HIGHLIGHTS OF THE ROBOMINERS DELPHI SURVEY (1ST ROUND)

Summary:

This document includes basic statistics on the 1st Round ROBOMINERS Delphi Survey statements together with commenting highlights made by the participants. These materials are to be used in preparation and as a guideline for the 2nd Round of the Delphi Survey.

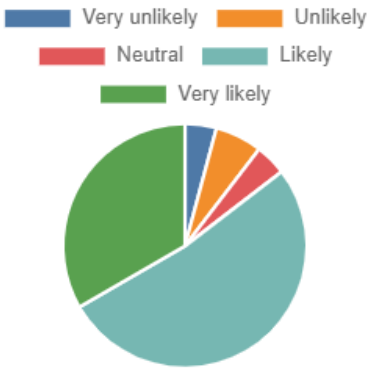
Authors:

Luís Lopes, La Palma Research Centre, Project Manager

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 820971.

1) Dependence on mineral raw materials drives political decisions that facilitate the widespread and uptake of innovative technologies by mining companies.

	Answers	Ratio
Very unlikely	2	4.2%
Unlikely	3	6.3%
Neutral	2	4.2%
Likely	25	52.1%
Very likely	16	33.3%
	48	100.0%



Non-supporting arguments

Mining companies are by far in front of any political decision in terms of technology.

Politicians are not able to understand this topic. The capital is the main decisionmaker.

Currently, political decisions are taken according the short term will of people (those who elect politicians every 4 years).

Most of the time companies have difficulties to obtain authorization for new equipment trial (old legislation) and also new mining or quarries extension.

Supporting arguments

A push to local sourcing (in the EU context) relies on innovation in mining technology to minimise factors that trigger public opposition to mining activities such as environmental and visual impacts, associated hazards etc. This should facilitate uptake of innovative solutions.

Especially in this recent war situation supply security is paramount.

I think new business models will emerge in such conditions, changing the landscape of how we understand mining companies nowadays.

When Governments realise the dependence on mining products of the real sustainable development of the countries, will (must) take the correct political decisions.

Mining has to be made more environmentally benign. This will also foster more public support for mining (hopefully).

See the effect of the Russia-Ukraine war on political decisions concerning the supply of food, energy and raw materials. EU politicians (and citizens) are fully aware of the implications and risks of depending on (external) countries that might go rogue.

A substantial part of policy support will be dedicated to research and the development of new technologies that will find their way to industry

Very difficult for breakthrough techs to gain a foothold in the market without supporting intervention.

Strong motivation generates more action.

Innovative technology lowers costs and increases profit.

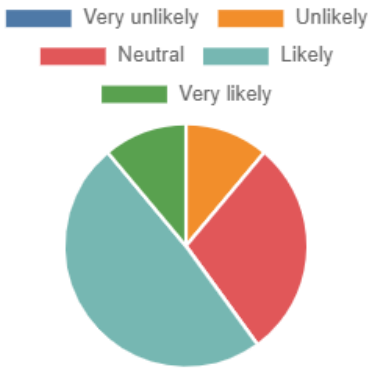
See recent threats to the EU by the Corona virus or now Russia. These will drive more, but more responsible mining in the EU.

After the recent Ukrainian war, whatever the outcome is, the raw materials policy of the EU and globally will be strongly reconsidered. Challenges with the climate change is another driver.

The criticality of some mineral raw materials will require disruptive and innovative methods and technologies, which shall be fostered by policies.

2) OPEX (Operating Expenses) reduction due to application of industry 4.0 solutions unblocks the mining potential in many areas

	Answers	Ratio
Very unlikely	0	0.0%
Unlikely	5	11.1%
Neutral	13	28.9%
Likely	22	48.9%
Very likely	5	11.1%
	45	100.0%



Non-supporting arguments

No direct connection between Industry 4.0 and Opex.

Mankind in the whole is not able to change its "business as usual".

Initial mining steps are not dependent of Ind. 4.0 solutions but good old milling techs. Development of new machines with 4.0 will only add data not better grinding.

Neutral

Industry 4.0 mostly relates to ICT technologies, but ICT alone does not solve anything, but requires suitable machinery.

OPEX do not include only industry 4.0 solution but also transportation costs for instance. Those can still stay very high.

CAPEX is also relevant and a bigger driver in NPV calculations.

Supporting arguments

From an economical point of view, yes. But there are still earlier barriers to cross to develop mining in many European areas e.g. public acceptance.

CAPEX is a bigger hurdle to changing systems.

Not sure whether this is really a boost to unblock potential, or if it "only" increases efficiency (in all aspects) of current operations.

Any measure that makes extraction less costly makes operations more profitable/more resilient in volatile markets and there increases the likelihood that a resource becomes interesting.

Industry 4.0 solutions have really strong potential to reduce the operation costs, however, other modifying factors remain also important.

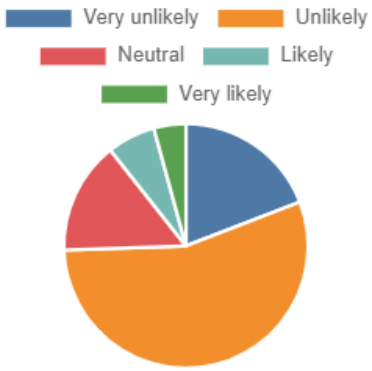
I think the main uncertainties here are transition period (time) it will take, but this is inevitable. Specially as in many mining jurisdictions cost of labour is greatest OPEX driver.

Since mining activities are related to the economic value of the raw material vs. costs for exploitation, reducing OPEX will naturally help mineral resources to become reserves that are economically viable to be exploited.

Some mining operations are interrupted due to economic reasons, therefore, a reduction in OPEX should naturally reopen some of these projects.

3) The NIMBY (Not In My BackYard) phenomenon has decreased in importance, due to wide social perception on the role of mining, facilitating mining activities throughout Europe

	Answers	Ratio
Very unlikely	9	19.1%
Unlikely	26	55.3%
Neutral	7	14.9%
Likely	3	6.4%
Very likely	2	4.3%
	47	100.0%



Non-supporting arguments

There is still a strong disconnect between perceptions of mining and the environment as bad and good respectively. Moreover, NIMBY has taken on new meaning because it is often not local protestors that block development, but fulltime campaigners who view the region or international contexts as their back yard.

NIMBY is still present concerning mining and the industry has by and large not changed its approach either (see Rio Tinto in Serbia or LI developments in Portugal/Spain).

A lot of communication has to be done to "convince" citizens about the benefits of mining for the modern society.

IMO, the best one can wish for is for the social opposition not to increase. The divide between people against mining and in favour will remain unchanged, and the public opposition to mining won't recede.

Mining has a bad reputation - nobody (in developed countries) will want a mine in their doorstep - be that a large open pit mine or a small shaft for robotic mining.

Population is still not well aware of the benefits of the sector and tend to be influenced by the bad memories of old mine operations.

I refer to the position of Germans against CO2 pipeline taking the gas to sequestration. People as a whole has got no rational mind and could be taken easily by any radical influencer group.

NIMBY is a part of the today raw-material colonialism.

The NIMBY syndrome is likely to persist and we are not at a turning point yet. However, there are wide differences in countries and regions. There is also the wider societal discourse that fuels the NIMBY or BANANA syndrome. There is also often an 'onion' phenomenon: local people are in favour of a mine, because it means income, but the region is in disfavour for different reasons. Increased automation in mining can also increase local resistance, because there are few employment opportunities in general and fewer job that can be filled by generally less qualified locals.

There is still a lot of work remaining in terms of social acceptance and understanding of mining processes and impacts to the environment and landscape. NIMBY is still a big issue to be addressed.

One thing is the rational part of any individual, the other thing is his backyard! Once a mining company moves to his backyard, all hell breaks lose! Mining companies MUST be unseen, out of site, no dust, no dirt, no tailing dams, no hole in the ground after mining, so people accept it in his back yard.

Neutral

This may be true as long as mining practices changes, including new ways of mining. This can be true for low footprint mining.

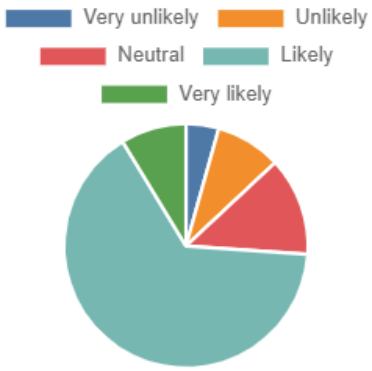
This is really an important issue, but the public perception has not really changed in the last 14 years despite the RMI was already aiming it. Public perception can change if the need for resources would be much stronger and directly affecting the public (by high prices).

Supporting arguments

Wartime situation raises abrupt need of actions toward securing the energy fuels and mineral resources needed for the industries and agriculture. Even more industrial efforts would be necessary along with the increases share of revenues towards the owners and users of land and local communities.

4) With ever less wide and easy to assess deposits, mining activities will turn to small and difficult to access deposits

	Answers	Ratio
Very unlikely	2	4.3%
Unlikely	4	8.7%
Neutral	6	13.0%
Likely	30	65.2%
Very likely	4	8.7%
	46	100.0%



Non-supporting arguments

There are many possibilities to mine large deposits. Small and difficult deposits mining have high energy consumption.

I think the number of operations might increase, but the few large operations will represent the weight of the industry. Chinese coal mines number 2200, but only a few dozen make up 80 % of the production, for example.

Deposits are now larger than ever before, with lower cut-offs and much better optimised technology allowing easier mining.

Neutral

Yes, if solutions can be found to mine such deposits economically or new sources of import.

Although the number of operations may grow, their total output will remain small and give only a smaller percentage of the total production.

It will depend on the advancements regarding extraction methods. Novel methods might make abandoned deposits economically interesting again, and the mining activities might resume some open pit, large deposits for decades.

Supporting arguments

Exploitation of smaller deposits will likely increase, especially when favouring European local production, but also I imagine an increase of lower grade deposits if prices change in the right direction, or of underexplored areas e.g. deep sea, or even a bigger interest in recycling of e.g. tailings.

Yet there will be an adjustment period, while large deposits are pursued into ever more challenging environments because it is perhaps easier to develop new exploration tools than to change the paradigm in which mining operates.

We're not there yet, but ore grades, deposit size and accessibility will decrease over time as the best deposits are already mined.

New technologies will allow exploitation of small and unavailable deposits.
The need to move mining operations to places where they are not seen or where they do not affect living areas will increase difficulties to open new operations

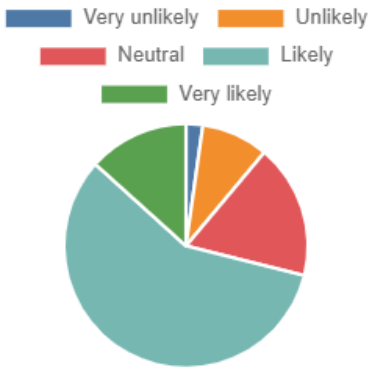
A logic consequence ... However, we also have many poorly explored areas.

This transition can be considered a natural consequence of the depletion of large, open-pit deposits. However, new technologies and methods might detect more economically interesting deposits in large areas that were not explored yet due to the current economical and technological circumstances.

The demand/prices will drive them to it! Mining companies will have to be at its best to mine these areas!

5) Real-time mineralogy identification combined with selective extraction unblock mining potential in many sites in Europe

	Answers	Ratio
Very unlikely	1	2.2%
Unlikely	4	8.9%
Neutral	8	17.8%
Likely	26	57.8%
Very likely	6	13.3%
	45	100.0%



Non-supporting arguments

There are many possibilities how to mine without real-time mineralogy.

If, then only in very special cases. Finally, the cost will be decisive.

Neutral

IMO having real-time mineralogy hasn't ever been an issue. Mining progresses according to plans, and getting real-time info simply means it would be easier to adapt the plans. But that doesn't unblock the mining potential.

It definitely helps. But I personally think that live mineralogy (e.g. for quality control) is overrated in terms of unlocking potential.

Supporting arguments

Necessary to manage complexity in small, high-grade ore deposits.

Costly investments, but may likely be the future.

Technologically yes, but economic and ESG feasibility not necessarily.

The better the selection and the discrimination systems the better mining operations will be economically feasible.

Selective extraction (in principle) reduces the amount of waste generated and thus the environmental issues associated with extractive waste management and hence public acceptance issues.

Selective extraction is of outmost importance.

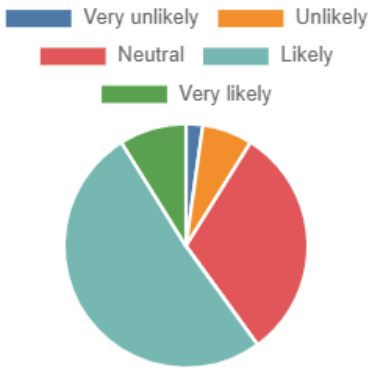
Portable SWIR, XRF, LIBS instruments are already important tools in mineral exploration.

The described technological capabilities will add value to the mining activities and, therefore, boost the potential of the sector in Europe and worldwide.

This is a big advancement and added value for the mining sector.

6) New advanced extraction technologies, include leaching, will make up for the bigger share of extraction methods

	Answers	Ratio
Very unlikely	1	2.2%
Unlikely	3	6.7%
Neutral	14	31.1%
Likely	23	51.1%
Very likely	4	8.9%
	45	100.0%



Non-supporting arguments

The high energy consumption and environmental protection are the main problems in leaching and other new technologies.

It is difficult to prove that environmental impacts will not be negative in the long-term. The chemical impact of leaching and leachate could be particularly problematic for gaining environmental licenses, including surface and ground water management.

For industrial minerals, it is possible that the old, widely used methods and machinery will still be the main extraction method. But it will depend on the costs involved in operations vs. price of the mined material.

Neutral

Depends on their economic and environmental cost.

Not all mineralogies are amenable to in situ leaching, so it really depends on the host rocks and ore forms. There is also regulatory resistance due to the problem of having to hydraulically control the leaching solutions. In many cases there may be public resistance, as there will be a need for 'fracking' to make the minerals accessible to leaching.

It will depend on the raw material. Industrial materials, for example, might be mined with the "same" conventional machinery, due to the extraction methods and cost of production of these materials. However, for more critical ones, such as metals, the innovative technologies shall be implemented to make mining economically viable.

Leaching will be a part of it with other solutions to make it safer and more productive.

Supporting arguments

Innovation & better efficiency in extraction techniques is a must for the future of mining.

New technologies are being researched and developed, at some point they will be put to use.

Of wastes; not of new mines.

There will be no other option. Conventional mining will be in decline, sooner or later.

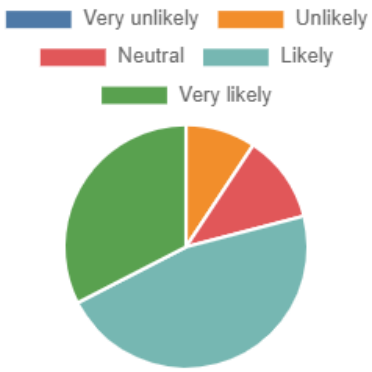
The case of Cobre las Cruces with a new patented electrochemical method proves the fact.

Leaching makes mining invisible, and that curbs public opposition to mining. And since this is a major issue, leaching is increasingly more important as an option. But notice it only works for a few metals (e.g Li, Cu, U, Cd, Sr).

Less environmental impacts and hence better social acceptance.

7) Autonomous mining robots will be a reality in mining operations

	Answers	Ratio
Very unlikely	0	0.0%
Unlikely	4	9.3%
Neutral	5	11.6%
Likely	20	46.5%
Very likely	14	32.6%
	43	100.0%



Non-supporting arguments

In small and medium scale mining operations the investment will be too big.

Maybe in a very small-scale mining.

Neutral

Still a long way for that.

Supporting arguments

I think this is likely the case in the future, but full automation in geological contexts is still something hard to envisage due to the large variability and complexity of deposits.

2050 looks a reasonable time horizon for this, but it will take time.

The question is what is meant by 'autonomous' ... remotely controlled mining already is performed in many areas, most notably in deep Canadian uranium mines.

This is what we have been seen in several research & innovation projects supported by the EU, and we expect that these innovative technologies will be widely implemented in the mining industry.

Yes, but this depends also on the timeframe and commodity type.

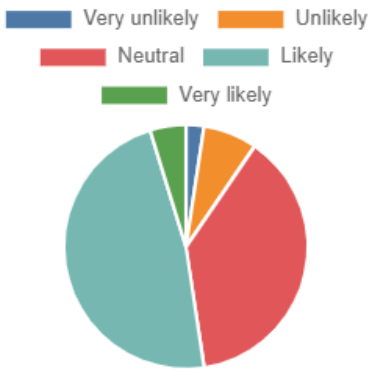
There is already autonomous mining and remotely controlled mining. It is not too much of a leap to autonomous robotic mining (certainly in preference to leaching) where it is an adaptation of what is already known and understood. It is likely that the advent of robotic autonomous mining will not initially be as highly innovative as Robominers concept, in order that technology can be accepted.

it's only a matter of time.

The rapid advancements in robotics and AI are already being implemented in various sectors, including the mining industry, therefore, this scenario is very likely to happen.

8) Colonies of robots will selectively mine ore deposits

	Answers	Ratio
Very unlikely	1	2.4%
Unlikely	3	7.1%
Neutral	16	38.1%
Likely	20	47.6%
Very likely	2	4.8%
	42	100.0%



Non-supporting arguments

The complexity of mineral reserves/ore will make this very unlikely.

I am not persuaded that there would be public trust placed in colonies of robots. Moreover, there may be implication in terms of civil unrest if the positive community impacts of mining are not realised.

I think that it is ineffective.

Neutral

Only, if they are economic feasible.

I guess there could be some trickle down from other industries, but these will be very special pilot/cases by 2050.

The precise technology is still open. Swarm-like operations are, however, a good way of thinking.

Supporting arguments

This could be the case but in a long long-term future.

2050 yes. I think we underestimate progress of 30 years...

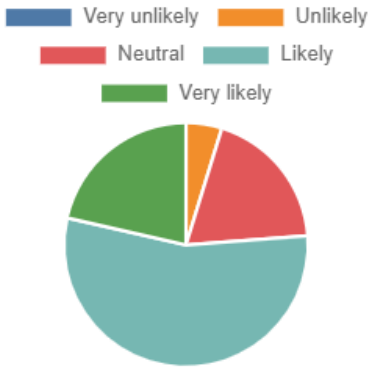
Synchronized work of robotic and automatic machines in a digital mine is already a reality.

For some deposits, collaborative robots can optimize the work. However, very small deposits might make it more difficult, therefore, it depends on the environment.

Yes, say in the 50-100 years timeframe. In a distant future.

9) Artificial Intelligence will enable the exploitation of difficult access deposits by robots

	Answers	Ratio
Very unlikely	0	0.0%
Unlikely	2	4.8%
Neutral	8	19.0%
Likely	23	54.8%
Very likely	9	21.4%
	42	100.0%



Non-supporting arguments

Maybe in very special cases.

AI will help in finding and planning the mining operation, but robots will not be able to selectively mine, it will good old fashion remove all, grind/milled and separate as usual.

Supporting arguments

AI can play a big role in the vectoring and identification of targets.

Likely, but it alone does not enable anything, also suitable machinery is needed.

Is going to be one of the enablers, but not enough on its own.

AI is a pre-requisite for robot operations. Which deposits will be tackled is not influenced by AI though.

The AI is clearly a necessary bet for that type of ore deposits.

Machine learning and pattern recognition certainly will help.

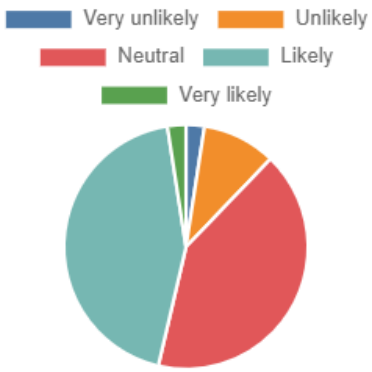
Strong AI components, mainly in navigation and perception of the environment, will potentially allow the robots to perform safely in difficult-to-access deposits.

AI is a key enabler in many domains, including mining.

We won't be able to extract difficult deposits without using AI. Robots will need to make decisions on the spot.

10) Mining is done by small autonomous robots without creating large cavities

	Answers	Ratio
Very unlikely	1	2.4%
Unlikely	4	9.8%
Neutral	17	41.5%
Likely	18	43.9%
Very likely	1	2.4%
	41	100.0%



Non-supporting arguments

Small robots cannot really perform mining.

Neutral

It might be very dependent on the deposit type. For large mineralised bodies it would probably not be the best solution.

Only for commodities with high added value - where quality of extracted ore is more important that quantity.

It depends fundamentally upon the nature of the lithology, whether comminution or leaching are needed. If blasting and comminution, then how much down-time will there be while small robots are periodically disassembled and removed. And how robust will they be in dealing with particulate materials? In the case of leaching, how will small-scale robotic components with a relatively large surface area for reaction fare against corrosive solutions? The maintenance solutions could be very problematic.

The extraction as such is not the problem, but the 3D-mapping of the mineral occurrence to navigate the robot into the right direction. Can this mapping/exploration be done with sufficient resolution to fully benefit from the theoretical benefit of 'keyhole' extraction?

It may depend on logistics and on the deposit geology, structure. Plus space is needed for underground waste management.

Supporting arguments

Downsizing is another approach to aim at difficult deposits.

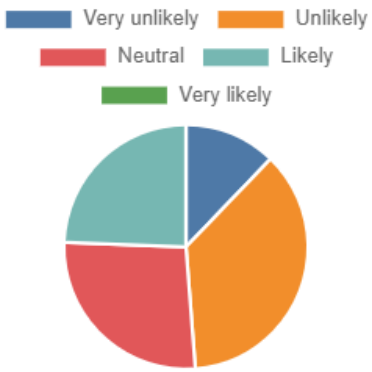
This can be done in very few deposits, but it can be done.

This will be just 1 method. large scale mining will still exist as well.
Very likely

The rapid developments in robotics will be able to lower the impacts in mining, such as more precise exploration and extraction methodologies that reduce pollution and visual impact in mining.

11) Robots will manage the waste to avoid any environmental impact and zero impact mine is reality

	Answers	Ratio
Very unlikely	5	12.2%
Unlikely	15	36.6%
Neutral	11	26.8%
Likely	10	24.4%
Very likely	0	0.0%
	41	100.0%



Non-supporting arguments

I think the term 'zero impact mine' is very problematic, at risk of being thought of as greenwashing, and should be avoided. Mining is an intervention in the inorganic environment - the rock is impacted. Perhaps what is imagine here is a mine with zero visibility on the surface? I like to think this is a very likely possibility. Waste management could be robotic.

Zero impact mine is never the reality. Just imagine the raw material necessary to robots construction and, robots are future waste also.

Not even with in-situ leaching. it will never be possible to get 100% of the metal from a mine. enrichment will happen in the plant, leaving waste behind.

I don't think zero impact mining is possible, changing (and extracting from) the subsurface will always bring impacts. But effective waste management would surely be a plus towards a low-impact activity.

Zero impact mining is utopia - underground mining has a frequent contact with underground water for instance, which can become polluted afterwards.

It is a question of semantics, but there is no mine without environmental impact. The reality is/will be that the impacts can be greatly reduced over many current mining practices.

Waste management is a reality by robotic solutions, however, zero impact mining is too ambitious - due to the different kinds of impact: Noise, atmosphere, visual, etc...

Neutral

Robots alone do not do that or enable that. Efficiency of robotic mining may enable incorporating enabling features without sacrificing productivity.

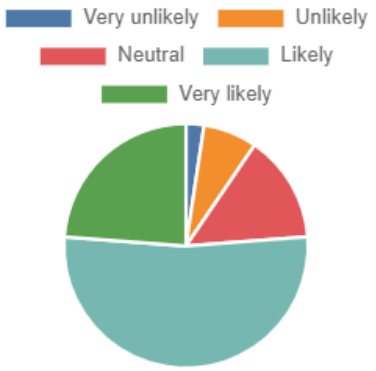
Supporting arguments

Zero impact is a difficult concept. If robots can be designed to mine profitably they can be designed to avoid environmental harms.

This is probably the key factor for the developing of new AI driven technologies: reduce EI.
In 2050, with the transition to sustainability and a circular economy, mining waste will not be socially acceptable anymore.

12) The uptake of robotics and other technologies in mining, leads to big changes on the mining ecosystem

	Answers	Ratio
Very unlikely	1	2.4%
Unlikely	3	7.1%
Neutral	6	14.3%
Likely	22	52.4%
Very likely	10	23.8%
	42	100.0%



Non-supporting arguments

The future is in a large-scale mining.

The technologies that are taken up to have to be able to connect with the rest of the mining ecosystem otherwise mining practitioners can't afford them.

Neutral

If the management is able to understand the advantage, it can be. If I see the management decisions in Germany concerning the connection between ITC and mining, I doubt.

Supporting arguments

Technology is here to make processes safer, more efficient, less wasteful, etc.

Yes, new players need to penetrate the industry.

The changes will be gradual, as robotic also involve a considerable CAPEX and one has to look at the net economic benefits in combination with the net environmental and societal benefits.

The social contract of mining ("jobs vs. environmental impacts") will also need to change.

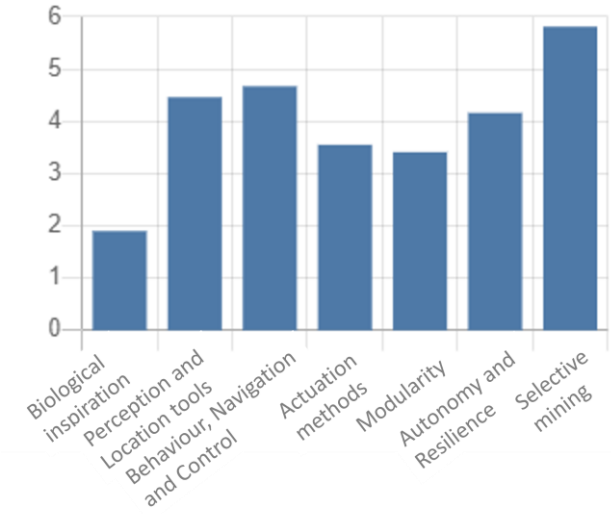
Robotics shall be seen as facilitators, to increase the (mechanical) processes in speed and efficiency. However, the human factor will still persist, like the mining engineer, due to the capability of thinking and intuition in the decision/making process.

This is already and always happening.

Mining systems need re-thinking and re-structuring if robots are there.
Robotics are already in the mining operations, and that can only increase.

13) For mining technologies targeting small and difficult to access deposits, order the following in terms of importance

	1	2	3	4	5	6	7	Score
Biological inspiration	2.320%	0.000%	4.650%	6.970%	6.970%	23.250%	55.810%	1.9
	1	0	2	3	3	10	24	43
Perception and Localisation tools	13.950%	27.900%	11.620%	11.620%	13.950%	13.950%	6.970%	4.46
	6	12	5	5	6	6	3	43
Behaviour, Navigation and Control	16.270%	13.950%	32.550%	11.620%	11.620%	11.620%	2.320%	4.67
	7	6	14	5	5	5	1	43
Actuaction methods	6.970%	9.300%	16.270%	13.950%	23.250%	13.950%	16.270%	3.55
	3	4	7	6	10	6	7	43
Modularity	0.000%	11.620%	13.950%	25.580%	16.270%	18.600%	13.950%	3.41
	0	5	6	11	7	8	6	43
Autonomy and Resilience	9.300%	16.270%	13.950%	18.600%	25.580%	16.270%	0.000%	4.16
	4	7	6	8	11	7	0	43
Selective mining	51.160%	20.930%	6.970%	11.620%	2.320%	2.320%	4.650%	5.81
	22	9	3	5	1	1	2	43



Comments

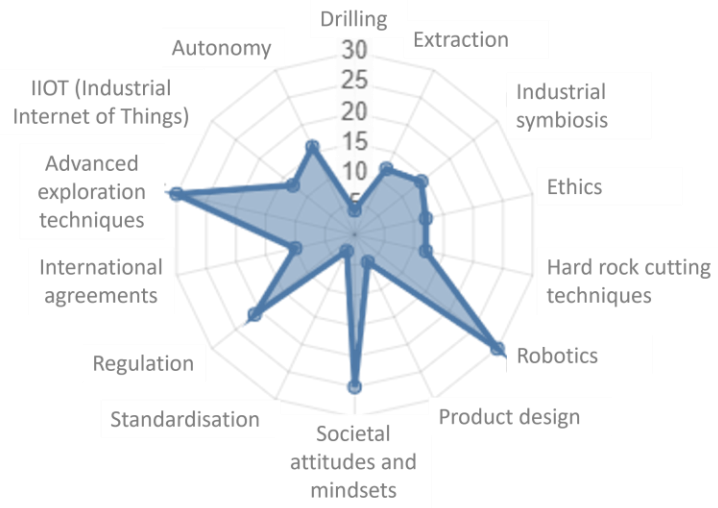
In my view navigation, selectiveness and modularity seem the key to target small & difficult to access deposits.

How appropriate the system is to the ore deposit context is most important. The thinking behind the idea may help with marketing but not necessarily with uptake.

The navigational capabilities are the priority. Afterwards, the importance comes regarding the actual mining activity.

14) Which of the following aspects will be more important for the mining environment in 2050?

	Answers	Ratio
Drilling	4	9.5%
Extraction	12	28.6%
Industrial symbiosis	14	33.3%
Ethics	12	28.6%
Hard rock cutting techniques	12	28.6%
Robotics	30	71.4%
Product design	5	11.9%
Societal attitudes and mindsets	25	59.5%
Standardisation	3	7.1%
Regulation	21	50.0%
International agreements	10	23.8%
Advanced exploration techniques	30	71.4%
IIOT (Industrial Internet of Things)	13	31.0%
Autonomy	16	38.1%
	42	100.0%



Comments

I imagine a more ethical, socially accepted mining environment, with a big role played by technological advancement.

The biggest challenges facing mining go beyond the technical.

There will not be a very big change in mining technologies. If may be in IOT. International agreements and industrial cooperation will be more important depending on societal possibilities and mindsets.

The complex of regulation and public acceptance will remain crucial, as it has been over the past 30 years. Exploration with sufficient spatial resolution will determine whether the advantages of selective and 'keyhole' extraction really can be played out. As we move to more difficult to mine mineralogies, cutting techniques in the wides sense will become more important together with their energy requirements.

15) What are the key domains that need to be addressed to support a sustainable mining vision by 2050?

Comments

Public acceptance, environmental impact, policy support: In the European context, there is a need of top-down policy to revive the mining industry; public acceptance, linked to minimising environmental impact, remains one of the main obstacles to overcome.

Autonomy and robotics

Robotics and mining technologies

Better exploration, clean pilot mines, more transparency, more efficient multi-commodities extraction, efficient remediation

Environment: Low impact mining activities, Waste management: Less waste and more mineral extraction, Exploration and Exploitation: Exploration methods that can be used in various geological scenarios and Extraction technologies that can be used in various conditions, ICT: inclusion of diverse ICT related areas into mining activities to support the previous items.

More productive mining operations with a less impact on environment.

Reuse of the mining wastes, very good ore concentration efficiency, to decrease impact on environment.

Integrated land use and electrification: Energy consumption is a big risk for mining. Sterilisation of land for mining, or by mining impacts dictates whether ore deposits become available and can remain eco-system supporting.

Environmental footprint of mining, climate change and limits to growth: Otherwise sometime later, for the remaining humans on earth, there will be no reasons to mine anything. They can live of the waste.

Blockchain responsible: blockchain or similar to guarantee responsible sourcing.

Social awareness in one side and responsible mining.

SLO mainly. Need to bring back mining to Europa and reduce dependence from third parties.

Political and economical stability.

Autonomy, robotics, detection, virtual reality etc.

I think social aspects at the community level and the diversity of community perceptions, the technological ecosystem supporting the mining industry and its ability to develop mining projects and operate in a responsible manner

Environment, social acceptance, digitalisation

Social responsibility

Efficiency

SLO, new exploration techniques, new processing systems

Societal awareness of raw materials needs

Perception and actuation of/on the mine and deposits by autonomous robots.

innovative mineral exploration, selective extraction technologies, lower-energy processing technologies

Product design, ethics, advanced exploration and extraction techniques: Mineral resources management should embrace the zero waste, circular economy and sustainable development way of thinking and doing. Interdisciplinarity is needed, transfer of ideas and solutions from other scientific disciplines should be encouraged.

SLO and CSR activities.

Social acceptance of mining, land-use-planning and zero waste and emissions

Targeting deeper deposits, autonomous mining, geometallurgy

Positive public perception, ~~novel extraction methods~~, favourable regulations

Cost-effective mineral exploration and exploitation techniques, and regulations

Tailings, recycling, re-mining/mining new sources/deposits

16) In a mining scenario where mining companies are targeting small and difficult to access deposits, which technologies/technology lines are most needed or successful?

Comments

Advanced exploration techniques, advanced tailored machinery: Technologies that allow for a precise geochemical and structural characterisation of the deposit prior to extraction, and technologies to build tailored machinery (size, shape, extraction method) for the ore mining.

Selective mining

Resilience, autonomy, fault tolerance, adaptability

Low impact exploitation, highly targeted remotely controlled (autonomous?) systems, real-time mineral content assessment

New extraction technologies, robotics

Targeted extraction that produces minimum waste, Mining system that can employ/use different extraction tools/methods depending on the conditions.

Targeting on deposit with ecological attention.

Selective mining, resilience of the equipment, energy transmission, low transportation costs

Low footprint and low energy consumption tech

Safe and efficient mining methods (Robotised?)

Small equipment, robots can drive a good advance on thisIT

Autonomy, AI, power supply, cutting technologies, separation technologies

Drilling, rock cutting, leaching...

Selective extraction, recovery of materials, waste revalorisation

Mechanical excavation, in-situ technologies, autonomy,

Robotics, AI, selective mining

High-resolution exploration

Artificial intelligence; autonomous robots; extraction methods

Leaching, autonomous robots

Predictive geochemical models based on multivariate datasets

Robotics, automatization, remote control,

Robotics, leaching, artificial intelligence, sensors

Artificial intelligence, autonomy, efficient navigation instruments and sensors

Robotics (miniaturisation, autonomy, navigation), big data processing

Grinding, milling, extraction, tailing