CEEC WORKSHOP ONEPAGERS:

Exploring the Now, New, and Next in Comminution Technologies

March 2025

INTRODUCTION

As part of **CEEC International's** ongoing commitment to accelerating eco-efficient mineral processing, this document presents a curated collection of advanced comminution technologies that will be the focus of technical evaluation during the upcoming CEEC Workshop in Cape Town, scheduled for late March 2025. These one-pagers provide a concise yet comprehensive overview of each technology's design principles, operating parameters, control strategies, and potential applications across various mineral processing contexts.

The objective of the workshop is to foster an open, collaborative exchange among industry professionals, researchers, and technology providers, aimed at critically assessing the viability, scalability, and impact of emerging comminution solutions. Through structured discussion and technical benchmarking, participants will explore how these technologies can support energy reduction, enhance mineral liberation, and align with broader decarbonization and sustainability goals.

This selection of technologies—including mechanical, thermal, electro-dynamic, and hybrid systems—reflects the growing need to rethink conventional approaches and integrate innovative tools into mine-to-mill flowsheets. Each one-pager serves as a reference point to guide comparative analysis and inspire dialogue on how we collectively advance the future of efficient, low-impact mineral processing.

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CONTENT

DISCLAIMER

This document is intended solely for informational and technical discussion purposes and does not constitute a definitive technical evaluation, validation, or endorsement of any specific technology or solution. All technology summaries herein have been compiled based on publicly available information, including technical publications, vendor data, and conference proceedings, without warranty as to completeness, accuracy, or performance guarantees.

CEEC International and the authors make no representation regarding the commercial readiness, comparative performance, or suitability of the technologies described in any specific operational context. Any implementation or investment decision should be based on independent technical due diligence, pilot testing, and economic analysis tailored to the specific characteristics of a given project or orebody.

Furthermore, this document does not serve as a promotional instrument for any individual technology developer, manufacturer, or provider. Readers are advised to consult with qualified experts and review the latest peer-reviewed research when considering the integration of any new technology into industrial applications.

TRANSCRITICAL CO_2 PULVERISATION

TECHNOLOGY OVERVIEW	Transcritical CO_2 Pulverisation is a novel pre-treatment method for mineral processing that utilizes high-pressure carbon dioxide in its transcritical or supercritical phase to induce internal fracturing in ore. This process enhances mineral liberation before traditional comminution stages, enabling improved downstream processing efficiency and energy reduction.
INDUSTRY APPLICATION	Copper, gold, nickel, lithium ores with complex gangue liberation; Arid regions with water-restricted grinding circuits; Greenfield and brownfield comminution circuit optimization.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ Supercritical CO_2 penetrates ore microcracks under controlled pressure-temperature conditions.
	  ○ Rapid depressurization causes explosive expansion within ore particles, creating fine fractures.
	• **Key Components:**
	  ○ High-pressure autoclave or pressure vessel
	  ○ CO_2 injection and regulation system
	  ○ Controlled depressurization and CO_2 recovery loop
	  ○ Safety systems: relief valves, thermal cut-offs, burst disks
	  ○ Optional tumbling/agitation system for uniform exposure
	• **Process Integration:**
	  ○ Pre-treatment stage ahead of SAG mills, HPGR, or ball mills
	  ○ Compatible with batch and semi-continuous processing

FEED & DISCHARGE CONDITIONS	• **Feed Size:** 10–50 mm ore particles
	• **Discharge Size:** Finely fractured particles with enhanced liberation characteristics
	• **Material Handling:**
	  ○ Discharge to conveyors/hoppers
	  ○ Integrated CO_2 venting, drying and dust control systems

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ PLC/SCADA-based control of pressure, temperature, and cycle timing
	• **Instrumentation & Feedback:**
	  ○ Pressure and temperature sensors
	  ○ CO_2 mass flow and purity analyzers
	  ○ Particle size monitoring post-discharge
	• **Safety Controls:**
	  ○ High-pressure alarms, emergency venting systems
	  ○ Leak detection and ventilation protocols

REPORTED PERFORMANCE & BENEFITS	• Reduces Bond Work Index (BWi) and energy required for grinding • Enhances mineral liberation, improving flotation recovery •

IMPTEC SUPER FINE CRUSHER

TECHNOLOGY OVERVIEW	The IMPTEC Super Fine Crusher is a vertical high-speed crushing technology engineered for ultra-fine particle production. It achieves efficient particle size reduction through the application of intense compressive and shear forces generated by a high-speed rotor system. This enables improved mineral liberation and downstream process efficiency, particularly in circuits targeting ultra-fine grinding or leaching stages.
INDUSTRY APPLICATION	Gold and silver ores with fine liberation requirements; Magnetite or hematite beneficiation circuits; Battery minerals (e.g., spodumene, graphite); Projects pursuing coarse gangue rejection prior to flotation.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ Vertical rotor system applies high kinetic energy to ore particles.
	  ○ Impact and attrition forces produce ultra-fine particle breakage with reduced overgrinding.
	• **Key Components:**
	  ○ High-speed vertical rotor with adjustable tip speed
	  ○ Impact anvils and classifier ring system
	  ○ Feed chute and precision feed control
	  ○ Integrated motor and variable speed drive (VSD)
	  ○ Optional air classification system for size control
	• **Process Integration:**
	  ○ Installed as a final crushing stage ahead of fine grinding, leaching, or flotation circuits
	  ○ Effective in energy-limited environments seeking fine liberation without high power milling

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Up to 20 mm feed particles
	• **Discharge Size:** Typically <100 µm particle size, optimized for mineral liberation and downstream recovery
	• **Material Handling:**
	  ○ Consistent feed via hopper or belt feeder
	  ○ Discharge stream managed through integrated classifier or external screening system

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ PLC-based control of rotor speed, air flow rate (if classifier is integrated), and feed rate
	• **Instrumentation & Feedback:**
	  ○ Particle size analysis (in-line or batch sampling)
	  ○ Monitoring of rotor speed and motor load for predictive maintenance
	  ○ Control loops based on product size specifications and energy draw

REPORTED PERFORMANCE & BENEFITS	• Produces high fines yield with minimal energy input compared to conventional grinding • Reduces circulating load and improves downstream leaching/flotation kinetics • Compact footprint and low capital cost relative to ultra-fine grinding mills • Flexible configuration for closed or open circuit operation

CONJUGATE ANVIL HAMMER MILL (CAHM)

TECHNOLOGY OVERVIEW	The Conjugate Anvil Hammer Mill (CAHM) is an innovative comminution technology that combines the benefits of high-pressure inter-particle breakage with high-frequency hammer impacts. Designed to replace traditional crushers or SAG mills, the CAHM promotes efficient energy transfer, resulting in enhanced mineral liberation and reduced energy consumption.
INDUSTRY APPLICATION	Gold, copper, and polymetallic ore bodies; Low-grade ores requiring intensive liberation; Projects targeting energy efficiency and water reduction.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ Utilizes opposing hammer rings and anvil surfaces to apply compression and shear forces simultaneously.
	  ○ Promotes inter-particle breakage with minimal overgrinding.
	• **Key Components:**
	  ○ Rotating hammer ring elements
	  ○ Stationary or counter-rotating anvil ring
	  ○ Hydraulic control system for impact energy tuning
	  ○ Drive motor and variable speed transmission
	  ○ Integrated feed chute and discharge handling system
	• **Process Integration:**
	  ○ Deployed in place of SAG or conventional crushing stages
	  ○ Compatible with dry or moist ore conditions

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Up to 60 mm input size
	• **Discharge Size:** Typically 1–10 mm, suitable for secondary grinding or leaching circuits
	• **Material Handling:**
	  ○ Controlled feed via conveyor systems
	  ○ Discharge into classifiers, screens or intermediate storage bins

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ PLC-based automation managing hammer speed, hydraulic system pressure, and feed rate
	• **Instrumentation & Feedback:**
	  ○ Real-time monitoring of motor load and energy consumption
	  ○ Particle size sensors for output quality control
	  ○ Pressure sensors for hydraulic force regulation
	• **Safety Systems:**
	  ○ Overpressure relief systems
	  ○ Emergency shutdown switches
	  ○ Load and vibration monitoring

REPORTED PERFORMANCE & BENEFITS	• High reduction ratios with controlled product size distribution • Energy-efficient alternative to SAG milling • Reduces downstream grinding requirements and enhances liberation • Compact design suitable for retrofitting existing circuits

HIGH-PRESSURE SLURRY ABLATION (HPSA)

TECHNOLOGY OVERVIEW	High-Pressure Slurry Ablation (HPSA) is an advanced pre-treatment technology used in mineral processing that harnesses high-pressure fluid jets within a slurry environment to induce particle fragmentation and surface cleaning. The system creates intense shear forces that dislodge coatings, release entrained minerals, and break particles at weak boundaries. HPSA is particularly effective in improving the surface quality of ore particles, thereby enhancing flotation, leaching, and overall downstream processing efficiency.
INDUSTRY APPLICATION	Sulfide flotation circuits targeting cleaner separation; Leach circuits requiring enhanced surface reactivity; Rare earth elements (REE), uranium, and refractory gold ores; Arsenic-bearing ores requiring surface pre-cleaning.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ High-pressure fluid jets are applied in a controlled slurry environment to generate turbulent shear and abrasive effects.
	  ○ Targeted surface scouring and micro-fracturing promote enhanced mineral liberation and reagent interaction.
	• **Key Components:**
	  ○ High-pressure slurry pumps
	  ○ Ablation chamber with wear-resistant linings
	  ○ Precision jet nozzles and nozzle arrays
	  ○ Slurry handling and recirculation system
	  ○ Density monitoring units and flow controllers
	• **Process Integration:**
	  ○ Pre-treatment step prior to flotation or chemical leaching
	  ○ Effective for ores with surface coatings, clays, slimes, or mineral encapsulation

FEED & DISCHARGE CONDITIONS	• **Feed Size:** 2–10 mm particles in slurry form
	• **Discharge Size:** Fine to medium-sized particles (e.g., <1 mm), often with improved liberation and surface cleanliness
	• **Material Handling:**
	  ○ Operates continuously within a closed-loop slurry system
	  ○ Slurry discharge is classified through hydrocyclones or screens before progressing to the next process stage

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ Centralized PLC/SCADA-based control of pump pressure, slurry density, and nozzle velocity
	• **Instrumentation & Feedback:**
	  ○ Real-time monitoring of pressure, flow rates, particle size, and density in the ablation chamber
	  ○ Closed-loop control to maintain optimal turbulence and particle residence time
	• **Safety Systems:**
	  ○ High-pressure relief valves
	  ○ Abrasion-resistant components in high-wear zones
	  ○ Automated emergency shutdown systems and predictive maintenance alerts

REPORTED PERFORMANCE & BENEFITS	• Improves mineral exposure and surface activation • Enhances flotation selectivity and leach kinetics • Reduces reagent consumption due to cleaner particle surfaces • Effective for dealing with clay-bound, slimy, or oxide-coated ores • Scalable design for retrofitting into existing circuits

MULTI-SHAFT MILL

TECHNOLOGY OVERVIEW	The Multi-Shaft Mill is an advanced fine grinding technology designed to maximize energy transfer and particle impact efficiency through multiple rotating shafts equipped with grinding elements. By applying combined impact and shear forces in a high-energy milling environment, this system is especially effective in regrind or fine grinding circuits where liberation of valuable minerals from finely disseminated ores is critical.
INDUSTRY APPLICATION	Base metal sulfide regrind circuits (Cu, Pb, Zn); Precious metal recovery (gold, silver); Industrial minerals (kaolin, graphite, talc); Specialty applications requiring narrow particle size distributions.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ Multiple independently driven or synchronized shafts generate intensive mixing and grinding action through impact pins, discs, or blades.
	  ○ Optimized grinding zone geometry enables high energy density and fine particle size control.
	• **Key Components:**
	  ○ Multiple rotating shafts with configurable grinding tools (pins, discs, vanes)
	  ○ Modular grinding chamber (horizontal or vertical setup)
	  ○ Variable speed drives (VSD) for each shaft
	  ○ Slurry feed and discharge systems
	  ○ Hydrocyclones or classifiers for size separation
	• **Process Integration:**
	  ○ Commonly integrated into regrind circuits downstream of flotation
	  ○ Suitable for ultrafine grinding applications or as a replacement for stirred mills

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Up to 10 mm in slurry form
	• **Discharge Size:** 50–200 µm range, depending on shaft speed, grinding element type, and process requirements
	• **Material Handling:**
	  ○ Operates in wet grinding mode with integrated slurry pumps and hydrocyclone classifiers
	  ○ Continuous discharge with optional recirculation loops for enhanced size control

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ Independent variable speed control per shaft to tailor grinding intensity and energy efficiency
	  ○ Automated slurry density and media addition regulation
	• **Instrumentation & Feedback:**
	  ○ Power draw sensors on each shaft drive
	  ○ Particle size monitoring in discharge stream
	  ○ Media wear tracking and alert systems
	• **Safety Systems:**
	  ○ Torque and vibration monitoring for overload protection
	  ○ Anti-jamming protocols and emergency shutdown functions
	  ○ Real-time interlocks for shaft synchronization and mechanical integrity

REPORTED PERFORMANCE & BENEFITS	• High-energy grinding in a compact footprint • Superior particle dispersion and size control for fine and ultrafine targets • Reduced overgrinding and improved liberation profiles • Flexibility in design for different ore types and throughput requirements • Scalable for both pilot and full-scale operations

ELECTRICAL FRAGMENTATION

TECHNOLOGY OVERVIEW	Electrical Fragmentation is a cutting-edge ore pre-treatment technology that applies high-voltage electrical pulses to generate shockwaves within a water-filled chamber. These pulses selectively weaken grain boundaries, promoting clean and energy-efficient mineral liberation. By concentrating energy on internal particle interfaces rather than bulk crushing, this method minimizes energy waste and overgrinding, offering a transformative alternative to conventional comminution techniques.
INDUSTRY APPLICATION	Complex polymetallic ores requiring selective liberation; Refractory gold and rare earth ores with mineral inclusions; Pre-concentration circuits focusing on coarse rejection; Advanced processing facilities targeting low-impact mineral liberation.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ High-voltage pulses (typically 50–500 kV) are applied across electrodes submerged in a water medium.
	  ○ Electrical discharges generate shockwaves and microfractures, preferentially along mineral grain boundaries.
	• **Key Components:**
	  ○ Pulse power generator and capacitor bank
	  ○ Water tank with immersion electrodes
	  ○ Ore feed chute and discharge system
	  ○ Pulse control and safety automation panel
	  ○ Conductivity control system for water medium
	• **Process Integration:**
	  ○ Deployed as a pre-treatment step ahead of traditional grinding, flotation, or leaching
	  ○ Ideal for ores with complex mineral intergrowths or selective liberation requirements

FEED & DISCHARGE CONDITIONS	• **Feed Size:** 10–100 mm ore particles
	• **Discharge Size:** Coarse to medium particles typically in the 1–20 mm range with enhanced liberation properties
	• **Material Handling:**
	  ○ Operates in batch or semi-continuous mode
	  ○ Water recirculation systems manage slurry and cooling
	  ○ Discharge via screens or gravity flow systems

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ Programmable pulse frequency and intensity based on ore characteristics
	  ○ Control of water conductivity and pulse timing for process optimization
	• **Instrumentation & Feedback:**
	  ○ Pulse strength and energy logging
	  ○ Monitoring of fragmentation yield and electrode wear
	  ○ Water level and conductivity sensors
	• **Safety Systems:**
	  ○ Overvoltage protection systems
	  ○ Emergency shutdown switches
	  ○ Electrode isolation and water containment protocols

REPORTED PERFORMANCE & BENEFITS	• Enhanced mineral liberation • Selective breakage along mineral interfaces improves flotation/leach performance • Reduces fines generation and overgrinding risk • Lower overall energy consumption compared to conventional crushers • Enables coarse gangue rejection and improved downstream efficiency

VERO LIBERATOR

TECHNOLOGY OVERVIEW	The VeRo Liberator is a novel high-impact comminution system designed to efficiently liberate valuable minerals through repeated high-intensity impacts. Utilizing a rotating impact drum with internal beaters, the technology creates selective breakage and controlled fragmentation across a wide particle size range. Positioned as an alternative or complement to conventional primary crushers, the VeRo Liberator emphasizes energy-efficient mineral liberation with minimal overgrinding.
INDUSTRY APPLICATION	Copper, gold, lithium, and polymetallic ores; Primary crushing of complex mineral assemblages; Pre-treatment for coarse gangue rejection; Greenfield and brownfield comminution circuit retrofits.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ High-speed rotating drum housing internal beaters creates a continuous stream of intense impacts on ore particles.
	  ○ Facilitates selective fracture along grain boundaries and reduces energy loss associated with compressive crushers.
	• **Key Components:**
	  ○ Cylindrical impact drum with internal rotor and beater elements
	  ○ Motorized drive system with variable speed control
	  ○ Feed hopper and vibration-assisted discharge chute
	  ○ Optional screening and classification modules
	• **Process Integration:**
	  ○ Integrated as a pre-crushing unit or within primary comminution circuits
	  ○ Suitable for replacing or complementing jaw, gyratory, or cone crushers

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Up to 150 mm ore particles
	• **Discharge Size:** 1–50 mm particle size range with enhanced liberation and reduced fines generation
	• **Material Handling:**
	  ○ Conveyor or hopper-fed operation with adjustable feed rate
	  ○ Discharge stream managed via vibrating screens, grizzlies, or classifiers

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ Centralized control of drum speed and feed rate to optimize impact intensity
	  ○ Feedback control for energy efficiency and discharge product quality
	• **Instrumentation & Feedback:**
	  ○ Drum torque sensors for process load monitoring
	  ○ Vibration sensors for early fault detection
	  ○ Particle size analyzers at discharge for real-time process tuning
	• **Safety Systems:**
	  ○ Emergency stop switches and interlocks
	  ○ Load monitoring with alarm protocols
	  ○ Anti-jamming logic and auto-reversal features

REPORTED PERFORMANCE & BENEFITS	• Enhanced mineral liberation due to repeated inter-particle impact • Reduces energy consumption by replacing compressive breakage mechanisms • High throughput capacity with broad feed tolerance • Modular and scalable for different capacities and ore types

MICROWAVE-ASSISTED COMMINUTION

TECHNOLOGY OVERVIEW	Microwave-Assisted Comminution is an advanced pre-treatment technology designed to enhance the efficiency of downstream grinding by selectively weakening ore particles through rapid internal heating. High-power microwave energy targets dielectric minerals within the ore, inducing differential thermal expansion and microcracking. This leads to improved liberation and reduced energy demand in conventional crushers and mills.
INDUSTRY APPLICATION	Copper, gold, and nickel sulfide ores; Refractory ores requiring improved liberation; Pre-treatment in energy-intensive grinding operations; Mines aiming to reduce overall comminution energy footprint.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ High-power microwave generators deliver controlled electromagnetic energy to ore particles as they pass through a microwave cavity.
	  ○ Localized internal heating induces microcracks along grain boundaries and stress zones.
	• **Key Components:**
	  ○ Microwave cavity and applicator chamber
	  ○ Waveguide system for energy distribution
	  ○ Ore conveyor belt with electromagnetic shielding
	  ○ High-voltage power supply and control cabinet
	  ○ Cooling system to manage thermal load
	• **Process Integration:**
	  ○ Used upstream of traditional crushing or milling equipment
	  ○ Effective in ores with distinct dielectric contrast between mineral phases

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Up to 100 mm ore particles
	• **Discharge Size:** Not reduced directly by the microwave system; subsequent milling produces finer particles with enhanced grindability
	• **Material Handling:**
	  ○ Continuous feed via conveyor system with shielding to prevent microwave leakage
	  ○ Discharge proceeds directly to primary crushers or mills

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ Centralized control system adjusts microwave power output, conveyor speed, and ore exposure time
	  ○ Adaptive process control based on ore throughput and thermal response
	• **Instrumentation & Feedback:**
	  ○ Temperature sensors within ore stream
	  ○ Arc detection systems for operational safety
	  ○ Throughput monitoring and energy logging
	• **Safety Systems:**
	  ○ Automatic shutdown in case of arcing or overheating
	  ○ Electromagnetic shielding and leakage sensors
	  ○ Emergency stop controls and fire suppression integration

REPORTED PERFORMANCE & BENEFITS	• Selective heating improves generates microcracks reducing Bond work index • Can be combined with sorting to reject on infrared characteristics

COARSE STIRRED MILLING

TECHNOLOGY OVERVIEW	Coarse Stirred Milling is an innovative adaptation of traditional stirred milling, specifically engineered to handle coarser particle feeds while delivering energy-efficient size reduction. By utilizing larger grinding chambers and optimized media configurations, this technology fills a critical niche between primary grinding and fine regrinding. It enhances process flexibility and promotes consistent liberation with lower energy consumption than conventional milling alternatives.
INDUSTRY APPLICATION	Base and precious metal concentrators (Cu, Zn, Au, Ag); Magnetite regrinding and pellet feed preparation; Battery and industrial minerals requiring mid-range size classification; Brownfield upgrades to improve comminution efficiency.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ Modified stirred mill with increased chamber volume and robust internal components to manage coarse particles.
	  ○ Promotes efficient energy transfer through high-shear, attrition, and mild impact forces.
	• **Key Components:**
	  ○ Rotating impeller or agitator assembly
	  ○ Enlarged grinding chamber for coarse media and higher slurry loads
	  ○ Media loading and handling systems
	  ○ Slurry recirculation pumps and flow control valves
	• **Process Integration:**
	  ○ Deployed as an intermediate stage between SAG or HPGR and fine grinding mills
	  ○ Suitable for circuit debottlenecking or stepwise energy reduction

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Typically 1–5 mm coarse particles in slurry form
	• **Discharge Size:** Final product typically in the range of 100–300 µm, suitable for downstream flotation or leaching
	• **Material Handling:**
	  ○ Operates as a continuous wet process
	  ○ Hydrocyclones or screens used for product classification and recycle stream control

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ Integrated control of impeller speed, media addition, and slurry density for process stability
	• **Instrumentation & Feedback:**
	  ○ Motor load sensors for real-time energy monitoring
	  ○ Slurry flow meters and density analyzers
	  ○ Cyclone performance tracking for classification efficiency
	• **Safety Systems:**
	  ○ Overflow detection and containment systems
	  ○ Anti-jamming logic for mechanical protection
	  ○ Emergency stop and interlock mechanisms

REPORTED PERFORMANCE & BENEFITS	• Bridges the gap between primary and fine grinding • Reduces overall energy consumption by optimizing grind size progression • Flexible for a variety of ore types and circuit designs • Compact, low-maintenance configuration with high throughput potential

VERTICAL ROLLER MILLS (VRM)

TECHNOLOGY OVERVIEW	Vertical Roller Mills (VRMs) are high-efficiency grinding systems that utilize the combined action of compressive and shearing forces applied by multiple rollers on a rotating grinding table. Designed for both fine and coarse grinding applications, VRMs are known for their compact footprint, low energy consumption, and integration flexibility across diverse mineral processing flowsheets. VRMs are increasingly applied in standalone grinding circuits, replacing conventional ball and tube mills.
INDUSTRY APPLICATION	Cement raw meal and clinker grinding; Iron ore pellet feed and tailings regrinding; Slag grinding and mineral filler production; Alternative to SAG and ball mills in fine grinding circuits.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ Ore is fed to the center of a rotating table where it is compressed and ground under rollers.
	  ○ Ground material is lifted by air through a dynamic classifier that separates fine product from coarse rejects.
	• **Key Components:**
	  ○ Grinding rollers (2–6 per mill depending on size and application)
	  ○ Rotating grinding table with wear liners
	  ○ Classifier system for particle size control
	  ○ Hydraulic system for roller pressure adjustment
	  ○ Gearbox and main drive system
	  ○ Integrated airflow and dust collection system (cyclones or bag filters)
	• **Process Integration:**
	  ○ Suitable for both raw grinding and finish grinding applications
	  ○ Commonly applied in cement, slag, and industrial mineral circuits, increasingly adopted in mining regrind and fine grinding circuits

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Typically up to 100 mm depending on ore hardness and mill configuration
	• **Discharge Size:** Typically 30–100 µm, adjustable via classifier settings
	• **Material Handling:**
	  ○ Material introduced through the center feed chute
	  ○ Fines carried upward by air to cyclones or baghouse filters
	  ○ Coarse particles recirculated within the grinding zone for further size reduction

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ Real-time automated control of roller pressure, table speed, classifier operation, and airflow balance
	• **Instrumentation & Feedback:**
	  ○ Vibration monitoring sensors for early detection of mechanical issues
	  ○ Roller pressure and hydraulic load monitoring
	  ○ Classifier speed and product fineness feedback loops
	• **Safety Systems:**
	  ○ Overpressure relief valves
	  ○ System temperature monitoring
	  ○ Fire suppression and explosion venting for dust-prone environments

REPORTED PERFORMANCE & BENEFITS	• Reduced specific energy consumption compared to ball mills • High drying efficiency when processing moist materials • Compact layout and lower infrastructure requirements • Control over product fineness and particle distribution • Lower wear rates and easier maintenance due to modular design

HIGH-PRESSURE GRINDING ROLLS (HPGR)

TECHNOLOGY OVERVIEW	High-Pressure Grinding Rolls (HPGR) are advanced energy-efficient comminution systems that use two counter-rotating rolls to compress and grind ore under high pressure. The selective breakage mechanism enhances mineral liberation while reducing overall energy consumption.
INDUSTRY APPLICATION	Gold, copper, platinum group metals (PGM), and iron ore grinding circuits; Heap leach and agglomeration processes; Pre-grinding in energy-efficient concentrator designs; Greenfield and brownfield retrofitting for sustainability upgrades.

EQUIPMENT CHARACTERISTICS	• **Design Concept:**
	  ○ Material is fed between a fixed roll and a floating roll, which is pushed against the feed by a high-pressure hydraulic system.
	  ○ Inter-particle compression leads to micro-fracturing and improved liberation.
	• **Key Components:**
	  ○ Hydraulic pressure system for roll force control
	  ○ Heavy-duty roll frame and bearing assemblies
	  ○ Tungsten carbide studded roll surfaces for high wear resistance
	  ○ Feed hopper with controlled delivery
	  ○ Discharge chute for crushed material
	• **Process Integration:**
	  ○ Commonly installed in closed grinding circuits with screens or air classifiers
	  ○ Effective as a pre-grinding stage for ball mills or in final grinding applications

FEED & DISCHARGE CONDITIONS	• **Feed Size:** Typically <50 mm, with some models capable of handling up to 75 mm depending on ore hardness and equipment size
	• **Discharge Size:** Final product with P80 ranging from 1–6 mm, depending on roll pressure and feed characteristics
	• **Material Handling:**
	  ○ Conveyor belt feed with variable speed control
	  ○ Discharge directed to classification or storage systems

CONTROL SYSTEM LOGIC	• **Automation Strategy:**
	  ○ PLC/SCADA-based control of roll speed and hydraulic pressure based on throughput and load feedback
	• **Instrumentation & Feedback:**
	  ○ Real-time motor load monitoring
	  ○ Roll gap sensors and pressure feedback loops
	  ○ Product size distribution monitoring via inline particle size analysis systems
	• **Safety Systems:**
	  ○ Hydraulic pressure relief valves
	  ○ Overload protection and auto-shutdown protocols
	  ○ Bearing temperature monitoring and vibration alarms

REPORTED PERFORMANCE & BENEFITS	• High energy efficiency and reduced specific energy consumption • Enhanced mineral liberation and downstream processing efficiency • Lower steel media consumption in ball milling circuits • Long roll surface life due to durable studded design

CEEC LISTED PAPERS, CONFERENCE & JOURNAL ARTICLES

To support deeper understanding and critical analysis of the technologies outlined in this document, the following selection of technical papers and publications is recommended. These references include peer-reviewed research, field trials, and benchmarking studies that provide insights into performance metrics, implementation challenges, and broader integration into mineral processing circuits. Readers are encouraged to explore these materials to contextualize the application of each technology and understand their maturity, variability, and technical nuances in real-world conditions.

Title	Abstract Summary
Trade-Off Realities in HPGR vs. SAG Milling—A Practical Comparison of Tropicana and Gruyere Comminution Circuits	This paper compares HPGR-ball and SABC (SAG mill, ball mill, pebble crusher) circuits at the Tropicana and Gruyere projects in Western Australia. While HPGR circuits are known for energy efficiency, this study explores broader trade-offs, including capital and operating costs, stability, maintenance, and auxiliary equipment impacts. The Tropicana circuit, expanded to 8.6 Mt/a, and the Gruyere circuit, treating 8.5 Mt/a, offer insights to guide future comminution trade-off studies.
Can we shift to a new paradigm of flexibility in mining and processing to build mines powered exclusively by the variable input of renewables?	An initiative to explore the viability of switching from the accepted business model of continuous operation under the exiting paradigm of a continuous, unconstrained supply of energy provides an alternative world view of how our essential minerals industry may lead global transformation in an energy-constrained world. Explores the feasibility of operating mines exclusively on renewable energy, focusing on the challenges of using solar power with battery energy storage systems (BESS). It highlights the high costs and resource demands of battery storage and proposes a balanced renewable energy mix, including wind power, to enhance economic viability. The study introduces a flexible mining and processing approach, emphasizing short-term operational adaptability to match energy availability. A novel Modular Vertical Extraction (MVX) mining concept and advanced comminution and flotation technologies are proposed to maximize efficiency and align operations with variable renewable energy supply. This flexible model could reduce upfront investments, extend mine life, and make smaller, agile mining projects viable while leveraging renewable energy sources.
Performance Analysis of HRC™ HPGR in Manufactured Sand Production	Evaluates HRC™HPGR technology for manufactured sand, demonstrating economic and environmental benefits by converting old tailings into high-value products, reducing costs and ecological impact.
Commercialisation pathway for low energy wet/dry gyratory rolls crusher comminution technology	Explores the development of GRolls® technology to reduce energy and water consumption, providing dry and wet crushing from ~20 mm to 20 µm fractions without media, replacing up to two stages of size reduction.
ESG Improvements Through Sensor-Based Sorting for Lithium Pegmatite Ores	ESG Improvements Through Sensor-Based Sorting for Lithium Pegmatite Ores
Evaluation of a Novel Electrode Design for High Voltage Pulse Ore Pre-Concentration	Introduces a grizzly electrode design for High Voltage Pulse (HVP) ore pre-concentration, demonstrating selective breakage and energy efficiency with synthetic particles and gold-copper ore.
The Versatility of Stirred Milling in Innovative Comminution Flowsheets	Highlights the advancements in stirred milling technology, which offers improved energy efficiency and narrower particle size distributions compared to ball mills. Recent upgrades by Swiss Tower Mills (STM) focus on handling coarser feed sizes (>200 µm) and utilizing larger media to enhance efficiency. The paper presents three case studies showcasing the versatility of vertical stirred mills: (1) debottlenecking a grinding circuit with Coarse Particle Flotation (CPF) and concentrate milling, (2) expanding gold processing capacity with HPGR and stirred milling, and (3) optimizing secondary grinding of magnetic separator concentrate with adaptable power draw and large media.
Pre-Concentration – More than Bulk Ore Sorting	Examines multiple pre-concentration technologies beyond bulk ore sorting (particle sorting, DMS, coarse gravity, etc.). Emphasizes site-specific heterogeneity analysis, sensor suitability, and integrated solutions. Presents case studies showing potential benefits where bulk sorting is suboptimal.
Pilot Testing and Plant Design Comparison of Dry VRM Milling plus Magnetic Separation with AG and Ball Milling plus Magnetic Separation for Grange Resources' Southdown Ore	This study evaluates the performance of Loesche's Vertical Roller Mill (VRM) technology compared to traditional autogenous (AG) and ball milling circuits for processing hard Southdown Magnetite ore in Western Australia. The VRM demonstrated superior energy efficiency, achieving 33-41% energy savings over AG/ball milling circuits. The VRM technology employs hydrostatic breakage, allowing selective liberation and coarse gangue rejection through dry magnetic separation. The pilot plant tests showed a 50% mass rejection of coarse non-magnetic grit while maintaining high magnetite recoveries (95-97%) to the final product. The study underscores the advantages of VRM technology in reducing water consumption, enhancing energy efficiency, and simplifying tailings management, offering a transformative approach to magnetite ore beneficiation and sustainable mining practices.

Title	Abstract Summary
The novel eds multishaft mill – a case study	The EDS Multishaft Mill demonstrates low energy consumption and improved liberation through high-speed impacts, achieving reduction ratios up to 18 and processing over 50,000 tons of material.
Microwave Heating Behaviour of Ores and its Application to High-Power Microwave Assisted Comminution and Ore Sorting	Investigates microwave pretreatment to selectively heat valuable minerals, causing microfractures. Demonstrates potential for reduced grinding energy, enhanced liberation, and improved ore sorting. Includes lab and pilot-scale tests.
Performance Analysis of HRC™ HPGR in Manufactured Sand Production	Evaluates HRC™ HPGR technology in manufactured sand production, achieving adequate product characteristics for concrete and filter sand, with specific energy consumption of 3.53 kWh/t.
Helping to Reduce Mining Industry Carbon Emissions: A Step-by-Step Guide to Sizing and Selection of Energy Efficient High Pressure Grinding Rolls Circuits	Presents a power-based methodology for HPGR circuit sizing and selection, highlighting significant energy and carbon emissions reductions possible with HPGR. Offers equations and worked examples to streamline HPGR adoption in hard-rock comminution.
Recent improvements in ore sorting at the Renison Tin Concentrator – target 1 Mt/a	Implementation of XRT Ore Sorting to upgrade Renison Tin Concentrator and achieve 1 Mt/a processing target. Mine-to-Mill and Geo-metallurgy practices discussed.
Pre-Concentration – More than Bulk Ore Sorting	Reviews pre-concentration methods such as sensor-based sorting, coarse gravity separation, and bulk ore sorting. Emphasizes site-specific solutions, heterogeneity, and sensor suitability to effectively reject gangue and optimize downstream comminution.