CEEC INTERNATIONAL LTD

Best Practice and Benchmarking for Eco-Efficient Comminution

The report of the CEEC workshop on eco-efficient comminution held in Vancouver, British Columbia, Canada, on 15-16 October 2014

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Executive Summary

Mineral processing plants are being designed and operated at less than optimal efficiency. The benefit of better performance, or the size of the prize, is sometimes not well understood in many sectors of the industry and neither is the relative ease with which some efficiency measures can be introduced. Energy efficiency is often not identified as a major factor in determining project value, partly because of the methods used to assess value. However, energy costs are increasing, and in some countries there are both technical and regulatory constraints on supply which are likely to grow. This has thrown the spotlight on comminution, being the largest consumer of energy on many mine sites.

The benefits of increasing energy efficiency are manifold, and although the potential improvements will differ substantially from project to project and between commodities, it is estimated that improvements of up to 30% kWh/metal unit are feasible now, perhaps 50% within 10 years, and more beyond that. One-off interventions that result in an efficiency step-change are rare, and cannot be relied on to solve the problem. Substantial gains can be made by the cumulative effect of relatively small improvements.

In 2012, CEEC hosted an inaugural Workshop to address the challenge of improving comminution efficiency. The seminal CEEC Roadmap report was produced from the contributions of this gathering of global industry leaders.

The key themes for the 2014 Workshop were best practice and benchmarking. The workshop took place in Vancouver over a 2-day period. Each day included keynote speakers who set the scene for the participants prior to break out sessions for discussion. Keynote speaker topics included but were not limited to industry drivers for change to best practice, energy efficiency opportunities, and innovation in the mining industry and best practice case studies.

Participants were divided into four groups for workshop discussions, to impart their experience and knowledge. The four groups reported their conclusions and recommendations to the 2014 CEEC Workshop participants to promote further discussions.

The outcome of the 2014 CEEC Workshop is cross-industry agreement to

1. Populate energy curves for gold, copper, platinum, nickel and more by October 2015.
2. Adopt the guidelines of the Industrial Comminution Standards Working Group within the Global Mining Standards Group: metrics and methodologies for benchmarking of industrial comminution efficiency within the hard rock mining sector.

NB: This report will benefit from being read in association with the CEEC Roadmap for Energy-Efficient Comminution[1] which was developed at the 2012 Workshop.

[1] Napier-Munn et al 2012

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Introduction

CEEC's mission is to raise awareness of research findings, alternative mineral processing strategies and installed outcomes relating to energy-efficient comminution. CEEC aims to accelerate information, knowledge and technology transfer with the objective of lower processing costs and improved shareholder returns as a result of improved comminution practices.

In 2012, CEEC hosted an inaugural Workshop to address the challenge of improving comminution efficiency. The seminal CEEC Roadmap report was produced from the contributions of this gathering of global industry leaders. The key actions to achieve improved industry performance were found to be

1. Measure current operational performance
2. Adopt best practice
3. Implement the appropriate business drivers and success measures
4. Communicate the benefits, motivate, engage and train staff working in the field.

Best practice and benchmarking were the key themes for the 2014 CEEC Workshop. The workshop took place in Vancouver over a 2-day period. Each day included keynote speakers who set the scene for the participants prior to break out sessions for discussion. Keynote speaker topics included, but were not limited to, industry drivers for change to best practice, energy efficiency opportunities, innovation in the mining industry and best practice case studies. A summary of the day-to-day outcomes from the workshop are available in the appendix.

This workshop was held in Vancouver, BC, Canada, on the 15th & 16th of October 2014. It was attended by invited guests only, who represented various parties in the mineral processing industry. Thirty six (36) guests attended. This report summarizes the outcomes of the two day workshop.

Business as usual

The crushing and grinding steps in the mineral processing of ores represent a substantial proportion of total energy cost in mining. For many mine sites the energy usage by crushing and grinding processes represents at least 40% of total energy consumption.

Furthermore, early research by the Department of Energy in the USA indicates that comminution represents up to 2% of world electrical power consumption. In resource intensive countries such as Australia electrical energy used for copper and gold processing alone could be as high as 1.3%[2].

[2] Ballantyne and Powell 2014

Mineral processing plants are being designed and operated at less than optimal efficiency. The benefit of better performance, or the size of the prize, is sometimes not well understood in many sectors of the industry and neither is the relative ease with which some efficiency measures can be introduced. Energy efficiency is often not identified as a major factor in determining project value, partly because of the methods used to assess value. However, energy costs are increasing, and in some countries there are both technical and regulatory constraints on supply which are likely to grow. This has thrown the spotlight on comminution, being the largest consumer of energy on many mine sites.

The benefits of increasing energy efficiency are manifold, and although the potential improvements will differ substantially from project to project and between commodities, it is estimated that improvements of up to 30% relative to metal output are feasible now, perhaps 50% within 10 years, and more beyond that. One-off interventions that result in an efficiency step-change are rare, and cannot be relied on to solve the problem. Substantial gains can be made by the cumulative effect of relatively small improvements.

The compelling need for change

Despite calls for industry benchmarks, the mineral processing industry does not commonly measure and compare its energy intensity. Historically, the concept of energy benchmarking has been challenged citing the inconsistencies of grind size, ore characteristics, flow sheet design and multiple other factors that are unique to each orebody.

Equally, it is challenging to define best practice when there are fundamental raw material differences from site to site. Operators monitor their own production throughput regularly, but lack an objective point of comparison. Each mineral processing site has a unique site of characteristics, equivalent to its own DNA.

The 2014 Workshop was opened by Jim Gowans, Co-President for Barrick Gold, who highlighted macro drivers for change in mineral processing. These included increasing energy costs, declining grades, rising capital intensity and increasing pressure on the social license to operate mines. With declining grades, investment has been made in larger mines to sustain the same metal output. This has not seen an equivalent rise in productivity of metal output. New frontiers for mineral extraction require new infrastructure and large long term investments to succeed. More remote sites also bring additional costs for operators in resources.

In recent years, the price of gold has fallen sharply, while labor and energy costs have not shifted. This has added significant pressure to find ways to reduce costs in

operating sites, presenting a strong case for benchmarking and best practice. End to end analysis of mineral processing efficiency will reveal improvement opportunities for productivity gains at the same or lower cost per unit of ore processed.

Analysis of mining productivity by global economists has revealed a significant drop in mining productivity over the past decade. This drop is driven by many factors, some of which are described in this report. Establishing best practice can reverse this trend.

Energy costs are rising, as the global population increases and demands on supply increase. Good work has been undertaken in the mining industry on renewable energy options, but the majority of the energy use on site is obtained from traditional sources. Energy prices will continue to increase over the long term.

Ore grades continue to decline, as the most accessible ore reserves are depleted. In addition, the fine grained nature of low grade deposits means that more grinding is required. Therefore, a different strategy is needed to ensure only the most ore bearing rock is ground, to minimize these costs.

Shareholder pressure for year on year dividend payments is high. Investors expect increasing annual returns and will move their funds to more profitable investments if this does not happen. This in turn drives short term decision making at senior levels of mining companies, as the executive team strive to fulfill their shareholders' expectations. A longer term investment approach is needed to facilitate innovation in mineral processing.

The 2012 Roadmap identified best practice and benchmarking as immediate actions to achieve efficiency in mineral processing. However, despite global engagement around the Roadmap, little if any change has occurred in the field. Therefore the CEEC Board identified the topic of best practice and benchmarking as its priority for the 2014 Workshop.

How can we move forward?

The 2012 CEEC Roadmap recommended the mineral processing sector develop clear benchmarks and standards for use by process designers, equipment manufacturers and project operators. This would allow performance to be compared with industry standards and with others operating in similar circumstances so that strategies could be devised to achieve best practice. Best practice needs to be viewed as a full system initiative, and include:

- Overall operational efficiency.
- Planning systems.

- Equipment efficiency.
- Maintenance systems.
- Control systems.
- Technical support systems.

Global guidelines

The Global Mining Standards Group (GMSG) commenced work on establishing best practice guidelines for industrial comminution in 2013. This group is a global organization for the mining community which develops, maintains, endorses, collaborates, educates, and communicates mining industry standards and guidelines which will be supported and used by mining stakeholders to improve the safety, operational, environmental, and financial performance of the mining industry.

The GMSG Industrial Comminution Efficiency (ICE) Working Group aims to standardize metrics and methodologies for benchmarking of industrial comminution efficiency within the hard rock mining sector. The working group aims to establish guidelines for measuring and comparing comminution circuit efficiency. These guidelines may differ in the accepted methods of hardness testing and the industry accepted empirical calculations applied. However the intent of the guidelines will remain shared across methods. The universal adoption of a single method of hardness testing within the industry is unlikely, hence the need for multiple guidelines.

Adopting the GMSG ICE guidelines will improve the effectiveness of best practice by allowing inter site comparisons. Best practice may be replicated by operators looking for improvement, using the recommended guidelines for measurement.

Energy curves

Processes for measuring optimal operation at each site have evolved regionally, based on proximal expert knowledge. Therefore, a range of measurement processes exist. This adds to the complexities of comparing operations across different sites.

Ballantyne (Ballantyne et al, 2014) presented a survey of the comminution energy requirements of gold and copper producing mines. He conducted this work to provide reliable benchmarking data which can be used to compare comminution energy consumption across different mine sites. The total gold and copper production of the mines included in the study equated to 15% and 24% respectively of global production and all of Australian production.

The comminution energy per unit metal product is presented in a graphical form similar to a cost curve. This simple technique allows individual mines to be ranked with respect to energy consumption and clearly displays the potential energy and cost benefits of moving down the graph into more efficient operating regimes. The

anonymity of the comprehensive, mine-specific data is maintained and the variability is visualised by constructing an 'energy curve' (a format similar to a cost curve). Since these types of curves are well known in the mining industry, this format is easily recognised and motivates behaviours that will move the mine down the curve. This approach also allows flexibility in the way comminution energy intensity is displayed (e.g. energy per rock milled or metal produced) thus providing a fairer comparison between sites.

The applications of energy curves are many and varied. It can be used to map the position of the mine as production progresses with year-on-year analysis. Circuit design proposals can be compared to assess the position of the mine on the energy curve when operational. Operational efficiency improvements can be mapped on the curves to visually assess the magnitude of reductions achievable through various strategies. The efficiency with which the various comminution devices achieve size reduction can be mapped down a circuit to identify opportunities for improvement and the magnitude of achievable gains.

Best practice

Strong visible leadership from the senior executive team was identified as critical to achieving change. A case was put for the use of Key Performance Indicators to act as rewards, to incentivize and motivate behaviors, rather than act as performance assessments.

Examples of best practice need more publicity, supported by evidence of their impact on financial outcomes. Delegates at the Workshop identified a number of examples of best practice currently in operation. Technologies such as high intensity blasting can improve ore separation effectiveness. The use of integrated sensors and data analytics can optimize pre-concentration, adding 15-50% to a project's NPV. The same system ensures valuable ore is not undetected.

ISO 50 001 has been awarded to one mining operation in Canada. In order to achieve accreditation, the site had to establish comprehensive energy measuring systems for the entire mineral processing operation. Benefits from this achievement include the ability to forecast energy requirements with more accuracy, more accurate costs allocation and improved budget planning.

What is stopping us?

Adopting new processes is inherently risky. Maintaining the current operation avoids risk while accepting the current drawbacks, while adopting a new strategy implies the drawbacks of no change are too great. Deloitte's Adriaan Davidse defined the latter approach as best defining innovation in his presentation at the 2014 Workshop.

Learnt bias underlies decision making. Loss aversion, planning fallacy, regret avoidance, framing, overconfidence and confirmation bias are all examples of cognitive bias. Underlying structures, patterns of behavior and metal models combine to control the outcomes of an organization. Disruptive thinking conflicts with these structures, making it challenging to drive innovation.

The process of understanding a new business situation and market pressure can be viewed as a three stage process. The initial analysis may over simplify the issue, using current knowledge. Further investigation results in too much information, leading to confusion, increased complexity and inertia. In due course, the right data is distilled to make a meaningful decision and take the appropriate corrective action.

Awareness and avoidance of these barriers to change is critical for improvement. Creating safe "zones" for new ideas, new processes, trails and testing is vital. Analysing success as well as failure will improve future outcomes.

Delegates at the Workshop highlighted these issues as barriers to change:

1. Commercial pressures e.g. time and budgets force decisions in the initial design phase. Existing proven systems are preferred as qualified solutions.
2. The mine design planning process is usually based on the current business drivers (exchange rates, oil prices etc.) with minimal regard to the dynamic nature of the global economy.
3. Poor organizational end-to-end alignment of budgets and outcomes result in limited benefits for efficiency initiatives.
4. Risk aversion: fast follower syndrome, lack of reward for efficiency initiatives; lack of time and resources to explore efficiency options; driven by KPIs only.
5. Resources (capital, skills, time etc.). The application of big data analysis as used in other complex industries may be useful.
6. Lack of leadership for eco-efficient processing.
7. High turnover of employees has resulted in less experienced decision makers.
8. Scheduling, planning and evaluation can limit the opportunity to look at new technologies, especially at the design stage, which leads to following the existing templates. Fixed decisions are set on a dynamic industry.
9. Management perception is disconnected from site operation and innovation groups. Management perspective of cutting spending versus investing to sustainably cut cost needs to be altered.
10. Risk aversion cripples innovation due to fear of failure and losing KPI.
11. Resources are limited. The industry culture is self-sufficient, whereas integrated systems can utilize resources among the stakeholders, similar to the oil and gas industry.

12. Lack of mentorship that would pass on knowledge and experience.

When can change be realized?

The delegates at the 2014 CEEC Workshop agreed to:

1. Populate energy curves for gold, copper, platinum, nickel and more by October 2015
2. Adopt the guidelines of the Industrial Comminution Standards Working Group within the Global Mining Standards Group: metrics and methodologies for benchmarking of industrial comminution efficiency within the hard rock mining sector.

Analysis of energy use in mineral processing of up to 75% of the world's gold sector will be reported in September 2015 in Vancouver, at a follow-up review meeting. A similar initiative will map the energy use in copper, platinum and nickel sectors in the future.

Multiple benefits will results from the measurement of current practice using a standardized set of measurements tools and common comparison tool. They include:

- Internal team building
- Internal data analysis
- Comprehensive energy monitoring
- Improved costs allocation
- Improved budget planning
- More appropriate KPIs
- Team building across production silos
- Closer collaboration with supply companies
- Optimized equipment performance on site
- Improved risk tolerance for trials of different processes
- Accurate cost analysis to support business case development
- Improved collaboration with business partners and communities
- Improved energy efficiency in mineral processing
- More efficient energy use on site
- Improved shareholder satisfaction

References

1. Napier-Munn, T., Drinkwater, D., Ballantyne, G., 2012. The CEEC Roadmap for Eco-Efficient Comminution. <http://www.ceecthefuture.org/resource centre/CEEC roadmap
2. Ballantyne, G.R., Powell, M.S., 2014. Benchmarking comminution energy consumption for the processing of copper and gold ores. Minerals Engineering, 65 (2014), 109-114.

Appendix 1: Workshop Delegates, Speakers and Organizers:

NB Speakers shown in bold

Name	Title	Company	Country
Mr. Mark Adams	Manager, Comminution Technologies	Outotec Ltd	Canada
Mr. Dan Alexander	CEO	JKTech Pty Ltd.	Australia
Mr. Grant Ballantyne	Research Fellow	JKMRC	Australia
Dr. Andrew Bamber	CEO	MineSense Technologies Ltd	Canada
Mr. Kyle Bartholomew	Senior Metallurgist	Metcom Technologies	USA
Mr. Russell Blades	Senior Manager, Energy and Greenhouse Gases	Barrick Gold Corporation	Canada
Mr. Peter Bokor	Executive Vice President	Ausenco	Canada
Ms. Sarah Boucaut	Executive Officer	CEEC International Ltd.	Australia
Mr. Stephen Boyce	Chief Mining Engineering	Orica Ltd.	Australia
Mr. Alan Boylston	VP Process Engineering Development	Mesto Minerals	USA
Mr. Mark Carlisle	Process Manager	FLSmidth, Inc.	USA
Mr. Gareth Clarke	Sector Manager, Mining	BC Hydro	Canada
Mr. Andrew Cooper	Energy Specialist	New Gold Inc.	Canada
Mr. Adrian Dance	Principal Consultant	SRK Consulting Inc.	Canada
Mr. Adriaan Danielse	Director	Deloitte Inc.	Canada
Mr. Kulvir Gill	Senior Principal	Clareo Partners	USA
Mr. James K. Gowans	Co President	Barrick Gold Corporation	Canada

Name	Title	Company	Country
Mr. Charles Haythornthwaite	Partner	Chrysalix EVC	Canada
Ms. Charli Jeltema	Sr. Metallurgist	FLSmidth Inc. – Salt Lake City Operations	USA
Mr. Peter Kondos	Sr. Director, Strategic Technology Solutions	Barrick Gold Corporation	Canada
Mr. Michael Larson	Senior Metallurgist	Glencore XT	Canada
Mrs. Virginia Lawson	General Manager Process Mineralogy	XPS Consulting & Test work Services	Canada
Mr. Geoff Locke	Manager Process Design	Barrick Gold Corporation	Canada
Mr. Ivan Mullany	Senior Vice President, Capital Projects	Barrick Gold Corporation	Canada
Mr. Ian Orford	Senior Process Engineer	AMEC	Canada
Mr. Joe Pease	Chairman	CEEC	Australia
Mr. Brian Putland	President	Orway Mineral Consulting	Canada
Mr. Peter Radziszewski	VP Solutions Offering Development	Metso	Canada
Mr. Bryan Rairdan	Manager, Mineral Process Engineering	Teck Resources Ltd.	Canada
Mr. Greg Rasmussen	Process Manager- Mineral Processing	XT-Canada	Canada
Dr. Reem Roufail	Associate Researcher	UBC (Canada) and Curtin University (Australia)	Canada
Mr. Mike Samuels	Corporate Metallurgist	New Gold Inc.	Canada
Mr. Fisher Wang	Metallurgist	Copper Mountain	Canada
Mr. Carl Weatherell	Executive Director & CEO	Canada Mining Innovation Council	Canada
Mr. Jobe Wheeler	Application Engineer	Derrick Corporation	USA
Mr. Edward Wipf	VP Process and Business Development	Weir Minerals	USA
Mr. Markus Zeller	Energy Engineer	BC Hydro	Canada