White paper

Sustainable comminution solutions

Innovative flowsheets to combat mining's most pressing challenges

Mining technology for a sustainable future

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Innovative flowsheets incorporating high pressure grinding roll (HPGR) technology, alongside advancements in coarse particle separation processes and dry classification, represents a significant leap forward in achieving higher energy-efficiency and lower carbon emissions, as well as adhering to the increased environment stewardship demands.

Flowsheets featuring fine HPGR grinding with air classification producing single product or multiple products, two-stage HPGR with interstage separation (e.g., magnetic separation or coarse particle flotation (CPF)), and integration of HPGRs with stirred milling have the potential for higher energy-efficiency, water savings, and/or direct contributions to reducing carbon footprint of future mineral processing circuits.

The effective implementation of such flowsheets requires collaboration and a detailed understanding of the ore body, project requirements and operational constraints.

Critical selection criteria

By adopting a systems-based approach to technology collaborations, the mining industry can scale up and clean up at the same time.

It's important that, when developing these solutions, Engineering, Procurement and Construction (EPCs), Original Equipment Manufacturers (OEMs) and miners take a full flowsheet-based approach.

For instance, a mine-to-mill analysis optimises what's actually being fed into the processing plant so that fragmentation can be optimised.

Furthermore, various sensor technologies allow operators to map the ore characteristics, which, in turn, allows them to prepare the operating parameters of the processing plant to ensure its optimised and tailored for the feed.

There are some general flowsheet design principles, but there always needs to be adaptations and concessions made based on a multitude of factors, like the characteristics of the ore body, the energy limitations of the site and regulatory requirements, etc.

How an individual piece of equipment performs impacts downstream requirements and circuit performance.

Processing plants should therefore be configured in such a way that the grinding circuit product is narrow and prevents excessive slimes generation. Over-grinding not only negatively influences recovery but also creates challenges in dewatering and tailings management.

Traditional tumbling mill-based circuits struggle to adapt to changing feeding conditions and, with high recirculating loads and extended mill residence time, there is a significant risk of overgrinding and slimes generation.

In contrast,

HPGRs are renowned for their flexibility, lower specific energy requirements and reduced residence time.

Moreover, HPGR's inter-particle comminution mechanism generates fines at relatively low specific energy. However, it should be noted that the technology isn't only suitable for applications in which fines are desirable, like flotation.

The circuit configuration and operating parameters can also be tailored to suit the specific feeding conditions and downstream requirements to yield product at the desirable size, rather than simply to produce fines.

Screening HPGR discharge typically requires a large vibrating screen because a HPGR in a closed circuit (figure 1) feeding a ball mill typically operates with 100-200% recirculation load, resulting in high screen feed rates.

Moreover, because the cut size of typical HPGR screens range from 1-4mm, larger wet banana screens than those usually employed in typical mining applications are required to ensure optimal classification efficiency.

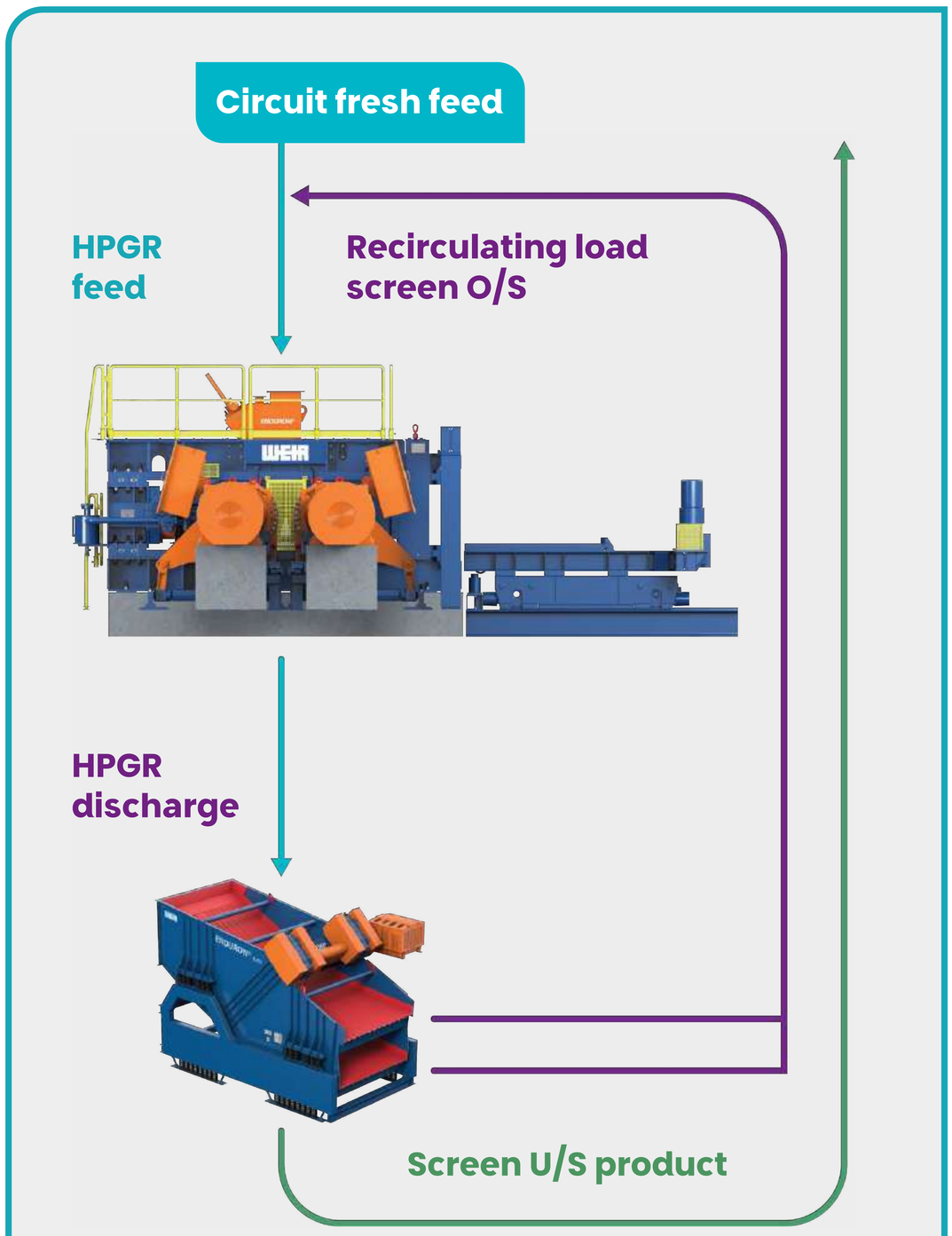

Figure 1: HPGR in closed (forward) circuit configuration with screening

When the ore and breakage characteristics presents a higher proportion of fines to the HPGR, a truncated (or pre-screened) configuration can be deployed. This will facilitate the by-pass of ore already at size and feed it to the subsequent processing stage.

In combination with a reduced hydraulic press force, a truncated configuration (figure 2) also facilitates the narrowing of the discharge PSD, as well as minimising the generation of ultra-fines. This can be beneficial when involving downstream processes, like dense media separation (DMS).

Wet pre-screening or scrubbing can also remove clayish fines from the HPGR feed, which improves grinding efficiency and the particle bed's suitability to apply grinding force while maintaining an effective operating gap.

Traditional classification can also be replaced by introducing mechanical splitters to the HPGR discharge, which subsequentially 'cuts' a proportion of the centre and edge material to be fed back to the HPGR head feed. This removes the need for an additional classification stage, which reduces the footprint and CAPEX and allows the circuit to operate at increased feed moisture levels. One downside of this configuration is that it doesn't have fixed size control over the product top size, so the risk of mill scatting needs to be considered when feeding the subsequent ball mill.

By enabling dynamic adjustment of recycling ratios during operation, both the recirculation load and overall product PSD can be modulated. This capacity facilitates precise control over the resulting PSD and allows the system to accommodate feed variability in real-time. This configuration is referred to as edge recycling or partial product recycling (figure 3). It's frequently deployed in heap leaching or pellet feed (re)grinding applications.

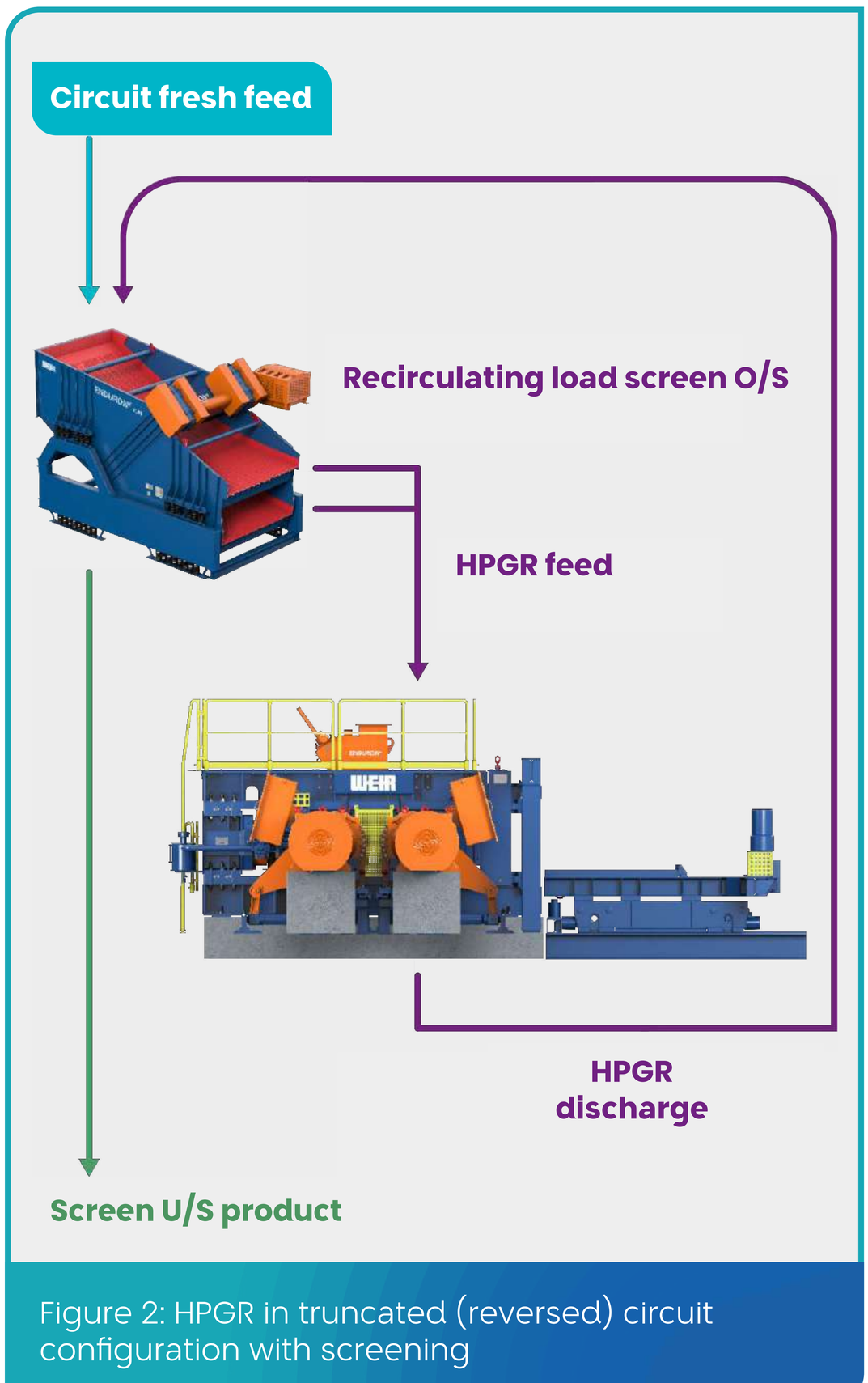

Figure 2: HPGR in truncated (reversed) circuit configuration with screening

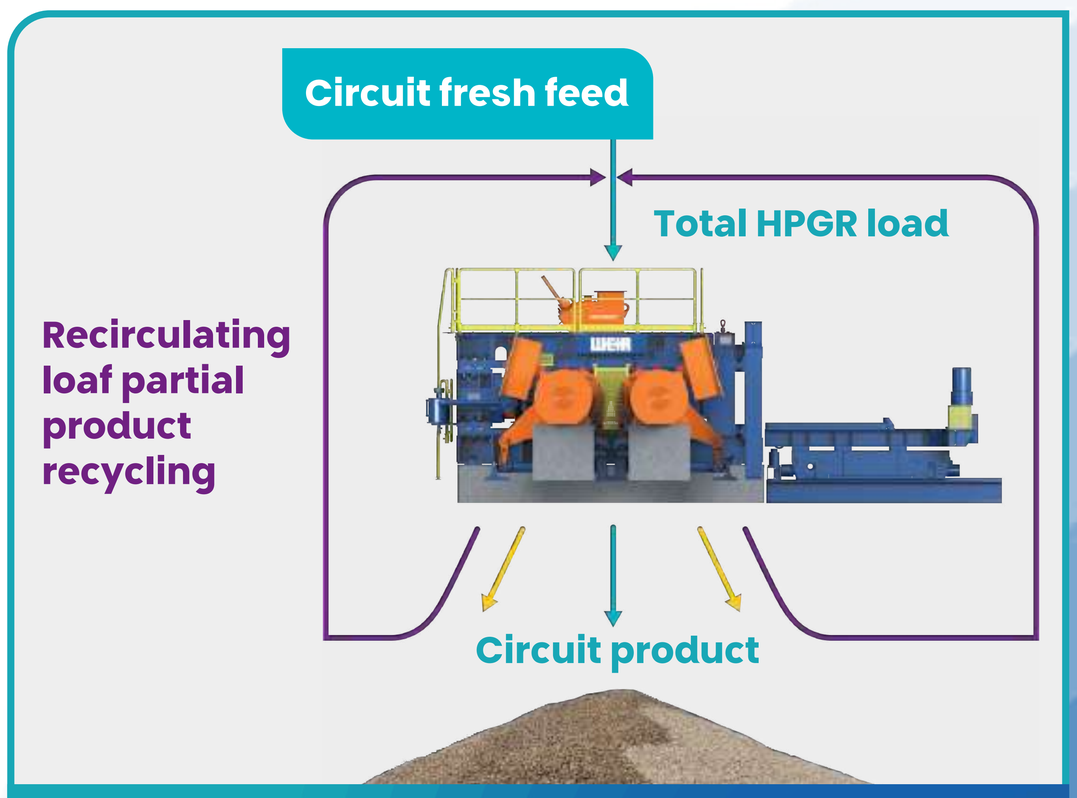

Figure 3: HPGR with partial product recycling

‘Parallel flowsheets’

Most current mineral concentrators employ flowsheets based on tumbling mills in series. These circuits consume energy – exponentially so with product fineness – and generate a mass split of slimes below the target product size, thereby resulting in diminishing recovery, increased tailings challenges, reduced throughput for a given installed power and higher operating costs.

Conventional semi-autogenous grinding (SAG) and ball mill-based flowsheets are typically inefficient when responding to variability in the feeding conditions. These traditional technologies often lead to the production of ultra-fine particles, which not only pose challenges to mineral liberation and recovery but also consume energy on particles that have already reached the targeted grind size.

In an effort to overcome the challenges and inefficiencies, Weir has developed a conceptual circuit that operates in ‘parallel’, rather than in series.

All the material that is initially generated to the required size is removed immediately from the comminution process and sent directly for separation of valuables.

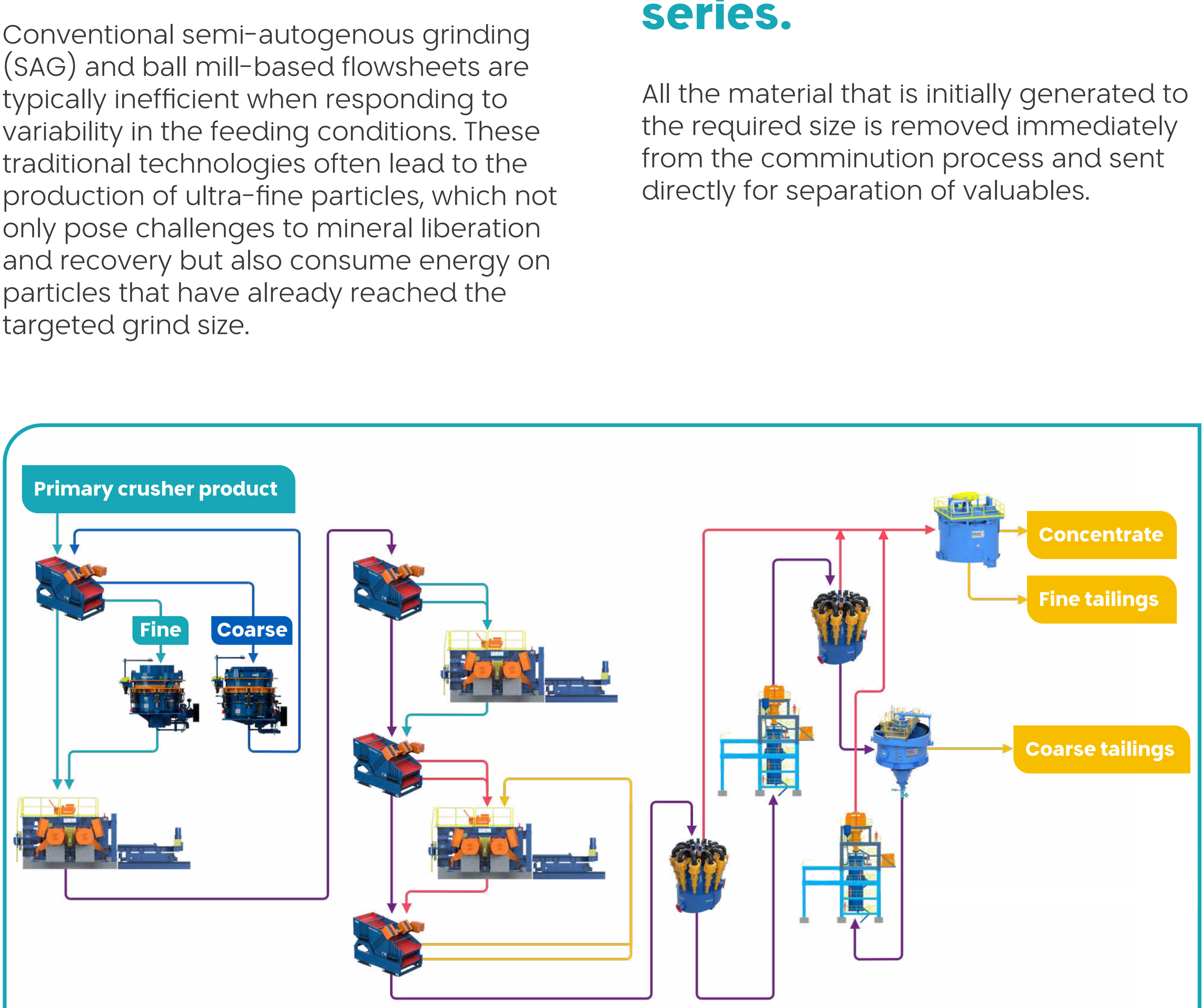

Figure 4: Simulated parallel flowsheet example

By this means, a more vertical particle size distribution (PSD) from the comminution circuit can be produced (with material size controlled in a narrower range of sizes),

greatly improving energy efficiency and tailings-water management.

The resulting conceptual flowsheet aims to only comminute material to the required liberation size.

This ‘parallel flowsheet’ is a novel multi-HPGR flowsheet design that pairs HPGRs with classifying screens at each stage to prevent overgrinding and significantly increase the comminution efficiency.

This flowsheet aims to both narrow and coarsen the final grinding circuit PSD, while maintaining recovery through the prevention of slimes generation and the use of CPF and early gangue rejection.

This flowsheet is referred to as the ‘parallel flowsheet’ because: firstly, it provides a parallel path to remove ore to final product that has reached the required size for liberation at any given grinding stage to prevent further breakage; and secondly, because it employs parallel coarse particle and conventional fines flotation lines.

Weir engaged the Julius Kruttschnitt Mineral Research Centre to review the ‘parallel flowsheet’ concept and to perform simulations to estimate its techno-economic performance. The performance of the ‘parallel flowsheet’ (figure 4) was assessed against the baseline SABC – a conventional and ubiquitous flowsheet in the industry.

The investigation into the use of the ‘parallel flowsheet’ concept for ultra-fines reduction, improved energy efficiency and tailing management improvements demonstrates promise in providing a step change in mineral processing techniques towards more sustainable and efficient practices.

The reduced power consumption of the ‘parallel flowsheet’ is substantial. In the modelled example, 22.5MW of total power was required compared to 36.5MW for a conventional semi-autogenous-ball mill-crusher (SABC) baseline – a 38% reduction to process a medium-hard ore.

It should be noted that, due to the conservative modelling assumptions for the stirred mills, energy savings could be even larger.

By integrating HPGR, CPF and vertical stirred milling in these circuits, the study shows improvements in energy consumption, operating cost efficiency and tailings management improvements while largely retaining mineral recovery rates.

‘Parallel flowsheets’

The ‘parallel flowsheet’ lends itself to the possibility of CPF (as well as other coarse gangue rejection technologies) opportunities along various streams. Advancements in flotation technologies, such as the Eriez HydroFloatTM for CPF and other devices, benefit from a more controlled feed PSD than the ‘parallel flowsheet’ aims to provide.

The coarse separation of particles using the HydroFloatTM equipment then produces a separate coarse tailings stream with a size range 600 to 150 µm (30 x 100 mesh). This significantly reduces the volume of fine tailings that need to be pumped to a tailings storage facility (TSF) and facilitates a stackable and conveyable product stream, which can potentially be used as a construction product.

These technologies and the ‘parallel flowsheet’ concept aim to control the tailings particle sizes that destabilise tailings heaps.

There are several other trends and developments that support this integrated approach – that’s to say, taking the downstream impacts of comminution solutions into account when developing flowsheets – and can help miners overcome some of their most pressing operational challenges.

Overcoming operational challenges

1 Water scarcity

If the industry is to avoid the projected supply shortfall of key minerals, it will have to develop ore deposits that are increasingly located in remote regions where essential utilities like water and electrical power may not be available.

This presents some operational challenges that have, in recent years, led to some emergent trends. For instance, there is a growing interest in dry mineral processing, as well as the deployment of satellite processing plants.

Unlike traditional tumbling mills, HPGRs don’t need water addition for grinding to deliver a consistent and size-controlled product to the subsequent processing stage.

The addition of an air classifier acts holistically like an industrial size vacuum cleaner, separating coarse and fine particles over a series of separation stages that utilises air flow.

When water is scarce or capital intensive to supply, dry air classification offers significant benefits to enable projects to be deployed in arid and water-scarce regions.

These solutions are already being implemented.

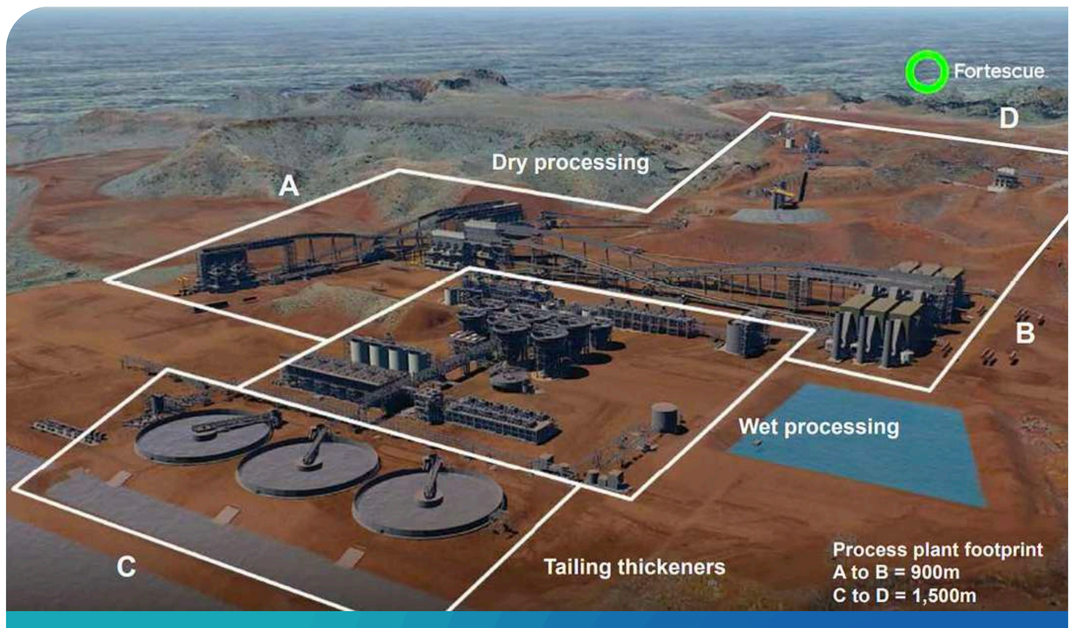

Figure 6: Iron Bridge plant footprint dry versus wet processing - Source: Fortescue

Fortescue's Iron Bridge project in Western Australia is the world's first large scale plant without tumbling mills.

The flowsheet that includes ENDURON® HPGRs with air classifiers and stirred mills (figure 5).

Enabling dry processing via HPGR and air classification technology significantly reduces the wet processing footprint of the plant (figure 6) which, in conventional mill circuits, is predominant.

The multi-staged HPGR circuit with dry interstage beneficiation has facilitated the removal of 13dmt of waste material from the circuit.

This not only significantly reduces operating costs (OPEX), it also reduces downstream dewatering requirements and capital costs (CAPEX) substantially.

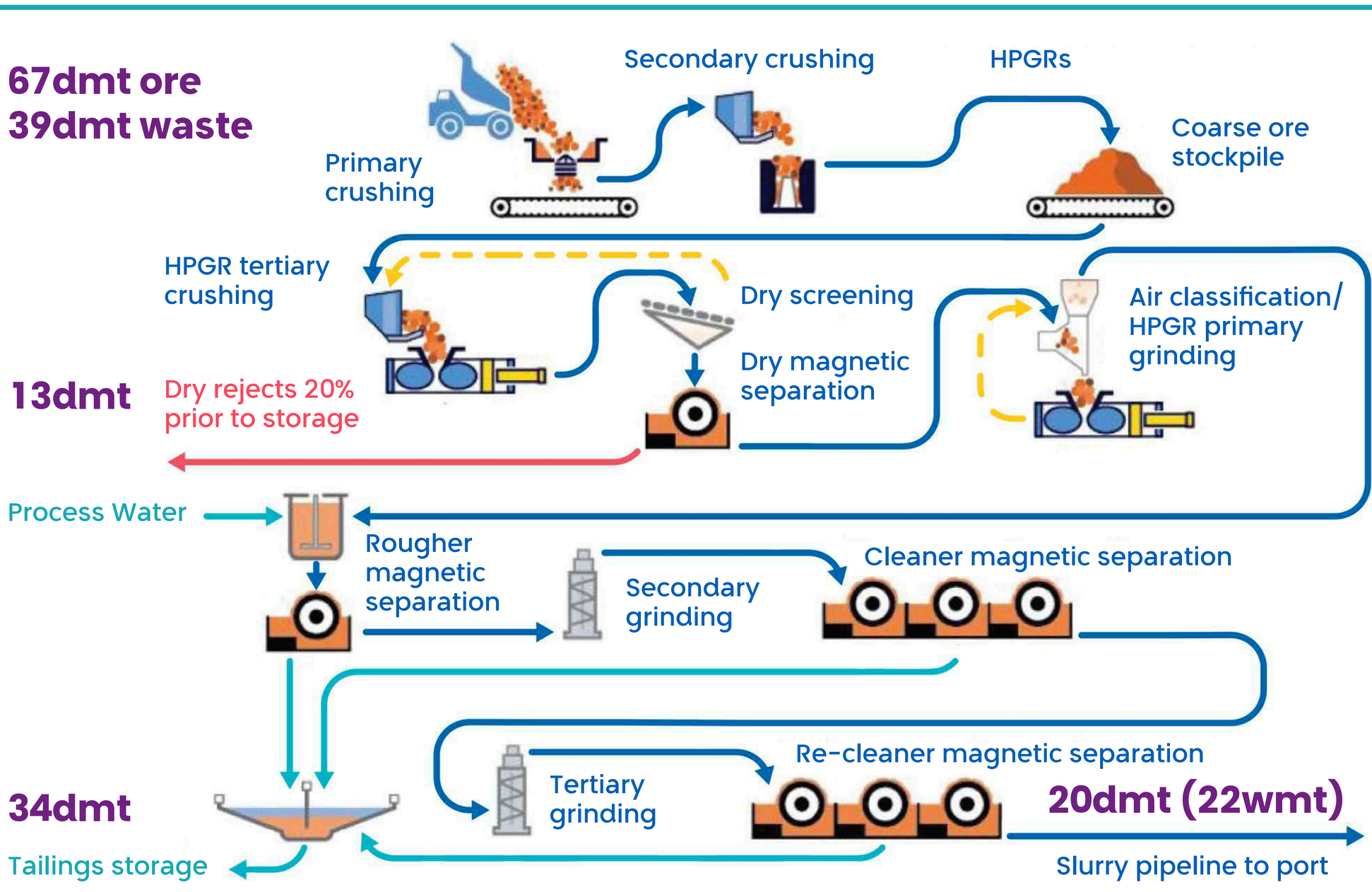

Figure 5: Iron Bridge flow diagram (tonnage numbers refer to LOM average) - Source: Fortescue

2 Complex ore bodies located in remote locations

The ability of OEMs to service and support very remote mines is, in many instances, more important than their role as an equipment supplier. Unplanned shutdowns can result in extended periods of downtime because it can take a long time to get the required people, parts and equipment to site to perform the required maintenance.

Preventing this requires careful planning and preparation. In many instances, OEMs need to have the infrastructure in place to support miners before production even begins.

Indeed, this has been a notable feature of several recent projects Weir has supplied comminution equipment for.

Weir recently opened its Port Hedland Service Centre, which is strategically located to support its customers in the Pilbara region of Western Australia. The centre features facilities for ENDURON® HPGR servicing, including tyre roller assembly.

In addition to Fortescue's Iron Bridge Operation, it also supports De Grey Mining's flagship Hemi Gold Project among others, allowing the miners to benefit from product training in close proximity to the mine site.

Similarly, the Reko Diq site in Balochistan, Pakistan is very remote, so as part of the contract to supply ENDURON® HPGRs, Weir will also resource the service centre on-site to enable the miner to utilise the technology they need, rather than simply opting for legacy solutions they might be more familiar with.

Indeed, servicing remote mine sites has become a hallmark of Weir's offering. At Endeavour's Lafigué gold project, situated in the north-central region of Côte d'Ivoire, Weir delivered the ENDURON® HPGR so that it could be installed modularly. It was pre-assembled at its factory in Venlo, the Netherlands, and it arrived at site as one unit excluding the drives. This helped streamline installation.

Weir also supported the design and provided advice and guidance on how the workshop should be laid out in order to streamline HPGR maintenance. This is the first time a workshop has been built next to the HPGR in Africa. The tyres are refurbished on-site in the workshop, thereby significantly de-risking operations and developing local skills. The workshop has a significant footprint because a lot of space is required to facilitate the tyre exchange.

Operators are also increasingly leverage digital technologies to allow them to monitor their equipment and processes remotely. But this is only the tip of the iceberg in terms of how digital is and potentially will transform mineral processing.

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3 Skills shortage

The mining industry is experiencing a skills shortage. While it's a global trend, it's particularly acute in remote regions where greenfield sites are increasingly located.

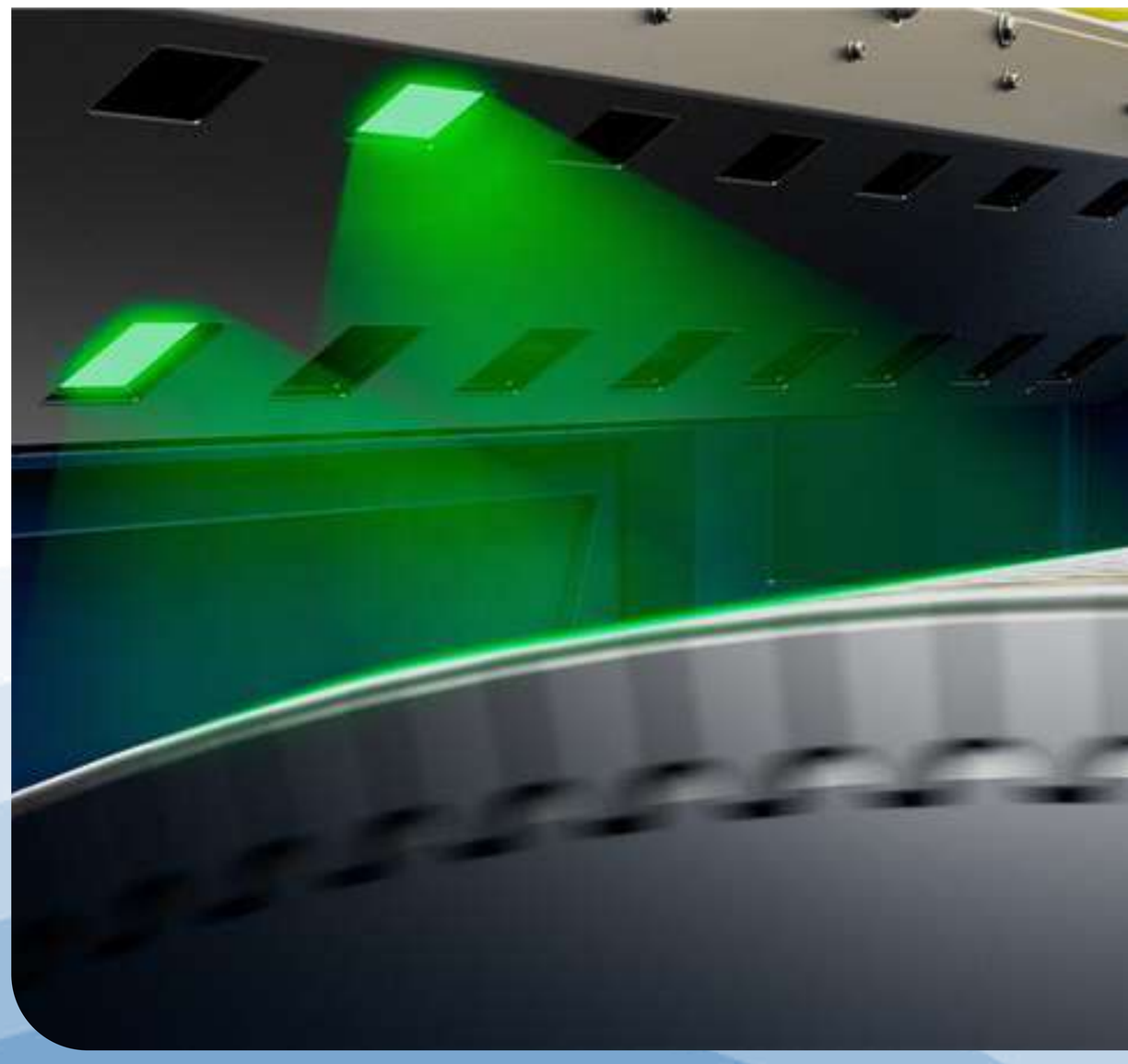
Digital technologies are playing a crucial role in alleviating and overcoming some of these related challenges. For instance, Weir is utilising its NEXT intelligent solutions to improve training and provide maintenance and operational personnel with a detailed understanding of the plant. They can identify potential risks before going on-site and, in a training setting, provide less experienced personnel with a comprehensive overview of how certain procedures should be executed safely.

Moreover, there are autonomous solutions that enable the removal of personnel from the line of fire and, instead, allow them to perform the work without direct human intervention. These solutions are more mature in underground operations, but they are becoming more common at the processing plant too.

As a case in point, Weir has developed an Automated Tyre Wear Measurement (ATWM) system to enable operators to automatically take measurements of the tyres' wear status, detect stud breakage and determine the remaining useful life.

These condition monitoring solutions can become even more transformative when combined with the power of artificial intelligence (AI).

Weir's NEXT intelligent solutions harness AI-driven technology to optimise the entire process and maximise efficiency. Weir brings the tested knowledge of experts together to train algorithms and models on what best practice looks like in pre-defining the most optimal operating conditions of the processing plant.



Flowsheet type	Key features	Benefits	Challenges/Considerations
Fine HPGR Grinding with Air Classification	• Single or multiple product streams • Dry processing	• Energy-efficient • Water-saving • Enabling mineral processing in dry and arid areas	• Higher energy consumption for material transportation via air flow • Auxiliary systems more complex for material handling
Two-Stage HPGR with Interstage benefication	• Allows for interstage benefication and early rejection of waste (barren)	• Enhanced energy efficiency • Early gangue rejection • Reduces CAPEX and OPEX by not processing non-valuable material	• Complex circuit design • Subject to mineralogy suitability
HPGR Integrated with Stirred Milling	• Combines HPGR with vertical stirred mills	• High energy efficiency • Flexible grinding system capable of handling feed variability • Increased recovery via steep particle size distribution as overgrinding is prevented	• Selecting optimum transfer size between HPGR and stirred mill to reduce wear and avoid excessive screening requirements • Conservative reduction ratio in coarse stirred milling for single stage
Closed (Forward) Circuit HPGR	• Proven configuration with screening post HPGR with fixed top size control	• Effective size control • Suitable for ball mill feed	• Requires large vibrating screens • Requires wet classification at finer cut sizes to maintain classification efficiency
Truncated (Reversed) Circuit HPGR	• Pre-screening before HPGR	• Prevents overgrinding of fines already present in HPGR feed • Enables efficient HPGR grinding of fine, high-moisture and clayish feed materials	• Requires ore with high fines content • Typically reduces HPGR specific capacity and mineral (autogenous) layer stability on roller surface
Partial Product Recycling (Edge Recycling)	• Mechanical splitters recycle part of centre and edge discharge streams	• Adaptive and tailored product PSD control • Removes need for separate classification system • Proven suitability for heap leach and pellet feed applications	• No fixed top size control • Cutter plates positioned in material stream require sound wear protection • Increased integrated material handling systems with reduced accessibility
Parallel Flowsheet	• Tailored processing path catered for optimum processing of specific ore types and particle sie distributions	• Prevents overgrinding • Improves energy efficiency • Enhances tailings management • Reduces power consumption (e.g. 38% vs SABC)	• Conceptual stage • Requires simulation and validation • Parallel processing increases number of mechanical equipment in the processing plant
Iron Bridge Flowsheet (Dry Processing)	• Dry mineral processing producing micron-sized product • Multi-stage HPGR with interstage barren rejection • Dry air classification • Vertical stirred milling	• Innovative, highly efficient magnetite processing without use of tumbling mills • Removes >20% of waste material out of the circuit completely dry • Simplifies tailings facility management and dewatering requirements	• Innovative circuit requires material handling systems to cater for extraction/ transportation of dry fine particles • Suitable for low moisture feed applications only without hot gas implementation

Innovative flowsheets to combat mining's most pressing challenges

Conclusion

WEIR

In its Mine 2025 report, PwC looked ahead and identified several key trends that will influence the trajectory of the mining industry in the coming decade:

Advancements will improve mining equipment performance, allowing for higher output with reduced resource consumption and improved safety… Due to the capital-intensive, long-life-cycle nature of mining, large-scale changes will first be implemented at new mines.

Existing mines will consider specific areas of adoption where it makes economic sense.

The rise in greenfield hard rock mines opting for HPGR-based flowsheets over traditional SABC circuits is only going to continue as the techno-economic case strengthens.

Weir has comminution solutions that can be tailored to each operations' specific requirements, but foundational to all of these is proven equipment and unrivalled support.

The mining sector cannot ignore the immense challenges involved in the energy transition. It has a responsibility to enable it by continuing to supply transition minerals, but, at the same time, it needs to become more sustainable. And nowhere in the mining value chain is the opportunity to transform the energy equation greater than in comminution.