MICROWAVE PROCESSING OF ORES – COMMERCIAL REALISATION OF A STEP CHANGE FOR THE MINERALS INDUSTRY

Sam Kingman[1], Andrew Batchelor[1], Richard Bearman[2], Herman Purutyan[3], David Craig[3]
[1] Faculty of Engineering, University of Nottingham, UK
[2] Bear Rock Solutions, Perth, Australia
[3] Jenike & Johanson, Tyngsboro, MA, USA
Presenter: David Craig dacraig@jenike.com

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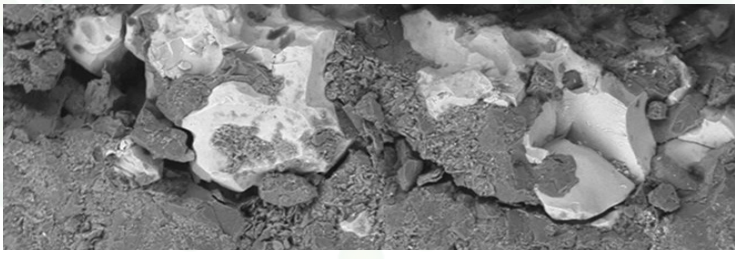
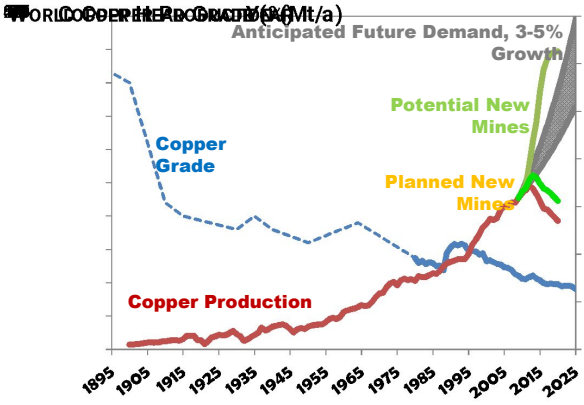
Presentation overview

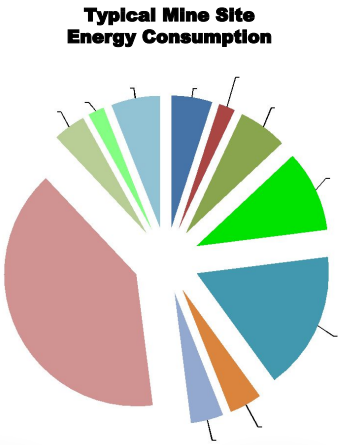
- Why is innovation needed?
- Existing comminution technology
- Basic principle of microwave comminution technology
- Development history
- Where are we now?
- Value proposition
- What are the potential benefits?



Mining industry drivers

Why is comminution innovation needed?





Energy reduction benefits

Increase Competitiveness

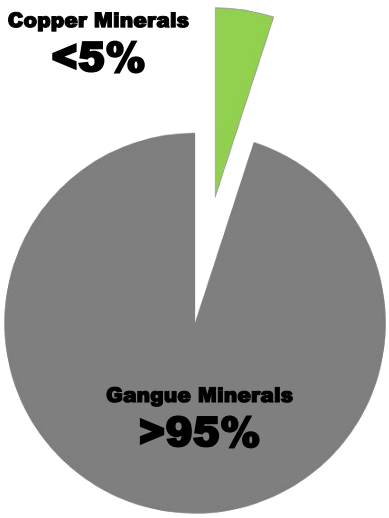
Fight Climate Change (i.e., decarbonization)

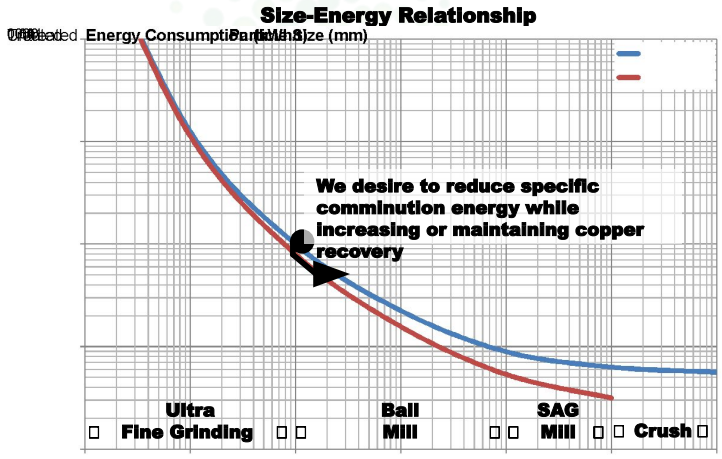
Higher Embodied Energy
- Decreasing Copper Grade
- Decreasing Grain & Grind Size
- Increasing Ore Hardness

Limited Mining Activity
- Growing Demand & Production
- Rising Costs (Utilites, Remote Locations)
- Falling Deposit Discovery

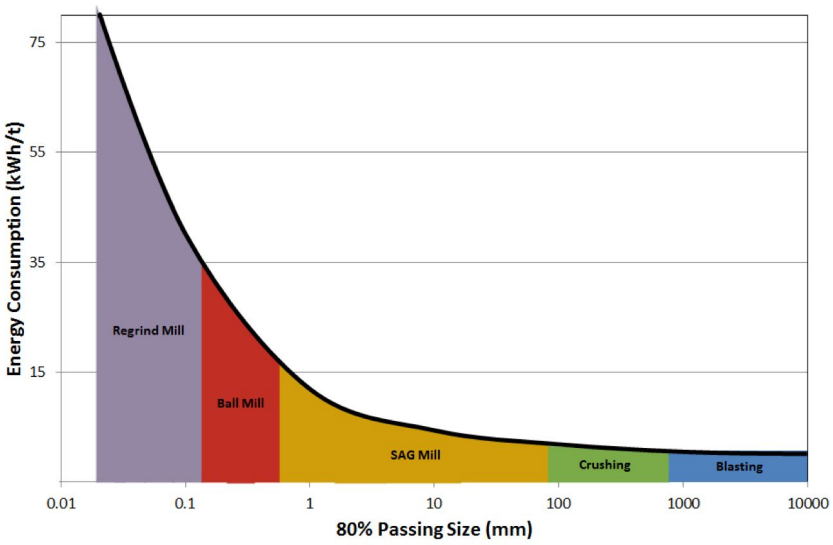
Mining industry drivers

Why is comminution innovation needed?





Existing comminution solutions



SAG mill

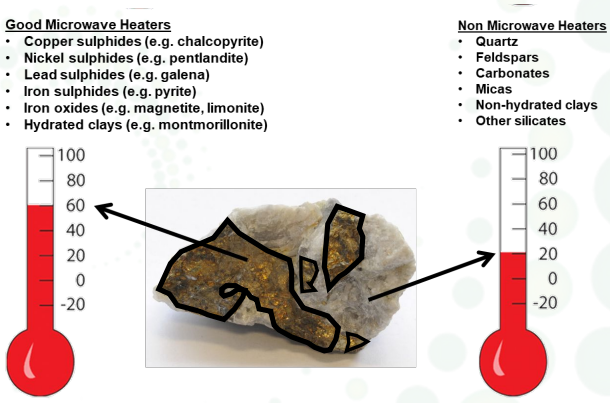
Ball mill

HPGR
(per FLS)

Microwave technology poised to complement existing solutions

Microwave technology – what is it?

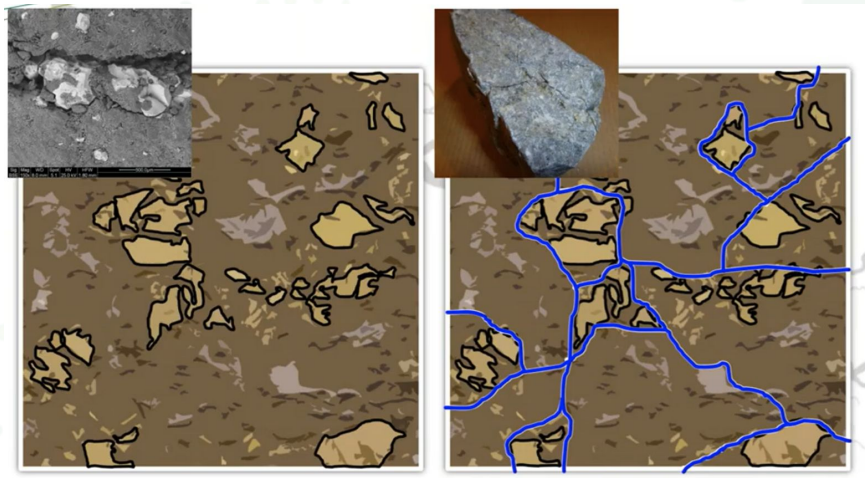
- Rocks contain mixtures of minerals with varying abilities to heat due to microwave application
- SHOT applies high-intensity electrical microwave energy to cause differential heating and generate thermal stresses primarily at the mineral-grain interface
- Overall effect controlled by mineralogy and texture



Energy usage:
0.3 to 3 kWh/t (typically <1 kWh/t)
i.e., << HPGR, Ball, SAG

Microwave technology – what is it?

- Benefits:
  - Competency reduction: Micro-fractures at the mineral-grain boundaries
  - Enhanced recovery: Preferential grain boundary cracking frees the valuable mineral at larger grain size

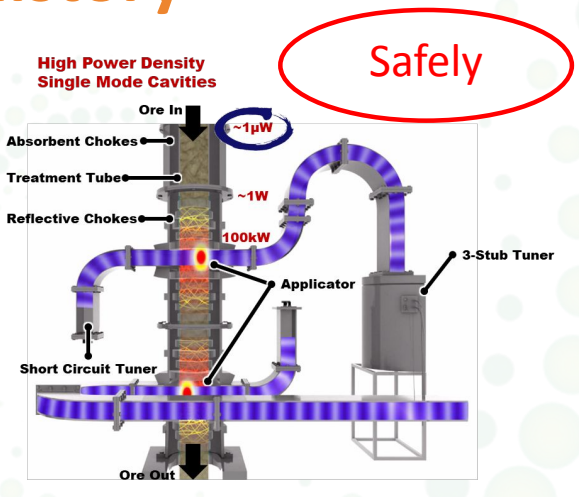


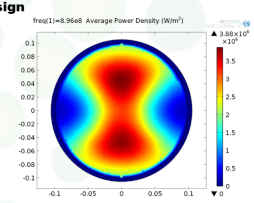
Micro-Fracture
(energy reduction, liberation)

Macro-Fracture
(leaching pathways)

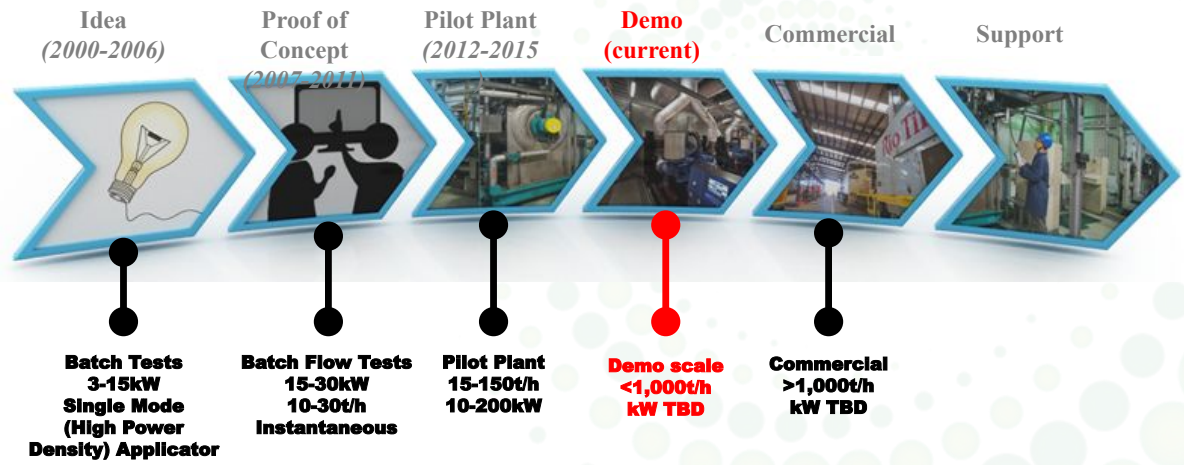
Microwave technology – history

- Developed by University of Nottingham
  - 20+ years of experience and have demonstrated world-class capability in the application of microwaves in mineral processing
- Lead developer
  - Professor Sam Kingman is a Pro-Vice- Chancellor and was Director of the National Centre for Industrial Microwave Processing (NCIMP). Published over 175 refereed journal papers and he is an inventor on over 150 patents within 29 patent families in the field of industrial microwave processing
  - Worked with a wide variety of mining companies during the early development phase of microwave processing
- Team and Facilities
  - World-first design for industrial system, using power intensifying methods
  - Test facilities and research teams in-place



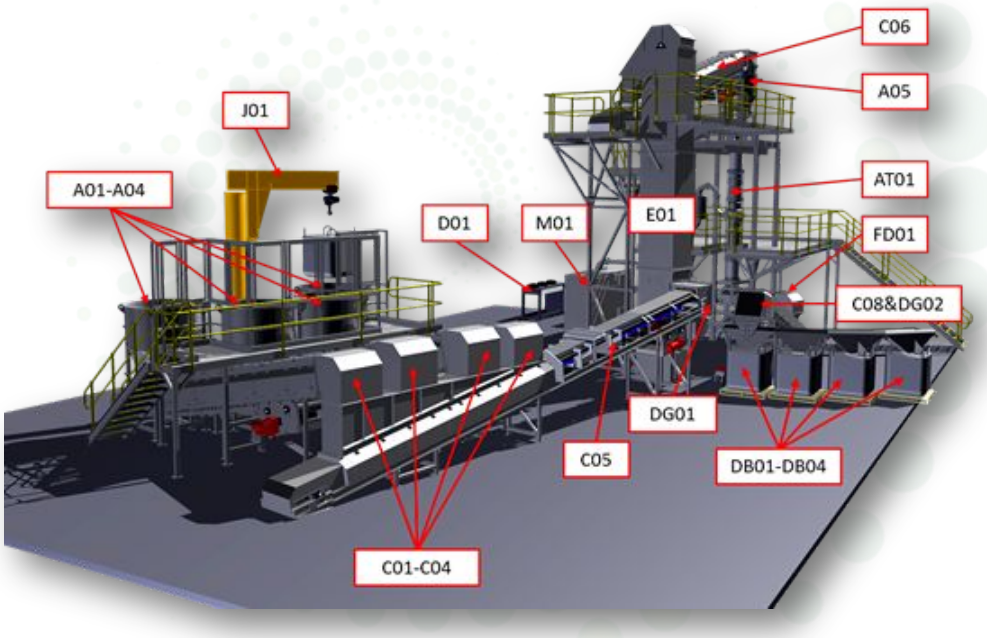


We are we?



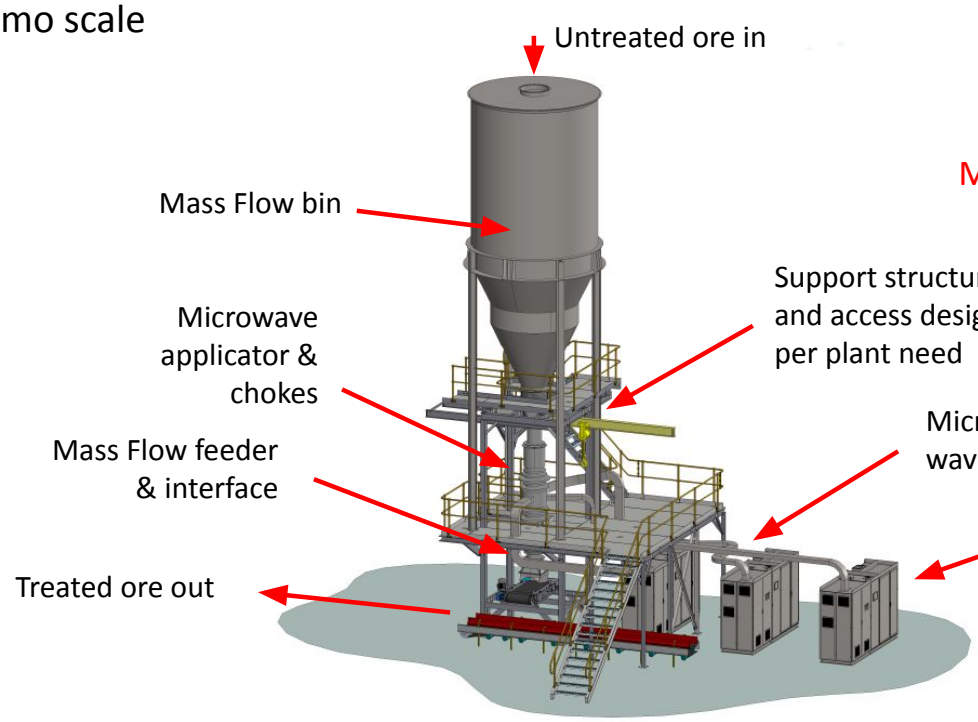
Microwave technology – pilot plant

- Designed, built and proven circa. 2012 to 2015
- 2 x 100 kW (896 MHz) microwave generators (AT01)
- 15 to 150 t/hr
- Up to 4 tonnes per batch run



SHOT microwave system

Demo scale



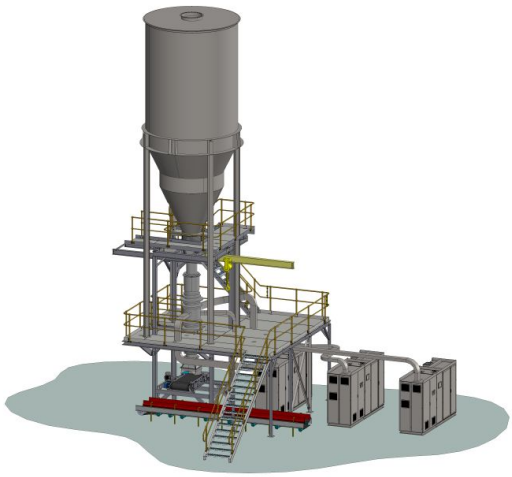
300 to 800 t/hr
PSD < 80 mm
0.3 to 3 kWh/t
Multiple 100 kW generators

"Patent protected"

SHOT microwave system

Demo scale

- Customizable
  - Designed for each particular application & ore
  - Positioning within plant can be fine-tuned for optimal energy reduction
- Comprised of:
  - Mass flow storage bin, microwave applicator & chokes, mass flow feeder, and microwave generator(s) and waveguides
- System design important



SHOT solution partners

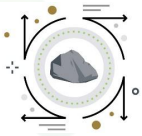
Jenike & Johanson are materials handling specialists and the engineering and equipment supply vendor for the SHOT system

The University of Nottingham are microwave process design experts and assess ore amenability to the SHOT system

Bear Rock Solutions are an experienced mineral processing consultancy providing client interaction, process modelling and value proposition definition services

Fight Climate Change

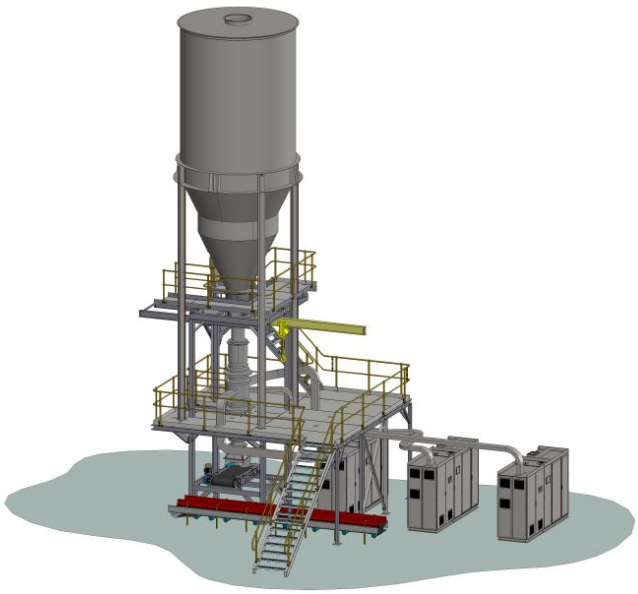
Increase Competitiveness



Transform the Mining Cycle

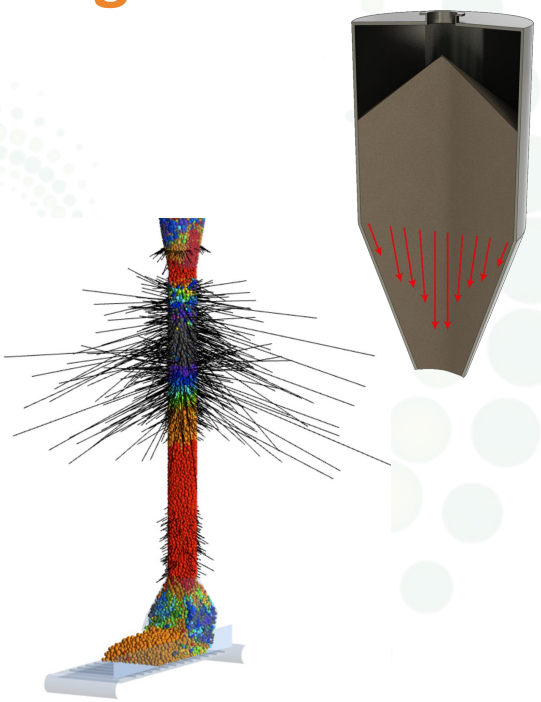
SHOT microwave system “kit”

- Solution: Microwave system equipment “kit”
- Underlying design process:
  - Evaluate ore for success using microwave technology
  - Ore tests
    - Microwave properties (e.g., dielectric properties and heating potential) – for design of generator, waveguides, applicator & chokes
    - Flowability properties – for design of materials handling equipment
  - Conceptual design
  - Detailed design
  - Equipment fabrication & supply



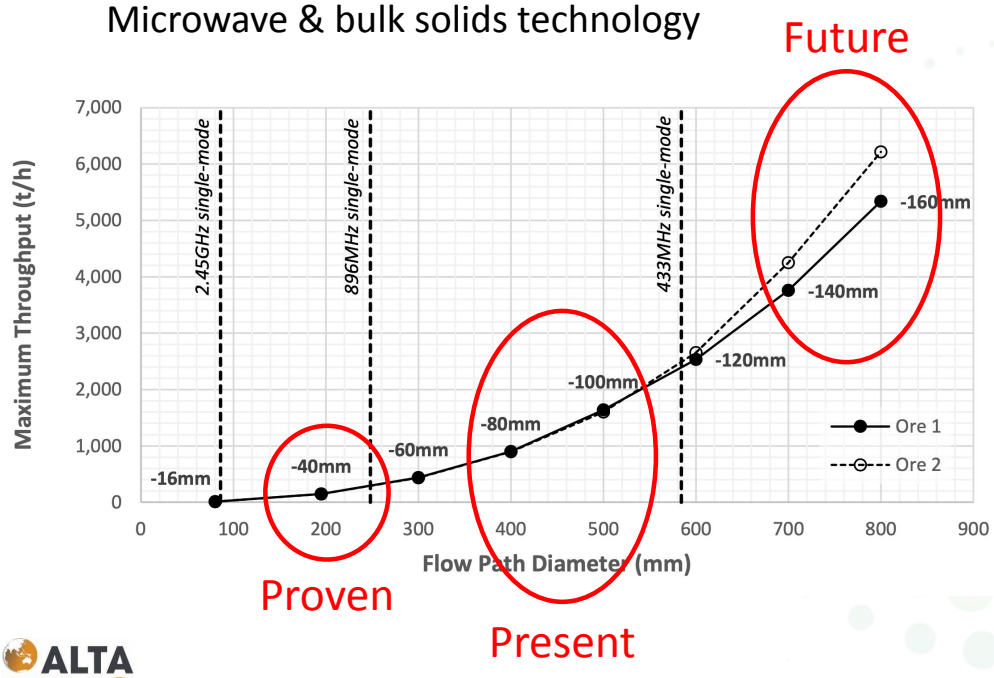
Importance of bulk solids handling

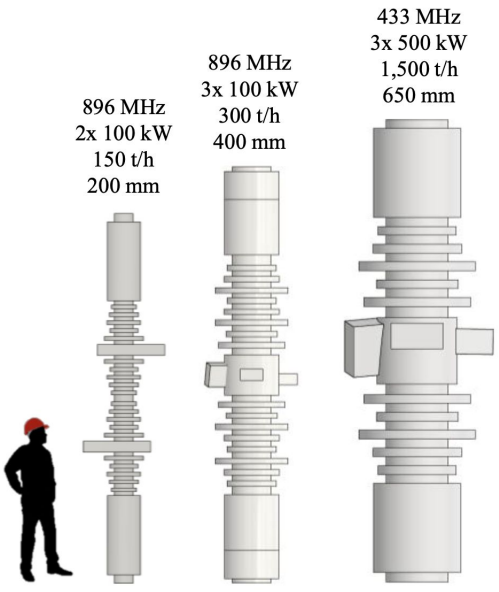
- Small footprint
- Suitable materials of construction
  - Electrical properties, mechanical properties, wear
- Low complexity
- Control of ore residence time
  - Unimpeded and stable solids flow
- Control of ore presentation to microwaves
  - Voidage, segregation, blockage, loads



Flow path diameter

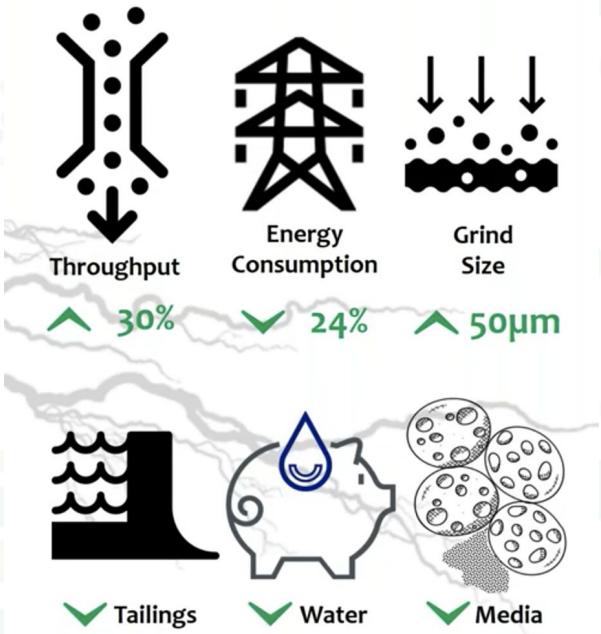
Microwave & bulk solids technology





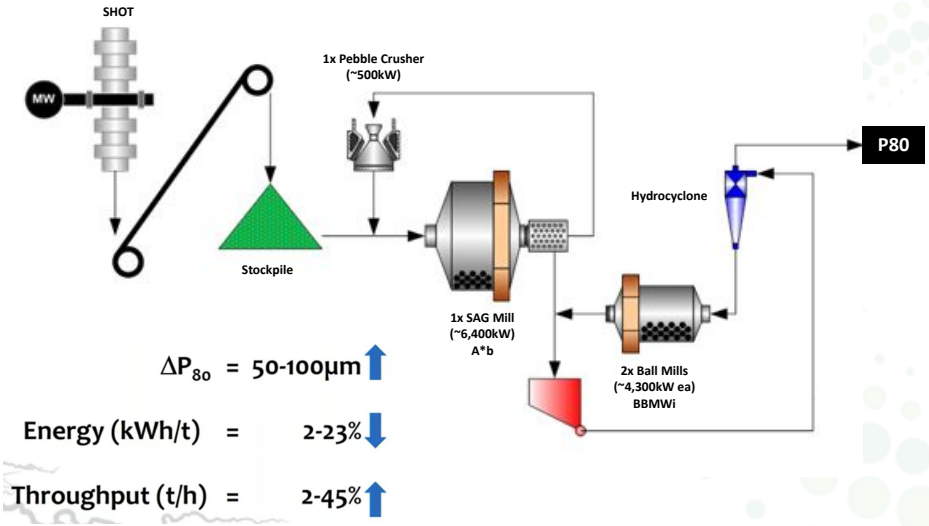
Value propositions

- Reduced ore competency
  - Reduced comminution energy requirement
- Enhanced liberation
  - Increased mineral recovery
  - Achieve mineral recovery at a coarser size
  - Aid preferential liberation
- Increased throughput
- Assist pre-concentration
- Increased heap leaching pathways
- Reduced water consumption
- Reduced grinding media consumption
- Reduced equipment wear



Example results

Flow sheet simulations



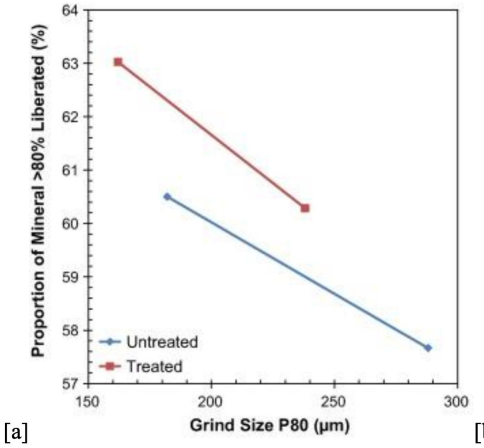
Ore 2	Untreated	Treated	Treated
A*b	39.3	44.8	44.8
BBMWi (kWh/t)	13.69	12.69	12.69
Product Size P80 (µm)	190	190	290
Total Power (kW)	15,081	14,988	14,638
Throughput (t/h)	1,500	1,590	1,756
	-	+6.0%	+17.1%
Specific Energy (kWh/t)	10.5	9.4	8.3
	-	-10.5%	-20.9%

Ore 3	Untreated	Treated	Treated
A*b	44.9	48.1	48.1
BBMWi (kWh/t)	9.27	9.19	9.19
Product Size P80 (µm)	190	190	290
Total Power (kW)	15,907	15,904	15,717
Throughput (t/h)	1,670	1,700	1,970
	-	+1.8%	+18.0%
Specific Energy (kWh/t)	9.5	9.4	8.0
	-	-1.8%	-16.2%

Liberation and recovery improvement

Example for porphyry copper ores after microwave treatment

- Increased liberation at same grind size
  - ΔLiberation ~5 to 10%
- Equivalent liberation at a coarser grind size
  - ΔP_{80} ~50 to 100 µm



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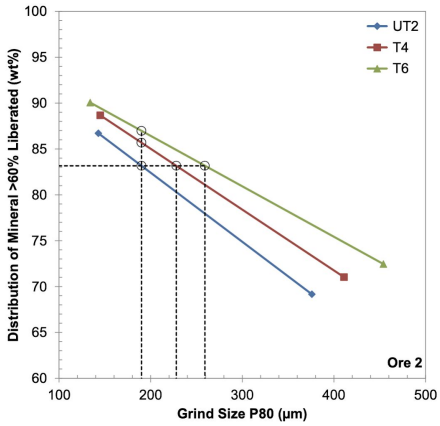
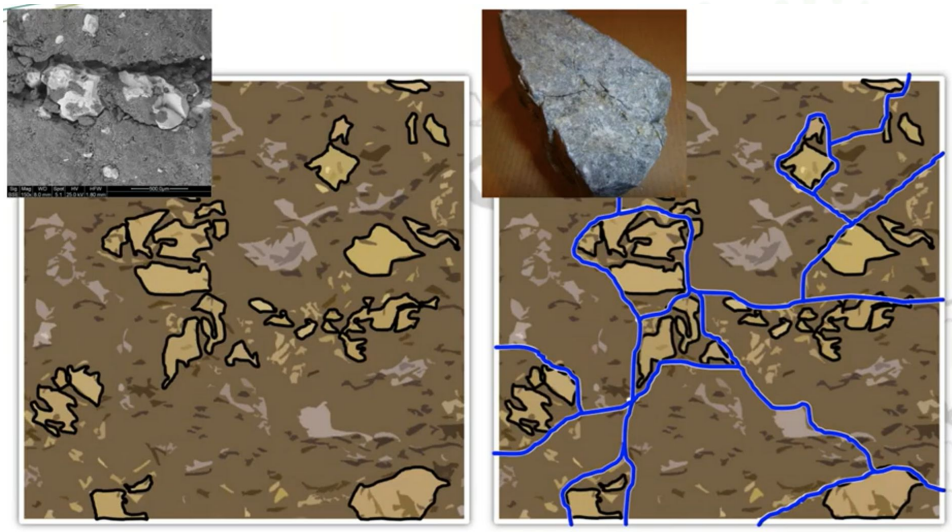


[b]

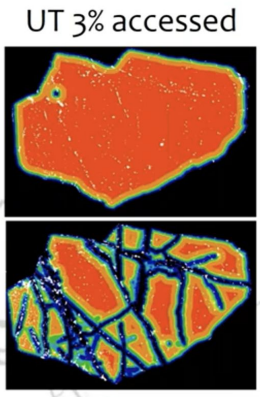
Heap leaching

The best way to save energy is to not grind the rock to begin with!



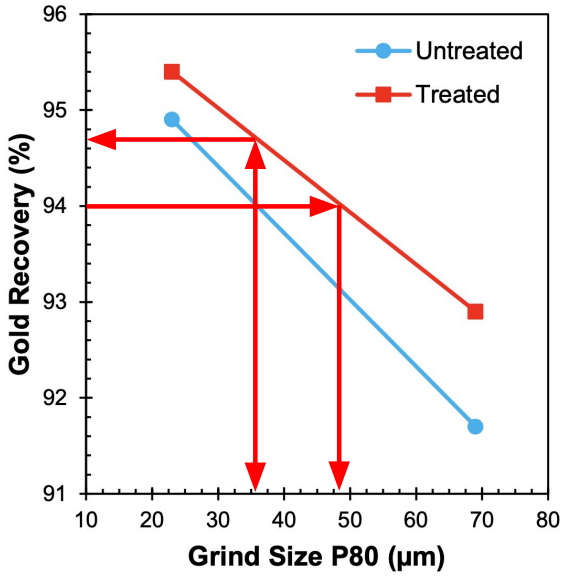
Micro-Fracture
(energy reduction, liberation)

Macro-Fracture
(leaching pathways)



Improvement in leaching

Gold leaching at fine grind sizes



Conclusions

- Microwave electrical comminution solution is proven both theoretically and at 150 tph pilot lab scale
- Presently available for industrial systems at ~300 to 800 t/hr at ~<1 kWh/t using 100 kW microwave generators
- Major benefit:
  - Fracture along mineral grain boundary seen to be critical leap forward in comminution technology
- Complements existing comminution solutions
  - Combined solution results in overall energy reduction, which ultimately results in positive environmental impact including decarbonization

Conclusions (cont.)

- Benefits can include:
  - Up to 70 µm increase in grind size for equivalent liberation
  - Up to 30 µm increase in grind size for equivalent recovery
  - Up to 1% increase in recovery at existing plant grind sizes
  - Up to 10% increase in plant throughput or reduction in specific comminution energy at existing plant grind sizes
  - Up to 30% increase in throughput or 20% reduction in specific comminution energy at coarser grind size for equivalent liberation

- *Ultimately needs to be engineered to particular site and material*

THANK YOU

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