“Innovation is destroying something you love” – Redefining Processing & Energy

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Innovation as Defined by Peter Drucker in 1967 *

- Innovation: purposeful and deliberate attempt to bring about, **through technological means**, a distinct change in the way man lives and in his environment – the economy, the society, the community, and so on.

- [Technology] has **become the battering ram which breaks through even the stoutest ramparts of tradition** and habit. …technological work is not done only for technological reasons but for the sake of a non-technological economic, social, or military end.

- …the test of **innovation is its impact on the way people live**.

Agenda

• The Goal(s)
• What Got Us Here, Won’t Get Us There
• Comminution Program
• Technology Roadmap
• Engagement Within our Innovation Ecosystem
• Key Learnings and Observations
• A Look Ahead
The Goal(s)

• 10 year goal: 50% reduction in energy, water, and footprint
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- Redefine cost curve (required as ore grades decrease)
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- Redefine cost curve (required as ore grades decrease)

- Address some of the questions from roadmapping session
  - “Why can’t mining do the stuff that is done elsewhere?”
  - “Do we see ourselves as others see us?”
  - “How do we get honest about risk?”
What Got Us Here, Won’t Get Us There

- Processing + Energy Groups merged
  → comminution is a key common issue
What Got Us Here, Won’t Get Us There

• Processing + Energy Groups merged
  → comminution is a key common issue

• Hatch technology scan → promising new technologies
  – Conjugated Anvil Hammer Mill (CAHM)
  – IMP Tech
Conjugate Anvil-Hammer Mill Breakage Zones

Anvil

Hammer

Crushing zone

Feed

“Hammer” Wheel

“Anvil” Wheel

Anvil Rock Exit

Anvil Liner Pocket
What Got Us Here, Won’t Get Us There

• Processing + Energy Groups merged → comminution is a key common issue
• Hatch technology scan → promising new technologies
  – Conjugated Anvil Hammer Mill (CAHM)
  – IMP Tech
• What else?
  – Technology road map → develop new portfolios of projects
  – CAHM → Larry Nordell and DEM → SAG optimization
  – Engagement within our innovation ecosystem
Comminution Program - CAHM

• Consortia developed (CMIC companies, Larry Nordell, UBC) for fatal flaw test work
  – Funding matched by MITACS
• Test work underway at UBC
Comminution Program - CAHM

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• NO FATAL FLAWS (yet; and yes, I’m shouting)
• Potentially ½ the energy of HPGR at same p80
  – Shear + compression combined breakage mechanisms

• Some sticking in pockets and subtle differences between DEM and real-world observations
  – Have ideas to resolve flow issue and recalibrating DEM
Comminution Program – SAG Optimization

• DEM, with enough computational horsepower, can model an entire SAG mill
  – Liners + end cones
• Builds on Cadia work
• Throughput ↑ or Energy ↓
  – 5-25% for existing SAG mills
  – Up to 30+% for optimized new SAG design
    • Mill torque control vs speed
• Risk management/tolerance
Technology Roadmap - Summary

**Objective:**
To unlock the intellectual power of the metallurgical industry to develop a roadmap for a transformational change in Energy/Mineral Processing

**Approach:**
- “divergent-convergent” process
- Identify strengths and constraints
- Jointly review the industry’s current design principles and developed alternate design principles
- Collaboratively hypothesize & develop shortlist of new approaches and solutions to that create significant value

**Focus**
- **CMIC 10yr Goals: 50% reduction of Energy, Water and Footprint**
- Long term goals: 10 year goals for CMIC and mineral processing
- Footprint = Mineral Processing + Mining inclusive of tailings being +50% of the overall footprint
- Mining is out of scope
Our current practice of “what works well” holds us where we are. To move forward we must continuously challenge what could be possible.

- Focus on maximising production capacity and throughput to drive value.
- Throughput trumps energy, recovery and efficiency
- You must accept variability that the mine sends you
  - Inflexible processing
- Reliant on quality up-front characterization
- Water is necessary
- Tailings are inevitable
Current Paradigms

- **Waste rock is a reality**, lower grades means more rock to the mill.
- **Blending enables consistency**: You must accept what the mine sends you. Mines are unpredictable, getting accurate “tons & grade” is hard enough so geochemical and geophysical properties all in real-time is not realistic.
- **Water is necessary**
- **Energy is required to liberate**
- **Throughput maximizes value**: maximum value is achieved by maximising throughout. 2nd consequence – large capital & footprint.
- **Infrastructure costs** drive project economics
- **Tailings** are inevitable
- We must continuously challenge what we believe to be true

Another Way?

- **Always reject Waste Rock**, through design, differentiation, sorting = pre-concentration
- **Accept that Orebodies are variable**, orebody knowledge is king, leverage variability into an asset = Real-time digital/TRUE model (Geo-Mine-Met-Env)
- **Always reduce Fresh Water**, water is not the answer
- **Always seek Energy efficiency**; effective liberation particle liberation maximizes value
- **Always scale from margin**: flexible, modular plants both decrease capital and footprint.
- **Shared Infrastructure**
- **Waterless Tailings** ensure sustainability
Technology Roadmap – New Design Principles

SMART SIZE REDUCTION
Use drill and blast and newer methods to reduce the size of the conventional crushing and grind circuits.

TARGETED ECO LIBERATION
Use energy & water efficient comminution technology.

GEO-MINE-MILL-ENV INTEGRATION
The mine and mill are now one integrated flow sheet. We have high fidelity on orebody characteristics, transparency and integration.

CONCENTRATION ALONG THE PATH
Mass rock(waste) rejection from mine face and along the path to the mill. We are using all available sorting technology before the conventional mill.

SMART PROCESSES
Design SMART processes (Plants) that are modular, flexible, and scalable.

DRY (SEPARATION) CONCENTRATION
Increasingly reduce the use of water to extract to final product. Engage other technologies to separate valuable mineral.

BRIGHT MINDS ECOSYSTEM
Recruit bright minds and build new intellectual ecosystem around the mining industry to deliver fast innovation that transforms the industry.
## Technology Roadmap – First Draft

<table>
<thead>
<tr>
<th>Pillars</th>
<th>Geo-Mine-Met Integration</th>
<th>Intelligent Selectivity</th>
<th>Eco-Liberation Concentration</th>
<th>Sustainable Metal Extraction</th>
<th>Bright Minds Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ready Now Technology</strong></td>
<td>Forward Looking</td>
<td>Particle Sorting</td>
<td>Grade-Recovery-Mineralogy</td>
<td>Metal Extraction</td>
<td>Build new intellectual ecosystem</td>
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<tr>
<td></td>
<td>• Analytics</td>
<td>• Speed of analysis</td>
<td>• Dry comminution (from cement industry)</td>
<td>• Selective Sort</td>
<td>• Drive open innovation and collaboration</td>
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<tr>
<td></td>
<td>• Modeling</td>
<td>• Accuracy</td>
<td>• Coarse float</td>
<td>• Flexible Processing</td>
<td>• Hackathon</td>
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<tr>
<td></td>
<td></td>
<td>• Sort criteria</td>
<td></td>
<td>• Mineral sensing</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• Size sorting</td>
<td></td>
<td>• Low mass high concentration extraction</td>
<td></td>
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<tr>
<td><strong>3-5 Years</strong></td>
<td>Predictive</td>
<td>Bulk rock rejection</td>
<td>30% energy reduction for Liberation</td>
<td>Integrated dry Processing</td>
<td>Collaborative Ecosystem</td>
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<tr>
<td></td>
<td>• Digitally enhanced</td>
<td>Advanced Model &amp; Simulation Mineral Sensing</td>
<td>• CAHM</td>
<td>• Low cost Modular process plants</td>
<td>• United messaging</td>
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<tr>
<td></td>
<td>• In-situ Assay by Mineral</td>
<td>• Large batch, Particle, Remote Multi-plant Operations, grade specific sort</td>
<td>• Smart Crush/grind</td>
<td>• In-situ leaching</td>
<td>• Government as a stakeholder</td>
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<tr>
<td></td>
<td>• Bore-hole</td>
<td></td>
<td>• Extend vertical / Disc mills to larger sizes</td>
<td>• Nano particle collectors/tagging</td>
<td>• EDC support</td>
</tr>
<tr>
<td><strong>5-10 Years</strong></td>
<td>Targeted</td>
<td>NSR in-transit Ore Selection</td>
<td>Targeted Liberation</td>
<td>Dry metal extraction processes</td>
<td>Open Sharing Ecosystem</td>
</tr>
<tr>
<td></td>
<td>• Separable particle scale</td>
<td>• Advanced Model &amp; Simulation</td>
<td>• Breakage on Mineral/Gangue Boundaries</td>
<td>• Next generation Lixivians</td>
<td>• Operators, vendors, EPCM’s, govt</td>
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<td></td>
<td>• Material tracking and reconciliation in real-time</td>
<td>• Mineral Recognition</td>
<td>• Low Grade Energy Recovery</td>
<td>• Fines recovery</td>
<td>• Audacious step-change developed collaboratively</td>
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<tr>
<td></td>
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<td>• Dry Metal Mineral Rec’y</td>
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<td></td>
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<td>• 1 step to product In-situ leaching</td>
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<tr>
<td><strong>End Results</strong></td>
<td>Mineral mapping &amp; tracking “end to end”</td>
<td>Mass Waste rock rejection (Value Concentration)</td>
<td>Increased energy and water efficiency</td>
<td>Selective waterless mineral recovery</td>
<td>Open technical sharing ecosystem hub</td>
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</tbody>
</table>

CMIC 10yr Goals ➔ 50% reduction of Energy, Water and Footprint
Orebody knowledge is the priority. The model includes Geological, Mining, Metallurgical, and Environmental criteria to ensure predictability and maximum value plus lowest liability.

Real-time digital information is used to selectively mine, reduce waste creation and reject waste ahead of processing.

Energy efficient comminution results in a targeted particle separation using limited water.

Waterless metal extraction without deleterious elements impacts ensures a sustainable environment.

People are at the center of everything we do. The new era enables open collaboration and utilizes the full ecosystem.

End Result
Mineral mapping & tracking “end to end”

End Result
In-flight Value Concentration “Mass Waste Rock Rejection”

End Result
Increased energy efficiency and less water

End Result
Selective mineral recovery

End Result
Open sharing technical ecosystem hub

CMIC 10yr Goals ➔ 50% reduction of Energy, Water and Footprint
Technology Roadmap – Additional Thoughts

• Transparency
  – Data → Information → Action or Knowledge

• Fundamentals – e.g. clays, rock fracture

• In-common processes so far
  → need some commodity-specific extensions
Key Learnings and Observations

• We’re all really busy
• Relationships really matter
  – Conductors and Champions

From A.P. Martin
Key Learnings and Observations

• We’re all really busy
• Relationships really matter
  – Conductors and Champions
• Organizational readiness matters
  – people + funding + risk + timing

• Diversity of commodities (and thus processes)
• Commercialization pathways are not well-understood

• Integration with other CMIC groups
  – Water treatment with ESI
  – Ore sorting and materials movement with Mining
  – Geo-Mine-Met-Env with all our groups
Engagement Within Our Innovation Ecosystem

- CANMETMining and NRC
  - Tailings, water, energy recovery
- Superclusters vs CRC
- Other Organizations

- Really limited by lack of bandwidth within industry and entrenched ways of thinking (rules) and doing things

  → We have some tough choices to make to really focus on outcomes

- Remember: “Innovation is destroying something you love…”
A Look Ahead

• People (and funding)

• Comminution program continues
  – Advance what we have and continue to scan

• Technology roadmap completion
  → Develop and advance new programs (themes)

• Systems and processes
• Engagement issues resolution
Acknowledgements

• CMIC team
• Volunteers
• Our respective organizations
Questions and Discussion

The greatest gift a leader can give is the way you think...
“Innovation in Minerals Processing: Distinguished Past and Uncertain Future”

Key Innovations Since 1948

Increases in scale
Dense media cyclones for minerals
High-pressure grinding rolls machines
High-intensity flotation (Jameson cells)
AG and SAG mills
Fine grinding mills (IsaMill)
Automated quantitative mineralogy
Process simulation
Instrumentation and control (sensors)

Key Barriers

Loss of skills and experience
• Loss of technical experts
• Loss of corporate memory
No time to think and play (and share)
Decline in innovation links
Retirement tsunami (especially leaders)
Risk acceptance
Timeframe – innovation time vs leaders
• 15 years average vs 3.5 years average