New Paradigms in the XXI Century Mining Technology

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- Introduction
- Energy in the Mining Business
- Ores and Minerals
- The Way We Do Things
- Final Remarks
What’s Up in the Mining Industry?

• Production target along last Supercycle was close or over the limit of capacity of many installations without appropriate long-term management practices.

• It produced falling off in capacity; uncertainty in results; low productivity and high cost; complex people relationship among company holders and unions, communities, suppliers and government authorities.

• Above that, technical experience came down due to imbalance in personnel turnover and the application of policy to reduce cost by taking away older (but experienced) people.

• In 2013 situation was unaffordable and since then producers started forcing cost reduction, mainly from supplier of services and consumables, but structural problems are still there.

• A relevant decision is the extent to which supplier costs should be squeezed to assure their permanence in the market.
Which are Main *Process* Challenges?
(From the technology viewpoint)

- Lower Energy Demand
- Lower Material Demand
- Higher Efficiency of Separation
- Environmentally Friendship
- Automated/Autonomous Systems
- Lower Water Demand
- Faster Process Kinetics
- Higher Capacity/Volume
- Continuous Processes

*Even solving all these challenges, results will not improve if we do not use them in the right way!*
A New Paradigm is Underway...

Mining and Process technologies are *not* expected to change significantly within the first quarter of the twenty first century. *Conversely, the way we use technology is going to change dramatically.*

This is true not only in the mining industry but also globally *in most of the social and economic human activities.*
Limitation of Human Beings...

We must accept that human beings have limited time, attention and accuracy, all of which means they are not very good neither at capturing data nor when processing in the real world...

If we had computers that knew everything there was to know about things, using data they gathered by themselves, we would be able to track and count everything and greatly reduce waste, loss and cost...
Mining Business Activities
Dynamically Controlled

Activities Controllability
(The way we do things)

Financial
Plant Operations
Mining Operation
Geology
Environment
Supply
Maintenance
Summarizing the Challenges...

• Continue the short-term process optimization. This gives the money to support the business today

• Change the way you drive the business, taking advantage of the new IT Tech

• Take special care of the structural mining limitations and look for breakthrough solutions
Specific Issues to Develop along this Talk:

- Energy in the Mining Business:
  - How can we reduce specific energy consumption?

- The Way We Do Things:
  - How can we assure optimum business results?

- Ores and Minerals:
  - How can we face the lower grades and non-desired component in orebodies?

- Short and Long-Term Technology:
  - How can we reduce specific energy consumption?
Energy in the Mining Business
Energy: Current Situation

• Within 2015 to 2050 the global economy will grow about four-fold.
• Growth will approach ten-fold in countries like China and India.
• Under “business-as-usual” 70% increase in oil demand is expected by 2050 and also 130% rise in CO$_2$ emissions raising by 6 degrees the global temperature.
• By the way, how does energy is globally consumed today?

http://www.eia.gov/tools/faqs/faq.cfm?id=447&t=1
Energy: The Global Strategy

The Smart Grid is an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated way across the energy system from the generation to consumers.

- CO₂ Capture and Storage
- Renewables
- Smart-Grid-Technology (The way we do things)
- Nuclear Power
- More-Efficient Processes and Machines
  (HPGR, Poly Met Linings, UHEB, others)
# Mining: Energy Efficiency Today

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flotation</th>
<th>Heap Leach</th>
<th>ROM Leach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore Head Grade, % Cu</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Strip Ratio, Waste/Ore</td>
<td>3.0</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Recovery, %</td>
<td>90</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>Product Grade</td>
<td>30</td>
<td>99.99</td>
<td>99.99</td>
</tr>
</tbody>
</table>

### Milling
- SAG Power Index, SPI
- Bond Work Index, BWI

- **Milling**
  - SAG Power Index, SPI: 150 minutes
  - Bond Work Index, BWI: 13.5 kWh/st (14.9 kWh/mt)

### Smelting & Refining
- Smelter Recovery: 97%
- Concentrate Truck Freight: 200 miles, 0.009 gal-diesel/ton-mile
- Concentrate Ocean Freight: 6,000 miles, 0.002 gal-oil/ton-mile
- Cathode Truck Freight: 200 miles, 0.009 gal-diesel/ton-mile

### Concentrate leaching
- High Temperature Recovery: 98.5%
- Medium Temperature Recovery: 97.5%

### Wear Steel Energy-Equivalent
- 5.23 MWh/st (5.75 MWh/mt)

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Energy Consumption Today

After Marsden, 2008
## Foreseen Improvement by Various Process Routes

<table>
<thead>
<tr>
<th>Process Route</th>
<th>Total Energy Consumption(^2) (kJ/lb)</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crush, heap leach, SX, EW (Base Case)</td>
<td>28,511</td>
<td>-</td>
</tr>
<tr>
<td>- With alternative anodes</td>
<td>27,304</td>
<td>4.2</td>
</tr>
<tr>
<td>- With ferrous/ferric reaction</td>
<td>25,298</td>
<td>11.3</td>
</tr>
<tr>
<td>SAG mill, ball mill, float, smelt, refine (Base case)</td>
<td>47,468</td>
<td>-</td>
</tr>
<tr>
<td>HPGR, ball ill, float, smelt, refine</td>
<td>41,169</td>
<td>13.3</td>
</tr>
<tr>
<td>SAG mill, ball mill, float, HT Concentrate Leach</td>
<td>47,055</td>
<td>0.9</td>
</tr>
<tr>
<td>SAG mill, ball mill, float, MT Concentrate Leach</td>
<td>45,453</td>
<td>4.2</td>
</tr>
<tr>
<td>HPGR, ball mill, float, MT Concentrate Leach</td>
<td>39,186</td>
<td>17.5</td>
</tr>
</tbody>
</table>

1. Includes energy for mining final cathode product
2. Assumes 40% efficiency factor to generate electric power (kJ to kWh).
One key concept which will dramatically change the Metal Extractive Metallurgy Technology within the next thirty years is the...

**OVER IMPOSITION OF FIELD FORCES TO BODY FORCES USED IN MOST CURRENT TECHNOLOGY**

Comminution?
Change the way, body forces have a limit...
Researchers are Not Sleeping!

<table>
<thead>
<tr>
<th>Some examples:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D97I1043, Utilización del Fenómeno Magneto Hidrodinámico en Procesos Pirometalúrgicos</td>
<td>D05I10098, Calentamiento de Soluciones Por Inducción Magnética</td>
</tr>
<tr>
<td>FONDEF 1100996, Innovative Sono Electrochemical Reactors vs. HPGR In Nanotechnology</td>
<td>D92I1021, Desarrollo de un Equipo Ultra Sónico para la Molienda de Minerales</td>
</tr>
</tbody>
</table>
Microwave Applicator Arrangement

J. Kobusheshe, “Microwave Enhanced Processing of Ores”, Ph.D. Thesis, June 2010, School of Chemical Environmental & Mining Engineering, University of Nottingham, UK.
Microwave Applications

Microwave assisted ore grinding

Microwave assisted pretreatment of refractory gold concentrate

Microwave assisted minerals leaching

Microwave assisted drying and anhydration

Microwave change of magnetic mineral properties

Microwave assisted waste management

Microwave assisted spent carbon regeneration

Microwave assisted carbothermic reduction of metal oxide

STATE OF DEVELOPMENT IS STILL LIMITED

Ores and Minerals
Ores and Minerals: Challenges

Decreasing Grades

Non Renewable Source

- Clayish Ores
- Refractory Ores
- Contaminated Ores
Grade Impact in Energy Consumption

After Marsden, 2008.
Mineral Sorting Jumps to First Place

I. Conditioning
II. Emitter-detector
III. Separation
IV. Data processing
V. Product stream
VI. Reject stream

Current Technology - Mineral Sensing
<table>
<thead>
<tr>
<th>Method</th>
<th>Sensor Type</th>
<th>Sort Type</th>
<th>Materials</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGNAA</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Limestone, Fe, Al, P, Mn, Cu, Zn</td>
<td>1-2 min. avg, &lt;500mm rock, &gt;20-30 kg/m, sub 1% detection</td>
</tr>
<tr>
<td>NITA II</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Coal, C, H, O, Fe, Ca, S, Al, Cu, Ni, Mn, Si, Ti</td>
<td>1-2 min. avg, &lt;300mm rock, &gt;350mm depth, need &gt;1% for detection</td>
</tr>
<tr>
<td>PFTNA</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Ni, Fe, Co, Mg, Si, Al, Mn, Cr, C, H, O</td>
<td>&lt;90mm rock, &lt;280mm depth, 50-150kg/m</td>
</tr>
<tr>
<td>RM</td>
<td>Penetrative</td>
<td>Particle</td>
<td>U</td>
<td>Only for radioactive mineral</td>
</tr>
<tr>
<td>XRT</td>
<td>Penetrative</td>
<td>Particle</td>
<td>Base metals, industrial minerals, coal, diamonds, Au/Ag indirect</td>
<td>2-300mm rock, &lt;300tph, &gt;4-5 AN diff</td>
</tr>
<tr>
<td>XRT</td>
<td>Surface</td>
<td>Particle</td>
<td>Ni, Cu, Zn, Au, Ag, Fe, Cr, Mn, U,W, Sn, Al</td>
<td>Requires long exposure time, limited to AN&gt;20, 30-250mm rock, 20-50 tph</td>
</tr>
<tr>
<td>XRL</td>
<td>Surface</td>
<td>Particle</td>
<td>Diamonds, fluorite, sphalerite, kunzite</td>
<td></td>
</tr>
<tr>
<td>UV</td>
<td>Surface</td>
<td>Particle</td>
<td>Scheelite</td>
<td>Few minerals naturally respond to UV excitation</td>
</tr>
<tr>
<td>VIS</td>
<td>Surface</td>
<td>Particle</td>
<td>Quarts, limestone, dolomite, feldspar, fluorite, gems, Au/Ag indirect</td>
<td></td>
</tr>
<tr>
<td>RGB</td>
<td>Surface</td>
<td>Particle</td>
<td>Industrial minerals, gemstones, Cr, Au, Ni, Pt, Cu oxides, Au/Ag indirect</td>
<td>5-20 tph</td>
</tr>
<tr>
<td>PM</td>
<td>Surface</td>
<td>Particle</td>
<td>Industrial minerals, diamonds</td>
<td></td>
</tr>
</tbody>
</table>

## Current Technology - Mineral Sensing

<table>
<thead>
<tr>
<th>Method</th>
<th>Sensor Type</th>
<th>Sort Type</th>
<th>Materials</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIBS</td>
<td>Surface</td>
<td>Particle</td>
<td>Elemental Analysis, most all elements</td>
<td>Sensitive to variations in distance from Lase/detector to target sample</td>
</tr>
<tr>
<td>LIF</td>
<td>Surface</td>
<td>Particle</td>
<td></td>
<td>Like LIBS, early stage of development few commercial applications</td>
</tr>
<tr>
<td>VNIR</td>
<td>Surface</td>
<td>Particle</td>
<td>Industrial minerals, Fe ore</td>
<td>2-120 mm rock, 20-100 tph, surface technique impacted by cleanliness and single perspective (though double sided set-ups exist)</td>
</tr>
<tr>
<td>SWIR</td>
<td>Surface</td>
<td>Particle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMIR</td>
<td>Surface</td>
<td>Particle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LWIR</td>
<td>Surface</td>
<td>Particle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIR</td>
<td>Surface</td>
<td>Particle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMS</td>
<td>Penetrative</td>
<td>Both</td>
<td>Fe ore, base metals with magnetic response</td>
<td>8-60 mm rock, 70 tph</td>
</tr>
<tr>
<td>IND</td>
<td>Penetrative</td>
<td>Both</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRS</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Chalcopyrite</td>
<td>300 mm rock, 1300 tph, Nota II nuclei are magnetic</td>
</tr>
</tbody>
</table>

(Contn.)
Sensing Technology - Providers

- ✓ Scan Tech
- ✓ Steinert
- ✓ Thermo Scientific
- ✓ Tomra
- ✓ IMA Engineering
- ✓ SGS/CoreScan
- ✓ Specim
- ✓ Spectral Evolution

- ✓ Comex
- ✓ CSIRO
- ✓ EVK
- ✓ LLA Instruments
- ✓ MineSense
- ✓ Multotec
- ✓ PANanalytical
- ✓ Rados

*Underlined: also sorting tech providers.*
PGNAA – Copper/Gold Plant

Remarks

• Sorting is becoming a main option to face the accelerated grade reduction. This has promoted new tech improvements.
• Able to pre-concentrate ores by rejection of waste materials.
• Able to remove clayish non valuable components.
• Able to reject contaminant components
• Pre-concentration reduces water and energy demand, among others.
• Pre-concentration enables lower cost, less selective mining methods.
• Pre-concentration can reduce mill OPEX and CAPEX.
• Can reduce cut-off grade to extend reserves and mine life.
• Sensing technology is now able to detect most all elements and minerals in real time at high speed and reasonable cost.
• Sorting technology can reduce or avoid excessive throughput.
The Way We Do Things
New Class of Products

• A new kind of smart connected technology products are appearing. These are “complex systems that combine hardware, sensors, data storage, microprocessors, software, and connectivity in myriad ways”.

• A single smart miniature device may contain multiple sensing functions along with chips for self-processing the data within a high connectivity ambient, embedded within any kind of object and even provided with a self-control of the power it consumes.

• These new types of products alter the industry structure and the nature of competition, exposing companies to new competitive opportunities and threats. They are reshaping industry boundaries and creating entirely new industries.
The Third IT Wave

• In the 1960s and 1970s, the Information Technology brought automation to a number of discrete business processes, including transaction processing, financial planning, engineering design, inventory management, payroll and personnel records.

• In the 1990s, the connectivity and universal reach of the Internet enabled companies to integrate and better coordinate all their various processes, as well as to go beyond the boundaries of the company and develop global supply chains and online customer services.

• The first two IT waves helped companies become significantly more productive by reengineering their operations, but their products were largely unaffected. This is now changing with the emerging of cloud computing, internet of things, big data and other major innovations composing the IT-03 technology wave and the ensuing new era of smart connected products.
Why Now?

• Capacity to communicate torrent of data is now possible due to introduction of the newest version of the Internet Protocol standard IPV6.

• The new address space expansion means we could “assign an IPV6 address to every atom on the surface of the earth, and still have enough addresses left to do another 100+ earths.” In other words, humans could easily assign an IP address to “everything” on the planet.

• In the coming scenario, machines, people, and ordinary objects are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. IoT has evolved from the convergence of wireless technologies, micro-electromechanical systems (MEMS) and the Internet.
Analytics to Increase Productivity and Reduce Cost

**Process Control:**
- Analysis of individual and integrated processes
- Analysis of the control system performance
- Set point revision
- Variability analysis
- Efficiency KPI’s

**Protocol Compliance:**
- Safety Analysis
- Operational Analysis
- Maintenance analysis
- Environmental analysis
- Cost analysis
- Efficiency KPI’s

**Process Optimization:**
- Efficiency gap estimates
- Maintenance gap estimates
- Technical & economical optimal set point
- Efficiency KPI’s

**Data Mining:**
- Correlation analysis
- Process response pattern
- Maintenance analysis
- Statistical analysis of data
- Integrated business analysis
- Probable scenarios

**Visual Analytics:**
- Care of people, machines and installations
- Analysis of behavioral pattern
- Multi level people interaction
- Efficiency KPI’s

**Artificial Intelligence Tools**

New applications for this key tool

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**Protocol Compliance:**
- Safety Analysis
- Operational Analysis
- Maintenance analysis
- Environmental analysis
- Cost analysis
- Efficiency KPI’s
Cloud Computing Ecosystem
Case Study: Optimizing the Unit Cost

- The “Unit Cost” is defined as the cost/production ratio.
- It can be minimized either by increasing the copper production and/or by reducing production cost.
- Production is on top when throughput, effective utilization of assets and metallurgical recovery are all at their maximum level.
- Costs are in a valley when consumption of energy, water and other consumables are minima as well as the cost of all relevant services. Wages should not be minimized but to stand within the market band.
- Safety of workers, rewards to communities and environment care are business constraints but not objectives by themselves.
- Implementation of this optimization tool requires: (i) Specific definition of objectives and KPI’s, (ii) Identification of controlling variables; (iii) Selection of monitoring and control system; (iv) Selection of analytics and (v) Selection of communication system, (vi) Implementation and integration to existing network.
Case Study: Optimizing the Unit Cost
Final Remarks

• The coming mining business will be marked by a sustained international demand, with increasing complexities in the production chain and changing market conditions, with prices strongly influenced by external variables.

• Potential profitability for producers in the short-term is mainly related to increase in their productivity and cost reduction by imposing a “new way of doing things”.

• Put on priority the evaluation of pre concentration techniques, either to increase grades and/or to remove clayish ores and/or to separate valuable components or to reject contaminants.

• Current technology linked to radiative energy may produce breakthrough improvements. Microwave is a golden key technology, but we feel we are still in incubating stages.
Final Remarks

How can we reduce specific energy consumption?

• Continue the short-term optimization
• Adopt the Smart energy-grid technology approach.
• Evaluate pre-concentration options to reduce ore throughput with same or higher metal feed.
• Support and encourage development of hybrid solutions involving radiative energy for the middle term.

How can we face the lower grades and non-desired component in orebodies?

• Undertake full characterization of your ore looking for separation options.
• Evaluate separation options and new business scenarios.

How can we assure optimum business results?

• Change the way of doing things; Introduce new control of management solutions, make use of embedded sensing, IoT, cloud computing and big data options.
THANKS