining Weekly*.

Investment in FCEVs also makes economic sense when considering the full picture. For example, although building hydrogen refuelling stations may appear costly compared to using the existing grid for BEVs, replacing many existing vehicles with BEVs would require substantial and expensive upgrades to the grid and recharging infrastructure.

The paper concludes that the energy transition in Europe needs a two-track strategy, with deployment of FCEVs prioritised alongside BEVs. But while the ramp-up of BEVs has seen substantial public and policy support in the last decade, the same is not true for FCEVs. The industry calls on policymakers to support their recommendations and urgently create a level playing field for FCEV manufacturing and refuelling infrastructure.

The PGM industry is leading the way on hydrogen development and is ready to scale up.

"But we can't do it alone. That's why we're calling on the EU to accelerate FCEV market scale with targeted fleet deployments, expand hydrogen infrastructure to meet 2030 targets, and bridge the cost gap for clean hydrogen production. The time to act is now," added Walter in a LinkedIn note.

PLATINUM UNLOCKS HYDROGEN ECONOMY

Meanwhile, the World Platinum Investment Council (WPIC) reports that platinum demand from electrolysers and hydrogen fuel cells is growing. It is forecast to become a meaningful segment of global platinum demand by 2030, reaching almost 900 000 oz.

Fuel cells used in both mobility on land, sea and air and stationary applications comprise the largest segment of projected hydrogen-related platinum demand, forecast to reach over 600 000 oz by 2030.

Proton exchange membrane (PEM) technology uses platinum catalysts in two key applications – electrolysers and hydrogen fuel cells to produce electricity.

FCEVs are a major market for hydrogen fuel cells. A PEM electrolyser produces carbon-free green hydrogen from renewable energy. If a FCEV is powered with green hydrogen it provides completely emissions-free transportation.

In an electrolyser, electricity is used to break water into hydrogen and oxygen in a process called electrolysis. If the electricity comes from renewable sources the hydrogen produced is green hydrogen. An electrolyser converts electrical energy into chemical energy, or electrons into molecules. PEM electrolysers harness the catalytic properties of platinum and its PGM associate metal iridium. The platinum catalyst enables the splitting of the water into its constituent parts, providing a highly reactive surface area that can withstand corrosive conditions.

PEM is coated with platinum at the cathode and iridium at the anode to make the catalyst coated membrane. Electrolysers can be scaled by combining individual cells to form an electrolyser stack, enabling multi-megawatt electrolyser installations.

PEM FUEL CELL

Hydrogen fuel cells provide emissions-free power – providing an alternative to battery electric solutions as a way of electrifying the global fleet of vehicles.

Fuel cells in heavy-duty vehicles such as trucks and buses are currently leading the growing market for FCEVs.

PEM fuel cells can also be used to provide stationary or back-up power in data centres or for cell phone masts.

The need to decarbonise is more acute than ever and platinum-based technologies have a significant role to play in the energy transition, WPIC outlines.

GREEN HYDROGEN AND SOUTH AFRICA

In South Africa, government projections suggest a green hydrogen economy could boost the country's GDP 3.6% and create 380 000 jobs by 2050. PGMs are also opening doors to new possibilities in technology and industry, Anglo American Platinum CEO Craig Miller stated in an opinion article.

"Importantly, PGMs also hold profound significance for South Africa's economy and society. Our country is blessed with the world's greatest PGM resource endowment, with more than 80% of the world's known reserves and resources. The PGM mining industry is a cornerstone of our economy — one of the largest sectors, employing almost 190 000 people and earning R90-billion in export revenue," Miller wrote.

"The global energy transition is under way, and PGMs are vital to that shift. Now is the time for us to double down on our efforts. We believe in the versatility of PGMs, and are committed to expanding their use across diverse sectors, ensuring they play their role across a range of industries in the years to come.

"We are standing on the edge of a new era, with PGMs playing a crucial role in building a greener, more sustainable future," Miller added.

South Africa aspires to become a major player in hydrogen, which stands out as a transformative force in the country's quest for sustainability, with development finance institutions (DFIs) helping to grow the hydrogen economy particularly in emerging markets and developing economies.

While hydrogen technology holds incredible promise, it demands substantial investment. In developing countries, where the annual need for funding can reach around $100-billion, traditional financiers often hesitate owing to the high risks and costs involved, which is where DFIs step in, Development Bank of Southern Africa chief economist Zeph Nhleko has pointed out.

DFIs specialise in funding projects that might seem too risky for conventional investors. They use innovative financial models like blended finance, equity, and loans to bridge the funding gap. For example, a DFI might provide initial funding or guarantees that help attract private investors. This approach not only derisks these projects but also brings in additional investment, making it feasible to push forward with ambitious hydrogen initiatives.

In the US, an automated PEM electrolyser production facility has been opened by Nel in Wallingford, Connecticut. This new site increases Nel's manufacturing capacity to 500 MW, setting a new benchmark for efficiency in hydrogen production.

"This is our future. Hydrogen and fuel cells are going to be a vital part of our energy future in order to fight climate change," said US Senator Richard Blumenthal, who took part in the unveiling of the expanded Wallingford facility.

In developing next-generation PEM electrolysers with its technology partner General Motors, Nel aims to cut costs by another 60% and reduce energy consumption by more than 10%, Nel CEO Håkon Volldal said at the opening.

Everyday PGMs in catalytic converters in internal combustion engine (ICE) vehicles reduce harmful emissions on global roads.

Greensteel Australia has been awarded a contract by global steelmaking technology leader Danieli to build a 600 000 t/y rolling mill that will be powered entirely by green hydrogen.

In cooperation with the Spanish corporate Cepsa, Algeria's oil company Sonatrach has signed a memorandum of understanding to conduct a joint feasibility study to develop an integrated project to produce green hydrogen and its derivatives in Algeria to mainly supply the European market.

In the UK, the Go-Ahead Group has announced a £500-million investment in a new fleet of up to 1 200 zero-emission buses in which Wrightbus will provide 43 FCEV buses for Metrobus services.

In Austria, STRABAG, in collaboration with Liebherr and Energie Steiermark, has launched a pilot project to test a hydrogen-powered wheel loader at the Gratkorn quarry in Styria, Austria. This innovative initiative, officially kicked off in the presence of Federal Minister Leonore Gewessler, aims to demonstrate the potential of hydrogen as a clean alternative to conventional diesel in heavy construction machinery.

In Norway, HyNjord, a project supported by Enova SF, with Østensjø Rederi and Equinor as project partners, involves liquid organic hydrogen carrier (LOHC) technology being installed onboard the Østensjø vessel Edda Ferd. The LOHC power system will include an LOHC release unit coupled to a PEM fuel cell to provide electrical power to ships.

In Sweden, a new hydrogen refuelling station for heavy vehicles has been strategically located at the Port of Gothenburg, right next to the Gothenburg RoRo Terminal, which has one of Sweden's busiest truck flows.

In China, Jiangsu Xingran Technology's 1.1 GW PEM electrolyser plant is set to enter full-scale operations in January, World Platinum Investment Council reports. H2 View understands that this has allowed Jiangsu Xingran to lower the manufacturing costs of PEM electrolysers by 40%.

China's role in the hydrogen industry has grown significantly over the past few years, offering electrolysers and key components at much lower prices, H2 View adds.

Earlier this year, Chongya, in partnership with China-based international hydrogen energy technology company Refire, debuted its hydrogen fuel cell-powered off-grid supercharger, which deploys PGM-based PEM fuel cell technology capable of delivering up to 480 kW of electricity on less than four square metres. The entire charging system can be placed almost anywhere without additional construction or grid-connection requirements, meaning that location can be selected by demand density, rather than by electrical connectivity or high-power availability.

In Japan, the first Japanese fund dedicated to the development of low-carbon hydrogen has been officially launched, with more than $400-million raised from investors including Toyota, Iwatani Sumitomo Mitsui Banking, MUFG Bank, Tokyo Century Corporation, Japan Green Investment, and Total Energies, whose Asia president Helle Kristofferse: "We're convinced that only a collective effort will enable low-carbon hydrogen solutions to emerge on an industrial scale."

The fund, which is expected to raise about $1-billion in the future, was launched by the Japan Hydrogen Association, the largest private hydrogen value chain promotion council in the country.

The future of coal country: Landscape on the brink of change

The Absaloka coal mine just north of the Crow Indian Reservation provided royalties that supported about 1,000 tribal government jobs. It ceased production in April 2024 after its last customer ended its contract.BEN ALLAN SMITH, Missoulian.

A drive through Montana's coal country starts at the Little Bighorn Battlefield and ends in an uncertain future.

The road rolls over prairie grasslands of the Crow Indian Reservation, just south of the Absaloka coal mine. Then it climbs the Wolf Mountains and crosses into the Northern Cheyenne Indian Reservation amid tumbling sandstone formations tipped with scoria, a clay formation toasted red by prehistoric burning in underground coal seams. At Lame Deer, the road bends northeast through hills cut by Rosebud Creek, until suddenly coming over a rise to reveal the four smokestacks of Colstrip's coal-fired power plant.

It's harder to see the actual coal unless you're in an airplane. The strip mines between Colstrip and Crow Agency expose long black beds of burnable carbon. From this northern edge of the Powder River Basin south into central Wyoming lies 41% of the United States' coal supply. For the past century, it has fed the nation's energy demand.

Nearly all that demand has vanished. The Absaloka coal mine on the Crow Reservation lost its last utility customer last year. Colstrip's power generating plant is losing utility customers as public utilities switch over to renewable energy sources such as wind and solar.

A switch to renewable energy could happen here, too. Tens of billions of federal and private dollars stand ready to reshape Montana's coal country, if its residents choose a path forward. Three communities central to the region's identity – Crow, Northern Cheyenne and Colstrip – have remarkably different attitudes toward that future. That leaves some big choices for people in Montana's coal country. The decisions they make will be refracted through economic forces beyond their control, as well as cultural and traditional perspectives that define what it means to live in coal country. And as this 2024 election year winds to a close, those residents can make their opinions known through their votes on races from tribal council seats to the White House.

SAME VIEW, DIFFERENT VISIONS

Where someone stands on the future of Montana's coal industry depends on where they sleep.

Although their 444,000-acre reservation has 23 billion tons of proven reserves, the Northern Cheyenne Tribe has

Excavating equipment sits idle at the Absaloka coal mine, which lost its last customer in April 2024. Stopping production resulted in more than 100 Crow tribal members losing mine jobs, which paid an average $75,000 a year. Credit: Ben Allan Smith / Missoulian.

declined to exploit its coal. Many tribal members work at Colstrip's mines or power plant. But they have rejected past proposals for developing industrial-scale coal operations on the reservation.

But the impact of the nation's ongoing energy transition has been much greater – nearly 1,000 jobs connected to the Crow tribal government have also lost their coal royalty revenue stream since 2017. While much of Indian Country in Montana has been a Democratic voting bloc, the Crow have ties with Republican Sen. Steve Daines, who has pushed a bill in Congress to give the tribe an option to share royalties from the Signal Peak coal mine just north of the 2.2 million-acre Crow Reservation through a mineral rights swap.

In Colstrip, decades of political influence has kept the state government focused on keeping the traditional coal industry viable. That's produced beneficial rulings at the Public Service Commission for NorthWestern Energy to keep coal in its portfolio, provided economic transition programs, and stalled efforts to develop renewable energy projects that might replace coal.

Those alternatives run the buffet line from $43.7 million for rooftop solar panels on private homes in tribal, low-income and economically distressed parts of Montana to a $700 million federal contribution to a $3.2 billion transmission line project that could link wind energy producers from North Dakota to Oregon.

To spur more development, the federal Energy Infrastructure Reinvestment Program has $5 billion in direct loan authority backed by $250 billion in loan guarantees. Fleshing out the federal investments are tax incentives for renewable energy programs, infrastructure grants for building projects, job training for new industries and remediation funds to clean up old coal mines.

If it all gets spent, the federal bill could cost $1 trillion. The Biden White House estimates that the benefits will total more than $5 trillion in worldwide ecological and economic benefits by 2050.

The Pryor Mountain wind farm just south of Crow Agency produces 240 megawatts of power at around 5 cents. A wind farm can generate power for 3 to 6 cents per kilowatt hour.BEN ALLAN SMITH, Missoulian.

But people all across coal country don't appear to be lining up for the next new thing.

For a variety of reasons, the federal spending opportunities have had difficulty getting attention. Part of that stems from the long allegiance to coal as a source of jobs, purpose and identity. Part comes from distrust or unfamiliarity with new technology. And perhaps some signifies a defense against the sheer blizzard of controversy surrounding global warming, economic upheaval, Indigenous/white culture friction and plain old change.

The landscape itself doesn't offer many hints at a future direction. The massive Yellowtail hydroelectric dam on the Bighorn River would remain, but without coal, not much else points toward an economic future. Southeast Montana is not among the state's most productive farming or cattle acreage. It lacks the tourist magnetism of the western part of the state. Any industrial production would face miles of transport expenses to reach a distribution hub like Billings. As is, about 60% of the price Pacific Coast power plants pay for Montana coal goes to cover the railroad shipping expense.

And while the wind blows hard and the sun shines bright across this bit of Montana, renewable energy doesn't appear to offer the same community impact that a climate-cooking coal mine does. As one Northern Cheyenne resident put it: "Ever seen a wind farm with a parking lot?"

TRIBAL PERSPECTIVES

Jason Small made that observation over a piece of coffee cake on the patio of the Custer Battlefield Trading Post, just across Highway 212 from the Little Bighorn Battlefield National Monument. That day he was wearing a sleeveless T-shirt and overalls, on his way to a boiler repair job in Helena. On different days, he'd be in a suit and tie as a Republican legislator representing Busby and the Northern Cheyenne Indian Reservation. He also wears the hat of the executive secretary for the Montana AFL-CIO, the state's biggest union network.

"There's night-and-day differences between the two tribes," Small said of the Northern Cheyenne and Crow. "Energy policy, politics, climate, everything. The Crow opened their mine in 1974, and it was putting $50 million, $60 million a year into their budget in the Obama years. On Northern Cheyenne, the traditional people didn't want to mine coal. There was a popular vote, and everyone decided to leave it alone."

The corporations developing the coal paid high wages for hard work, averaging $75,000 a year. They also provided scholarships for kids to go to college or get job training. The royalties from state coal severance taxes flow back to local governments in lieu of local mill levies, or come back circuitously through the Montana Coal Tax Trust Fund. In 2023, that fund (enshrined in the state Constitution) held about $1 billion. However, by 2024, Montana tax collectors were

A solar farm north of Billings in August. Regionally, the solar and wind farms between Pryor Mountain and Billings now produce more day after day than Colstrip does.BEN ALLAN SMITH, Missoulian.

receiving more from cigarette sales than from coal royalties.

“People don’t want to lose the opportunities they have,” Small said. “Something new comes along, they don’t want to take a step backward.”

But coal may not be able to take a step forward.

CAN COAL COMPETE?

Next to the long, straight seams of coal currently under excavation west of Colstrip, an observer can see a smaller series of gouges in the earth that look a little like a Wi-Fi symbol. Those are the revegetated remains of Northern Pacific Railroad coal mines from the turn of the 20th century, when this part of Montana started playing a part in the nation’s industrial development.

Montana’s coal took an even more prominent role in the 1970s, after scientists confirmed the link between the more sulphureous Appalachian coal and acid rain, which was poisoning lakes across the eastern United States. The subbituminous coal of the Powder River Basin doesn’t generate as much heat when burned as the bituminous coal of West Virginia, but its exhaust has less sulphuric acid.

Although Montana encloses most of the Powder River Basin deposit, Wyoming digs much more of that coal – 244 million tons in 2022. Montana added about 30 million tons that year, despite sitting on 74 billion tons of recoverable reserves stretching from Wyoming to the Canadian border.

Nevertheless, coal of either type produced the single greatest amount of greenhouse gases driving up global temperatures. Oil company researchers in the 1970s connected the dots between burning fossil fuels and global warming. But those same companies, including ExxonMobil, mounted decades of counter-campaigns disputing the danger of climate change while burying their own science.

Growing awareness of climate-change impacts such as longer wildfire seasons and shorter ski seasons led to global social pressure to move away from fossil fuel burning. That included decisions by Colstrip power clients such as Puget Sound Energy and Avista Corp. to drop their investments in Montana coal in 2025. Those moves were prompted by state law changes in Oregon and Washington requiring the states’ energy utilities to seek greener energy sources.

At the same time, other market forces undercut coal’s economics. Methane, commonly known as natural gas, costs around 6 cents a kilowatt hour, while coal-fired electricity costs upwards of 14 cents. Both fossil fuels face growing opposition because their burning warms the atmosphere, scrambling planetary weather patterns and intensifying natural disasters like hurricanes and wildfires.

A wind farm can generate power for 3 to 6 cents per kilowatt hour. The Pryor Mountain wind farm just south of Crow Agency produces 240 megawatts of power at around 5 cents per kilowatt. An 800-acre solar farm on the Billings rims adds another 80 megawatts.

A megawatt of electricity powers about 800 homes in the northwest United States. Renewable energy sources are becoming more affordable and reliable. In September, wind and solar generators in the four-state region that covers Colstrip produced 6.6 gigawatts of electricity, while coal facilities in the same region produced 7.1 gigawatts.

For its part, Colstrip generated only half its 1.4-gigawatt capacity on 12 days of that month. Whereas wind and solar had only 14 hours when they produced less than Colstrip's full potential. In other words, even when the wind wasn't blowing or the sun shining, wind and solar out-generated Colstrip's coal furnaces.

MONEY AND VOTES

Incumbent U.S. Sen. Jon Tester, a three-term Democrat, was part of the final negotiating team that produced the bipartisan Inflation Reduction Act and Bipartisan Infrastructure and Jobs Act – legislation offering billions of federal dollars for investment in coal country. Tester's Republican challenger, political newcomer Tim Sheehy, was recruited by Sen. Steve Daines and the National Republican Senatorial Committee Daines chairs. National polling shows Montana's Senate race "leaning Republican."

That makes getting the attention of Indian Country essential to both candidates. Native Americans make up about 7% of Montana's million residents – the only demographically significant minority in an otherwise overwhelmingly white state. But while voter turnout for tribal elections tends to be strong on reservations, that hasn't translated to predictable results in state and federal races. And although Native Americans nationally tend to vote Democratic, tribal differences such as those seen on the Crow and Northern Cheyenne reservations make the voting bloc murky.

Colstrip has been a Republican stronghold for decades, as have most of the surrounding counties. As president, Republican Donald Trump promised to "bring back coal." However, his administration saw the closure of 75 coal-fired power plants and the loss of about 13,000 coal jobs nationally. In Montana that included the closure of Colstrip Units 1 and 2, the Decker mine, the Lewis and Clark Generating Station in Sidney and the Savage mine. It also included the bankruptcies of Westmoreland, Cloud Peak, Lighthouse and Talen.

Democratic President Joe Biden has actively supported unions and the heavy infrastructure spending that are trying to bring renewable energy projects and dollars to Montana's coal country. But he also imposed new air pollution regulations that NorthWestern Energy officials claim will force premature closure of Colstrip. On Oct. 4, the U.S. Supreme Court declined to block Biden's rules.

Many of those economic and political forces will play out within the next year. The election takes place Nov. 5. In his City Hall office, recently rebuilt with local coal revenue, Colstrip Mayor John Williams said the changes can't be ignored.

"We don't want to be defined by the stacks," Williams said, referring to the four landmark exhaust towers of Colstrip's generating station. "We're more than that."

Jason Small is a Republican legislator representing Busby and the Northern Cheyenne Indian Reservation. "There's night-and-day differences between the two tribes," Small said of the Northern Cheyenne and Crow. "Energy policy, politics, climate, everything. The Crow opened their mine in 1974, and it was putting $50 million, $60 million a year into their budget in the Obama years. On Northern Cheyenne, the traditional people didn't want to mine coal. There was a popular vote, and everyone decided to leave it alone."BEN ALLAN SMITH, Missoulian.