CHALLENGES FACING THE SOUTH AFRICAN MINING INDUSTRY

South African Academy of Engineering Annual Lecture 2016-2017
The grand challenges for the minerals industry

- Economics – the commodity cycles
- Need to reduce utilization of water and energy
- Need to reduce waste production – reuse waste
- Earning the “licence to operate” through care for:
  - the environment
  - the health & safety of all employees
  - the indigenous population
- Navigating the complex legislative environment
- Addressing the skills shortage
Some issues of particular significance to South African mining companies - which speak to the challenges (Monitor Deloitte)

- Achieving a step change in profitability without compromising on safety
- Attracting and retaining critical skills
- Raising the capital needed for South African operations and optimising the sustainable use of capital
- Balancing the conflicting needs of different stakeholders
Who are the stakeholders?
THE CONTEXT OF THE CHALLENGES

- Mining in South Africa – its history
- Global economic challenges
- Technology challenges – energy, water, waste
- Societal and environmental challenges - the “licence to operate” debate including health & safety challenges
- Legislative issues
- Skills
Some interesting facts regarding mining in South Africa

1. Mining in South Africa directly contributed to the establishment of the Johannesburg Stock Exchange in the late 19th century and still accounts for a significant fraction of its market capitalisation.

2. The oldest known mine globally on archaeological record is the "Lion Cave" in Swaziland which radiocarbon dating shows to be about 43,000 years old. At this site Paleolithic humans mined hematite to make the red pigment ochre.

3. The deepest mines in the world - TauTone (Western Deep Levels, 1 shaft), Savuka and Mponeng (WDL 3) will work down to 4500 m in the coming years (compare Los Bronches in Chile – 4000 m above sea level!).

4. These mines also have the harshest conditions for hard rock mining, where temperatures of up to 45 °C (113 °F) need to be reduced using massive refrigeration plants. This presents major technical challenges for gold miners!
SOUTH AFRICA’S MINERAL WEALTH
City Group has estimated that RSA possesses the world’s most significant mineral wealth

<table>
<thead>
<tr>
<th>Commodity</th>
<th>%</th>
<th>Commodity</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGMs</td>
<td>88</td>
<td>Fluorspar</td>
<td>12</td>
</tr>
<tr>
<td>Manganese</td>
<td>83</td>
<td>Titanium</td>
<td>11</td>
</tr>
<tr>
<td>Chromium</td>
<td>73</td>
<td>Coal</td>
<td>11</td>
</tr>
<tr>
<td>Vanadium</td>
<td>45</td>
<td>Nickel</td>
<td>10</td>
</tr>
<tr>
<td>Ferrochrome</td>
<td>40</td>
<td>Uranium</td>
<td>8</td>
</tr>
<tr>
<td>Gold</td>
<td>39</td>
<td>Phosphate</td>
<td>7</td>
</tr>
<tr>
<td>Alumino-silicates</td>
<td>37</td>
<td>Antimony</td>
<td>5</td>
</tr>
<tr>
<td>Zirconium</td>
<td>26</td>
<td>Zinc</td>
<td>5</td>
</tr>
</tbody>
</table>

Estimated % of World Reserves.

Contributions to global production:

- Gold: 19.0%
- PGM: 79.0%
- Base metals: 0.6%
- Ferrous metals: 4.2%
- Mineral sands: 25.6%
- Coal: 3.0%

World’s 5th largest exporter.
Do we need mining?

- The old adage: If you can’t grow it, you have to mine it!!
- Copper and rare earths are needed to make computers (There are 66 individual minerals that contribute to the typical computer)
- Phosphates, nitrates are needed for fertilizers for food
- Oil and coal are needed for polymers, fuel
- Iron ore, chrome, nickel are needed to make steel
- Etc etc etc
THE CONTEXT OF THE CHALLENGES

- Mining in South Africa – its history
- Global economic challenges
  In 2014 the combined value of the top 40 global mining companies shrank by $156-billion (approximately 14 %)
- Technology challenges – energy, water, waste
- Societal and environmental challenges - the “licence to operate “ debate including Health & Safety challenges
- Legislative issues
- Skills
Declining prices, reserves and grades are major challenges e.g. Gold Production since 1940

Gold price
US$700/oz
R1=$1.32!!
Some historical commodity price trends. Prices are arguably returning to their norm!?

Comparison of JSE mining index and HSBC Global mining index

China’s economic growth rate since 1995
In 2014 the mining sector contributed **R18 billion** to the South African fiscus

A total of **495,568** people were employed in the mining sector in 2014 (9% of non-agricultural sector)(CoM)

The multiplier effect: **Each person** employed in the mining sector has up to **nine indirect dependents**

In 2013 ~9% of GDP (in 1970, 21%!)
THE CONTEXT OF THE CHALLENGES

- Mining in South Africa – its history
- Global economic challenges
- Technology challenges – energy, water, waste
- Societal and environmental challenges - the “licence to operate “ debate including Health & Safety challenges
- Legislative issues
- Skills
TECHNOLOGY CHALLENGES
There have been significant technology developments – but over past 150 years!!

**Major Steps**

- Electrolysis (Aluminium 1875)
- Flotation (Broken Hill 1906)
- Solvent Extraction-Ion Exchange (1940s)

**Enablers**

- Electricity for industry (1890)
- Tonnage Oxygen (Linde 1903)
- Inert Materials
- Chemical Synthesis
- Hydrocyclones (1939 – DSM)
- Computer Modelling
- Cyanide treatment of gold
BUT - even though there is a huge demand for new technology it represents "High Risk".

BUT - even though there is a huge demand for new technology it represents "High Risk".

Probability of Failure

Mining Industry is renowned for being risk averse.

25-40% 40-50% 45-60% 60-75% 75-95%

Process impact

Technology Familiarity

New to business
Augmentation of existing
Already in use
But the risk averse approach is understandable – mineral processing operations have a long life

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Expected lifetime (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power plant</td>
<td>75+</td>
</tr>
<tr>
<td>Commercial building</td>
<td>45+</td>
</tr>
<tr>
<td>Coal fired power plant</td>
<td>45+</td>
</tr>
<tr>
<td>Nuclear power plant</td>
<td>30-60</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>25</td>
</tr>
<tr>
<td>Mines – Ore Dependent</td>
<td>15-50</td>
</tr>
<tr>
<td>Concentrator</td>
<td>30+</td>
</tr>
<tr>
<td>Smelter</td>
<td>30+</td>
</tr>
</tbody>
</table>
Commercial success is difficult

Source: Stevens and Burley, *Plotting the rocket of radical innovation*, 2003

- Finding an Opportunity
  - 3,000 raw ideas
  - 300 ideas submitted
  - 125 small projects
  - 9 early stage developments
  - 4 major developments
  - 1.7 launches
  - 1 success

- Achieving Value from Implementation
  - Market place

Number of ideas
BUT THERE ARE OPPORTUNITIES FOR “MODERATE COST – HIGH REWARD” TECHNOLOGICAL IMPROVEMENTS
Process Control is a key technological opportunity

- Low Capital Cost Expansion
- Cost & Net Energy Use Reductions
- Environmental Improvements
- New Instruments are available

**But**

- Many Plant Control Loops Inoperable
- Instruments Hard to Maintain
- Poor Links Between Measurements and Control
- Limited **Skilled Staff** Available

**Needs People Investment not just Computers**
Major new developments in **AUTOMATION** e.g. El Teniente in Chile (world’s largest underground copper mine)

El Teniente’s New Mine Level will be an automated operation with the mining, processing and transport activities controlled remotely from the corporate building in the city of Rancagua, located 50km from the mine site (1hr from Santiago).
Remote operation and control at El Teniente

Control rooms are located in a new corporate building located 50 km from the mine (Rancagua). Greater use of *Autonomous Haulage Systems (AHS)*

**Advantages:**
- Enhanced personal safety by decreasing personnel exposure inside the mine
- Improved working conditions
- Increase in team productivity and equipment usage
- Improvement in controlling draw production schedules
- More effective operation of equipment
- Smoother operation means less damage and wear on the machines
- Real time process optimisation
“Productivity takes on a fresh slant when you approach the employee as a human being rather than a production unit” (Bernard Swanepoel).
Labour productivity (COMSA 2014)
Productivity example

- Vale (Brazil) produces iron ore at $11/ton
- BHP, Rio Tinto produces at $20-28/ton
- Kumba (South Africa) produces at $40-45/ton
- Similar comparisons are not possible for gold since in South Africa gold is mined at very great depths
- As well as for Platinum since South Africa is essentially the only producer
Step-change/Leap-frog Technology Can Add Value

Example: Rapid Development of Underground Mines

Opportunity: Too much face time is spent on support
Bioleaching is an exciting technological opportunity – bugs leaching out the valuables from ores

Bioleach pad showing irrigation lines
Arequipa, Peru
ENERGY
CHALLENGES

DEMAND SIDE SITUATION
Energy Consumption in South Africa

In terms of total energy consumption, the mining sector accounts for about 15% (predates load shedding) = about 7.5GW

Non-energy: e.g. coal used for purposes other than energy generation

Source: Based on SANE A (2003)
Concentrators are large consumers of energy: crushing & grinding ores probably accounts for 10% of the country’s energy; smelters are also large consumers of energy.
### Highest consumers and lowest efficiency

Diesel equipment in RSA mining uses 10% of country’s diesel.

#### Exhibit 23. Energy Requirements and Efficiencies of Equipment Types in Coal Mining in Btu/yr (neglecting electricity losses)

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction</td>
<td>Drilling</td>
<td>8,800</td>
<td>47%</td>
<td>59%</td>
<td>7,000</td>
<td>81%</td>
<td>5,100</td>
<td>4,200</td>
</tr>
<tr>
<td></td>
<td>Blasting</td>
<td>5,100</td>
<td>23%</td>
<td>30%</td>
<td>3,800</td>
<td>56%</td>
<td>2,000</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Digging</td>
<td>10,500</td>
<td>53%</td>
<td>66%</td>
<td>8,500</td>
<td>78%</td>
<td>7,200</td>
<td>5,600</td>
</tr>
<tr>
<td></td>
<td>Ventilation</td>
<td>23,400</td>
<td>75%</td>
<td>82%</td>
<td>21,300</td>
<td>93%</td>
<td>18,800</td>
<td>17,600</td>
</tr>
<tr>
<td></td>
<td>Dewatering</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials Handling</td>
<td>Diesel Equipment</td>
<td>43,300</td>
<td>30%</td>
<td>45%</td>
<td>28,900</td>
<td>63%</td>
<td>20,600</td>
<td>13,000</td>
</tr>
<tr>
<td></td>
<td>Electric Equipment</td>
<td>10,900</td>
<td></td>
<td></td>
<td>9,700</td>
<td>0%</td>
<td>9400</td>
<td>9,300</td>
</tr>
<tr>
<td></td>
<td>Conveyor (motor)</td>
<td>500</td>
<td>85%</td>
<td>95%</td>
<td>400</td>
<td>98%</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Load Haul Dump pumps</td>
<td>10,400</td>
<td>85%</td>
<td>95%</td>
<td>9,300</td>
<td>98%</td>
<td>9000</td>
<td>8,900</td>
</tr>
<tr>
<td>Beneficiation and Processing</td>
<td>Crushing and Grinding</td>
<td>50,400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crushing</td>
<td>3,500</td>
<td>50%</td>
<td>80%</td>
<td>2,200</td>
<td>92%</td>
<td>1,900</td>
<td>1,800</td>
</tr>
<tr>
<td></td>
<td>Grinding</td>
<td>46,900</td>
<td>1%</td>
<td>41%</td>
<td>39,900</td>
<td>86%</td>
<td>13,600</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Separations</td>
<td>2,100</td>
<td></td>
<td></td>
<td>1,000</td>
<td>86%</td>
<td>800</td>
<td>700</td>
</tr>
<tr>
<td></td>
<td>Centrifuge</td>
<td>1800</td>
<td>27%</td>
<td>41%</td>
<td>700</td>
<td>86%</td>
<td>600</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Flotation</td>
<td>400</td>
<td>64%</td>
<td>79%</td>
<td>300</td>
<td>86%</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Subtotal</td>
<td>154,600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ancillary Operations</td>
<td>1,700</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>156,200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: Values are approximate and may vary depending on specific conditions and equipment models.*
Energy consumed in crushing and grinding is dominant. Part. Size has same affect on Water Usage. As the need to reduce particle size increases so the energy consumption increases exponentially.
Exhibit 18. Energy Consumption and Saving Potential by Equipment Type (TBtu/Yr)

- **Blasting**: Current 24, Best Practice 18, Practical Minimum 10, Theoretical Minimum 5
- **Dewatering**: Current 28, Best Practice 25, Practical Minimum 23, Theoretical Minimum 7
- **Separations**: Current 46, Best Practice 8, Practical Minimum 7, Theoretical Minimum 2
- **Electric Equipment**: Current 48, Best Practice 43, Practical Minimum 40, Theoretical Minimum 13
- **Crushing**: Current 52, Best Practice 32, Practical Minimum 27, Theoretical Minimum 8
- **Drilling**: Current 67, Best Practice 54, Practical Minimum 32, Theoretical Minimum 9
- **Ancillary Operations**: Current 75, Best Practice 75, Practical Minimum 72, Theoretical Minimum 24
- **Digging**: Current 79, Best Practice 60, Practical Minimum 35, Theoretical Minimum 22
- **Ventilation**: Current 122, Best Practice 111, Practical Minimum 94, Theoretical Minimum 29
- **Materials Handling-Diesel**: Current 211, Best Practice 141, Practical Minimum 101, Theoretical Minimum 63
- **Grinding**: Current 494, Best Practice 420, Practical Minimum 138, Theoretical Minimum 2

Energy Saving Opportunities:
Energy Consumption In The Minerals Sector

Compare pyro- vs hydro-metallurgical processes

Energy Consumption (MJ/t metal)

- Cu - Pyromet
- Cu - Hydromet
- Ni - Pyromet
- Ni - Hydromet
- Pb - BF
- Pb - ISF
- Zn - ISF
- Zn - Electrolytic
- Al
- Iron
- Steel

- Metal Extraction
- Refining
- Mineral Processing & Concentration
Comparison of Underground & Above Ground Mining: A Canadian scenario

Source data extracted from 'Natural Resources Canada - Benchmarking Report 2006' & further analysed
Energy Consumption

Energy in Underground Mining - Example

[Diagram showing energy consumption distribution with categories: Surface, Mining, Conveying, Concentrator, Grinding, Pumps, Flotation, Other]
Energy Consumption vs. Head Grade in a declining head grade scenario

Total energy consumption as a function of ore head grade for various process routes
Breakdown of the demand for energy

- **Energy Consumption breakdown**

  - Materials Handling: 42%
  - Extraction: 19%
  - Beneficiation & Processing: 39%

- **Opportunities**

  1. Reduce energy consumption in Materials Handling
     
     Estimated that diesel accounts for 87% of energy used in Materials Handling – but alternatives not cost effective

  2. Reduce the energy consumption in Beneficiation & Processing
     
     Comminution activities account for 75% of energy used in Beneficiation & Processing

  3. Reduce the energy consumption and increase recovery efficiencies in Extraction
     
     In-situ processing methods e.g. biohydro-methods
     Pumps account for 41% of Extraction costs
     Introduce automated ore sorting methods
Block Caving can lower energy in Mining

Block caving in Palabora Mining Company
Is block caving the route to the Mine of the Future?
Mining underneath cities?
The invisible mine?

Deep, fractured by caving, and underground concentration process
ENERGY CHALLENGES

SUPPLY SIDE SITUATION
South Africa’s Energy Reserves: Excluding renewables

ANNUAL CONSUMPTION ~1.3 ExaJ ($1.3 \times 10^{18}$ J)
THE CHALLENGE FOR SOUTH AFRICA’S ENERGY DEMAND-SUPPLY SCENARIO

35 GW Gap in 2030, that is 7 Medupi’s we need to build in 15 years!!
Future Options For Energy Supply

- Coal – local, low cost and plenty; but CO2 emissions problems
- Hydro – foreign dependency (Inga)
- Nuclear – advantage of low CO2 emissions; good supply of uranium; spent fuel disposal challenges; cost???
- Gas
- Renewables (eg wind, solar)
Sources of energy for Southern Africa

Eskom nominal installed capacity ~44 000MW (will increase by 8 800MW when Kusile & Matimba are commissioned)

Grand Inga Hydroelectric Project

The proposed 4th dam is largest of a series of dams that have been built or are proposed for the lower end of the Congo River in the Democratic Republic of the Congo (DRC). Grand Inga should be able to generate 40,000 MW, and will be constructed in 6 phases of which the Inga III Dam is the first phase.

Mozambique channel estimated gas resources = 441 tcf
Note: 2tcf ~ 20GW using CCGT (McKinsey)

Karoo shale gas estimated gas resources = 19-23 tcf (Note: Mossgas = 1 tcf)
Table 2 – Technology options arising from IRP 2010 and the Update Base Case in 2030

<table>
<thead>
<tr>
<th>Technology option</th>
<th>IRP 2010 (MW)</th>
<th>Base Case (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Coal</td>
<td>34746</td>
<td>36230</td>
</tr>
<tr>
<td>New Coal</td>
<td>6250</td>
<td>2450</td>
</tr>
<tr>
<td>CCGT</td>
<td>2370</td>
<td>3550</td>
</tr>
<tr>
<td>OCGT / Gas Engines</td>
<td>7330</td>
<td>7680</td>
</tr>
<tr>
<td>Hydro Imports</td>
<td>4109</td>
<td>3000</td>
</tr>
<tr>
<td>Hydro Domestic</td>
<td>700</td>
<td>690</td>
</tr>
<tr>
<td>PS (incl Imports)</td>
<td>2912</td>
<td>2900</td>
</tr>
<tr>
<td>Nuclear</td>
<td>11400</td>
<td>6660</td>
</tr>
<tr>
<td>PV</td>
<td>8400</td>
<td>9770</td>
</tr>
<tr>
<td>CSP</td>
<td>1200</td>
<td>3300</td>
</tr>
<tr>
<td>Wind³</td>
<td>9200</td>
<td>4360</td>
</tr>
<tr>
<td>Other</td>
<td>915</td>
<td>640</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>89532</strong></td>
<td><strong>81350</strong></td>
</tr>
</tbody>
</table>

Notes:
1. Demand Response options added to IRP 2010 to ensure comparability (previously not considered in IRP).
2. “Existing” coal includes Medupi and Kusile.
Solar can work – Codelco’s mine provides 80% of energy for SX-EW plant!

Codelco to harness world’s largest solar plant for mining

Codelco’s Energy & Water senior manager Andres Alonso said “internal resistance within companies is the biggest challenge for implementing projects such as Pampa Elvira Solar. The mining industry finds it hard to be innovative because we produce 24 hours a day, seven days a week; if you say ‘let’s have a new way of operating, let’s change this issue’, this tends to be resisted as people want to keep on producing. “It requires a great commitment from management. Fortunately there was great support from our management and we were able to overcome internal barriers that all mining companies have.”
WATER CHALLENGES

DEMAND SIDE SITUATION
The complex nature of the energy consumption - water consumption - waste generation equation

<table>
<thead>
<tr>
<th></th>
<th>Electricity Consumption (GWh/a)(^4)</th>
<th>Water Utilisation (GL/a)(^4)</th>
<th>Solid waste outputs (Mt/a)(^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>4300</td>
<td>240</td>
<td>190</td>
</tr>
<tr>
<td>PGM's</td>
<td>2100</td>
<td>120</td>
<td>114</td>
</tr>
<tr>
<td>Base metals</td>
<td>1460</td>
<td>0.29</td>
<td>60</td>
</tr>
<tr>
<td>Ferrous metals</td>
<td>26 000</td>
<td>13.1</td>
<td>5.7</td>
</tr>
<tr>
<td>Mineral sands</td>
<td>3200</td>
<td>8.5-11</td>
<td>11.9</td>
</tr>
<tr>
<td>Coal</td>
<td>3100(^5)</td>
<td>31</td>
<td>45</td>
</tr>
</tbody>
</table>

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\(^4\) Based on 1999 data from Stewart (1999)
\(^5\) Based on 2005 data from ESKOM (2005)
\(^6\) Based on 2003 data from an in-house inventory database by the WRC (2003)
Mining & Industrial consumes 8% of South Africa’s water! (Mining about 3%)
Agriculture consumes 54%!!
Similar Situation In The USA –
The World’s Largest Mining Country
In Terms Of Tonnes Treated!

Mining water withdrawals, 2000

Mining freshwater withdrawals, 2000

Total withdrawals:
- Total surface water
  - Mining: 1,240 (≤1%)
  - Other: 261,000 (>99%)

Total groundwater:
- Total ground water
  - Mining: 767 (1%)
  - Other: 82,900 (>99%)

(Withdrawals are in million gallons per day)
WATER CHALLENGES

SUPPLY SIDE SITUATION
Southern Africa Is Dry Country!!
Some Interesting Reflections On Water Resources in South Africa!

- Evaporation rate exceeds rainfall by factor of ~2 in the east and ~12 in the west
- Only 8.5% of rainfall becomes runoff into rivers and dams and total runoff is \(54000\text{m}^3/\text{a}\)
- Only 60% of runoff is exploitable i.e. about \(34000\text{m}^3/\text{a}\)
- Water storage capacity is about \(27000\text{m}^3/\text{a}\) of which 27% is lost through evaporation.
Typical Environmental Impacts Of Mining On Water Resources

- Need for process water – demand on local and regional water resources. Hence the zero effluent concept is now being pursued aggressively

- Discharge of effluents and seepage from solid waste / tailings dams

- Alteration of ground water flows by pollution control activities

- Erosion of unprotected surfaces - increased sediment loads in streams

- Contamination from explosives residues
Influence Of Acid Mine Drainage on Water Quality Problems In Receiving Waters

- Lower pH values – altered chemical equilibria
- Increased metal concentrations – toxicity to aquatic organisms and human users
- Increased total dissolved salts – salinity problems for agriculture and sensitive users
- Toxic precipitates in streams
- Increased sediment loads
- Increased water treatment costs to other users
- Corrosion problems in distribution systems
Key interventions

- Water footprint studies
- Mines to become much more sensitive to costs of water
- Greater emphasis on minimizing water losses
- Determining minimum water quality before this begins to negatively impact on process efficiencies e.g. flotation
When will the water wars begin – or have they already begun?

‘Water as an asset class will, in my view, eventually become the single most important physical commodity-based asset class, dwarfing oil, copper, agricultural commodities and precious metals.’

Willem Buiter, Citi Economist
WASTE, ENVIRONMENTAL IMPACT AND HEALTH & SAFETY CHALLENGES
Creek running through the tailings of an abandoned mine, Montana

Red Mud Slurry deposition in the Kwinana region south of Perth – ALCOA’s major worldwide bauxite operation!
Mining has a long history of “Bad Press”

(Georgius Agricola wrote in “De Re Metallica” in 1556:

“…. The fields are devastated by mining operations…. Further, when the ores are washed, the water which has been used poisons the brooks and streams, and either destroys the fish or drives them away. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers, find great difficulty in procuring the necessaries of life, and by reason of the destruction of the timber they are forced to greater expense in erecting buildings. Thus it is said, it is clear to all that there is greater detriment from mining than the values of the metals which the mining produces”
Typical environmental impacts of mining

- Atmospheric emissions
- Discharge and spillage of chemicals used in metal extraction process
- Release of potentially harmful substances such as radio-nuclides and metals into the aquatic environment
- A recent estimate of cost of treating polluted water from Wits basin is R12billion
Profitable uses of waste

- **Waste rock**: backfill, landscaping material, aggregate
- **Manganese tailings**: agro-forestry, buildings and construction materials,
- **Clay-rich tailings**: bricks, floor tiles, and cement
- **Slag**: road construction, and in concrete and cement
- **Red mud**: soil amender, in waste water treatment (Kwinana story!!)
- **Mine water**: dust suppression and mineral processing (closed water cycle)
- **Water treatment sludge**: Sludge from ARD treatment for use in pigments
- **Sulphur oxide emissions**: sulphuric acid production
Tailings dams: Monitoring and Instrumentation

Disasters:

- **2015 Bento Rodrigues**, Mariana, Brazil (17 deaths); 60m m3 slurry to Atlantic ocean;
- **1994 Merriespruit**, Virginia (17 deaths); 600k m3 flowed 4 km.

Atabasca problem

- Greater use of modern technology e.g. satellite, drone monitoring
- Improved underground stability monitoring using advanced technologies, e.g. radar, lasers etc
In Terms Of CO₂ Emissions, Steel Production Is The Greatest Challenge!

Annual GHG Emission - Worldwide Metal Industry

World Annual Metal Production

CO2 EMISSIONS

Million tonnes CO₂,e
Environment, Community and Mine Closure issues

- Long-term stability of workings (sink holes)
- Groundwater
- Surface water
- Ecosystem
- Wild life
- Contamination of soil
- Tailings
- Illegal miners

Large sinkhole (± 15 m diameter) triggered by ingress of water (Centurion, Gauteng)
Major health and safety challenges (Mine H&S Council)

- Airborne pollutants - pneumoconiosis
- Occupational diseases – effect of HIV/AIDS on respiratory diseases
- Behavioural OHS – risk taking behaviour induced by outside lifestyles
- Explosives and fires – coal dust
- Rock falls – single largest contributor to fatalities
- Physical hazards – noise, vibration, temperature
- Machinery and transport – conveyors, scrapers
**Industry fatalities: 2003-2013 (CoM)**

88% reduction since 1994

**Context:** In a study of 40,000 miners on Platinum Mines between 1992-2008

- 138 died from occupational injuries and
- 356 from road deaths
Safety in the context of Productivity in South African mining – debate around balance between safety and productivity

Figure 2 - Index of Production, Employment and Average Monthly Earnings based on data from StatsSA and the Department of Mineral Resources.
Health and Safety Initiatives - Robotics

A ground-breaking partnership between Anglo American and Carnegie Mellon University will explore the use of robotics to improve safety and boost productivity and efficiency in our underground mining operations.

Anglo American’s technology development group will collaborate with CMU’s Robotics Institute through its National Robotics Engineering Centre and Field Robotics Centre to design, build, and deploy mining robots, robotic tools, and autonomous technologies.

Dave Babbitt, group head of technology development for Mining & Technology, says: "This collaboration represents huge potential to improve safety in mining, but it is important that we also improve productivity and efficiency." The partnership will focus on developing automated systems to enhance safety and productivity in the mining industry.

"We are thrilled that Anglo American selected CMU as its partner for developing innovative mining robotics. This agreement will undoubtedly break new ground in mining technology."

Tony Stark, director of CMU’s National Robotics Engineering Centre, says: "This is an exciting opportunity to work with Anglo American on developing automated systems that can improve safety and productivity in the mining industry."

The robots being developed will be able to work in dangerous environments, reducing the risk of injury to workers. They will be equipped with advanced sensors and artificial intelligence to operate safely and efficiently in the mining environment.

"The robots developed under this agreement will be used to test new technologies and improve safety in mining operations. This is a significant step forward in the development of automated systems for the mining industry."

What's more, the project will also advance the research into autonomous robotics, providing valuable insights into the future of mining technology.
LEGISLATIVE CHALLENGES
Creating a successful mining sector
(Dr Roger Baxter, CEO, CoM)

- More effective problem solving partnership between government, business and organised labour

- Regulatory and legislative environment that is stable, predictable and competitive

- Stable and constructive labour relations environment and better social license to operate

- Access to available, efficient and cost effective infrastructure (electricity, rail)

- Solutions to improve productivity (next generation mining) and reduce cost pressures
The legislative environment

- Communities expect mining companies to become engines of socio-economic development of their areas.
- Government policy covers the spectrum of state-owned mining companies, and some private ownership with a large BEE ownership component - increasing the percentage of BEE ownership required from its current 26%.
- There has been some regulatory and legislative uncertainty e.g. the Mineral and Petroleum Resources Development Bill (approved by NCOP on 1 Nov. 2016 after 4 yr delay) but not yet finalized.
- This is compounded by complex labour relations issues and, much positive, community activism which also includes many safety, health and environmental compliance issues.
COST OF SAFETY INCIDENTS
An unintended consequence

When accidents occur, the Department of Mineral Resources can shut down the affected area or even an entire mine while it investigates.

Safety shut downs after accidents cost:
- AngloGold and Sibanye Gold, the country’s biggest gold producers, $112 million of bullion in the first half of 2016
- Anglo American Platinum couldn’t mine about $33 million of metal

London based mining analyst, Richard Hatch: “It’s very difficult to shut these assets down in a hard stop. In some cases, hundreds if not thousands of people need to be removed from a mine, then retrained. Heavy equipment takes time to start back up. Mistakes can be made which increases the risk of more accidents.”
SKILLS CHALLENGES
<table>
<thead>
<tr>
<th>Ranking/100</th>
<th>OCCUPATIONAL TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electrical Engineer</td>
</tr>
<tr>
<td>2</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>3</td>
<td>Mechanical Engineer</td>
</tr>
<tr>
<td>4</td>
<td>Quantity Surveyor</td>
</tr>
<tr>
<td>5</td>
<td>Programme or Project Manager</td>
</tr>
<tr>
<td>6</td>
<td>Finance Manager</td>
</tr>
<tr>
<td>6</td>
<td>Physical and Engineering Science Technicians*</td>
</tr>
<tr>
<td>8</td>
<td>Industrial and Production Engineers*</td>
</tr>
<tr>
<td>8</td>
<td>Electrician</td>
</tr>
<tr>
<td>10</td>
<td>Chemical Engineer</td>
</tr>
<tr>
<td>11</td>
<td>Construction Project Manager</td>
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<tr>
<td>12</td>
<td>Mining Engineer</td>
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<tr>
<td>12</td>
<td>Accountant (General)</td>
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<td>14</td>
<td>Energy Engineer</td>
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<td>15</td>
<td>Materials Engineer</td>
</tr>
<tr>
<td>16</td>
<td>Electronics Engineer</td>
</tr>
<tr>
<td>17</td>
<td>Metallurgical Engineer</td>
</tr>
</tbody>
</table>
Current Global situation
Mineral Processing Graduates
~ 5500 graduates in 2010
THE CHALLENGES

- Global economic challenges
- Technology challenges – energy, water, waste
- Societal and environmental challenges - the “licence to operate” debate including health & safety challenges
- Legislative issues
- Skills
AND SO WHAT?

It is self-evident that there are pressures arising from:

- Actual or forecasted shortages of energy and water
- Low commodity prices and decreasing head grades
- Need to protect and preserve the environment
- Need to earn the “social licence to operate”
- An often uncertain legislative/regulatory environment
- Shortages of the necessary skilled personnel

SOME OF THESE WE CAN CONTROL – OTHERS NOT!
And these uncertainties are probably our greatest challenges!
1. Mining and mineral processing in the future will be very different, more sustainable and hardly visible.

2. It will have to use:
   - Less energy and water, produce less waste
   - Be more socially responsible by improving its safety record through, inter alia, ensuring a greater degree of automation, process control and overall greater efficiency levels. But this will not contribute to job creation!

3. Focus on developing smart technologies and “up our act” in R&D activities.
Tribute and appreciation to great Wits academics who were fellow South African members of the US National Academy of Engineering and all with an interest in mining and metallurgy

Frank Nabarro
Danie Krige
Peter King
Acknowledgements

- Many DMR and Chamber of Mines reports
- Dr Ray Shaw, Consultant (formerly of RioTinto)
- Professor Harald Winkler, UCT
- Professor Ismet Canbulat, Dept. of Mining Engineering, Uni. New South Wales
- Professor Robin Batterham, Uni. Melbourne, former Chief Scientist of Australia and Chief Technologist of Rio Tinto
- Dr F Prinsloo, W Cape Govt.
- Apologies for many other references used but not acknowledged. None of the contents of this presentation represents my own work.
THANK YOU
And with due acknowledgements to many!
Purpose

1. to demonstrate that there are many research opportunities for other engineering disciplines in mining

2. to demonstrate to future mining engineers that they are still required as we have many challenges in the mining industry
Mining Methods

- Underground Mining, and
- Surface Mining
Underground Mining Methods

Naturally Supported
- Room and Pillar
- Sublevel and Longhole Open

Artificially supported
- Bench-and-fill stoping
- Cut-and-fill Stoping
- Vertical Crater Retreat
- Shrink Stoping

Unsupported
- Sublevel Caving
- Longwall Mining
- Block Caving

After Brady and Brown, 2004
Surface Mining Methods

Mechanical Excavation
- Open pit
- Stripping
- Terrace Mining
- Auger

Aqueous
- Placer
  - Dredging
  - Hydraulicking

Solution
- In-situ
- Surface

*After Hartman and Mutmansky, 2002*
Great Engineering Achievements in Mining

- Mechanisation and capacity mining equipment
- Continuous miner, longwall mining, draglines, trucks etc
- Mode of *in situ* rock failure - controlled by both the properties of the rock itself and by the load-deformation characteristics of the surrounding rock mass
- High capacity processing plants
- Safe mining practices
- Ventilation and gas flow modelling
- Environmental impacts
- Improved numerical modelling of rock mass behaviour, particularly in block rock masses.
Economies of scale can help reduce overall energy demand/treated.
Safety in the Mining Industry (2013)

NOTE: Mining fatalities include those that occur in coal and metal ore mining, oil and gas extraction, sand and gravel quarrying, exploration and support services.

Source: Safe Work Australia
Productivity, Reliability and Automation

Courtesy Redpath
Productivity, Reliability and Automation

Average Weekly Delay Time
50.2hrs Previously 75.0hrs

NRT Downtime
0hrs Previously 0hrs

Unplanned Downtime
29.0hrs Previously 41.3hrs

Planned Downtime
20.0hrs Previously 34.3hrs

Unplanned Maint Downtime
12.1hrs Previously 15.3hrs

Planned Maint Downtime
8.4hrs Previously 18.9hrs

Unplanned Operational Downtime
19hrs

Unplanned Operational Downtime
12hrs Previously 15.3hrs

Unplanned Check Downtime
4.4hrs Previously 3.1hrs

Unplanned Shear Downtime
5.8hrs Previously 3hrs

Unplanned Electrical Supply Syst Downtime
2hrs Previously 4.9hrs

Unplanned Down time All Other Delays
8.3hrs Previously 12.3hrs

Unplanned hose / Fitting Downtime
1.2hrs Previously 0hrs

Unplanned Failed Downtime
3.0hrs Previously 0hrs

Unplanned Failed Downtime
3.6hrs Previously 0hrs

Unplanned Failed Downtime
3.6hrs Previously 0hrs

Unplanned Failed Downtime
3.6hrs Previously 0hrs

Unplanned Observation Downtime
0.6hrs Previously 1hrs

Unplanned CDS Downtime
1.5hrs Previously 5.3hrs

Unplanned Electrical Supply Syst Downtime
0.4hrs Previously 0.6hrs

Unplanned AFC Downtime
0.3hrs Previously 0.6hrs

Unplanned Other Delays
5.7hrs Previously 11.6hrs

Unplanned Overload Downtime
0.4hrs Previously 0hrs

Unplanned Blockage Downtime
0.7hrs Previously 0hrs

Unplanned Blockage Downtime
1.5hrs Previously 0hrs
Big Data – not that big

- Geological information
- Seismic information
- Monitoring data
  - Geotechnical
  - Ventilation
  - Gas
  - Dust
  - Water (surface and underground)
- Equipment health, productivity and efficiency
- Surveying
- Processing, etc.
Monitoring and Instrumentation

- Aid in exploration
- Equipment effectiveness
- Establish benchmark data for environmental approval and licensing purposes
- Determine properties for input into mine design
- Validate mine design
- Validate the quality of ground support hardware
- Validate the quality of ground support installations
- Research the unknown
- Provide timely warning of deviation from predicted ground conditions and design performance, both in the short and long term, and
- Identify, quantify and verify mining effects, impacts and consequences.

Source: J Galvin, 2015
Monitoring and Instrumentation

- Still premature compare to other industries
- Pro-active monitoring requires improvements
- Equipment performance monitoring is rarely done; however not analysed for appropriate decision making
- Environment monitoring (mainly strata and gas) is conducted extensive but majority of them premature, mostly not even real-time.
- Improved underground stability monitoring using advanced technologies, e.g. radar, lasers etc
- Remote machinery to take people out of danger zones and to increase productivity (further mechanisation)
• Numerical models has improved; however we need new failure criteria – e.g., strain based failure criteria
• The laboratory study of the mechanical properties of rock was already reasonably well advanced but little is known about the rock mass strength, particularly in soft rock
• More realistic models are emerging but still there are many assumptions on them that need further evaluation
• Coal/rock burst phenomenon is not well understood
• Time to failure of rock is probably one of the most challenging questions
Identification of Geological Structures

- One of the highest safety risks and has the potential to adversely impact the production in longwall mining.

- Current methods are slow and unreliable for structures that are thinner than the seam thickness.

- Prefer method to identify the structures during exploration but it is difficult using the current technology.

- Excellent progress to use seismic tomograph to identify the structures ahead of longwall face and has been successful but not proven in production cycle.
Conclusions

• There are still major engineering challenges in the mining industry that require urgent solutions.

• No doubt UNSW has the best expertise to be able to assist the mining industry.
Acknowledgments

• UNSW Australia
• Faculty of Engineering
• The School of Mining Engineering
• Prof Jim Galvin
• Dan Payne
• Dr Xun Luo
• Dr Seher Ata
• Joy Global
• Anglo American
• Minerals Council of Australia
• Semsa and Tolga
Annual mining revenue per commodity (R billions)

Coal  PGMs  Iron Ore  Other  Gold
Concentrators

CLASSICAL CONCENTRATOR CIRCUIT

MINERAL SANDS CONCENTRATOR

IRON ORE CONCENTRATOR

AN ANGLOPLAT CONCENTRATOR
Grinding Circuits Have Changed

- AG/SAG Mills – increased size and power
  - Now Gearless Motor Drive with 28MW Power
- Large Ball Mills – less use of Rod Mills
- Improved Liner Designs – discharges
  - Underpinned by mechanical engineering and modelling
World Primary Energy Demand By Fuel

### 2010

- **Coal**: 23.1 Mtoe
- **Oil**: 35.8 Mtoe
- **Gas**: 21.5 Mtoe
- **Nuclear**: 6.3 Mtoe
- **Hydro**: 2.2 Mtoe
- **Other**: 2.2 Mtoe

**Total**: 12,200 Mtoe (million tonnes of oil equivalent)

### 2030

- **Coal**: 22.9 Mtoe
- **Oil**: 34.1 Mtoe
- **Gas**: 24.2 Mtoe
- **Nuclear**: 2.3 Mtoe
- **Hydro**: 4.7 Mtoe
- **Other**: 2.3 Mtoe

**Total**: 16,500 Mtoe (million tonnes of oil equivalent)

**Source**: IEA Key World Energy Statistics, 2006
Final Industrial Energy Consumption By Sub-sector

2001 total = 1302 x10^6 GJ
Mine to Concentrate Energy

Underground block cave copper mine & concentrator

Figure 3: Detailed Electricity Profile - 2005
Target 1 - New Technologies

Improved Equipment & Optimisation
- Control, Design
- HPGR’s for Base Metals
- Better Classification

Alternative Breakage Systems
- New Mechanical Systems
- Microwaves
- Electric Pulse
- Ultrasonics

Capital Efficiency outweighs Technical Performance
Energy consumption by sector in South Africa

- Industry: 36%
- Transport: 26%
- Residential: 18%
- Commerce: 7%
- Mining: 7%
- Agriculture: 3%
- Other: 3%
<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Extraction</td>
<td>Drilling</td>
<td>8,800</td>
<td>47%</td>
<td>59%</td>
<td>7,000</td>
<td>81%</td>
<td>5,100</td>
<td>4,200</td>
</tr>
<tr>
<td>Extraction</td>
<td>Blasting</td>
<td>5,100</td>
<td>23%</td>
<td>30%</td>
<td>3,800</td>
<td>56%</td>
<td>2,000</td>
<td>1,100</td>
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<tr>
<td>Extraction</td>
<td>Digging</td>
<td>10,500</td>
<td>53%</td>
<td>66%</td>
<td>8,500</td>
<td>78%</td>
<td>7,200</td>
<td>5,600</td>
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<tr>
<td>Extraction</td>
<td>Ventilation</td>
<td>23,400</td>
<td>75%</td>
<td>82%</td>
<td>21,300</td>
<td>93%</td>
<td>18,800</td>
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<tr>
<td>Materials Handling</td>
<td>Diesel Equipment</td>
<td>43,300</td>
<td>30%</td>
<td>45%</td>
<td>28,900</td>
<td>63%</td>
<td>20,600</td>
<td>13,000</td>
</tr>
<tr>
<td>Materials Handling</td>
<td>Electric Equipment</td>
<td>10,900</td>
<td>0%</td>
<td>9%</td>
<td>9,700</td>
<td>0%</td>
<td>9400</td>
<td>9,300</td>
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<tr>
<td>Materials Handling</td>
<td>Conveyor (motor)</td>
<td>500</td>
<td>85%</td>
<td>95%</td>
<td>400</td>
<td>98%</td>
<td>400</td>
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<tr>
<td>Materials Handling</td>
<td>Load Haul Dump</td>
<td>10,400</td>
<td>85%</td>
<td>95%</td>
<td>9,300</td>
<td>98%</td>
<td>9000</td>
<td>8,900</td>
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<tr>
<td>Materials Handling</td>
<td>pumps</td>
<td>400</td>
<td>85%</td>
<td>95%</td>
<td>9,300</td>
<td>98%</td>
<td>9000</td>
<td>8,900</td>
</tr>
<tr>
<td>Beneficiation and Processing</td>
<td>Crushing and Grinding</td>
<td>50,400</td>
<td>50%</td>
<td>80%</td>
<td>2200</td>
<td>92%</td>
<td>1900</td>
<td>1800</td>
</tr>
<tr>
<td>Beneficiation and Processing</td>
<td>Crushing</td>
<td>3,500</td>
<td>50%</td>
<td>80%</td>
<td>2200</td>
<td>92%</td>
<td>1900</td>
<td>1800</td>
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<tr>
<td>Beneficiation and Processing</td>
<td>Grinding</td>
<td>46,900</td>
<td>1%</td>
<td>39,900</td>
<td>13,600</td>
<td>86%</td>
<td>600</td>
<td>500</td>
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<tr>
<td>Beneficiation and Processing</td>
<td>Separations</td>
<td>2,100</td>
<td>27%</td>
<td>41%</td>
<td>700</td>
<td>86%</td>
<td>600</td>
<td>500</td>
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<td>Beneficiation and Processing</td>
<td>Centrifuge</td>
<td>1800</td>
<td>27%</td>
<td>41%</td>
<td>700</td>
<td>86%</td>
<td>600</td>
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<tr>
<td>Beneficiation and Processing</td>
<td>Flotation</td>
<td>400</td>
<td>64%</td>
<td>79%</td>
<td>300</td>
<td>86%</td>
<td>300</td>
<td>200</td>
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<td>Total</td>
<td>Subtotal</td>
<td>154,600</td>
<td>122,300</td>
<td>79,500</td>
<td>55,900</td>
<td>1,700</td>
<td>1,700</td>
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<tr>
<td>Beneficiation and Processing</td>
<td>Ancillary Operations</td>
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<td>1,700</td>
<td>1,700</td>
<td>1,700</td>
<td>1,700</td>
<td>1,700</td>
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<tr>
<td>Total</td>
<td>Total</td>
<td>156,200</td>
<td>124,000</td>
<td>81,200</td>
<td>57,600</td>
<td>1,700</td>
<td>1,700</td>
<td>1,700</td>
</tr>
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</table>
Electricity Generation

Feed and emissions for a 1,000MW utility

- Coal: 10,000 tpd
- Water: 50,000 tpd
- Flue gas: 105,000 tpd
- SOx: 72 tpd
- NOx: 70 tpd
- Mercury: 0.6 kgpd
- Fly Ash: 850 tpd
- CO2: 22,500 tpd
- Coal: 10,000 tpd
- Water: 50,000 tpd
Revenue is difficult to predict and this impacts on investment especially in a high risk uncertain environment.

Which one to use for investment decisions?
And in summary the challenges are:

- Economic – global financial crisis
- Resource utilization – energy, water
- Environmental compliance: licence to operate, health & safety, care for the indigenous population
- Labour
- Productivity
- Regulatory and Legislative issues
And in summary the challenges are:

- Economic – global financial crisis
- Resource utilization – energy, water
- Environmental compliance: licence to operate, health & safety, care for the indigenous population
- Labour
- Productivity
- Regulatory and Legislative issues
Global energy use is projected to increase by two thirds by 2030 & treble by the end of the 21st century.

To meet society’s burgeoning demand, every possible source of energy needs to be expanded.

The world needs a whole portfolio of options, including clean fossil, nuclear and renewables.

Source: Preston Chiaro, Chief Executive, Rio Tinto Energy
In 2005 world primary energy consumption grew by 2.7%, above the 10 year average

- Natural gas consumption grew by 2.3%
- Nuclear power grew by 0.6% (below 10 year average)!!
- Hydroelectric generation rose by 4.2%
- Coal again the fastest growing fuel, with global consumption growing by 5% (twice ten year average)!!

China accounted for more than half of global energy growth

![Energy Savings Opportunity Chart](chart.png)

- **Extraction**
  - Blasting
  - Digging
  - Drilling
  - Dewatering
  - Ventilation

- **Materials Transport/Handling**
  - Diesel
  - Electric

- **Beneficiation & Processing**
  - Crushing
  - Grinding
  - Separations

Energy Savings Opportunity (Trillion Btu/Year)

- **Coal**
- **Minerals**
- **Metals**
Exhibit 18. Energy Consumption and Saving Potential by Equipment Type (TBtu/Yr)

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Current</th>
<th>Best Practice</th>
<th>Practical Minimum</th>
<th>Theoretical Minimum</th>
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</thead>
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<tr>
<td>Blasting</td>
<td>24</td>
<td>18</td>
<td>10</td>
<td>5</td>
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<td>75</td>
<td>72</td>
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<td>22</td>
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<td>Ventilation</td>
<td>122</td>
<td>111</td>
<td>94</td>
<td>29</td>
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<td>Materials Handling-Diesel</td>
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<td>101</td>
<td>63</td>
</tr>
<tr>
<td>Grinding</td>
<td>494</td>
<td>420</td>
<td>138</td>
<td>2</td>
</tr>
</tbody>
</table>
Reserve Margin Projections

![Graph showing the reserve margin projections with and without DSM from 2000 to 2030. The pink line represents the reserve margin with DSM, and the blue line represents the reserve margin without DSM. The reserve margin decreases over time, with the line for DSM showing a slight increase in some years.]  

DSM = Demand side management
AS A MATTER OF INTEREST

- Cement clinker production is the largest CO₂ source among industrial processes, contributing about 4% of global total CO₂ emissions from fuel use and industrial activities.

- Share of CO₂ from cement production in national total CO₂ emissions:
  
  **China:** 6200 megatonne CO₂ in total – 550 megatonne from cement production.

  **USA:** 5800 megatonne CO₂ in total - 50 megatonne from cement production.
CO2 equivalent production for various minerals processes
(Note difference order between energy consumption and CO2 prod.)
Customers Footprint

Customers use of our products even more significant
Other Interventions

- Improved smelter efficiencies
- Sequestration
- Alternative electricity production technologies
  - E.g. Inga project in DRC (capable of producing 100GW hydroelectric power)
Context Capital

Open cut copper mine & concentrator

Concentrator > Mine
Comminution > Flotation

Capital Efficiency outweighs Technical Efficiency
Technology Opportunities

Energy Consumption

- Crushing and grinding
- In situ processes (including leaching)
- Alternative fuels (biodiesel, ethanol, hydrogen)
- Aluminium smelting
- Iron making
- On line analysis, automation and process control

Energy Generation

- Coal gasification and carbon capture
- Renewable energy forms (wind/ solar/ biomass)
Underground workings at Northam’s Booysendal mine – a modern, mechanised mine in the PGM sector
Copper Production By Technology

M tonnes pa

- Smelt/Cemented/Electrorefined
- Leach/Electrowon
- Fire Refined

Perth Joint Committee of IEAust and IChemE, Perth 28 September 2006
SEM of bioleached arsenopyrite concentrate from Fairview showing

*Leptospirillum ferrphilum*

*Acidithiobacillus caldus*

Hexagonal holes

Preferential leaching along mineral interfaces
Number Of Graduates

AVERAGE OF 1271 PER ANNUM

AVERAGE OF 2035 PER ANNUM!
New Technology needs Drivers

- Enabling – we can do something new
- Expansion – increasing throughput
- Decreasing Costs
  - Energy
  - Water
  - Labour
  - Materials

We need to pick the right technologies to work on
Enabling New Deposits

A Major Driver for new Processes

- Not competing with established technology
- Low Grade Orebodies and/or waste rocks
- Unable to produce marketable concentrates
- Prohibitive Transport Costs
- Political Issues
  - Sanctions
New Technology Commercialisation

- Doesn’t just Happen

- Must Focus on Outcomes
  - In the technologies we use
  - In managing our people
  - In meeting community expectations

- The Process is critical
But there are few New Processes

<table>
<thead>
<tr>
<th>Metal</th>
<th>Tonnage (mT)</th>
<th>Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Major</td>
<td>Minor</td>
</tr>
<tr>
<td>Copper</td>
<td>18.5</td>
<td>2</td>
</tr>
<tr>
<td>Gold</td>
<td>0.3</td>
<td>1</td>
</tr>
<tr>
<td>Zinc</td>
<td>11.2</td>
<td>1</td>
</tr>
<tr>
<td>Nickel</td>
<td>2.4</td>
<td>3</td>
</tr>
<tr>
<td>Iron</td>
<td>1180</td>
<td>1</td>
</tr>
<tr>
<td>Aluminium</td>
<td>49.3</td>
<td>1</td>
</tr>
</tbody>
</table>

Copper SX-EW and Gold CIP-CIL most Recent Successes (Both >25 years ago)
Mining in Southern Africa

- **Botswana**  World’s largest world diamond producer
- **DRC**  Largest African copper producer (80% of exports)
- **Mozambique**  Mining to increase from 2 to 12% of GDP by 2020
- **Namibia**  Mining sector to expand by 12.5% pa (50% of exports)
- **South Africa**  Largest world platinum producer (50% of exports)
- **Tanzania**  Mining to increase from 3 to 10% of GDP by 2025
- **Zambia**  Copper/cobalt account for 10% of GDP and 70% of exports
- **Zimbabwe**  Second largest world deposits of platinum
Mining in Africa

• Africa accounts for nearly two-thirds of the world’s mineral reserves and more than half of gold, platinum group metals, cobalt and diamonds (Business Without Borders 2014)

• Of the 54 African sovereign states 46 have mineral resources of commercial importance (United Nations 2013)

• Africa represents half of the top 20 countries globally with the highest mineral export contributions (Mining Indaba 2015)

• Southern Africa produces over two-thirds of Africa’s mineral exports by value (Business Without Borders 2014)
The Basic Steps in Commercialisation

• Ensure there is a Strategic Fit

• Analyse the Tangible Factors

• Objectively Assess the Intangibles

&

Ensure there is an efficient implementation plan
A Challenge is Evaluating Opportunities

- Good Projects Provide Good Returns and Deliver Value

- They can also “Make” the Company

- We must be prepared to “kill” projects
  - Not all are worth doing
  - Some we are not capable of doing
  - Some are better sold for others to do

- Most project Proponents are Optimists
  - Exploration Geologists thrive on Risk
  - Inventors and Researchers Downplay Risks

- Evaluation must be Objective and Realistic but not just Conservative
  - Doing the wrong project destroys value
  - Doing the right project badly also destroys value
  - Not doing the right project is a lost opportunity and also destroys value
Some simple rules of thumb

- **Time is a major risk factor**
  - Payback period is very important and location dependant
  - Capital risk very linked to Construction time
  - Ramp up rates should be short

- **Adding steps Adds Risks**
  - Further processing to “improve” economics is dangerous
  - Always look at potential break points in the project

- **Cash costs should be low**
  - At least lowest half and preferably bottom quartile

- **The Implementation Plan must be sound**

- **Government Rules can Change Overnight**
  - Projects based on Tax Breaks have an added risk factor

A dog remains a dog even with clothes on
Who Evaluates Opportunities?

- **Early Stage**
  - Usually Proponent
  - Internal
  - Subjective
  - Optimistic

- **Final Stage**
  - Financier – Client
  - External
  - Objective
  - Conservative

*Whichever you are* **Do it Well**
Comparison of normalised feed grades for selected world-class porphyry Cu deposits
Rock Burst and Seismicity

Courtesy of D. Ortlepp
Grade Quality and Processing Efficiency

- As the mining investment declining and the operations are maturing they are becoming lower quality, which requires fine grinding and grade drops off. Grinding is the most expensive processing unit.
- Optimising the process efficiency of individual unit operations.
- Detecting and eliminating dynamic coal losses.
- Optimising maintenance practices and equipment designs to deliver improved process efficiency at lower costs.
- Sustainability - improve health and safety outcomes and reduce the environmental impacts and water management.
- Development of new processing technologies that are higher capacity, lower cost, or more efficient.
- Deployment of existing technologies and approaches from other industries in a coal specific context.
- Automation of mobile equipment in coal and mineral handling applications such as dozer push.

Source: CRCORE
Transport and Port Facilities

- Efficient loading of wagons/trains
- Efficient modelling of train runs
- Spontaneous combustion during transportation
- Blending (at ports and on trains)
Rio Tinto Energy Profile

- Smelting: 53%
- Mining: 14%
- Milling: 12%
- Refining: 6%
- Electricity & Steam: 9%
- Other: 6%
- Total: 270 PJ per annum
Morenci crushed ore (bio)-heap leaching

Electrowinning and electrorefining
Gold and Platinum price history over 10 years

Gold

Platinum
Socio-Economic Importance of Mining

- In 2014 the mining sector contributed **R18 billion** to the South African fiscus
- A total of **495,568** people were employed in the mining sector in 2014 (9% of non-agricultural sector)
- The multiplier effect: Each person employed in the mining sector has up to nine indirect dependents
- In 2013 ~9% of GDP (in 1970, 21%!)

![Annual mining revenue by commodity](chart.png)

- Coal
- PGMs
- Iron ore
- Other
- Gold
What about the impact of mining on world energy consumption and the environment

- **A computer contains ~ 1kg of copper** which began as began by being mined as copper sulphide.

- **MINING IMPACT**: If the ore contained 0.9 percent copper a computer requires excavating 127kg of ore and at least 136kg of other rock lying on top of the ore.

- **MINERAL PROCESSING IMPACT**: The ore was ground and then treated using various complex processes to obtain pure copper.

- **ENVIRONMENTAL IMPACT**: This treatment also produced sulfur dioxide (S02), which causes acid rain.

- **ENERGY IMPACT**: Mining, crushing, grinding and smelting the 1kg of copper required the energy equivalent of 275 litres of petrol. Mining and producing metals accounts for about 7 percent of global energy consumption.
Declining ore grades

Some major mining challenges

- Safety
- Productivity
- Automation
- New mining methods – waste reduction

Some major mineral processing challenges

- Improved technologies to reduce energy & water utilization
- Environmental protection
- Responsible management of waste material
Circuits are rarely simple, especially at 1.3 mt/d

Escondida: operations overview

Escondida Pit
Escondida Norte Pit

Los Colorados Laguna Seca Concentrator Plants

Approximately 230 ktpd ore processed

Approximately 3.5 mtpa of concentrate shipped

Dumps

Waste

Oxide

Mix Ore

Sulphide

Crusher

Copper Concentrate

Coloso Port

More than 200 ktpd of ore stacked

Oxide Ore Stock

Mixed Ore Stock

Sulphide Ore Stock

Sulphide Bio Leach

Oxide Acid Leach

Copper Cathodes

Port of Antofagasta

Oxide

Mining accounts for ~15% of SA’s total electricity consumption - almost equivalent to the total domestic or residential consumption.

The relatively low cost of electricity in SA used to encourage the growth of energy-intensive mining and mining-related activities, such as aluminium smelting, and production of iron, ferrous metal alloys, stainless steel and titanium slag. Are the crows coming home to roost??

As the generation of electricity is largely coal-based, an increase in electricity consumption also has implications in terms of solid waste generation and disposal, resulting in more discards from coal mining, and more power station ashes to be disposed, CO₂ emission issues, etc.
Concentrator costs by cost element
Energy Consumption

Energy in Underground Mining - Example

- Conveying
- Surface
- Mining
- Concentrator

- Grinding
- Pumps
- Flotation
- Other
% Contribution of different minerals to the industry

Source: Gross domestic product (PO441), 3rd quarter 2014  http://www.statssa.gov.za
Energy - Underground Mining

Source data extracted from 'Natural Resources Canada - Benchmarking Report 2006' & further analysed
Types Of Impacts Of Mining On Water

- **Chemical impacts:**
  - Acidity / alkalinity
  - Radioactivity
  - Arsenic
  - Mercury / Cyanide
  - Heavy metals

- **Physical impacts:**
  - Water use
  - Diversions
  - De-vegetation
  - Salinization
  - Siltation

Which leads us to the next challenge ……………..
Influence Of Acid Mine Drainage on Water Quality Problems In Receiving Waters

- Lower pH values – altered chemical equilibria
- Increased metal concentrations – toxicity to aquatic organisms and human users
- Increased total dissolved salts – salinity problems for agriculture and sensitive users
- Toxic precipitates in streams
- Increased sediment loads
- Increased water treatment costs to other users
- Corrosion problems in distribution systems
Science

- Impacts > previously thought
- Past 2°C tipping point – can make 3°C
- Emissions must peak 2030 – 2050 and decline thereafter

Economics

- Carbon prices of US$30 - $100 needed
- Up to 3% decrease in global GDP
- Regional impacts on GDP could vary significantly

Politics

- Global agreement required
- Action required by all countries
- Rhetoric on need for technology not matched by funding. Need to dramatically ratchet up technical effort
And New Technology is Needed

- New Products: Unlikely
- New High Tonnage Processes: Unlikely
- New Process Steps: Possibly
- Current Process Step Improvements: Hopefully
- Incremental Improvements: Ongoing
Projects require time and money

- R&D is only a small component
- Normally 5-10% of Total
- Researchers risk time
- Companies risk money

A Successful New Cu Process

- Pilot Plant (4%)
- Construction (87%)
- Modifications (6%)
- R&D (3%)

YEARS
DOLLARS ('000)
Rejecting torbanite from coal with XRay transmission
The implications for improving productivity in the South African mining sector are clear. Companies serious about both cost control and productivity need to have a greater focus on the efficiency of their equipment. This means stepping beyond short term cost reduction initiatives and a preoccupation with extra tonnes leaving the mines.
Health and Safety in the Mining Industry

- Detection, prediction, selection and design of systems to control spontaneous combustion, ignitions, explosions, outbursts, ventilation and strata.
- Improving equipment operator interfaces and collision avoidance, improved automation and remote monitoring and control.
- Better controls for airborne contaminants (e.g., dust and diesel emissions) and noise exposure by attenuation.
- Protection and removal of personnel from hazardous situations
- General improvement to the health and safety of mining and maintenance operations.

Source: ACARP
The irony is that in almost all these cases it is the very same engineering skills which are already in short supply that will be needed to address these challenges.

One critical intervention is to ensure that we produce a generation of engineers/scientists who:

- have the technical competence to ensure an on-going highly efficient supply of the key mineral products the world needs while also
- ensuring that these processes are implemented in a way which will preserve the environment and the general quality of life of future generations.
Global GHG Emissions in Mining & Metals

Mining & Metals a significant contributor to global emissions

Total Emissions 2.2 billion tonnes CO$_2$e p.a.

Source: CSIRO, 2006
Emissions are steadily increasing

Carbon Tax of $20/t-CO2 = $1bn Cost by 2020

Graph showing fatalities per 100,000 workers in various industries. The graph indicates a significantly higher fatality rate in mining compared to other industries. The color coding is as follows:

- **RED** = 2004
- **ORANGE** = 2014

Industries listed include:

- Agriculture, forestry & fishing
- Transport, postal & warehousing
- Electricity, gas, water & waste services
- Arts & recreation services
- Mining
- Construction
- Rental, hiring & real estate services
- Other services
- Wholesale trade
- Public administration & safety
- Administrative & support services
- Manufacturing
- Retail trade
- Accommodation & food services
- Health care & social assistance
- Professional, scientific & technical services
- Information media & telecommunications
- Financial & insurance services
- Education & training

**Fatalities per 100,000 workers**

- Agriculture, forestry & fishing: 108
- Platinum: 66
- Coa: 20
- Other: 53

**Safe work Australia**
MINING EMPLOYMENT AS A % OF TOTAL NON-AGRICULTURAL EMPLOYMENT

Source: South African Reserve Bank quarterly bulletin
A Typical Concentrator Scene
A concentrator is essentially a complex set of processes aimed at producing the final metal from the ore delivered from the mine. This is a PGM Concentrator.
Global demand grows by more than half over the next quarter of a century, with coal use rising most in absolute terms.

Source: IEA Modelling 2006
The Situation In The USA – The World’s Largest Mining Country In Terms Of Tonnes Treated!
Other Interventions

- Dramatic reduction in water usage through new tailings management approaches
- Re-working of tailings deposits for economic minerals
- Experimental use of wetlands as “low maintenance systems” to neutralize acid rock drainage
- Improved smelter efficiencies
Global and Local influences on South African Mining Companies

Lane et al: JSAIMM, 115, 6, 2015
Energy consumption for Copper mining

By Fuel

- Electricity
- Diesel
- Natural gas
- Gasoline
- Propane
- Process Emissions

Total Emission = 7161 t CO$_2$-e / kt copper metal

By Unit Operation

- Mining
- Mineral Processing
- Smelting
- Electrorefining

Total Emission = 7161 t CO$_2$-e / kt copper metal
Trade Test Statistics
Vision and strategy

To promote sustainable development of the South African minerals processing industry through the development of globally competitive, innovative technology, driven by people with world-class skills.

SAMMRI is run by industry and its objectives are achieved by:

1. Supporting emerging academics and researchers at South African universities by funding appropriate research projects.
2. Developing a joint venture between industry and the DST to provide such funding.
3. Identifying projects of real interest to industry members and to mentor both the researchers and post-graduate students involved with these projects.
IMPORTANCE OF MINING TO SOUTH AFRICAN EXPORTS IN 2012

[Diagram showing the importance of various mining products to South African exports in 2012]
## Mining provides key raw materials

### Demand for minerals
- Infrastructure
- Modern lifestyle needs e.g. autocats, jewellery, copper (China building boom)
- Electronics
- Building materials
- etc

### Supply of minerals
- South Africa is a treasure chest of minerals
- But lower grades, weaker prices, environmental challenges
Figure 1: Breakdown of anticipated average electricity price path (saiia.org.za)

Average electricity price in 2010 ZAR/kWh

Maximum price scenario, highly depends on asset value methodology for existing fleet and Eskom transmission and distribution

1.12
0.98

PV CSP
Wind
Peak-OCGT
Gas-CCGT
Hydro
Nuclear
Coal

Total price effect of new builds in 2030

Fuel costs of existing fleet Eskom transmission and distribution costs plus non-fuel costs of existing fleet*

Price hike for existing fleet without any new builds = 0.78 ZAR/kWh

* Does not include costs of non-Eskom distribution network
Let’s reflect for a moment on the “Grand Challenges for Engineering”

• Make solar energy economical
• Provide energy from fusion
• Develop carbon sequestration methods
• Manage the nitrogen cycle
• Provide access to clean water
• Restore and improve urban infrastructure
• Advance health informatics
• Engineer better medicines
• Reverse-engineer the brain
• Prevent nuclear terror
• Secure cyberspace
• Enhance virtual reality
• Advance personalized learning
• Engineer the tools of scientific discovery

Ref: NAE USA
Mining in Southern Africa

- **Botswana**  World’s largest world diamond producer
- **DRC**  Largest African copper producer (80% of exports)
- **Mozambique**  Mining to increase from 2 to 12% of GDP by 2020
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- **Zambia**  Copper/cobalt account for 10% of GDP and 70% of exports
- **Zimbabwe**  Second largest world deposits of platinum
Barriers to improved efficiencies

- **Materials Handling**
  - Globally alternatives to diesel trucks are presently not cost effective or technology proven.

- **Beneficiation & Processing**
  - Materials that can withstand these high-impact environments
  - Need to optimize design and operation of crushing and grinding processes.

- **Extraction**
  - Lack of ore sorting process sensors and methods for selective mining
  - Lack of knowledge to expand application of in-situ mining for other commodities.
  - Greater use of sophisticated process control
## Energy consumption on a mine-concentrator

<table>
<thead>
<tr>
<th>Product and process</th>
<th>Feedstock</th>
<th>Product</th>
<th>Estimated mine and beneficiation plant electricity usage (kWh/t ore)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground block cave mining</td>
<td>Molybdenite ore</td>
<td>Molybdenite ore</td>
<td>123</td>
</tr>
<tr>
<td>Underground crusher</td>
<td>Molybdenite ore</td>
<td>Molybdenite ore</td>
<td>3.4</td>
</tr>
<tr>
<td>Underground-surface belt</td>
<td>Molybdenite ore</td>
<td>Molybdenite ore</td>
<td>1.7</td>
</tr>
<tr>
<td>Beneficiation (primarily crush, grind, float, dry, and disposal of tailings)</td>
<td>Molybdenite ore</td>
<td>Molybdenite concentrate</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>--</strong></td>
<td><strong>--</strong></td>
<td><strong>34</strong></td>
</tr>
</tbody>
</table>
## Polymetallic base metal sulphides

<table>
<thead>
<tr>
<th>Process</th>
<th>Feedstock</th>
<th>Product(s)</th>
<th>Estimated mine and beneficiation plant electricity usage (kWh/t ore produced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground mining</td>
<td>Ore</td>
<td>Polymetallic ore</td>
<td>51</td>
</tr>
<tr>
<td>Beneficiation (crush, grind, float (producing two concentrates) and tailings disposal)</td>
<td>Ore</td>
<td>Precious metal concentrate and concentrate containing Cu, Co, Ni, and Zn</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>--</td>
<td></td>
<td>91</td>
</tr>
<tr>
<td>Crushing</td>
<td>Ore</td>
<td>Crushed ore</td>
<td>3–7</td>
</tr>
<tr>
<td>Grinding</td>
<td>Crushed ore</td>
<td>Ground ore</td>
<td>12–16</td>
</tr>
<tr>
<td>Flotation (two concentrates)</td>
<td>Ground ore</td>
<td>Concentrate</td>
<td>7–14</td>
</tr>
<tr>
<td>Tailings (waste) treatment and disposal</td>
<td>Tailing s (slurry)</td>
<td>Tailings (slurry)</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>N/A</td>
<td>N/A</td>
<td>1–3</td>
</tr>
<tr>
<td>Total</td>
<td>--</td>
<td>--</td>
<td>25–42</td>
</tr>
</tbody>
</table>
CSIR Report on latest IRP!

Least-cost: 70% RE energy in South African electricity sector by 2040
Comparison of energy supply for BAU and a Re-optimised scenario

1. Business as Usual
   - Electricity supplied in TWh per year
   - 2016: 361 TWh
   - 2020: 472 TWh
   - 2025: 500 TWh
   - 2030: 500 TWh
   - 2040: 500 TWh

   - Solar PV: 7% (18 TWh/yr)
   - CSP: 18% (64 TWh/yr)
   - Wind: 19% (91 TWh/yr)
   - Other RE: 7% (18 TWh/yr)
   - Peaking: 40% (146 TWh/yr)
   - Other (incl. cogen): 71% (332 TWh/yr)
   - Gas (CCGT): 215 Mt
   - Hydro (incl. PS): 250 Mt
   - Nuclear: 215 Mt
   - Coal: 103 Mt

2. Re-optimised
   - Electricity supplied in TWh per year
   - 2016: 366 TWh
   - 2020: 474 TWh
   - 2025: 500 TWh
   - 2030: 500 TWh
   - 2040: 500 TWh

   - Solar PV: 7% (18 TWh/yr)
   - CSP: 18% (64 TWh/yr)
   - Wind: 19% (91 TWh/yr)
   - Other RE: 7% (18 TWh/yr)
   - Peaking: 40% (146 TWh/yr)
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   - Hydro (incl. PS): 250 Mt
   - Nuclear: 215 Mt
   - Coal: 103 Mt

Sources: CSIR analysis
An interesting Reflection On Water Usage in South Africa!

- Agriculture is arguably an inefficient user of water!
- It takes 7000 litres of water to produce R1 of lucerne
- But only 45 litres to produce R1 of steel!!
Great Engineering Achievements in Mining

- Mechanisation and capacity mining equipment
- Continuous miner, longwall mining, draglines, trucks etc
- High capacity mineral processing plants
- Safe mining practices
- Ventilation and gas flow modelling
- Environmental impacts
- Improved numerical modelling of rock mass behaviour, particularly in block rock masses.

Ref: Prof Ismet Canbulat, Dept. of Mining Engineering, UNSW
Possible Interventions

- Dramatic **reduction in water usage** through new tailings management approaches
- **Re-working of tailings deposits** for economic minerals
- Experimental use of wetlands as “low maintenance systems” to neutralize acid rock drainage
- Improved **smelter efficiencies**
Economies of scale can help reduce overall energy demand/treated.
Our choices with regard to sustainability are neither simple nor easy. But we must keep on looking for the sweet spot in which mining can serve the needs of our society without destroying its future

Prof. Hanri Mostert,
SarchI Chair in Mineral Law, UCT
How successful are we in producing engineers and artisans

- The throughput rate (% of graduates) in engineering after 10 years is ~57%. This means that just over half of those who enter undergraduate degrees graduate\(^1\).

- In 2009/10 MQA had Year1 learnerships of 2663 out of a total of 53644 (4.9%) and Yr 5 learnerships of 4706/43579 (10%)\(^2\)

1. Report: 2000 to 2008 first time entering undergraduate cohort studies for public higher education institutions; 31 March 2016

2. A technical report on learnership and apprenticeship population databases in South Africa (Jan 2012)