Riding the perfect storm facing the mining sector

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The South African mining industry has made a significant contribution to the country's economy for more than a century. Changes in legislation for mining operating licences, stricter health and safety targets, and stronger focus on reducing the impact on the environment coupled with increasing labour and electricity costs are some of the major impacts that significantly changed the landscape in which the mining industry now operates. Further to this, low commodity prices force South African mines to seek new, more technically advanced, cost-effective ways of increasing production without compromising occupational health and safety.

Research, development, and innovation (RD&I) in the mining sector are therefore required to ensure that mining operations find solutions that are cheaper, safer, and more efficient. Alternative programmes must be developed and put in place to translate South Africa's comparative mineral endowment advantages into more sustainable and globally competitive strengths.

This paper will discuss the recently developed and accepted South African Mining Extraction Research, Development & Innovation (SAMERDI) strategy which has a strong focus on productivity-related aspects for ensuring that the mineral resources can be converted into mineable reserves economically, safely and with minimal impact on the environment. Furthermore the paper will discuss the merits of revitalisating the Mining RD&I environment through the strenghtening and consolidation of offerings in a manner that is collaborative and ultimately sustainable.

INTRODUCTION

Hood (2004) commented that if miners from the early part of the last century were transported into a current mining operation that they would not be surprised by what they see. This statement certainly holds true for a South African gold mining operation. The depth of mining operations may have changed, and that has been probably the most significant change. The winning of ore from the host rock is still done by the use of explosives, which requires blast-holes to be drilled into the rock mass. Detonation of the explosives is now done in a much more controlled and coordinated manner by the use of centralized blasting and electronic detonators, rather than the manual lighting of each fuse by the miner in the early days of mining. Scraper and winch technologies that were first introduced in the 1920s, are still being used today. Support systems, to this day, comprise either between rock, *in-situ* pillars or backfill, or alternatively wood, or both. Although there have been improvements with time within the industry; these improvements have been small and incremental.

Mining in South Africa is labour intensive and is dependent on drilling and blasting. The need to clear the entire mine because of the toxic fumes that are released from blasting results in a significant period of inactivity in the mine. Some may argue that this time is not a complete loss as during this period, seismicity that follows the blasting is allowed to subside.

The underground coal mining industry underwent a resurgence when blasting practices were replaced by the use of the continuous miner. Not only was there a significant improvement in productivity and efficiency; the safety record dramatically improved. Hard rock miners have been 'jealous' ever since and have invested many millions of US dollars into trying to find similar technology for their narrow-reef, tabular metalliferous mines.

MINING IN SOUTH AFRICA

South Africa's mineral resources endowment is the foremost in the world, in not only gold and platinum group metals (PGMs) but also manganese and chromium, to name but a few. The minerals industry contributes significantly to South Africa's internal energy requirements, trade balance, internal investment, domestic savings, foreign capital, and direct and indirect employment creation.

Mining has had a significant impact on and contribution to the South African economy for more than a century. Within the domestic minerals sector, many of the challenges facing the industry over the medium to long term parallel those occurring at the global level.

- South Africa faces increased competition in terms of attracting foreign direct investment in the minerals sector
- Mining horizons within existing orebodies are becoming deeper and more difficult to access and process, necessitating the adoption of mechanized extraction methods, optimization of existing process flow sheets, and development of new and improved methods to maintain efficiency and improve recoveries
- There is an increasing push for the development of technologies capable of maximizing energy and water efficiency and ensuring environmental integrity
- Furthermore, as the prices across all the mining commodities continue in a downward slump, marginal mines face the ever-increasing risk of closure and thus the post-mining rehabilitation and regeneration of mine land is another critical issue that needs to be addressed now.

The fact is that overall productivity across the gold, PGMs, coal, and iron ore sectors has decreased significantly from its peaks over the past two decades as shown in Figure 1.

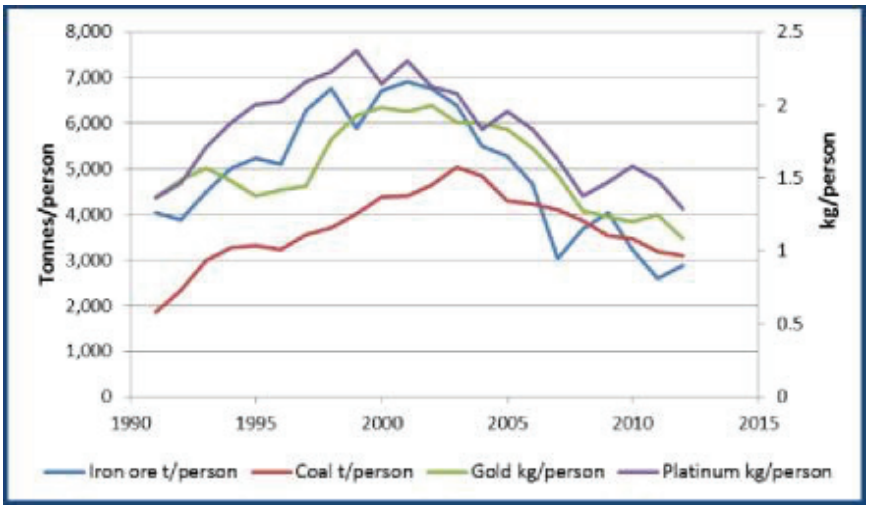

Figure 1. Mining productivity trends across South Africa's top mineral commodities, 1991-2012.

THE COMPONENTS OF A PERFECT STORM

In physics, the definition of a *constructive interference* is when two or more waves of equal frequency and phase combine, resulting in their reinforcement and producing a wave of single amplitude equal to the sum of the amplitudes of the individual waves, as shown in Figure 2.

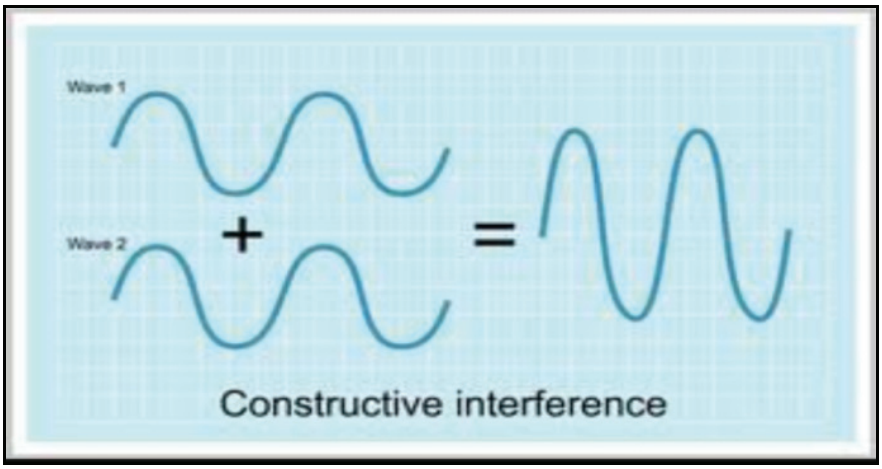

Figure 2. Constructive Interference of waves.

While constructive interference may be seen as a positive outcome due to the increased output, if the influencing factors (the individual waves) have a negative impact and are in -phase and at the right frequency then the outcomes could be disastrous if they the coincide. Colloquially, or more dramatically, this is referred to as a '*perfect storm*'.

From a South African mining industry perspective, with a strong focus on the four major commodities that influence the South African economy (gold, PGMs, iron ore and coal), the issues are summarized as follows:

- The South African gold industry has been characterized by decreasing levels of production, increasing depths of operations, and harder-to-access payable material volumes. Labour and other costs have increased significantly and have impacted on the profitability and sustainability of gold mining in South Africa
- In the case of PGMs, South Africa dominates global production. Labour costs and rising steel and electricity costs all result in production being marginal in terms of operational costs
- In the iron ore industry, transport infrastructure and transport costs major problems. The low commodity price as well as a decrease in the demand for steel has had a negative impact on this sector
- Decentralization of coal production by major producers to many smaller individual companies has had a negative effect by reducing economies of scale and creating a number of higher cost marginal producers battling with major environmental issues, transport costs, and export quotas. The uncertainties associated with the resources in the Waterberg coalfields are a huge challenge that awaits the coal sector.

In addition to the above specific issues, there are a few generic challenges that are common to all commodities being mined:

- The need to ensure that mine rehabilitation requirements are well resourced and funded so that the environmental impact is minimized both now during mining as well as once mining activities have stopped
- Skills shortage both from a technical as well as operational perspective

- Socio-economic issues, especially in the communities where mining operations are taking place.

A graphical summation of the above is shown in Figure 3.

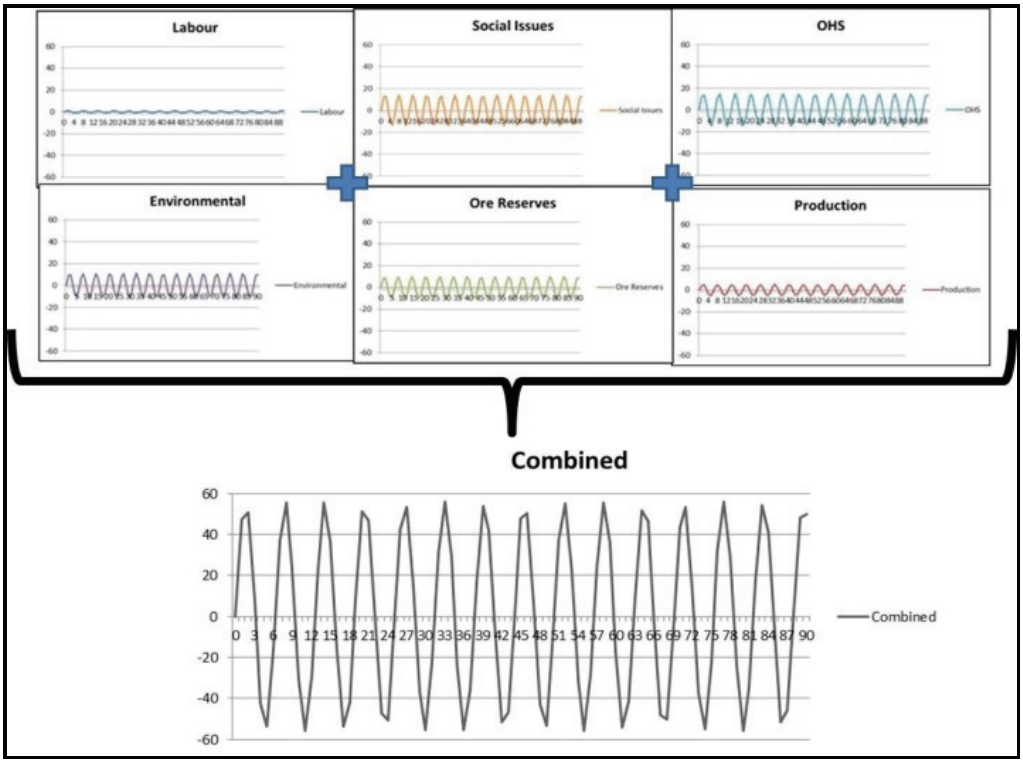

Figure 3. Confluence of factors impacting on mining.

Utilizing the definition of constructive interference (noting the negative connotations for mining) it can be postulated that the South African mining sector is facing the *perfect storm*.

'TAKING ON WATER'

The South African government identified the need to intervene in the mining sector considering the severity of the impacts of the perfect storm:

- 40 000 jobs have been lost in the last three years
- South Africa is no longer among the top 10 mining investment destinations on the continent;
- There were 515 971 working days lost to industrial action in 2013
- Low commodity prices have exacerbated the crises in the industry – 40% of the South African platinum mining industry and 31% of the gold mining industry is loss-making
- Mining's contribution to the GDP has declined from 21.9% in 1970 to just 5.1% in 2014;
- Having led the world in gold production in 2006, South Africa now ranks 7th
- Easy accessible resources, especially in gold, are becoming depleted
- The industry has left a legacy of environmental problems, including acid mine drainage.

ALL HANDS ON DECK

Following the Malaysian model for quick tangible results, the South African government-led Phakisa process was applied in areas that would help foster growth and the attainment of national development goals. Phakisa is essentially a collaborative process, convened by government but

involving a range of key stakeholders, to plan and oversee the implementation of initiatives that will have a positive catalytic impact on the economy and society. Mining was one such area.

The mining cluster is facing deep-seated economic and socio-economic historical, structural, and immediate challenges. Phakisa has the challenge of developing collaborative interventions that will meaningfully impact on the short- and medium-term challenges faced by the mining cluster and putting in place institutional mechanisms that will entrench the collaboration.

The broad aim of the Mining Phakisa as a whole is to galvanize growth, transformation, investment, and employment creation along the entire mining value chain, in relevant input sectors and in mining-related communities.

The Mining Phakisa outcomes identified that in order to address the challenges in the mining sector, one of the critical paths to be followed was to *'extend the life of Platinum and Gold mines in South Africa beyond 2025 and establish global leadership in narrow-reef, hard rock mining systems'.*

The above statement was strengthened with the following caveat: *'this is enabled through partnerships in research and development, skills and competitive local manufacturing capability that will focus on the current and future mining operations through next generation mining systems. To achieve this, a just transition must be at the core'* (Mining Phakisa, 2015).

Many leaders of mining companies have spoken of the need to modernize mining in the country. However, modernization is often confused with mechanization. Mechanization could be a part of modernization, but modernization is more than just mechanization.

Improving mining...
a systems approach is needed...
Modernisation is the first step...

Modernization of mines via mechanization and automation and ultimately fully autonomous operations is the envisaged path that will bring change to processes, technologies, skill-sets, and social and environmental impacts associated with current mining practices. One measure used by national governments across the world to determine economic growth and competitiveness is the amount of money spent on R&D as a percentage of GDP. A report by Khan (2009) on the spending on research and development (R&D) has shown that South Africa's investment in R&D as a percentage of GDP has bottomed out after four years of decline. South Africa spent approximately R22 billion in 2011/2012, which equated to 0.76% of the GDP, compared to the average 1.77% spend by countries such as Brazil, Russia, India, and China (BRICS). The percentage of South African GDP spend on R&D is significantly behind China, which spent 1.84% of its GDP on R&D.

Taking this assessment, even further, to the various industrial sectors and in particular for the mining sector, shows that significant R&D investment is required into the mining sector and the country to address the challenges that lie ahead.

Further to this, a vibrant, strongly capacitated and adequately resourced local mining R&D community is needed to ensure that the solutions are designed for South African conditions from both a socio-economic as well as technical perspective, due to the nature of the mining geotechnical parameters and the complexity of addressing the social imbalances of the past.

The Mining R&D Strategy for the South African mining industry should be guided by the following vision:

To maximise the returns of the South Africa's mineral wealth through collaborative, sustainable RESEARCH, DEVELOPMENT & INNOVATION of mining technologies in a socially, environmentally & financially acceptable manner that is rooted in the wellbeing of local communities and the national economy.

THE RESCUE PLAN - A STRATEGY FOR MINING

In November 2014, under the leadership of the Deputy Minister of Mineral Resources, Mr. Godfrey Oliphant, stakeholders discussed R&D within the mining sector. During the subsequent discussions, the CSIR was tasked to develop a consolidated mining strategy utilizing the draft documents of the Department of Science and Technology (DST) (Craven *et al*., 2014) and the Department of Mineral Resources (DMR) (Vogt and McGill, 2014) respectively. The resulting document was called the *South African Mining Extraction Research, Development and Innovation (SAMERDI) Strategy*. SAMERDI served as an input document into the Mining Phakisa[1] that was held in November 2015. There have been significant watershed outcomes of the Mining Phakisa and more so for mining R&D.

Firstly, after many attempts stakeholders agreed that SAMERDI Strategy would be the consolidated strategy for Mining Extraction.

Secondly, there is a collective agreement, as seen by the Phakisa Outcome called *'Advancing the Cluster'* whereby the discussions on various platforms led by various government departments as well as business organizations agree that there is a need to strengthen mining extraction research capability and capacity in South Africa as the sector moves towards modernization of mining. Stakeholders agreed that the consolidation of the various resources and research offerings in one common space is clear and necessary.

Finally, there was agreement that there is a need to develop systems that will migrate current mining from conventional, labour-intensive, highly diluted methods to the utilization of mechanized drilling and blasting equipment and ultimately to a continuous mining method that is independent of the use of explosives. Further to this will be the need to develop the appropriate supporting systems and infrastructure necessary for implementation. This is defined as the Next Generation Mining Systems (NGMS).

At the core of the SAMERDI Strategy, aligned to the visions, are the following objectives:

i. To improve the competitiveness of the sector and create new opportunities for South African based companies to operate in areas along the entire value chain from the innovations stemming from the RD&I areas
ii. To rebuild and reposition South Africa as the world leader in Mining RD&I by building human resources skills, capabilities and capacities across, industry, academia and the science councils ensuring its sustainability.

THE SOLUTION DESIGN

Two strategic outcomes of the Mining Phakisa process related to Advancing the Cluster were:

Mining R&D Programme: An intensively collaborative Research and Development model with a holistic systems approach that is substantially funded which will must focus on building core IP, patents and commercialisation opportunities and ultimately position South Africa as a global leader in next-generation mining systems

- **Mining Manufacturing Equipment Cluster (MMEC):** A mining manufacturing equipment cluster that is embedded with other existing, clusters and initiatives, which will ensure development requirements are translated into coherent R&D programmes, enabling local partnerships to develop and manufacture equipment for next-generation mining systems.

Figure 4 shows the focus areas for both streams for the short term, medium term and long term objectives.

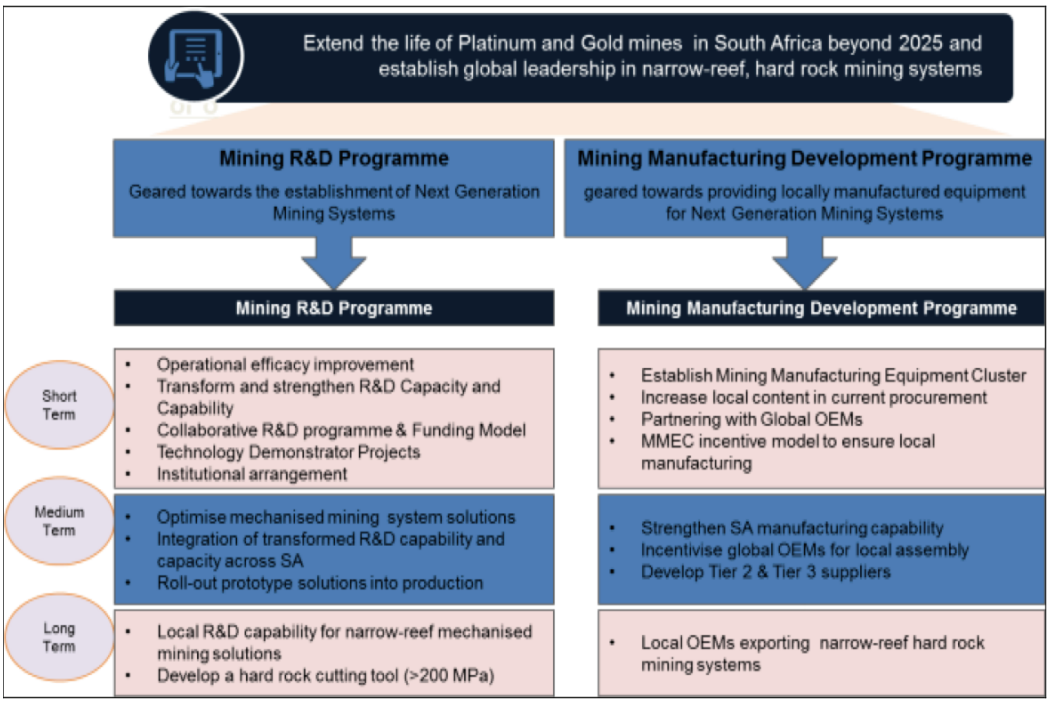

Figure 4. Advancing the Mining Cluster through R&D and mining manufacturing equipment capability.

The Mining R&D programme has two delivery pathways:

i. The development of a Mining R&D hub
ii. The development of mechanized mining solutions for gold and platinum mines.

The above pathways were expanded utilizing the top-down approach where the highest strategic level is set at '100 000 foot' cascading down to a more operational level of *'1000 foot'* level as shown in Table I. (*Note: the implementation plan (at a '3 foot' level was not included in this report due to the information not being officially released).*

Table I. Advancing the cluster through R&D and NGMS.

100 000 ft.	10 000 ft.	1000 ft.
Consolidate and integrate mining extraction R&D capability	Develop appropriate institutional arrangement	Develop hub & spoke model - mining research & development (R&D) hub
		Finalize funding for mining R&D
		Develop governance framework
	Develop research capacity	Build skills capacity
		Enhance and maintain existing safety critical research infrastructure
		Development of education curriculum
Develop mining solutions for PGM and gold mining	Optimize current conventional mining systems	Establish platform to discuss optimization of current conventional mining systems
		Energy consumption & costs
	Develop mechanized drill and blast systems for gold	Complete development of face production prototypes
		Develop supporting systems for NGMS
	Develop mechanized drill and blast and clean systems for PGMs (LP to UP)	Implement selected pilot projects
		Develop supporting systems for NGMS
	Develop mechanized 24/7 mining systems	Develop rock cutting tool for >220 MPa rock for 24/7ops
		Develop supporting systems for NGMS
	Develop product commercialization path	Drive commercialization of R&D

The Mining Hub

The participants[2] in the Phakisa process agreed that there was a dire need for a vibrant, strongly capacitated, and adequately resourced local mining RD&I community to ensure that the solutions for the South African mining industry addressed the local socio-economic as well as technical challenges as identified in the SAMERDI Strategy.

To this end the Phakisa process identified that the CSIR facilities in Carlow Road will be the geographical location of the Mining Hub. The DST appointed the CSIR to lead the implementation of the Mining Hub.

The Mining Hub is based on a 'hub and spoke' model with a collaborative approach from all stakeholders, *viz*. government, industry, state-owned enterprises, science councils, and universities, such that that there is greater return on the investment from each of the research sponsors. The model provides for opportunities for larger research programmes to build research capacity and capability towards finding solutions for the current and future issues facing the mining sector.

The *hub and spoke* model allows for the leveraging of the existing strengths of the host organization, thereby reducing administrative costs for support staff while calling on the technological capabilities of other partners simultaneously.

The function of the Hub is to coordinate the research activities towards the revitalization of mining for South African mining operations through the development of next-generation mining systems (NGMS).

To advance the cluster the focus areas are:
a) Current mining operations: to increase the life of mine (LoM) of current mining, by addressing efficiency of extraction, improvement in occupational health and safety and reduction in costs
b) Mechanized drilling and blasting for gold mines: to develop fully mechanised mining systems that will allow for the drilling of narrow hard rock mines (in particular the deeplevel gold mines)
c) Ultra-low profile (ULP) mechanized drilling and blasting for PGM mines: to develop ULP fleet of mechanised mining equipment and supporting systems that will allow for the mining of PGMs at substantially reduced stoping widths
d) 24/7 non-explosive rockbreaking: to develop complete mining systems for extraction that are completely independent of the use of explosives for both PGM and gold mines.

The R&D Programme
The SAMERDI Strategy has seven thematic areas with a total of 54 programmes of work from each of the areas shown below:
1. Real-time information management systems (RTIMS)
2. Input resources optimization (IRO)
3. Modernized mining engineering (MME)
4. Non-explosive rockbreaking
5. Human factors (HF)
6. Environmental impact management (EIM)
7. Mine design.

The final work programme was prioritized based on the timescale as proposed below:
1. Programmes that should be undertaken within the next 1 to 3 years
2. Programme that should start within 3 to 5 years from approval of the strategy
3. Programmes that should start no later than 5 years from approval of the strategy.

For the purposes of this paper only the projects that should be started immediately are shown in Table II.

Table II. Research projects for immediate commencement.

Thematic areas	**Programme**
Real-time information management systems (RTIMS)	Better imaging (remote sensing)
	3D modelling of mine processes
	Underground data collection & monitoring
	Visualization & virtual reality
	Automation: Including collision avoidance standards, development of sensors,
Input resources optimization (IRO)	Power efficiency
Modernized mining engineering (MME)	Mining at <800 mm
	Prevention of spontaneous combustion in coal
Non-explosive rockbreaking	Mine design for de-stressing
	Rock pre-conditioning methodologies;
	Rock breaking/crushing technologies & systems

Mine design	Planning systems
	Logistics for personnel movement

Next-generation Mining Systems (NGMS)

The other significant aspect to *Advancing the Cluster* is the need to develop a manufacturing capability for mechanized mining equipment to operate in narrow tabular orebodies.

NGMS is often misinterpreted as simply the deployment of mechanized mining equipment. This is not the case. The misinterpretation is negated by considering the systems approach of *modernization of mines*. Modernization via mechanization and automation and ultimately, fully autonomous operation, is the envisaged path that will bring change to processes, technologies, skill-sets, and social and environmental impacts associated with current mining practices.

Potential NGMS Solutions

In the development of technologically advanced equipment there are various stages of technology readiness levels (TRLs). In order to ensure that there is a strong focus on research and development and to distinguish between product developments, the following definitions for the different levels are provided (NASA, 2012):

- **TRL 1:** scientific research is beginning and results are being translated into future research and development
- **TRL 2:** occurs once the basic principles have been studied and practical applications can be applied to those initial findings
- When active research and design begin, a technology is elevated to **TRL 3**
- Once the proof-of-concept technology is ready, the technology advances to **TRL 4**
- **TRL 5** is a continuation of TRL 4
- At **TRL 6**, the technology has a fully functional prototype or representational model
- **TRL 7** is when the technology requires that the working model or prototype be demonstrated in an appropriate environment
- **TRL 8** technology has been tested and 'flight qualified' and it's ready for implementation into an already existing technology or technology system
- Once a technology has been 'flight proven' during a successful mission, it can be called **TRL 9.**

For R&D purposes, only those initiatives at a TRL 6 and below will be considered for funding. Technologies above TRL 6 will be allocated to the Mining Manufacturing Equipment Cluster (MMEC) for development into commercialisation opportunities.

With the call for modernization of South African mines and the nature of the orebodies (depth, reef width, and the dip of the reef), the solutions that need to be sought will be uniquely South African.

Mechanization is not new to the South African mining sector and has been used with varying degrees of success for different mineral commodities, particularly in the coal mining sector and most recently in some platinum operations. Gold mines have had the least successes of all commodities in deploying mechanized (trackless) mining except for two gold mines that exploit massive orebodies. The depth of mining, the steep angle of the orebodies, as well as the narrow width of the reef package will require significant investment into RD&I to understand the various challenges such as rock engineering requirements, the mechanical design of the equipment, and related ventilation flow into the mines.

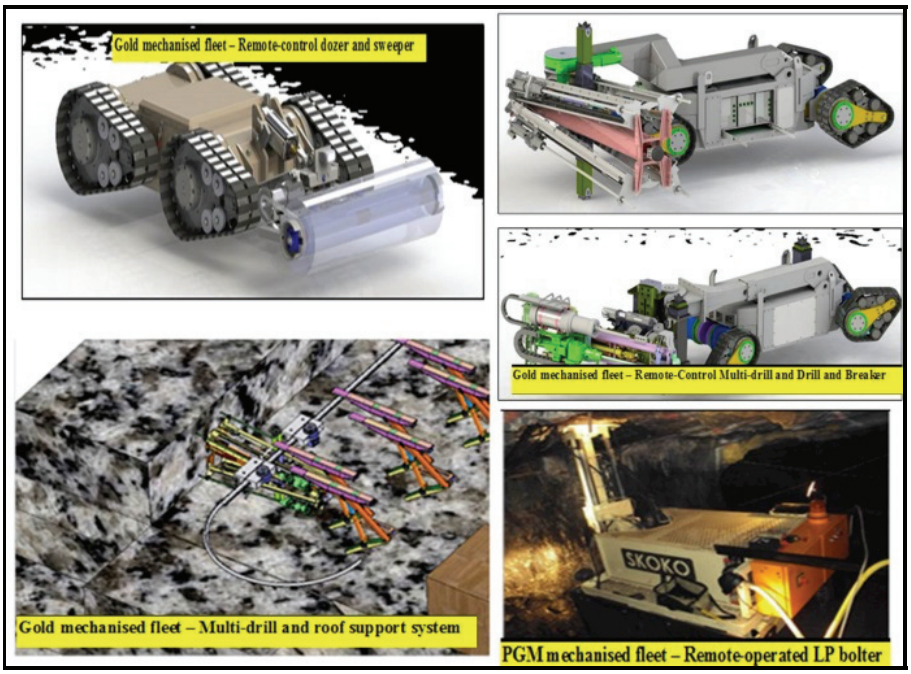

Figure 5. Some examples of potential NGMS projects under consideration.

The DST has provided funding through is Industry Innovation Partnership Fund (IIPF), a programme that seeks to improve the competitiveness of existing economic sectors, under the management of the CSIR to commence work on projects linked to NGMS. Engagements will be planned with members of the Chamber of Mines, in particular Anglo Platinum, Sibanye Gold, and AngloGold Ashanti, all of whom currently have various mechanization and modernization programmes underway.

Just Transition

While modernization, via the need for new technological innovations, is paramount to the future of the mining sector, it is important to remember that the human factors component of introducing change needs to be considered. There is a direct impact on the workforce and inevitably the number of people employed in mining. This has a follow-on impact on the communities dependent on mining. Apart from the technical challenges, such as the development of suitable technologies, and mining and geotechnical constraints, critical aspects such as change management and leadership, re-skilling, associated training requirements, work planning and operation of the mine, and relationships with supporting industries need to be considered.

CONCLUSIONS

The need to access and process low-grade mineral deposits that lie at greater depths, under more complex geotechnical constraints, in areas with sparse infrastructure, under increasing calls for maximum socio-economic returns of mining, and with increasing costs of energy and water and labour present the *perfect storm***.**

There is a collective agreement from all stakeholders that ensuring the longevity of the South African mining industry will require a coherent, collaborative approach to the current and future challenges facing the sector.

The plateauing of production against the constant increase in costs and the ubiquitous need to improve safety in a global market when commodity prices are low and forecast to remain low for years to come, calls for the revitalization the mining R&D capabilities in South Africa.

The South African Mining Extraction Research, Development & Innovation (SAMERDI) strategy provides a roadmap on how to work collectively towards technological solutions that will increase safety and productivity, reduce costs. and ultimately extend the life of mines.

Thus the implementation of SAMERDI strategy through collaboration and support from researchers, government departments, mining houses (individually and collectively), organized labour unions, and universities can be the solution to ride the *perfect storm* the mining sector finds itself in.

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The members of the DMR, and in particular those involved in the Mining Industry Growth Development and Employment Task Team (MIGDETT), are thanked for their foresight in undertaking the DMR project '*A Technology Innovation Roadmap for the South African Minerals Industry'.*

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- *Declan Vogt - University of the Witwatersrand*
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- *Alan McKenzie - Mintek*

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