

Development of a Platform for Sustainable Development in Africa through Minerals and Metals

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Abstract

By adopting the ambitious set of seventeen Sustainable Development Goals (SDGs) incorporated into the UN's 'Transforming our world; the 2030 Agenda for Sustainable Development'¹, the member states recognised that it was no longer 'business as usual'. In order to achieve these goals in the time frames set, fundamental transformation of how the world lives, works and thinks is necessary. All sectors of society are needed to cooperate and work together to achieve them. Since universities, and particularly research-intensive universities, are enablers of transformation through a number of roles, their participation is critical. In particular, they provide development of new tools and technologies; build capacity through education and equipping future leaders; foster independent and critical thought-leadership; and have the convening power to stage platforms for discussion and debate by a range of stakeholders. The University of Cape Town (UCT) established the Minerals to Metals Initiative (MtM) in 2007 in recognition of the need for interdisciplinary research in minerals beneficiation. This paper discusses how this Initiative provides a platform for sustainable development through minerals and metals, and is playing a pivotal role in this area.

Introduction

Minerals and metals fundamentally underpin every aspect of modern society, with no carbon-neutral economy possible without mining. However, the global mining industry is facing increasingly complex, multi-faceted internal and external challenges which require innovative, integrated and interdisciplinary approaches to address them². In its scoping paper, 'Mining and metals in a sustainable world', the World Economic Forum³ emphasised, amongst other things, the need for appropriate research and development

¹ "Transforming our world: the 2030 Agenda for Sustainable Development," United Nations, Resolution adopted by the General Assembly, 25 September 2015, accessed 15 August, 2017,

http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

² S. Pityana, "Green Mining, Beyond the Myth," Keynote address, Green Mining: Beyond the Myth interactive workshop, University of Cape Town, 11 August, 2017.

³ "Scoping paper: Mining and metals in a sustainable world", World Economic Forum, 2014, accessed 15 August 2017,

http://www3.weforum.org/docs/WEF_MM_MiningMetalSustainableWorld_ScopingPaper_2014.pdf

of technologies to operate in a clean and safe environment in frontiers previously considered inaccessible. It also recognized that the skills and capabilities needed to operate in a sustainable world are different from those required currently, and need to be cultivated.

Africa, and Southern Africa in particular, is well-endowed with mineral resources, which have the potential to serve as a vehicle for significant economic growth within the region. The Africa Mining Vision endorsed by Africa's heads of states in 2009 calls for 'the transparent, equitable and optimal exploitation of mineral resources to underpin broad-based sustainable and socio-economic development'⁴. For the contribution of the minerals sector to be sustainable, however, these economic benefits need to be fully realized and extended to all facets of society, whilst simultaneously preserving the local environment.

In May 2007, the University of Cape Town (UCT) established the Minerals to Metals Initiative (MtM) as a small research grouping in the Department of Chemical Engineering with the aim of integrating and expanding capacity in minerals beneficiation research. Since then, MtM has fostered active collaboration with academics and experts in other fields and disciplines (including the sciences, commerce, law, medicine and the humanities) at UCT and at other universities, both in South Africa and beyond, and now comprises nearly forty active participants, including five adjunct professors⁵. Student numbers have grown from four in 2007 to over forty in 2017. Since 2007, MtM has graduated eight PhD's and forty-five Master's degrees, produced more than seventy publications in peer-reviewed journals and refereed conference proceedings, and established a new Master of Philosophy (MPhil) degree specializing in 'Sustainable Mineral Resource Development', which is hosted by MtM.

There are three inter-connected activity areas, viz., education, research, and engagement, which are aligned with UCT's mission 'to be an outstanding teaching and research university, educating for life and addressing the challenges facing our society'. Education, of which the cultivation of the 'skills and capabilities needed to operate in a sustainable world' is an essential part, includes the mentoring and supervision of post-graduate research students, the holding of a weekly Forum for the interchange of ideas, and the hosting of the new MPhil degree. There is a problem-oriented approach to developing research solutions focused on enhanced value addition and resource productivity, through the conversion of minerals to metals in a manner congruent with providing a sustainable future for people in Africa and their environment. Engagement is undertaken through participating in or hosting a range of activities with various internal and external stakeholders, including other universities, industry, government bodies, and NGOs.

This paper presents an overview of the activities of MtM, now in its tenth year of operation, highlighting the education, research and engagement frameworks, which together create a platform for sustainable development in Africa through minerals and metals.

⁴ "African Mining Vision", African Union, 2009, accessed 15 August, 2017, http://www.africaminingvision.org/amv_resources/AMV/Africa_Mining_Vision_English.pdf

⁵ "Self-review portfolio 2011-2016", Minerals to Metals Initiative, University of Cape Town, November 2016.

Education Framework

The drive for educating for a sustainable world was articulated strongly during the 2002 World Summit on Sustainable Development (WSSD). At this Summit, the world-leading educational and scientific organizations signed the Ubuntu Declaration on Education, Science and Technology for Sustainable Development⁶, the main goals of which are:

- Strengthening of collaboration between educators and researchers;
- Better integration of science and technology into educational programs for sustainable development at all levels;
- Problem-based approach for education and scientific research; and
- Innovation in knowledge transfer to bridge the gaps and inequalities in knowledge.

This is aligned with continued adherence to the Milos declaration⁷, which states that ‘the engineers, scientists, technical experts, and academics who work in, consult for, educate, study, or are in some other manner associated with the minerals industry ... share a mutual responsibility with all individuals to ensure that our actions meet the needs of today without compromising the ability of future generations to satisfy their own needs’.

MtM espouses these principles in its education framework, believing that the next generation of leaders in the mining industry will require a range of skills that can be best learned in a dynamic, multi-disciplinary, industry-focused education environment. MtM aims to produce graduate professionals who can operate from an integrated systems perspective whilst at the same time having a strong discipline understanding and competence, and a sensitivity to engage constructively with different stakeholders (see Figure 1). Such individuals will be comfortable working outside of their core discipline in multi-disciplinary teams, as well as being mentally agile, able to identify and respond to non-intuitive opportunities that will provide step changes, and capable of leading the way in developing a sustainable mining Industry. It is envisaged that these graduates will join the community of practice equipped to lead, shape and sustain the mining industry.

Education and training of MtM post-graduate students and post-doctoral fellows occurs through mentorship, supervision of research projects, attendance at external and internal courses, and involvement in the various MtM engagements outlined in the “Engagement Platform” section below. Research is carried out by post-graduate students, both master’s and doctoral, supplemented by post-doctoral research fellows. Students and post-doctoral fellows are usually supervised by two academics from different disciplines and/or research groupings; this encourages inter-disciplinary and trans-disciplinary collaboration, and exposes students to different perspectives and approaches.

⁶ “Mobilizing for education for sustainable development: towards a global learning space based on regional centres of expertise,” United Nations University Institute of Advanced Studies (UNU-IAS), Yokohama, Japan, 2005.

⁷ “Contribution of the Minerals Professional Community to Sustainable Development,” Milos Statement, 2003, accessed 15 August, 2017, http://www.sdimi.org/milos_decl_org.pdf

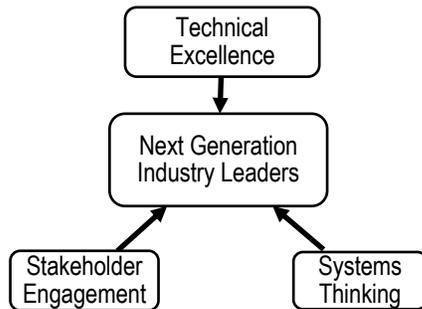


Figure 1 Attributes of the “next generation” leaders

Students are encouraged and supported to attend short courses designed to enhance and broaden their exposure and skills base. All MtM students undertake the ‘Research Methodology and Communication’ course offered in UCT’s Faculty of Engineering and the Built Environment. Some students are given the opportunity to attend the ‘Sustainable Development’ and ‘Strategic Social Engagement’ courses offered as part of the new MPhil degree (see below). MtM is also involved in undergraduate education, through the supervision of final year engineering student projects, and researchers feeding their thinking back into the teaching of undergraduate courses.

Developing the next generation of leaders in the mining industry also requires non-formal development of a more personal nature. This includes helping individuals to learn how to deal with complexity, diversity, conflict, innovation and creativity, which are all required for higher-order problem solving. The Thursday Forum is a weekly meeting initiated and hosted by MtM to develop social skills that are often left underdeveloped within a rigorous technical environment. The central objectives of the Forum are to build trust, improve listening and communication skills, learn from new cultures and perspectives, and develop social contextual understanding. The topics for discussion in the Thursday Forum have varied widely, but there has been an underlying focus on culture, beliefs and values. Particularly memorable were the discussions around the anniversary of the Marikana massacre, and around the documentaries ‘Miners Shot Down’ and ‘Black Lives Matter’.

MtM also hosts the new UCT MPhil degree program specializing in ‘Sustainable Mineral Resource Development’, to provide an inter-disciplinary postgraduate qualification that highlights the critical factors of sustainable development in the context of mining and minerals processing in Africa. The program was inaugurated in 2014, and is delivered collaboratively by UCT and the University of Zambia (UNZA). To date, fifty-four students from six countries have registered for the degree, in four cohorts, with backgrounds ranging from mining and geology to economics, social work, and forestry. This leads to lively discussions in the classroom, and an enhanced appreciation and understanding of the complexity of sustainable minerals resource development. The majority of the students are in full-time employment, and are thus in a position to apply the skills and expertise gained in the taught courses to real-life case studies within their working environment in the form of research projects. In addition, all students are required to complete a field-based internship with a host organisation, which contributes to their learning experience,

and makes a useful contribution to the host. More details of the MPhil may be found in Broadhurst (this conference)⁸.

Research Framework

The continually evolving research program that falls under MtM is aimed simultaneously at reducing the environmental and social impacts of mineral beneficiation operations, developing safe and sustainable operational practice, and increasing the amount of mineral or metal extracted from each ore body beneficiated. Thus, technology choices are developed and evaluated not only in terms of the conventional economic returns, but also with regard to their impact on the natural and human environments, which allows stakeholders to make more holistically informed decisions. The research is underpinned by a number of industry-based projects and case studies, which explore the sustainability challenges facing the minerals sector from both a fundamental and a systemic perspective, and establish linkages between traditionally separate but cognate research areas.

MtM research projects have their origins in real problems and are developed on the basis of academic interaction with relevant stakeholders, including mining companies, industry consultants, government representatives and NGOs, as well as academic partners from a range of disciplines and backgrounds.

The fundamental research portfolio is science and technology based, and is aimed at developing an understanding of the underlying physical and chemical principles that govern processes within the minerals extraction and beneficiation chain and the interactions with, or impact on, the remainder of the system. Systemic research projects are concerned with the performance of minerals processing and beneficiation systems as a whole, and their interface with the environment and society, as well as their technical or economic merit.

Figure 2 illustrates how the understanding of the fundamental perspective at the particulate (first, or lowest) level underpins the understanding of the processes and linkages in the system, with level 2 representing a single unit operation, level 3 a number of unit operations connected in stages or circuits, level 4 a combination of stages or circuits into an entire mineral beneficiation operation (from pre-feasibility to closure), and level 5 taking into account the environmental, social and economic linkages around a mining operation and beyond (regional, national and even continental and global scale). The bottom-up/top-down approach to the development of minerals-to-metals processes extends the system boundary beyond the fundamental R&D and flowsheet design levels to include decision-making. This approach is based on recognition of the following:

⁸ J. Broadhurst, "A transdisciplinary post-graduate degree programme specializing in sustainable mineral resource development," paper to be presented at the Fifth Annual International Conference on Sustainable Development (ICSD), 18-19 September, 2017, Columbia University, New York.

1. A fundamental understanding of process performance on a unit-operation or technology level is a prerequisite for sustainable process design and industry decision-making.
2. It is equally important that the development of technologies and process flowsheets is guided by, and consistent with, the overarching sustainability objectives of the business and industry as a whole.

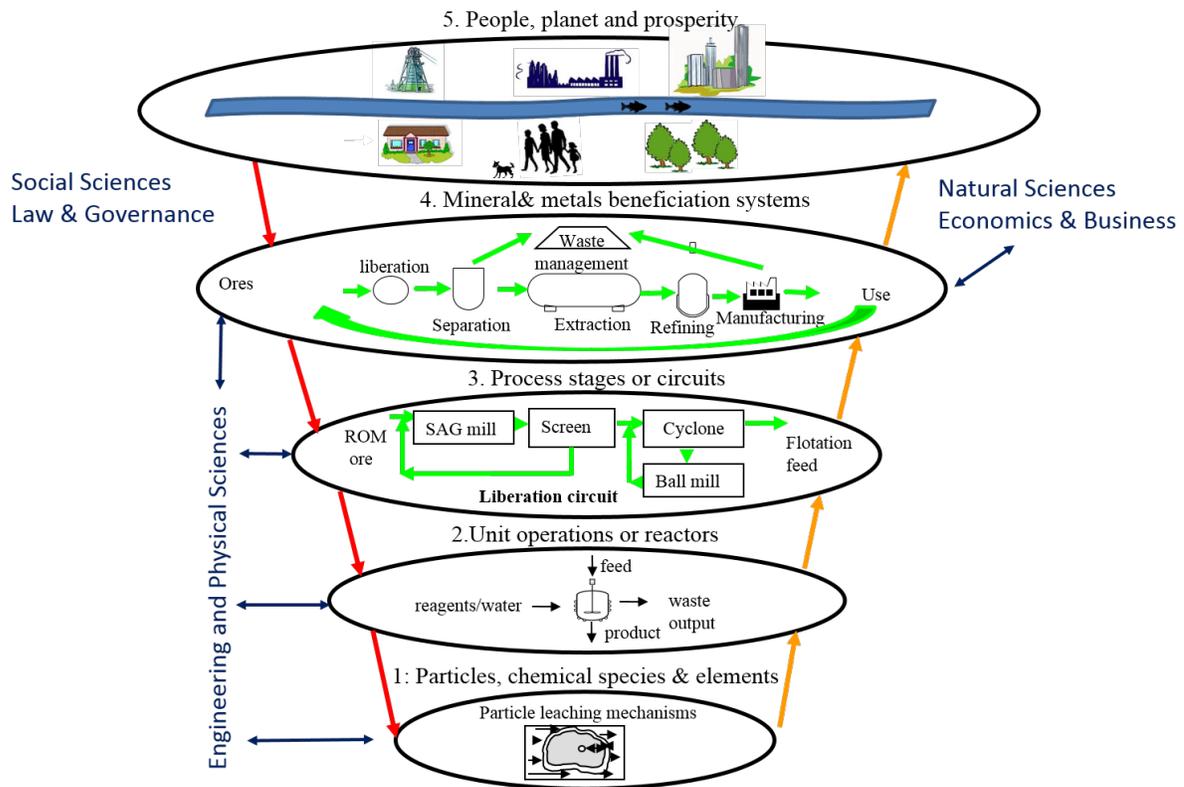


Figure 2 Schematic illustrating the various levels and linkages in MtM's research focus

It is postulated that this approach will play a key role in supporting the sustainability of primary metal production industries by:

1. Ensuring that technology and flowsheet design, and the related fundamental R&D activities, are in line with the sustainability criteria and objectives relevant to the primary metal production industry.
2. Providing a means of integrating process performance data and information into decision-making processes in a cost and time effective, yet reliable, manner.

The fifth, or highest, level incorporates the interactions between mining, society and the environment, covering the three pillars of sustainability, viz., people, planet and prosperity, and implies the development of resilient communities. The need to address the challenges at this level has led naturally to inter-disciplinary and trans-disciplinary work and

collaboration. This has been further boosted with the advent of the new MPhil degree specializing in 'Sustainable Mineral Resource Development'⁹ hosted by MtM, in which students from many different disciplines and backgrounds are registered. Some examples of past and current research projects and programmes are presented in the next section below.

Research Program

MtM conducts research projects that work across technical boundaries with an emphasis on moving the industry into a more sustainable paradigm. The research occurs at both a fundamental and a systemic level, although these two cannot be considered in isolation (see Figure 2), and the overarching aim of both is to develop cleaner mineral extraction options and technologies, improve process performance, reduce energy and water consumption, and improve the quality of effluent streams. Systemic projects aim, further, to understand and analyse all operations and performance objectives across the entire minerals chain, in an integrated manner, and provide guidance (and metrics) for environmentally sustainable decision making during mineral processing flowsheet design.

At the particulate level, there has been a focus on comminution (crushing and milling), and on hydrometallurgical processes. This has required the development of skills and understanding in mineralogy, rheology and electrochemistry. A seminal investigation, which is frequently cited, explored the chemical and bioleaching behavior of large sphalerite (zinc ore) particles, produced by different comminution methods, in a heap leach scenario, using a combination of mineralogical, chemical and physical characterization tools, and column leach experiments. Heap leaching has also been investigated for low-grade gold and copper ores. Different types of comminution have been examined with the aim of reducing energy use.

Rheological investigations have been carried out into the behavior of phyllosilicate minerals that commonly occur as problematic gangue in the beneficiation of low grade ores: one study led indirectly to a major improvement in the recovery of platinum group minerals (PGMs) at one of the world's largest platinum producers. The rheology of coal-water mixtures has been measured, to determine the type and dosage of dispersant required to produce coal-water slurries capable of being pumped over long distances (reducing transportation costs, and pollution). Another seminal project established a unique granular rheology for particles moving on a vibrating screen: improving screening efficiency in mineral operations could result in enormous reductions in energy use in comminution.

Electrochemistry research has included investigations into the bio-leaching of a copper ore (chalcopyrite), as well as an electrochemical and leach study of the dissolution of chalcopyrite in ammonium sulfate-ammonium hydroxide solutions, using pure mineral electrodes. The latter project has led to a new understanding of the mechanism involved, which in turn could lead to hydrometallurgical processing replacing the conventional high-temperature energy-intensive extraction process. Another hydrometallurgical project characterized and modelled the decay of ion-exchange resins after protracted use.

Ultimately, fundamental research is the domain of individual academic disciplines and research groupings: MtM adds value through promoting collaborations to add depth and

⁹ J Broadhurst, *op. cit.*

systemic input to the fundamental research, and facilitating wider, inter-disciplinary investigations that require intensive collaboration. In this way new knowledge, technologies and tools are developed that would not be possible in any single academic discipline.

From the systemic perspective, one of the key focus areas of MtM over the past decade has been the development of an integrated approach to the management of sulfide-containing mine tailings that mitigates risks of acid rock drainage (ARD) pollution while providing opportunities for value recovery and re-allocation of unavoidable wastes for other uses. Major studies have been carried out on porphyry-type copper ores as well as coal ultrafines. New tools and protocols have been developed for the accurate and reliable characterization and prediction of ARD generation associated with solid mine wastes. The studies have highlighted the important role of mineralogy, both in characterising the acid generating potential of a sample directly and in assisting in the interpretation of the geochemical reactions and governing species controlling the acid generating behavior. A geochemical mass transport model to simulate the potential ARD risks in full-scale sulphide-bearing mine waste deposits was also developed.

Also falling under the theme of value from waste are the program of research into the potential for using mine waste for CO₂ sequestration through mineral carbonation, the development of a novel flowsheet that employs flotation to recover high-value monazite from a zircon reject stream at a heavy minerals plant, and the investigation into the use of platinum mine tailings to improve the quality of soils and ameliorate plant growth. A new initiative is looking into the development of methods for the extraction of metals from e-waste, particularly printed circuit boards, using various hydrometallurgical and bio-hydrometallurgical methods, and underpinned by the characterisation and understanding of mineral behaviour. The potential to extend and develop this initiative into UCT's Urban Mine by including social innovation and the formation of a social enterprise is being explored.

In the area of energy utilization and greenhouse gas emissions, a study was conducted on the energy-related performance trends and the barriers and drivers for the implementation of energy efficiency measures in the gold mining industry in South Africa; another project evaluated the use of life-cycle based eco-efficiency indicators in strategic and design decision making, and whether this could add any environmental value to the processing of PGMs. A previous study explored the strengths and limitations of eco-efficiency indicators as performance metrics in guiding environmentally sustainable decision making during minerals process design.

The area of mine safety is also being researched: a framework that was developed for investigating the causes of accidents in the South African platinum mining industry is being extended to copper mines in Zambia by students undertaking the new MPhil degree. Other MPhil research includes developing an integrated approach for improving the sustainability signature of mining operations; assessing the benefits and sustainability impacts of a proposed coal mine in Australia; exploring the lived experiences of families re-settled because of new mining operations; investigating the impacts of mine waste on post-mining land use; and assessing the relationships between ore geology and mine water risks. The aim is to develop knowledge at an advanced level in and around the African mining industry through research.

These are some examples of past and present research topics undertaken by MtM. More

details of all the research projects may be found on the MtM website (www.mineralstometals@uct.ac.za).

MtM research has been acknowledged and strengthened by the award of a SARCHI Chair in Minerals Beneficiation to one of the co-authors of this paper (J-P Franzidis) in 2008. The South African Research Chairs Initiative (SARCHI) programme is a national knowledge and human resource development intervention, led by the Department of Science and Technology and managed by the National Research Foundation (NRF) (<http://hicd.nrf.ac.za/>). The current incumbent of this chair (Dee Bradshaw, another co-author of this paper) applied successfully in 2017 for the continued funding of the Chair until 2022.

Engagement Platform

At UCT, engagement or social responsiveness refers to the utilisation of an academic's scholarly or professional expertise for public purpose or benefit. Since much of MtM's academic activity occurs at the interface of academia, industry and civil society, both in terms of research and education, MtM is a natural platform for engagement and a catalyst for new connections and the co-production of new knowledge. In this way, MtM aims to:

1. Bridge the gap between and science and policy by conducting evidence-based research to support industry and government policy making.
2. Provide a neutral and independent platform for multi-stakeholder engagement.
3. Provide students and academics with a broader understanding of the real issues and challenges faced by practitioners, to ensure that research is both relevant and pertinent.

One of the first and most fruitful engagements has been ESDA (Education for Sustainable Development in Africa), a joint undertaking of a consortium of eight partner African universities and the United Nations University in Tokyo to initiate three master's programs in Africa, on sustainable urban development, sustainable and integrated rural development, and sustainable management of mineral resources, respectively¹⁰. All three programs emphasize field-work to strengthen the problem-solving capacities and interpersonal work skills of post-graduate students. The MPhil specializing in 'Sustainable Mineral Resource Development', which is hosted by MtM, grew out of this initiative, which has resulted in new and growing collaboration with the School of Mines at the University of Zambia, the Sustainability Institute at the University of Stellenbosch and UCT's Graduate School of Business, all of whom present courses into this degree. The consortium continues to meet regularly, and constitutes a network of academics committed to training leaders for Africa's sustainable development. The African Development Bank is supporting the project financially. A new ESDA initiative is now underway to develop a Master's program in youth entrepreneurship in Africa. A Next

¹⁰ "Education for Sustainable Development in Africa (ESDA)," United Nations University, Tokyo, 2016, <http://unu.edu/projects/education-for-sustainable-development-in-africa-esda.html#outline>.

Generation Researchers program, aimed at supporting nominated young faculty members in the eight partner universities, has also been established

Another highly successful collaboration was the development of a minerals beneficiation strategy for the KwaZulu-Natal Department of Economic Development and Tourism, a four-year project undertaken in collaboration with The Green House, a niche sustainability and environmental management consultancy, based in Cape Town. This included the completion of four Master's degrees, co-supervised by UCT academics in the Departments of Social Anthropology and Economics, and some members of The Green House.

There has also been significant engagement with mining companies. Between 2008 and 2014 MtM was involved in delivering a safety risk management course to mining company managers and senior personnel in South Africa, Namibia and Botswana, aimed at reducing the number of accidents and fatalities that occur in mining. The course was developed by Professor Jim Joy of the University of Queensland for Anglo American, who later made it available to other mining companies. The week-long course was presented twelve to fifteen times a year, to around 1500 delegates in all. Over the years, the course was modified to include health and environmental risk, and operational risk. It was suspended in mid-2014 owing to the global financial crisis, but discussions are underway to revive it, and include sustainability principles into the risk assessment, with material being contributed by MtM. Anglo American also contracted MtM, in 2012, to undertake a review of hydrometallurgical research activities in South Africa, in response to a growing concern regarding the decline in the expertise and capability in this area. This has led to the holding of annual hydrometallurgical workshop and seminars in Cape Town, attended by postgraduate students from South African universities where hydrometallurgical research is carried out.

MtM is also engaged with other mining companies, in various ways. For example, a partnership is being established with AngloGold Ashanti to co-develop resilience and innovation principles for sustainability that will involve trans-disciplinary research, education and training, and stake-holder and community engagement. Recently, MtM has facilitated visits by different groups of UCT students to Kropz's Elandsfontein phosphate mine, which borders the West Coast National Park, and which has incorporated sustainability principles into the design and operation of the mine and processing facility, to view this premier example of 'Green Mining' in practice.

In terms of NGOs, MtM participated with WEF in the consultation process for the preparation of the 'Mapping Mining to the Sustainable Development Goals: An Atlas' document, released in New York in July 2016, and initiated a program entitled 'Operationalising the Sustainable Development Goals for Mining in Emerging Economies', which was presented at a meeting in New York in September 2016. The aims were to assess the extent to which mining companies already contribute towards the SDG objectives, quantitatively and qualitatively, and then identify ways in which the sector could adapt and improve. MtM has also engaged with the Bench Marks Foundation, a non-profit, faith-based organization that monitors corporate social responsibility in South Africa; the HeadRoom Initiative, a group of mining practitioners that has successfully implemented sustainable turnaround solutions for mining operations that were previously marginal; and KudosAfrica, a sustainable investment rating provider in South Africa. MtM staff and postgraduate students are also involved with local LEAP schools, which provide student-

centred mathematics and science-focused education to economically disadvantaged high-school pupils.

MtM is in a unique position to invite local and world-renowned experts in various fields to offer short courses, workshops, and public seminars, which bring stakeholders together in a non-confrontational environment to reflect on issues around sustainability in mining. Recent events have included a workshop on 'Green Mining: Beyond the Myth', aimed at exploring opportunities to shift the mining sector into a more sustainable paradigm; a research and engagement day entitled 'Mining and Waste: The Law's Response to Theory and Practice', organized in association with the SARChI Research Chair for Mineral Law in Africa at UCT, and coupled with a photographic exhibition, which challenged participants to look at mining and waste with new/fresh eyes and question traditional conceptions of mining; and a workshop to showcase activities and available expertise within and beyond UCT in the area of mine dust, develop trans-disciplinary, multi-stakeholder approaches to the various issues, and discuss possibilities of collaborative research and funding. A mining company–community engagement round table was also held to consider issues that a mining company should consider if it were to engage with the community five years before a mine started.

These engagements promote trans-disciplinary and multi-stakeholder solutions to the complex problems facing the mining industry, which has the potential to deliver sustainable development in Africa. They enrich the quality of MtM activities and lead to the coproduction of new knowledge, also known as 'engaged scholarship'. By participating in these activities, MtM students (future graduate professionals) gain a deeper appreciation of the working environment they will enter, making them better equipped to do so.

Conclusion

It is clear that there is great potential for Africa's mineral wealth to contribute to its sustainable development. The Minerals to Metals Initiative at the University of Cape Town is delivering a new generation of professionals for whom sustainability thinking in a mining context is no longer an add-on but integral to all activities. The education framework inculcates critical thinking and a values-driven problem-solving approach, together with social and communication skills and the experience of collaborative, inter-disciplinary research. The research being undertaken is providing solutions that can be directly applied to contribute to the mining industry's sustainability. The engagement with other universities, the mining industry, government bodies and NGOs, both local and international, enrich the learning experience and bring staff and students face-to-face with real-world issues. It is expected that future decision makers will come from this platform and be equipped to realise the promise of sustainable development in Africa.

Acknowledgements

This work is supported by the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation (NRF) of South Africa. Any opinion, finding, conclusion, or recommendation expressed in this material is that of the authors and the NRF does not accept any liability in this regard.