So you have it crushed and on a conveyor – Now what? Optimizing value through ore sorting

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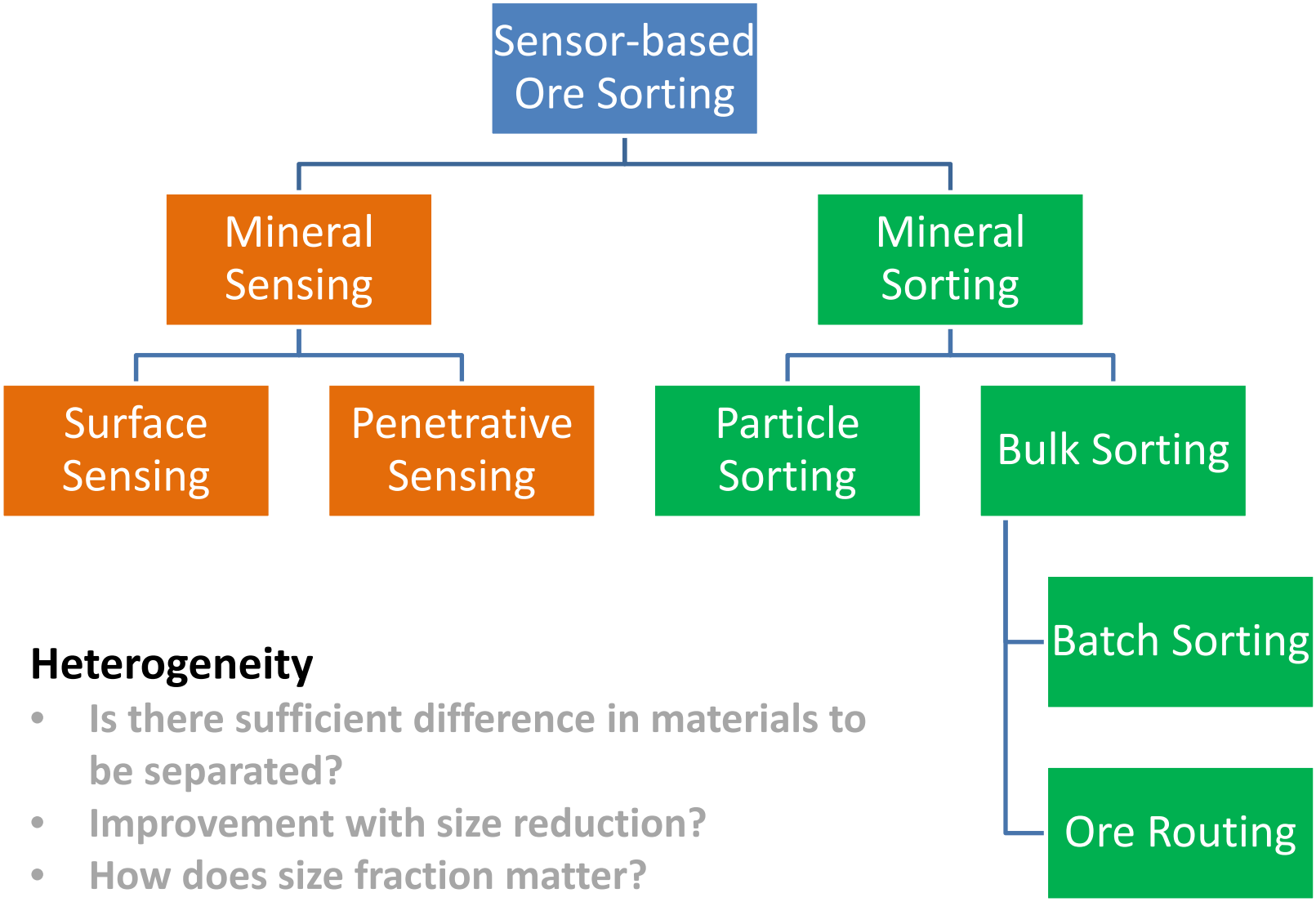
Outline

- What and Why
- Terminology
- Current technology
- Technology providers
- Applications
- Potential and limitations
- SRK assistance
- Conclusions

What and why?

- Ore-Sorting: sensor-based concentration, pre-concentration, or scavenging
- For pre-concentration, reject the waste before treating unnecessarily (money and resources)
  - Natural heterogeneity
  - Planned dilution – internal and external
  - Unplanned dilution
- Advances in recycling and food industries have increased the options in sensing technology, most of which are equally applicable to mineral sensing
- Advances in computing power for mineral sensing algorithms
- Crushed material, on a conveyor, is a prime candidate for ore sorting
- Ore sorting is almost wholly applied to conveyed materials

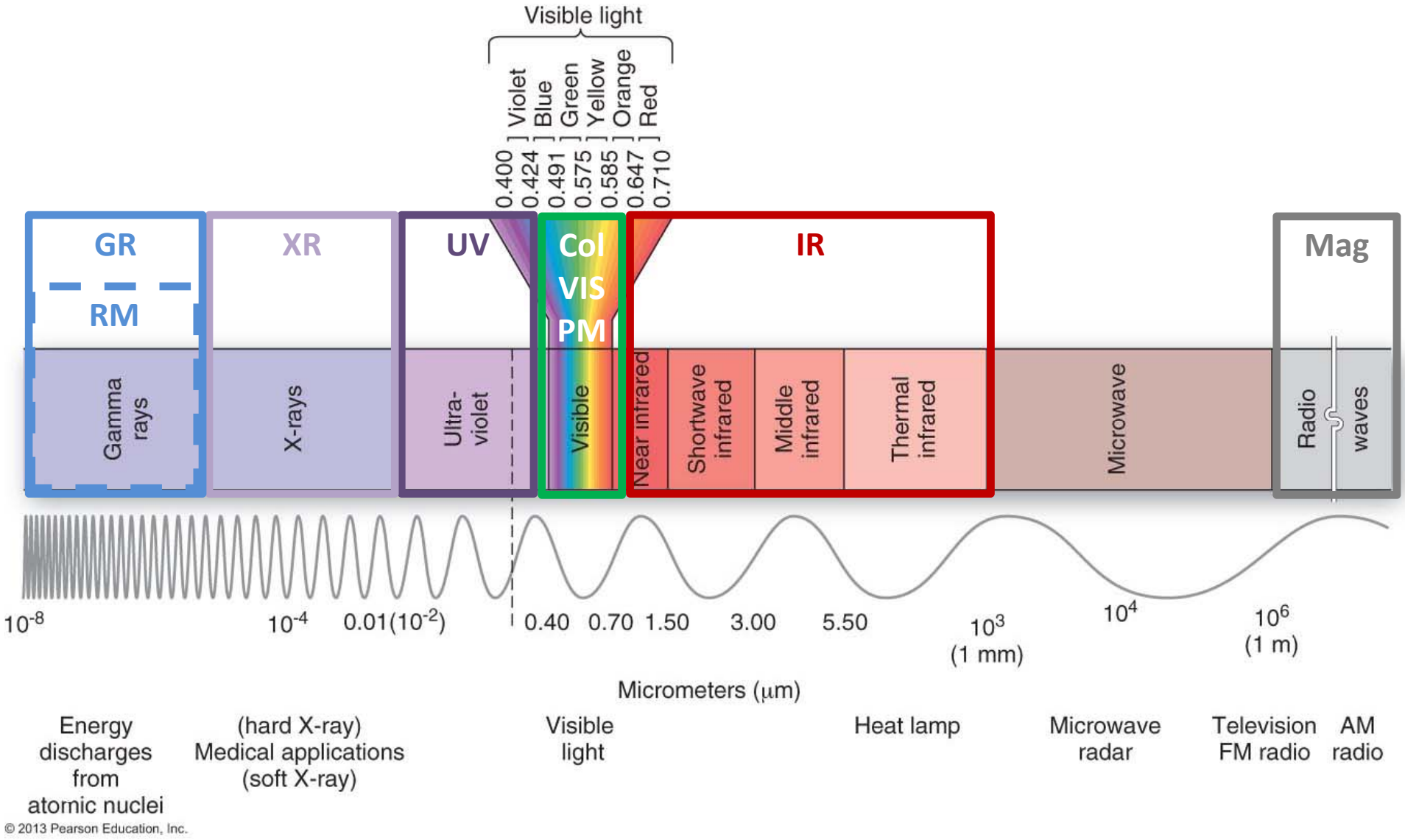
Terminology



Heterogeneity

- Is there sufficient difference in materials to be separated?
- Improvement with size reduction?
- How does size fraction matter?

Current Technology – Mineral Sensing



Current Technology – Mineral Sensing

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

Current Technology – Mineral Sensing

Method	Sensor Type	Sort Type	Materials	Limits
LIBS	Surface	Particle	Elemental Analysis, most all elements	Sensitive to variations in distance from Laser/detector to target sample
LIF	Surface	Particle		Like LIBS, early stage of development few commercial applications
VNIR	Surface	Particle	Industrial minerals, Fe ore	2-120 mm rock, 20-100 tph, surface technique impacted by cleanliness and single perspective (though double sided set-ups exist)
SWIR	Surface	Particle		
MWIR	Surface	Particle		
LWIR	Surface	Particle		
FIR	Surface	Particle		
EMS	Penetrative	Both	Fe ore, base metals with magnetic response	8-60 mm rock, 70 tph
IND	Penetrative	Both		
MRS	Penetrative	Bulk	Chalcopyrite	300 mm rock, 1300 tph, Not all nuclei are magnetic

Current Technology – Mineral Sorting

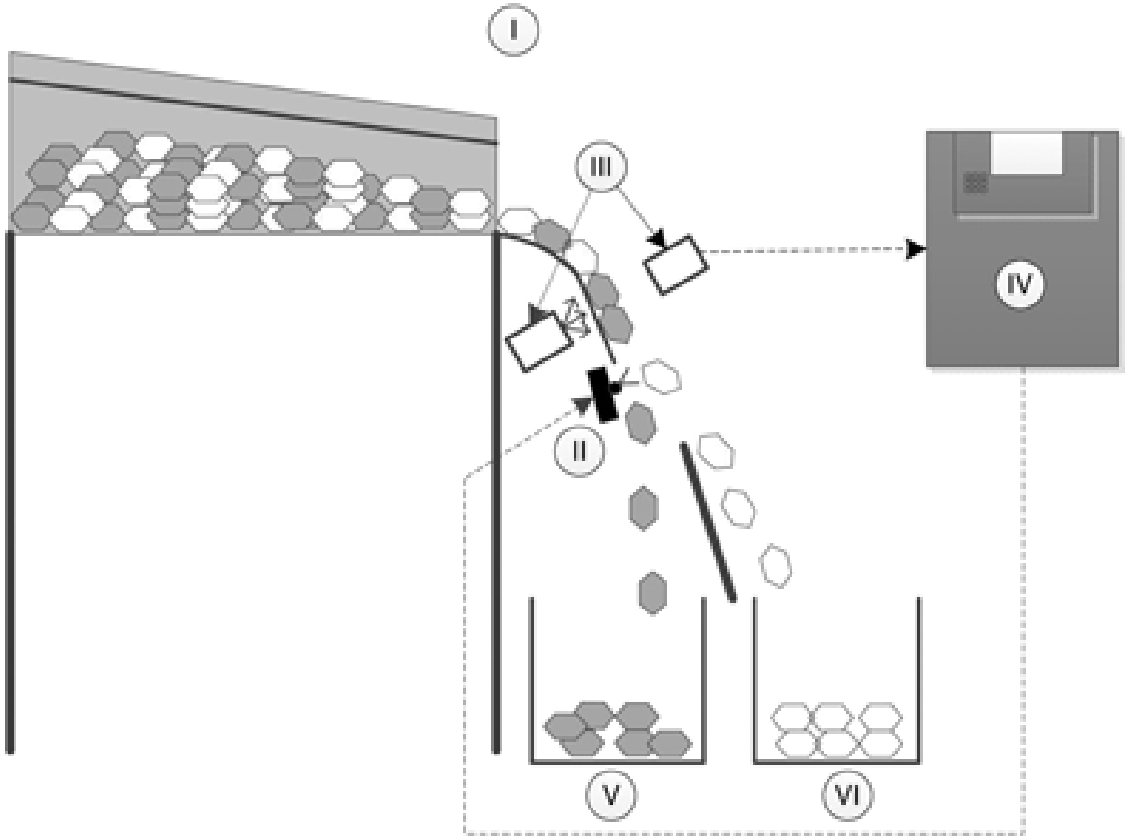
Particle Sorting Process

1. Material Conditioning
   - Sizing and washing (depending on sensing technology)
2. Feed and Presentation
3. Detection and Evaluation
4. Mechanical Ejection

Current Technology – Mineral Sorting

Chute sorter

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

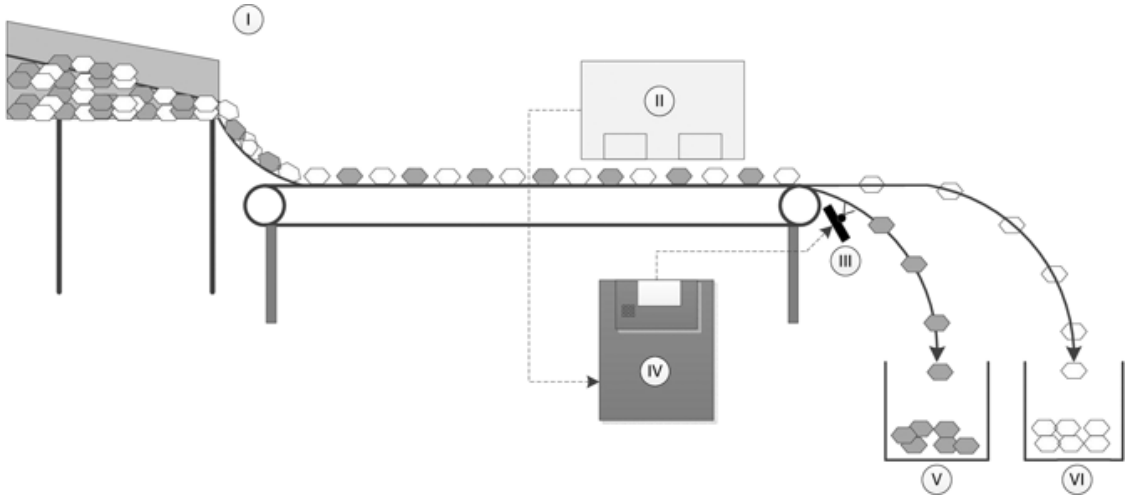


H. Wotruba, *European Mineral Resources Conference*, Leoben, September **2012**

Current Technology – Mineral Sorting

Conveyor belt sorter

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



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Current Technology – Mineral Sorting

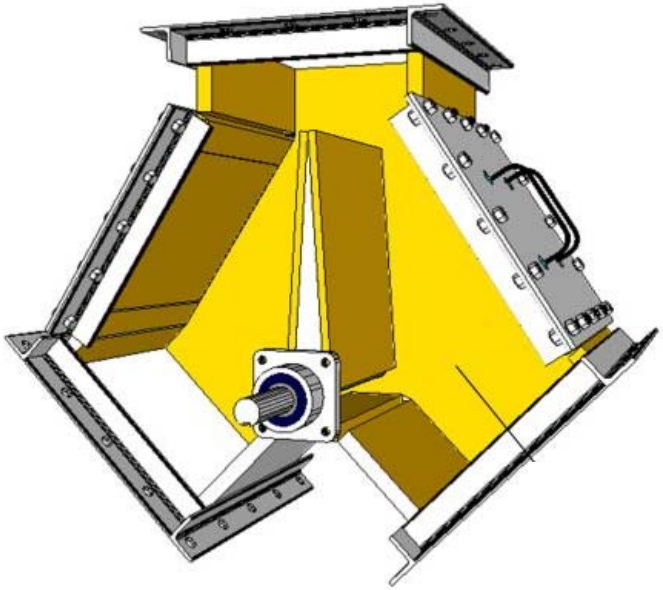
Mechanical ejection

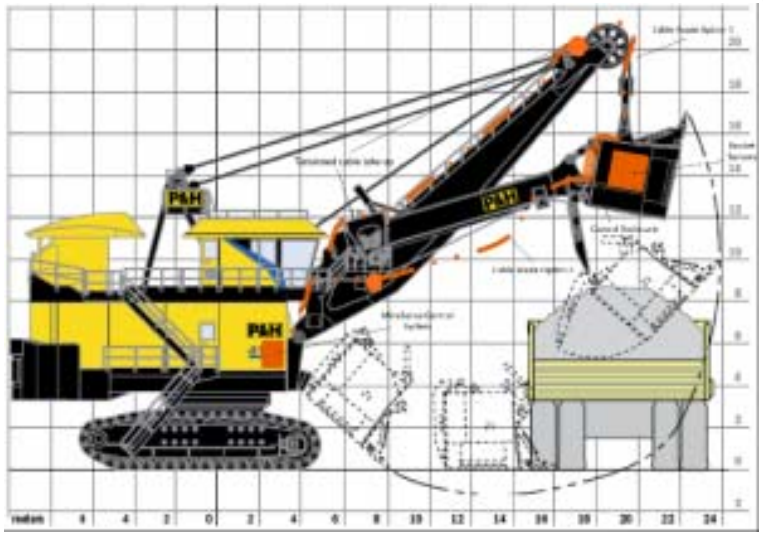
- Compressed air jets
  - 2 ms response
- Paddles/flaps
  - Pneumatic or hydraulic
  - 20 ms response – 5 m/s movement=100 mm req'd. separation
- Water jets

Current Technology – Mineral Sorting

Bulk Sorting

- Conveyor based
  - Telescopic conveyor
  - Reversible conveyor
  - Flop gates
  - Trippers
- Shovel bucket





From MineSense

Sensing Technology Providers

	Electromagnetic	Infrared	Optical	Ultraviolet	X-Ray	Gamma
Comex		NIR	Colour	UV	XRT	
CSIRO	MRS					
EVK		NIR, SWIR				
LLA Instruments		NIR				
MineSense	EMS		LIBS		XRF	
Multotec						NITA II
PANanalytical		NIR			XRF	PFTNA
Rados					XRF	
ScanTech						PGNAA, DUET
Steinert	Induction, Magnetic				XRT	
Thermo Scientific						PGNAA
Tomra	EMS	NIR, IR, MWIR	VIS, Colour, PM		XRT XRF,XRL	RM
IMA Engineering			LIBS, LIF		XRF	
SGS/CoreScan		VNIR, SWIR				
Specim		VNIR, SWIR, LWIR	RGB			
Spectral Evolution		NIR	VIS	UV		

Company also provides sorting

Surface sensing

Penetrative sensing

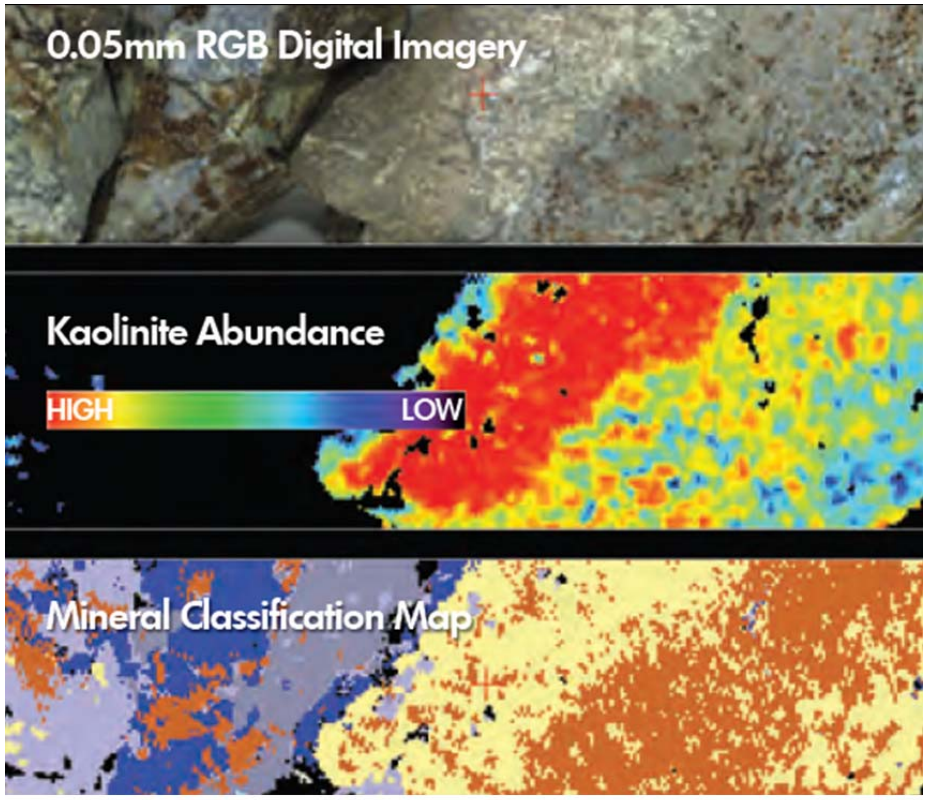
Technology Providers

- Primarily from recycling industry, dabbling in minerals
- Some dedicated to mining
- Sensing companies – many
- Sorting companies – few
- Secretive – some

- Opportunities – many!

Applications

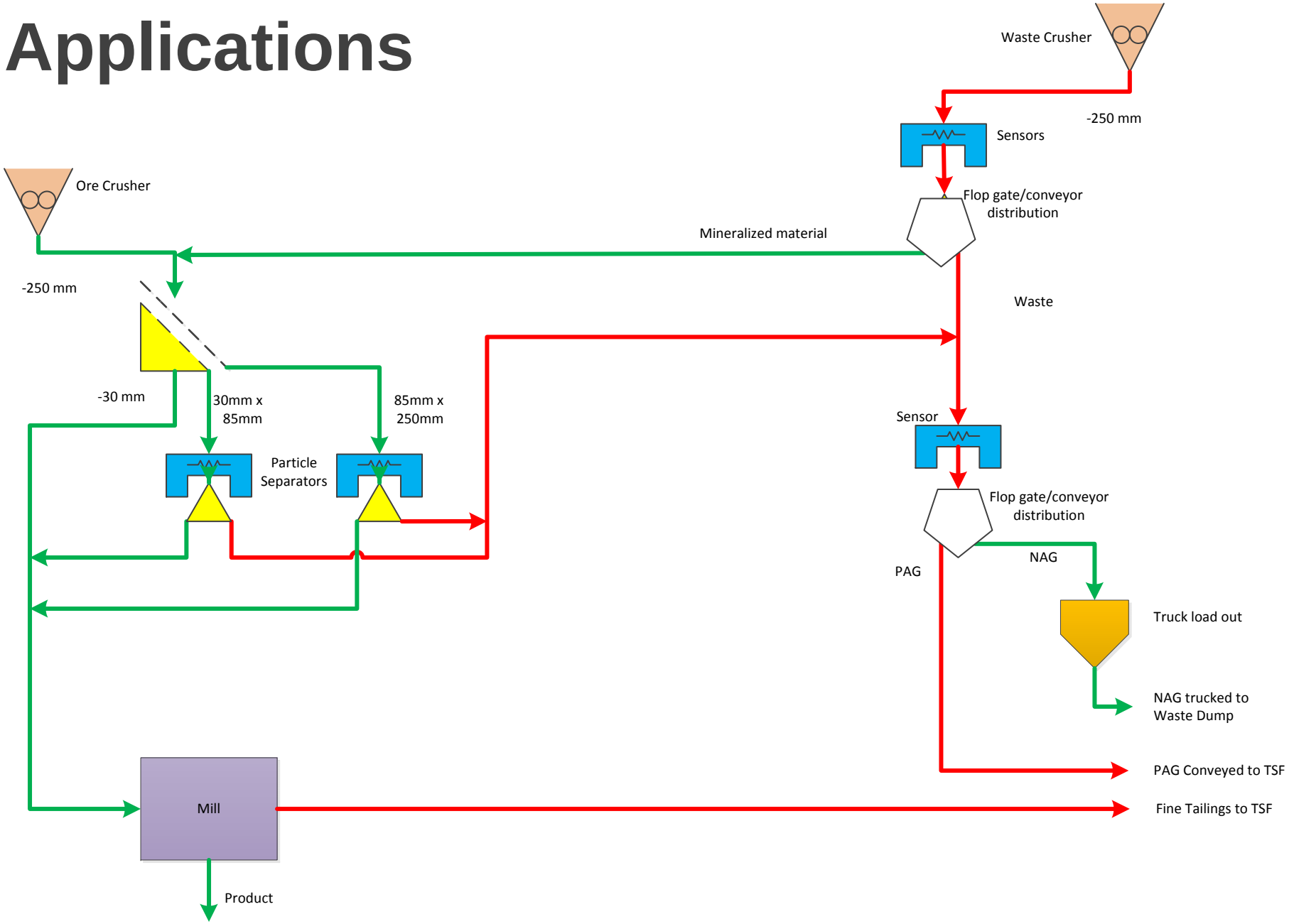
- Material characterization
  - Drill logging
  - Core scanning



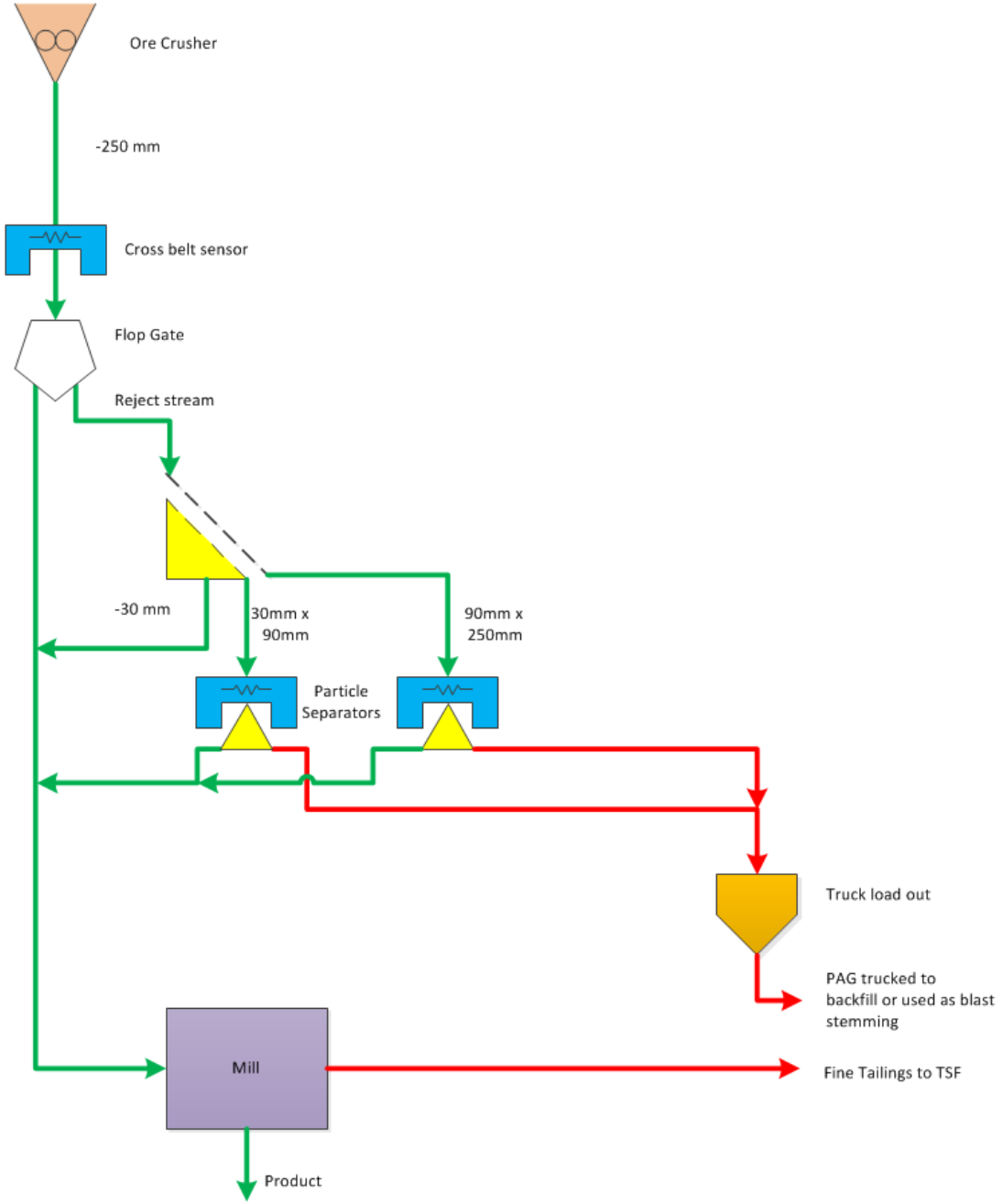
Applications

- Sorting
  - Concentration (finished product) vs pre-concentration (waste removal) vs scavenging (product from waste)
  - Waste Rejection: at face or post primary crushing
    - Waste use potential – road material, stemming, aggregate
  - Underground pre-concentration
    - Save on hoisting, transport
    - Provide backfill
  - PAG material removal (sulphides)
  - SAG/AG pebbles
  - Multi-stage and multi-technology
    - Remove material in stages to reduce throughput for technologies that require throughput limiting computational analysis or limiting mechanical separation
    - Multiple sensors on same built to identify waste; first technology tags particle as waste so that subsequent sensors/algorithms do not have to process

Applications



Applications

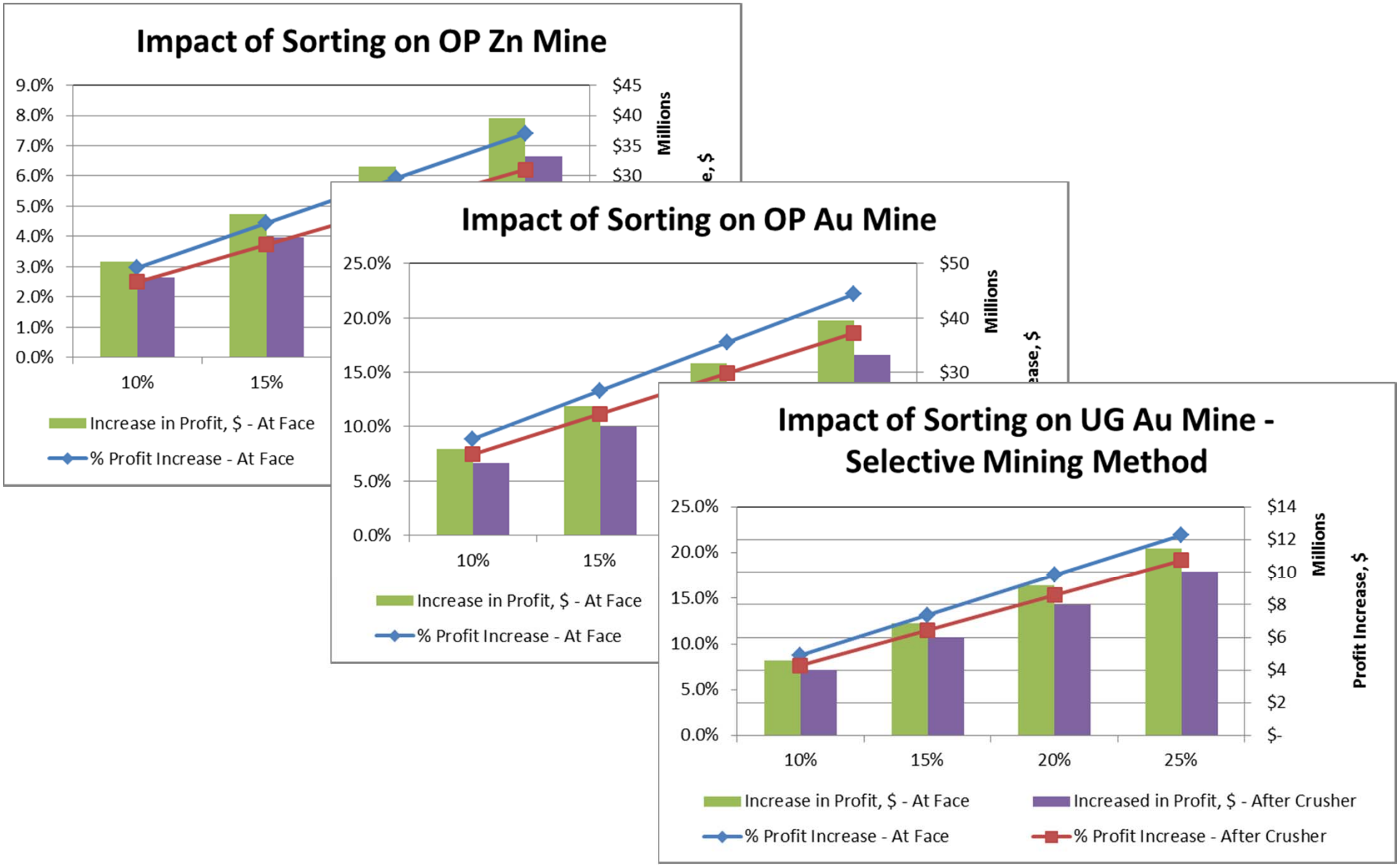


Potential and Limitations

Potential

- Consider 3 hypothetical mining operations:
  - A Zn open pit mine, 10 Mtpa
  - A Au open pit mine, 10 Mtpa
  - A Au underground mine, 2 Mtpa
- All have 10% dilution
- OP mines have similar milling costs; UG has scaled higher milling unit costs
- Consider material rejection (10-25%) in 2 scenarios:
  - In mine (“at face”)
  - After primary crusher

Potential and Limitations

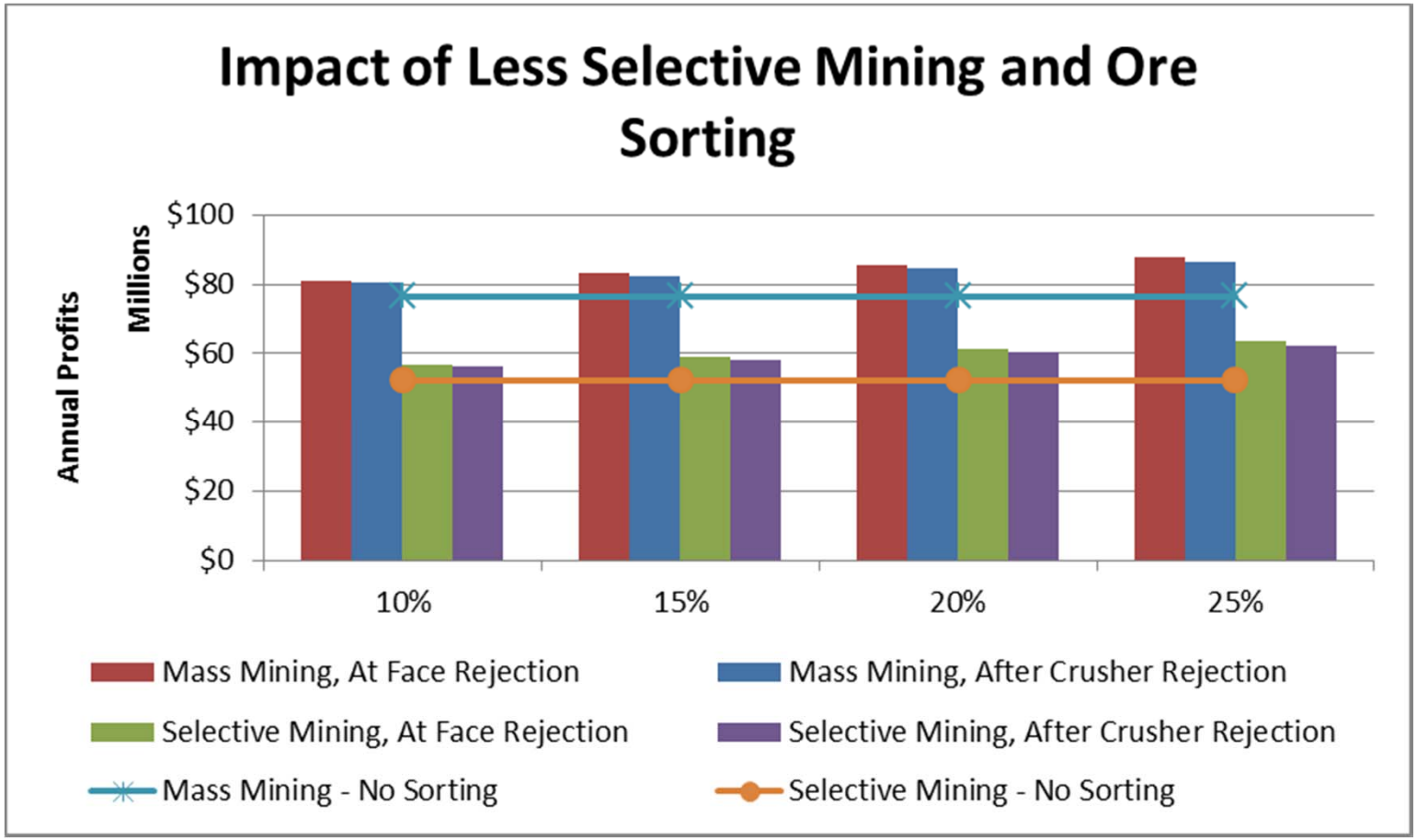


Potential and Limitations

Potential – cont'd

- Consider impact of increasing dilution in UG Au mine in adopting a less selective mining method
- Mining cost of $70/tonne (vs $100/tonne)
- 25% dilution (vs 10%)
- All else remains the same

Potential and Limitations



Potential and Limitations

Limitations

- General
  - Analysis complexity – limiting algorithms
  - False negatives
  - Lack of heterogeneity
  - Deposit variability
- Particle sorting
  - Feed presentation – one or two sides, clean
  - Requires consistency of particle size (<3:1 variation)
  - Maintainability of compressed air ejection systems
  - Max 300 tph/m sorter width for particles 200-300 mm (XRT, Opt, NIR) vs 10-30 tph/m for XRF
- Bulk sorting
  - Conveyor-based: minimum batch size
  - Entrained good material

Potential and Limitations

Realized Examples

- Iron ore
  - 56% Fe / 0.15% S sorted to 62% Fe / 0.04% S DSO by multi-stage XRT and Optical
- Tungsten-moly-bismuth
  - XRT rejected 50% of feed as waste to double the plant capacity
- Limestone
  - Low quality material, previously wasted, is upgraded such that only half the total material previously mined is now mined

SRK Assistance

*** - member of ICS (Intelligent Conveyor Systems) Consortium**

Conclusions

- Sorting is a concept and technology that has been around for a while and continues to develop
- Able to pre-concentrate ores by rejection of waste materials
- Pre-concentration reduces demands on water, energy, etc.
- Pre-concentration enables lower cost, less selective mining methods
- Pre-concentration can reduce mill opex and capex
- Can reduce cut-off grade to extend reserves and mine life
- Sensing technology is now able to detect most all elements and minerals in real time and at high speed
- Sorting technology can be throughput limiting
- Multi-stage sorting, including mix of bulk and particle sorting, can improve throughput
- Scope of potential applications is extensive

Thank-you!

- For more information:

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