MINING THE GAP

Innovation Forum

Session 1

Presenting industry insights and current challenges for In-Place Mining and addressing the solutions that need to be developed

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A Mine of the Future; Mine Design Concepts for IPM

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Why Alternative Mining Methods?

Risks in Undeveloped Copper Projects

- 96% of 308 undeveloped copper projects associated with Environmental, Social, and Governance (ESG) concerns.

ESG Risks in Other Projects

- Iron Projects: 47% encounter medium to high ESG risks.
- Bauxite Projects: 88% encounter medium to high ESG risks.
- Copper Projects: 63% encounter medium to high ESG risks.

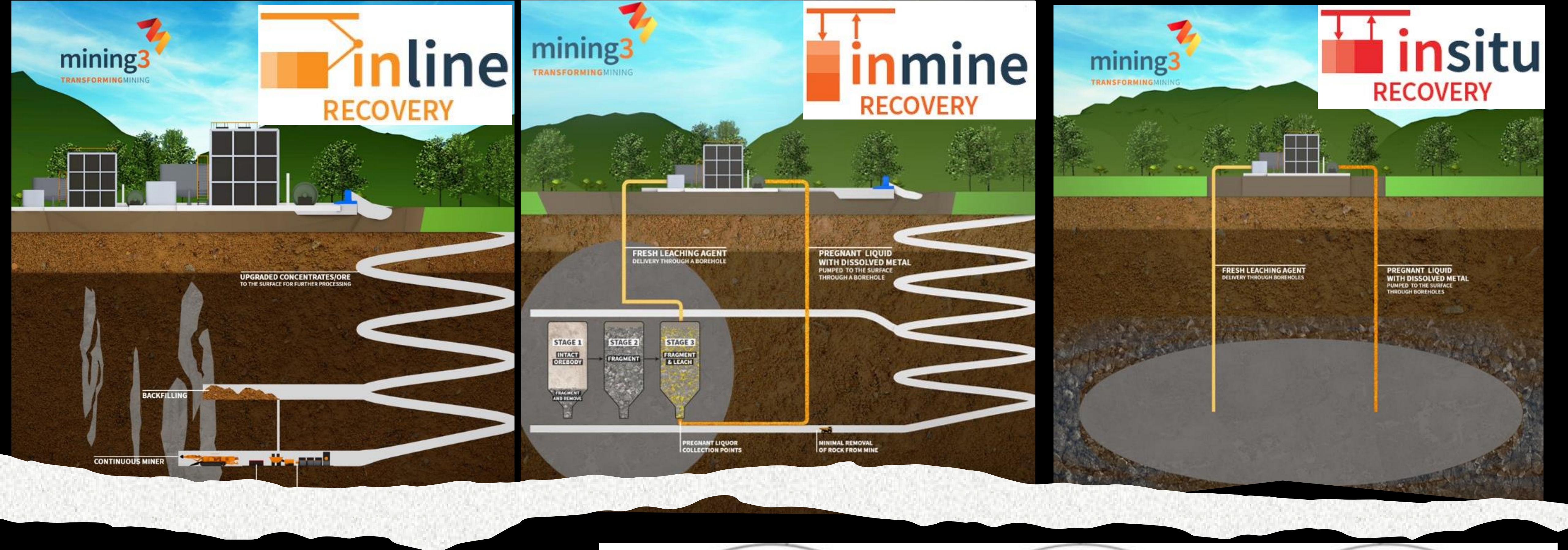
- **ESG Risks: Indirectly linked to market prices.**

Australia's Ore Reserves and Mineral Resources of selected commodities at operating mines in 2021.

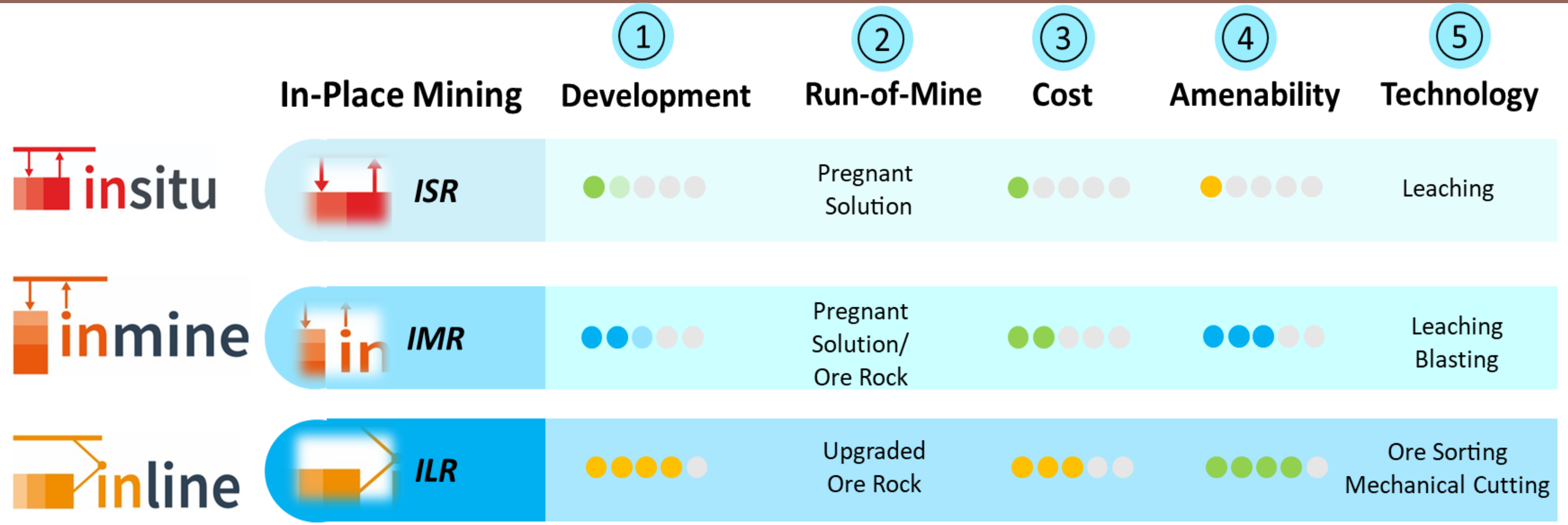
Commodity	Unit	Ore Reserves[2]	Measured and Indicated Mineral Resources[3]	Inferred Mineral Resources[4]	Reserve Life (years)	Resource Life 1 (years)
Bauxite	Mt	1,554	2,956	2,475	15	29
Cobalt	kt Co	146	247	22	28	47
Copper	Mt Cu	18.55	81.36	26.50	23	99
Gold	t Au	3,402	7,744	2,755	11	25
Iron Ore	Mt	11,205	30,643	42,653	12	33
Lead	Mt Pb	8.30	27.18	8.56	17	56
Lithium	kt Li	2,559	3,373	1,360	47	61
Manganese Ore	Mt	108	209	75	22	43

'Modifying Factors' are considerations used to convert Mineral Resources to Ore Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.

R. Valenta, D. Kemp, J. Owen, G. Corder, and É. Lèbre, 'Re-thinking complex orebodies: Consequences for the future world supply of copper', *Journal of Cleaner Production*, vol. 220, pp. 816–826, 2019.
É. Lèbre, J. R. Owen, G. D. Corder, D. Kemp, M. Stringer, and R. K. Valenta, 'Source risks as constraints to future metal supply', *Environmental science & technology*, vol. 53, no. 18, pp. 10571–10579, 2019.
https://www.ga.gov.au/digital-publication/aimr2022/australias-estimated-ore-reserves



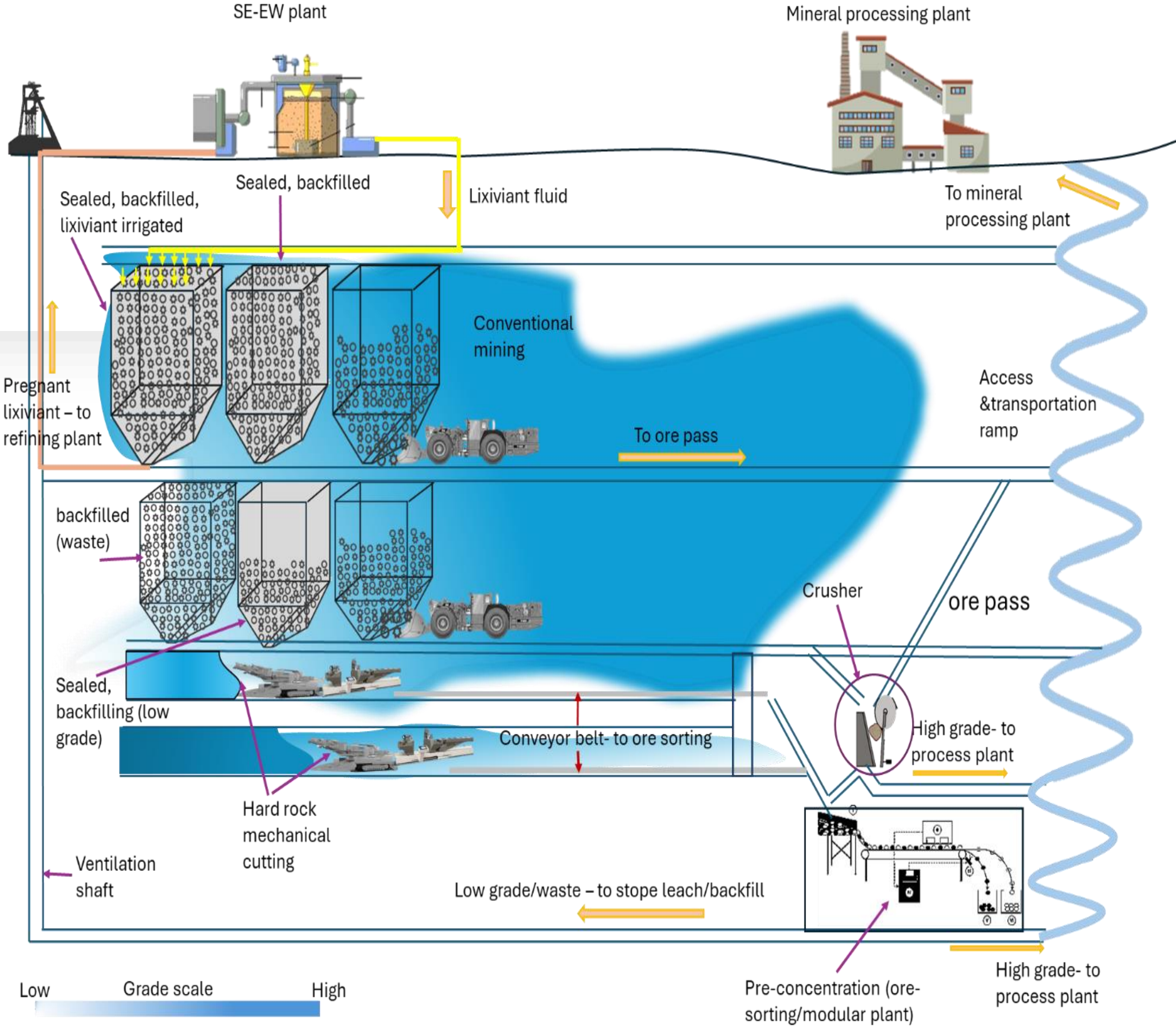
Alternative Mining Method-
In-Place Mining



Variant	Challenges
ISR	• Orebody must be located between impermeable layers and under aquifer level • Low permeability leading inefficient performance of the leaching solution. • Low recovery rates due to mineral characteristics
IMR	• The risk of preferential flow patterns, leading to flow channelling • Flow leakage into surrounding areas, posing environmental concerns, • Mineralogy limitations contribute to lower recovery rates.
ILM	• Low production rates, particularly in hard rock formations. • Ore sorting recovery (ore waste discrimination accuracy)

Reducing Risk by Hybrid IPM & CM

- For high-grade areas and initial production stages, conventional mining is recommended.
- In multi-layered ore bodies where, lower layers meet ISR requirements, ISR is advised.
- In the areas with highly diluted stopes or narrow ore bodies, ILM is recommended.
- Empty stopes can serve as leaching tanks with pre-sealed walls, and low-grade material can be recovered using IMR.
- Secondary stopes can be sealed and recovered using IMR.



Navigating Complexity for Optimum Decision

- **OPEX and CAPEX Dynamics:**
  Impact on costs over the mine's lifespan?
- **Process Satisfaction:**
  Fulfilling the full-capacity processing plants?
- **Grade-Tonnage Distribution Consideration:**
  Incorporating diverse grade distributions?
- **Economic Viability:**
  Minimum recovery/upgrading for financial reliability?
- **Integrated Mine Planning:**
  Transforming mine planning dynamics?
- **Strategic Setup:**
  Optimal location for efficiency?
- **Mining Boundaries**:
  Expanding mine for higher resource utilisation?
- **Cut-off-Grade Calculation**
  Minimum grade requirement for each process?

The Challenge:

A Multi-dimensional decision-making problem with uncertain inputs and interconnectivity of the main variables

OptIn3

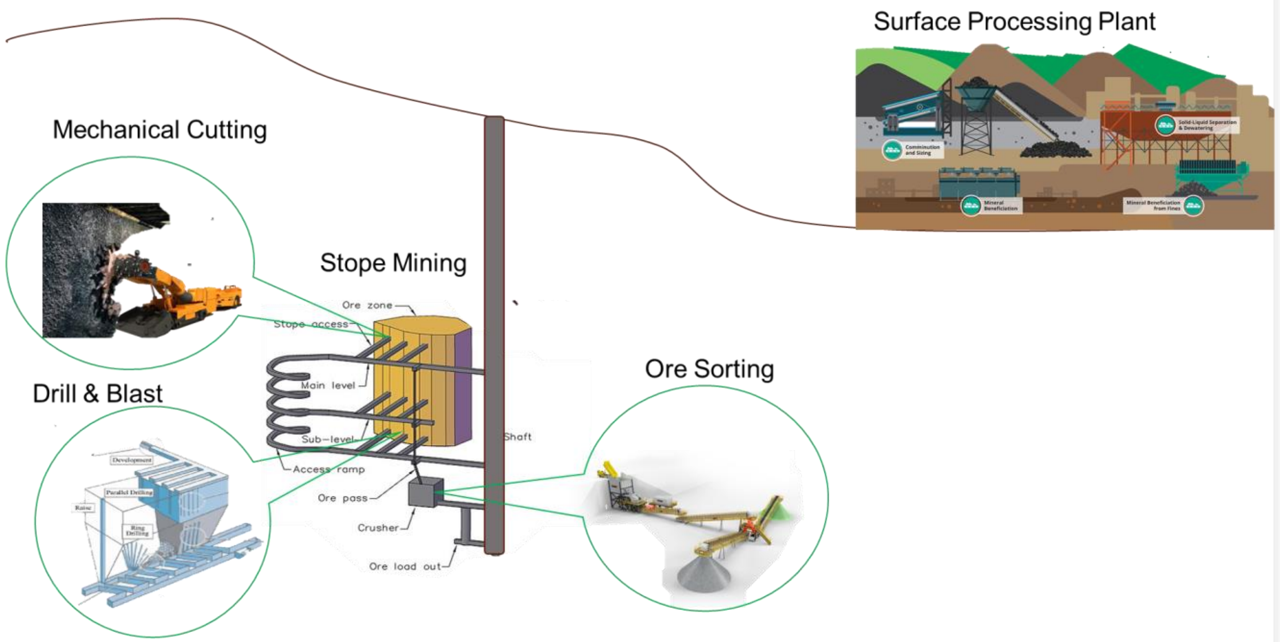
Optimised Decison Making for In-Place Mining

Rigorous Mathematical Framework:	Robust mathematical foundation ensuring precision in decision-making.
Flexibility with Constraints:	Adaptable design allowing integration of diverse operational constraints.
Scenario-Based Analysis:	Capability for scenario-based analysis, empowering informed decision.
3D Ore Resource Distribution:	Incorporates the 3D distribution of ore resources for realistic modelling.
Cost-Dependent Optimisation:	Addressing cost dependencies, optimizing strategic decisions.
Flexible Applicability:	Applicable to both Brownfield and Greenfield projects.
Dynamic Cut-off Grade:	Calculating dynamic cut-off grade, ensuring maximum NPV

TRANSFORMINGMINING

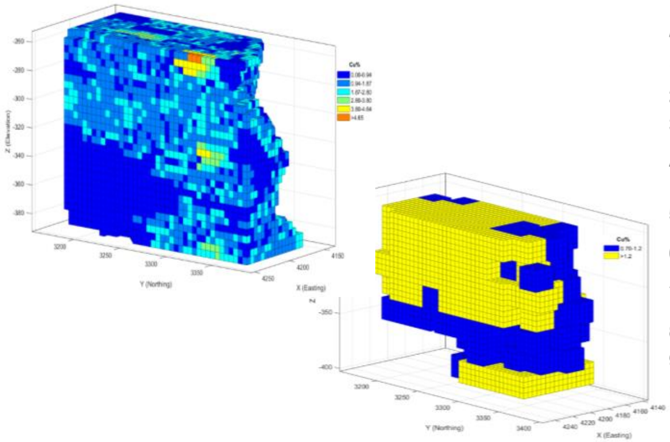
A Show Case

- Can the integration of pre-concentration bring changes?
- What is the optimum capacity for pre-concentration?
- In what ways does pre-concentration impact the economic viability of our mining operations?
- How does pre-concentration influence resource utilisation?
- Which pre-concentration technologies best works with ore characteristics?
- How does the introduction of pre-concentration influence our long-term mine planning strategies?
- What are the cut-off-grade and cross-over cut-off-grade?
- What are the target stopes for pre-concentration?



Solution Framework

Step 1: From a Block Model to a Stope Model

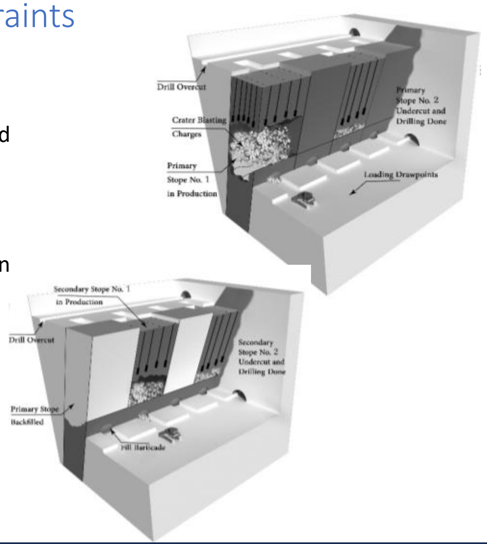


A Generic Pseudocode for Stope Layout Optimisation

```
Input: Block Model (B)
Output: Economic Minable Stopes (S)
  while B is not empty
      Select block b with the lowest coordinates
      B_s ← Create stope s of a pre-specified size on block b
      if the value of stope s is positive
          Update S←s
          Update B←B-B_s
      else update B←B-b
      end-if
  end-while
```

Step 2: Set Operational Constraints

- ❖ Two adjacent stopes cannot be mined simultaneously
- ❖ Levels opening can be sequenced
- ❖ Lag can be implemented between extraction and backfilling
- ❖ Mechanical cutting zones can be separated
- ❖ .....



Step 3: Construct a Cost Model

- ○ Define OPEX and CAPEX for each possible mining method
- ○ Define OPEX and CAPEX of potential processing stream
- ○ Define cost adjustment factors for mining and processing:
- ○ Specify technical parameters such as recovery, mass reject, dilution, ...
- ○ Set upper and lower bounds for mining and processing
- ○ Define opportunity cost for undercapacity working situation
- ○ Define cost-production functions

CM	ILM	Mining_Fixed_Cost ($)	Mining_Cost_CM ($)	Mining_Cost_ILM ($)	Processing_Cost_CM ($)	Processing_Cost_ILM ($)
2945128.79	2806534.49	0.00	1976340.23	1949591.496	$ 1,050,504.01	$ 630,571.24
4513675.69	4301267.42	0.00	2050495.46	2022743.076	1089920.486	654231.2084
10231626.52	9750138.21	0.00	2287410.45	2256451.543	1215850.293	729821.319
7282879.66	6940155.91	0.00	2170807.06	2141426.32	1153870.92	692617.8345
5660103.45	5393745.64	0.00	2101778.24	2073331.775	1117179.34	670593.4968
2886989.50	2751131.17	0.00	1973492.19	1946782.008	1048990.165	629662.5414
5269212.84	5021249.89	0.00	2084544.36	2056331.141	1108018.84	665094.8522
6553964.17	6245542.33	0.00	2140280.24	2111312.663	1137644.692	682877.9451
6366190.00	6066604.59	0.00	2132292.75	2103433.289	1133399.026	680329.459
5338352.68	5087136.08	0.00	2087611.01	2059356.293	1109648.891	666073.3002
3001905.54	2860639.39	0.00	1979114.19	1952327.915	1051978.481	631456.2962
5653211.62	5387178.13	0.00	2101476.55	2073034.165	1117018.978	670497.2387

Step 4: Production Scheduling and Value Calculation

$$\sum_{t\in T}\sum_{p\in P}\sum_{s\in S}(1+\varepsilon)^{-t}x_{sp}^{t}\vartheta_{sp}-\sum_{t\in T}\sum_{l\in L}C^{l}\Theta_{l}^{t}(1+\varepsilon)^{-t}-\sum_{t\in T}\sum_{s\epsilon S}\sum_{p\epsilon\mathcal{R}}\beta_{sp}^{t}\,\delta_{s}^{p}-\sum_{t=1}^{T}\sum_{s\epsilon S}\sum_{p\epsilon\mathcal{R}}\omega_{s}^{t}\gamma_{s}$$
$$-\sum_{t=1}^{T-1}\sum_{p\epsilon P}\frac{(\tau_{p}^{t+1}-\tau_{p}^{t})C^{p}}{(1+\varepsilon)^{t}}-\sum_{p\epsilon P}\tau_{p}^{1}\,C^{p}-\Phi DC^{a}-C^{I}$$

x_{sp}^{t} : if stope $s \in S$ is mined in period $t \in T$ and is sent to processing stream $p \in P$.

y_{s}^{t} : if stope $s \in S$, backfilled in period by $t \in T$.

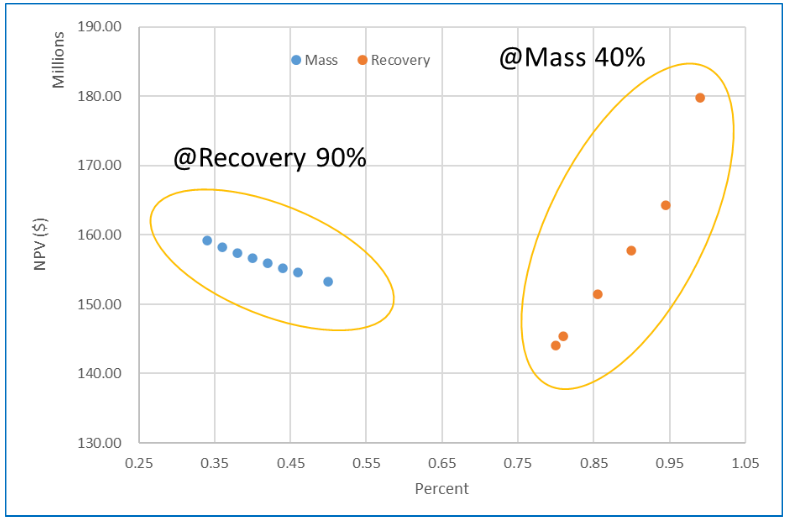
τ_{p}^{t} : if processing stream $p \in P$ is employed in time t.

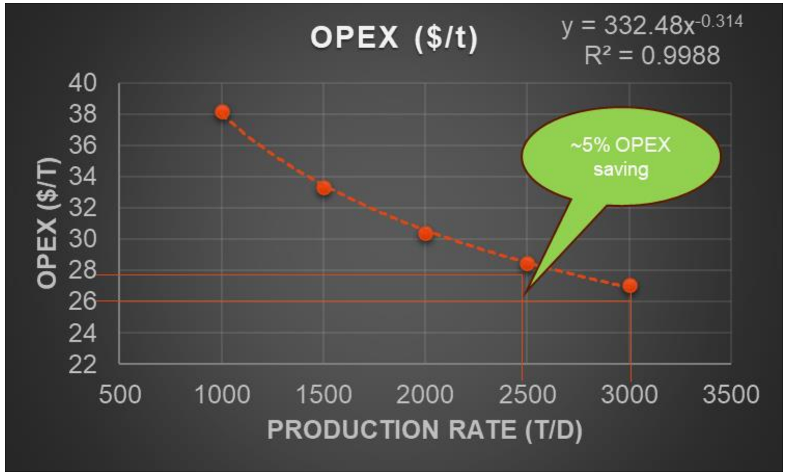
Θ_{l}^{t} : if level $l \in L$ is opened in time $t \in T$.

Φ : lowest level of the mine.

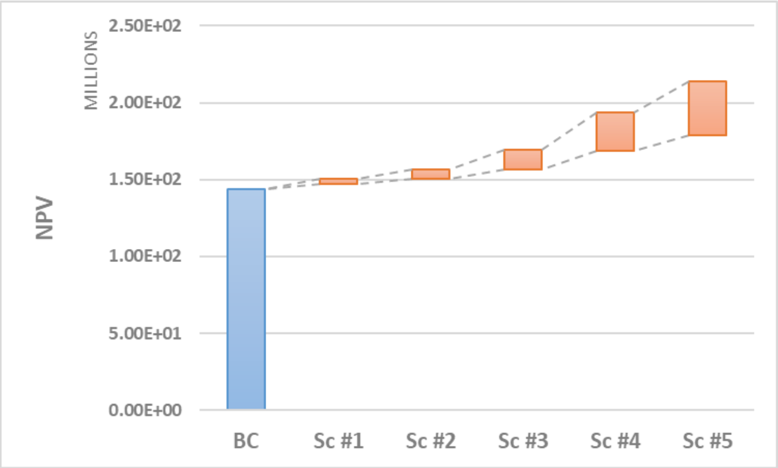
β_{sp}^{t} : tonnes of material backfilled in stope s from processing stream $p \in \mathcal{P}$ in period $t \in T$

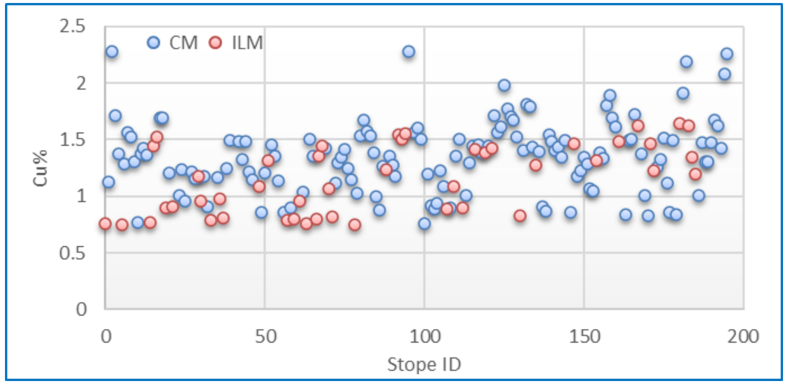
ω_{s}^{t} : tonnes of material backfilled in stope s from surface resources in period $t \in T$





Typical Results





Thank You

Christine Charles

Chairperson of the Board

ENVIRO COPPER
THE INVISIBLE MINE

A "plant of the future" to match the "mine of the future"

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ISR: Mine of the Future, Plant of the Future

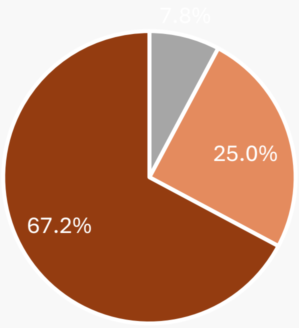
Christine Charles

September 2024

About EnviroCopper

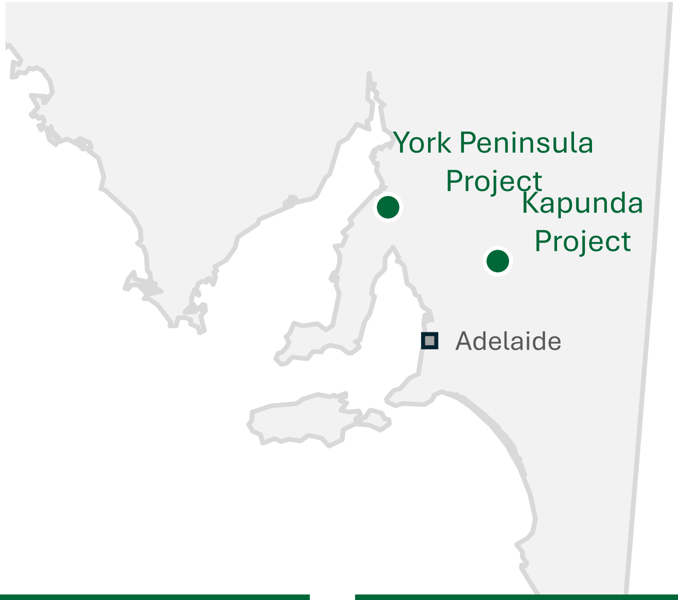
Company Background

- Private company incorporated in 2017, established by team of ISR specialists and mining entrepreneurs to commercialise copper ISR opportunities
- Circa **$8.5 million** in cash and in-kind expended on projects to date
- Awarded **$2.8m CRCP grant** which advanced research in ISR extraction in a fractured rock environment.
- **$2.6m** funding agreement **with BHP** to complete in ground trials at Kapunda and recent corporate funding deal and technical partnership with **Alligator Energy**.



Company Ownership

- Alligator Energy
- Thor Mining
- Directors & Founders



Kapunda

- EnviroCopper **Earning 75%**
- JORC resource **119kt Cu** with gold mineralisation upside
- Siltstone, fracture fill mineralization
- Completed column leaching and in ground hydro test work
- Currently completing in ground recovery trials

York Peninsula

- EnviroCopper **100%**
- JORC resource **114kt Cu** (JORC exploration target **428 – 713kt Cu**)
- Deeply weathered troughs hosting oxidized copper with impermeable boundary rock
- Completed lab and column leaching, currently undertaking in-ground hydro testing

ENVIRO COPPER THE INVISIBLE MINE

EnviroCopper's Core Mission

1. *To build a world class team and become a technology leader in the application of ISR for copper (and gold) recovery*

2. *Unlock value through the **low environmental impact development** of stranded copper (and gold) assets utilising ISR*

Copper Supply – Structural Issues

With increasing community sensitivities towards the impact of mining on the environment, timelines for mining project regulatory approvals continue to increase. Adversely impacting the ability of the industry to bring on new supply in a timely fashion.

Research undertaken by the University of Queensland into the supply constraints facing the copper market indicated that 75% of copper inventory faces "non-technical" ESG challenges to their development. With their research concluding that many of these issues will not be resolved through an increase in copper prices.

"The average mine lead time continues to trend upward, reaching 17.9 years for mines coming online in 2020–23 compared with 12.7 years for mines that started up 15 years ago.

All the main points that we presented in our previous study have held true in this iteration. It takes an average of approximately 16 years for a mine to go from discovery of a deposit to startup. Open-pit mines have a longer average lead time than underground mines due to the longer exploration and permitting phases."

S&P Global

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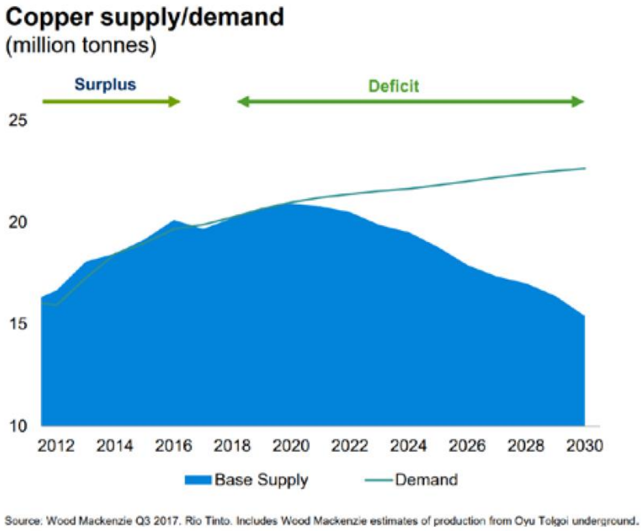
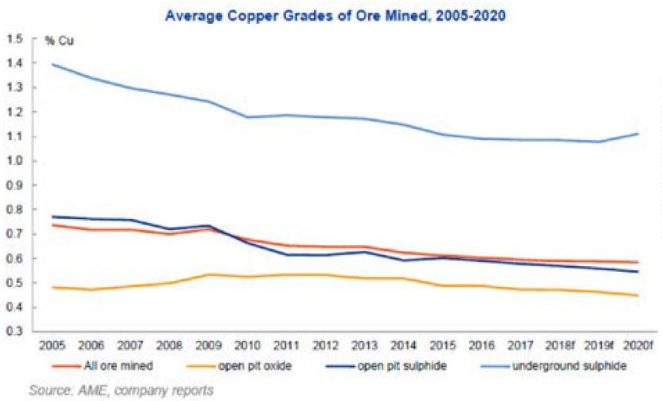
Undeveloped Copper Deposits

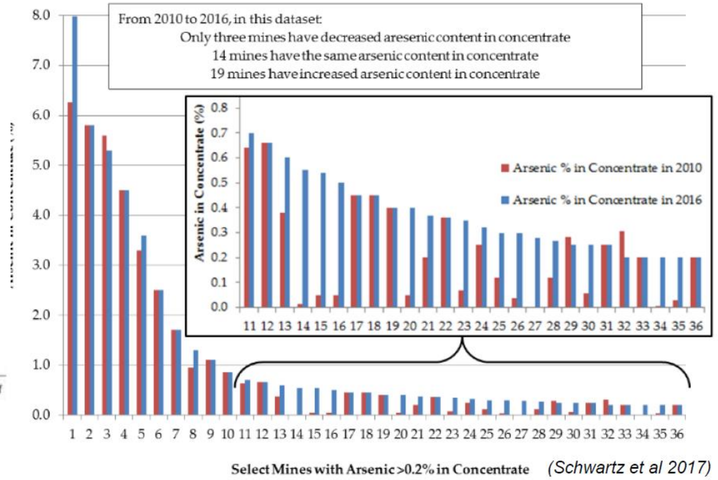
- Approx 1 billion tonnes copper metal*



Supply Gap



Decreasing Grades

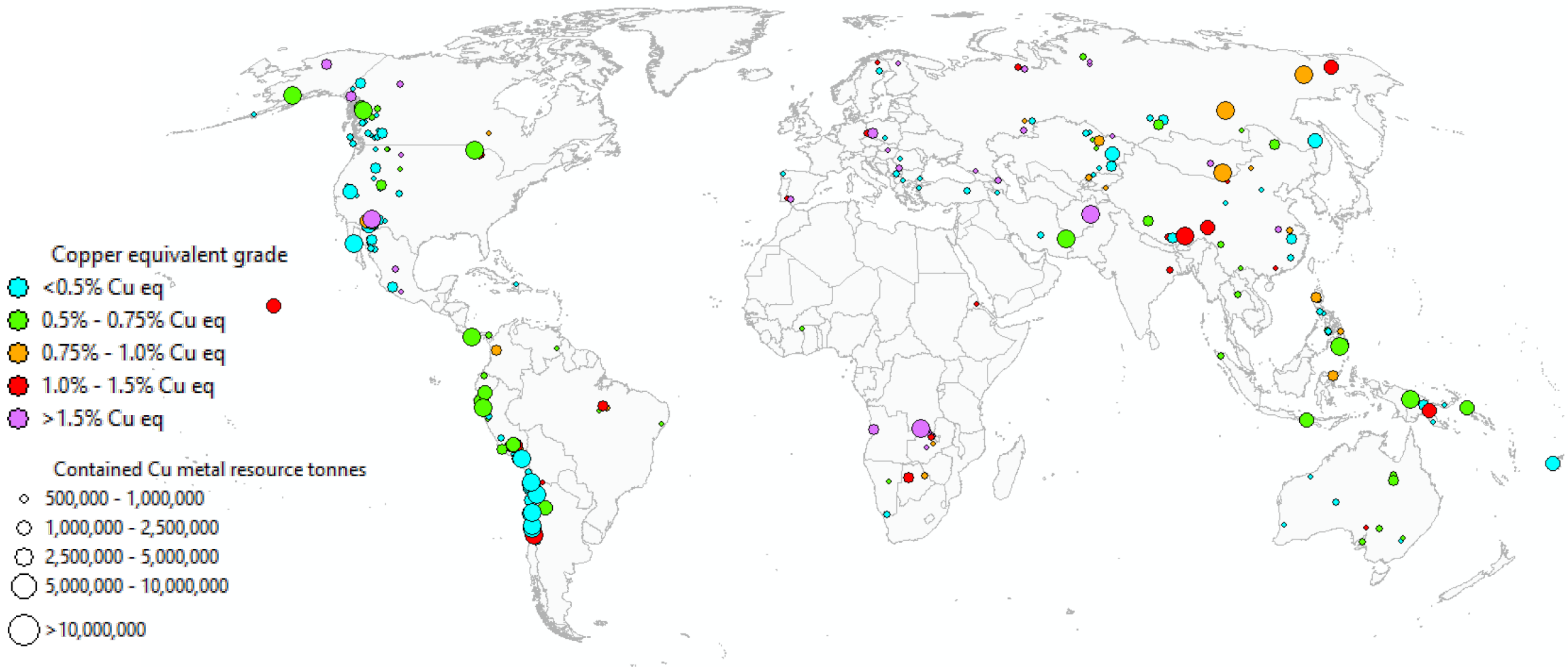


Increasing Complexity

Can a Simple Price-rise Unlock Complex Copper Orebodies?

**S&P Market Intelligence; >500kT Cu metal; not production-visible*

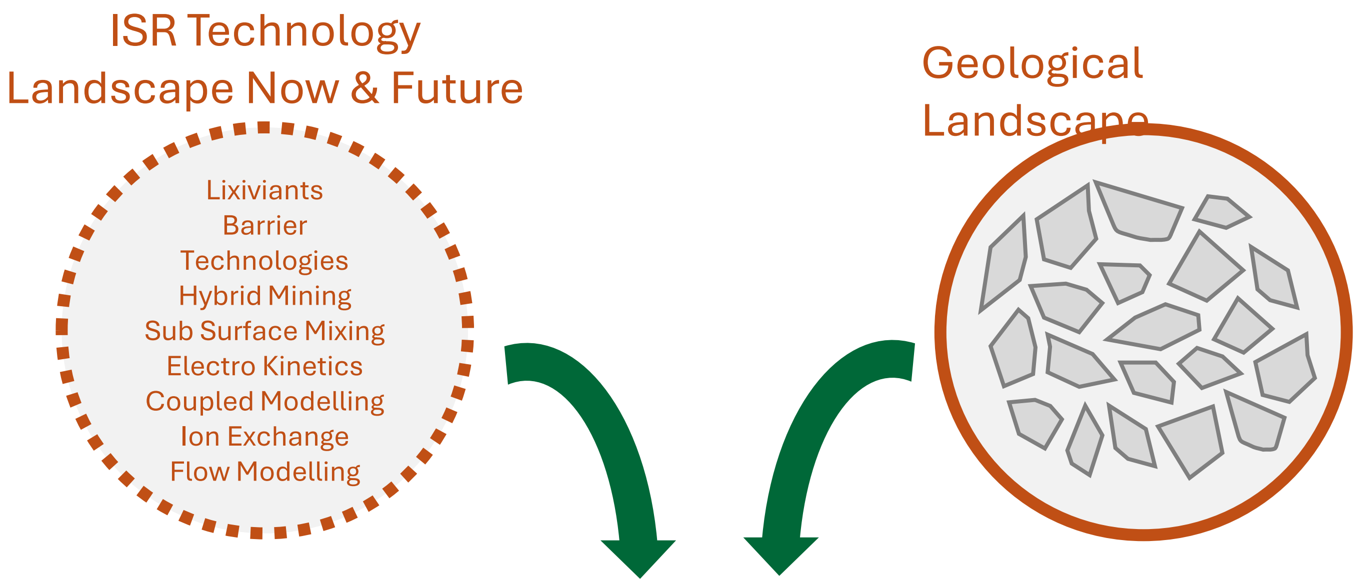
Undeveloped Copper Deposits



Source: S&P Market Intelligence

The University of Queensland Australia | Create change

The Big Picture



Value is created through

1) Understanding the impact and application of the emerging ISR technical landscape
2) Assessing which geological conditions these technologies can be applied in the optimal way
3) Derisking project development through lab, simulation and in ground trials

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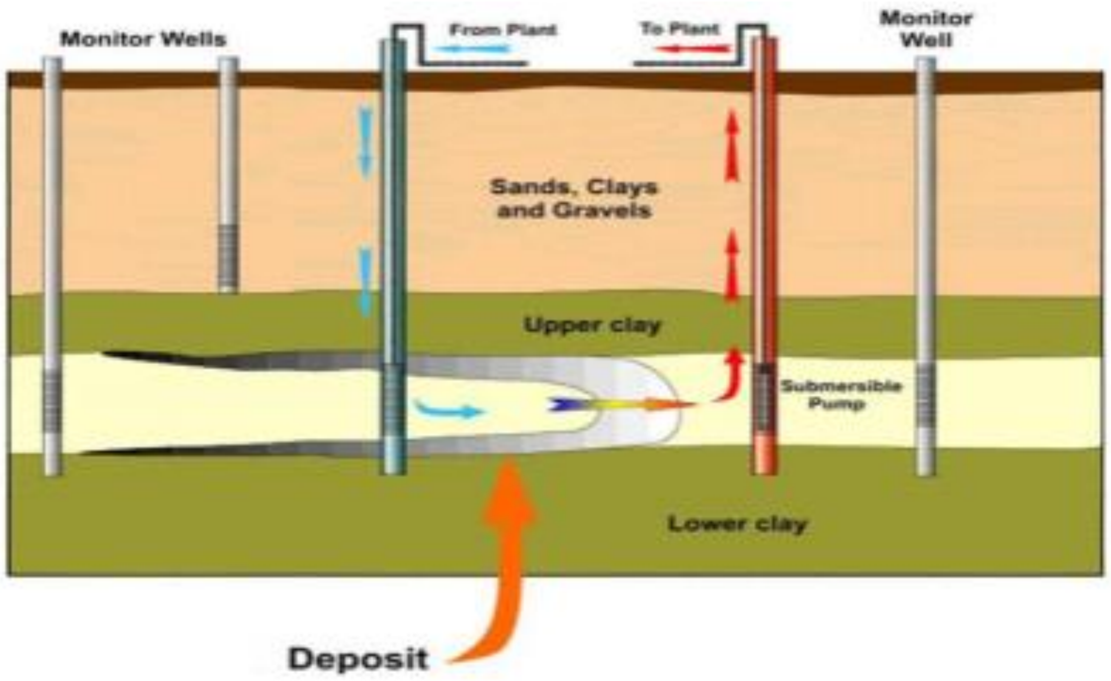
What is ISR?

In the right geological setting - ISR is a high volume, low pressure and low-cost bulk mining operation

- Recovery is achieved through production and recovery wells using a lixiviant to dissolve the ore into solution
- Successfully used in uranium since the 60's. ISR mines are some of the lowest cost sources of Uranium production
- Has been successfully applied to copper in the US (Arizona)
- Advances in lixiviant and drilling technology have and will continue to broaden the scope of ISR application in base and precious metals



CRC-MInSitu Recovery Research

Current Knowledge Gaps (from U Industry)	Research Outcomes (for Cu & Au)
Current lixiviants are environmentally unsuitable and significantly change groundwater pH	Targeted suite of biodegradable lixiviants (ECHA) identified
Difficult to monitor fluid flow in fractured rock for environmental & economic management	Accurate fracture/flow model developed - allows simulation of fluid flow in fractured rock environment
Difficult to accurately estimate metal recovery leading to lower confidence in production economics	Fracture/flow work was coupled with reactive transport model to simulate metal recovery rates and allow testing of economic parameters
Environmental issues a community concern- difficult to get community acceptance	Communication of monitored environmental values in a mining project leading to social acceptance.
No “template” for ISR and regulatory framework currently not the best fit	Designing an industry Cu & Au ISR regulatory template and framework for future projects

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CSIRO

mining3
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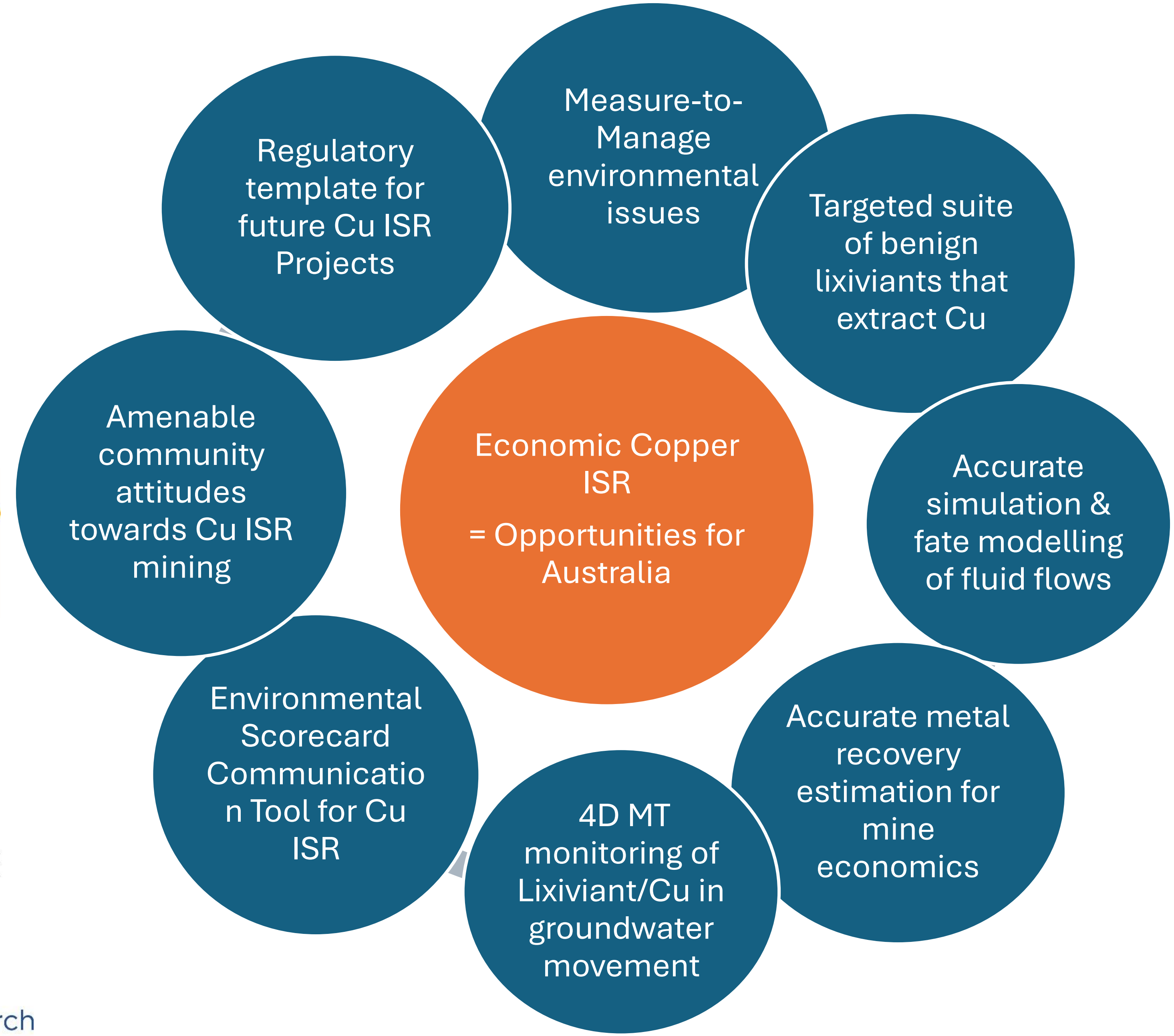
Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Program

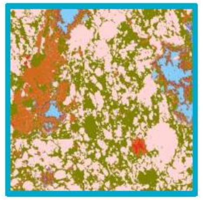


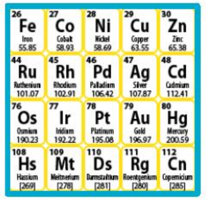
The Journey – Panel of Lixiviants to Extract Cu

Orebody characterisation and hydrometallurgical leach tests

Design and optimise lixiviant system, estimate probable recovery and recovery rates

Phase 1. Mineralogical characterisation ✓





Phase 2. Lixiviant system screening ✓

Phase 3. Mini-column leach tests ✓

Phase 4. Large-particle saturated column leach tests

Phase 5. Value-metal recovery

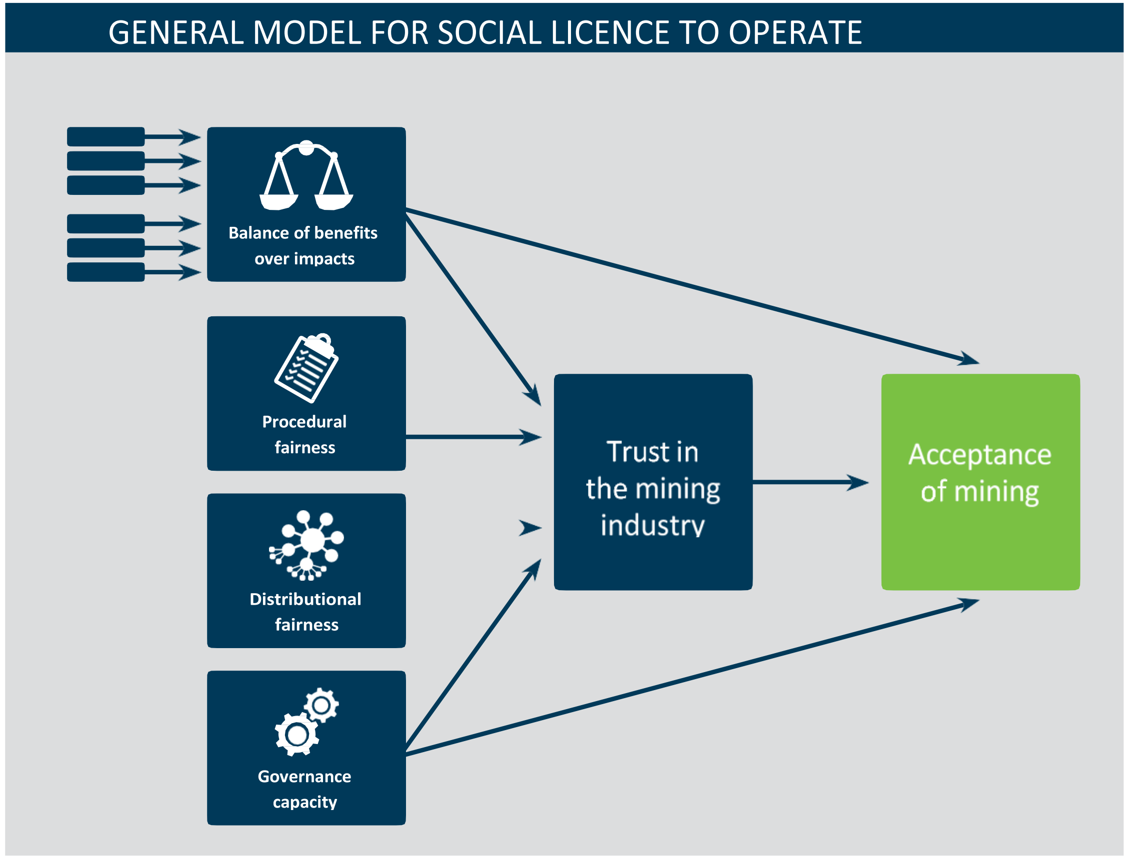
CSIRO

The Journey – Community Engagement

CSIRO – Social Science Group at Land & Water outcomes:

Supportive of Copper ISR Mine if:

- ✓ Genuinely listen to issues and concerns
- ✓ Regular & varied communication
- ✓ Avoid overstating benefits and minimising risks
- ✓ Well regulated



18 months of Land Access negotiations within Local Govt Act 1999, Heritage Act 1993 and WHS Act 2012.

Light Council now looking at Private Public Partnership

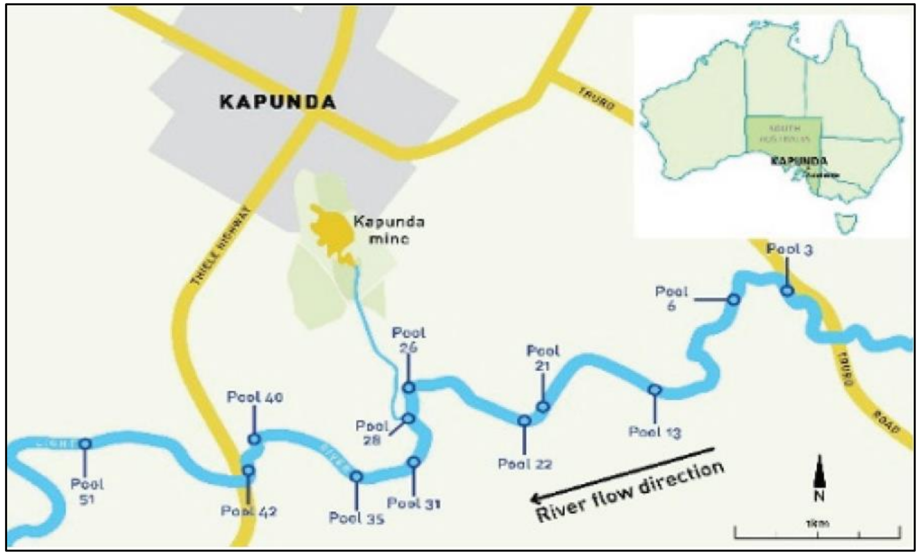
The Journey – Environmental Monitoring

› CSIRO Land and Water developed a mining industry first, Web and Ap based Environmental Scorecard application based on site specific Water Quality Indicators (WQI).

› Water quality indicators are a tool for assessing potential impacts to aquatic ecosystems from contaminants and other stressors.

› This lead to the development of proposed management actions for a range of water quality indicators

› Further partnership with CSIRO with final trials to commercialise their real time downhole Vesi Sensors.

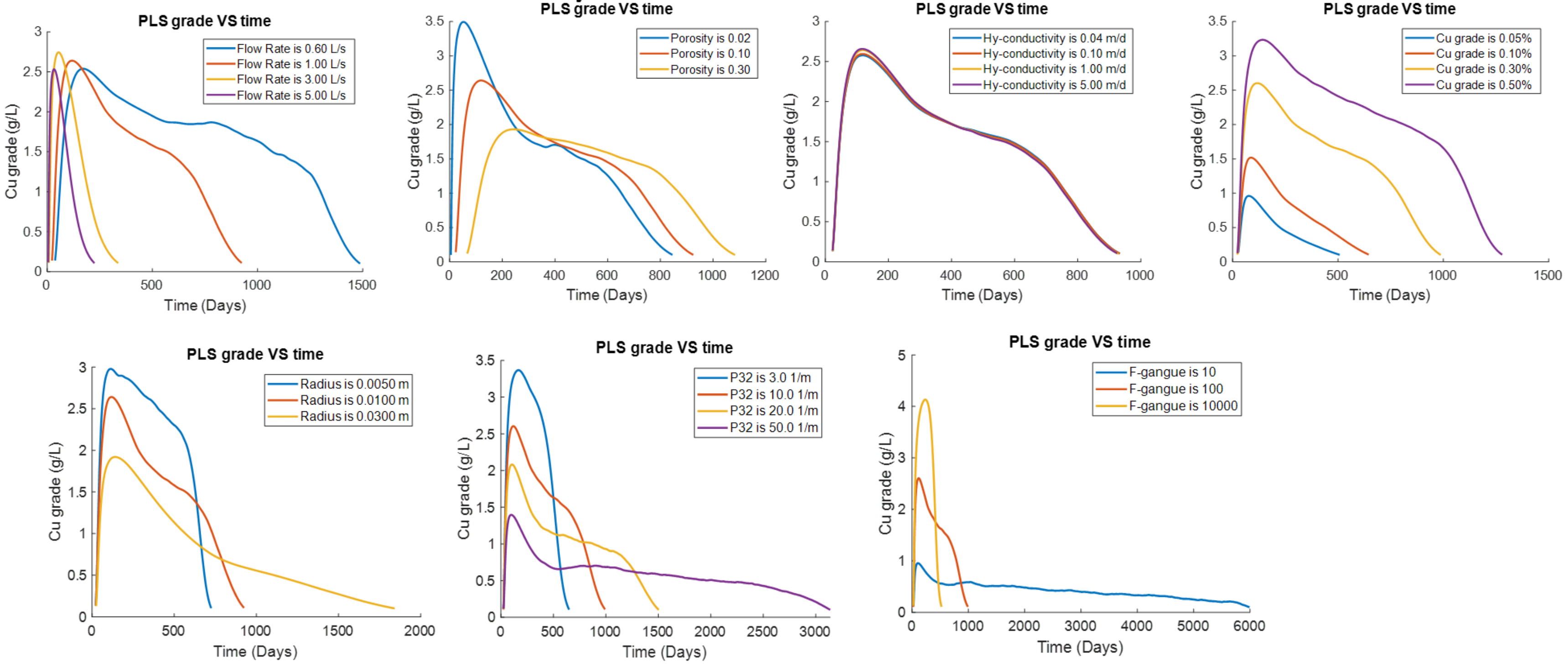


A baseline water quality monitoring program commenced in November 2018 to derive Light River site-specific guidance values (S-GV) for water quality indicators

No exceedance DGV/S-GV	No action; continue seasonal water quality monitoring
Minor change	Increased water quality monitoring undertaken to identify source(s) or seasonal variability
Moderate change	Increased water quality monitoring to identify source(s) and variability. If source of water quality change identified to be associated with ISR operations - management and controls undertaken (as soon as reasonably possible) to reduce impacts on water quality and aquatic ecosystems.
Major change	Increased water monitoring to identify source(s) and variability. If source of water quality change identified to be associated with ISR operations – management actions (postponed/stopped) and remediation (as soon as reasonably possible) to clean-up and e impacts on water quality and aquatic ecosystems.

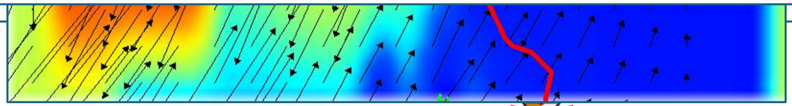
The Journey – Fracture/Flow modelling

Parametric study results



Conclusions:

1. Lower flow rate → higher average PLS grade and longer recovery time
2. Lower porosity → higher peak PLS grade and shorter recovery time
3. Hydraulic conductivity alone does not affect the ISR performance given same flow rate and porosity.
4. Higher in-situ SSA (smaller particle size) → higher PLS grade and shorter recovery time
5. Lower P32 (given same flow rate) → higher PLS grade and shorter recovery time (more acid for Cu reaction)
6. Lower F-gangue (faster the gangue-acid reaction) → lower PLS grade and longer recovery time



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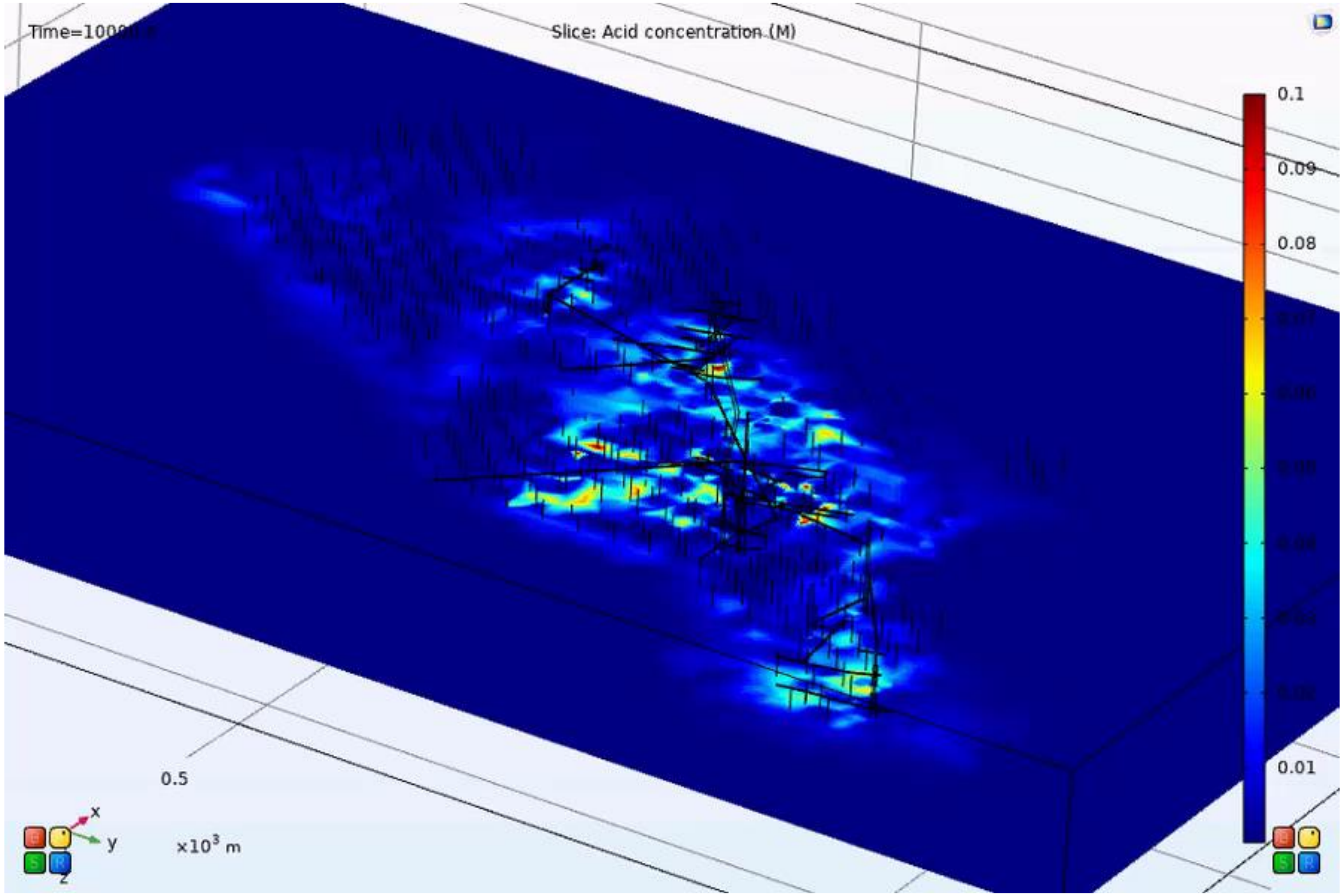
The Journey – Fracture/Flow modelling



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The Journey – Regulatory Framework

- First phase of in ground work is equivalent metallurgical studies in conventional project.
- Only U ISR experience under RL
- Initial ISR investigation needs to be under an Exploration License to minimise time and cost - otherwise juniors may be reluctant to adopt the technology.
- Developed SELT concept for hydrogeological and test circulation work – Scoping Studies
- ECR successfully received Ministerial Determination November 2020.

STAGE OF PROJECT	EXPLORATION PEPR					RETENTION	
FOCUS OF ACTIVITY	EXPLORATION	JORC RESOURCE	PROOF OF CONCEPT	SCOPING STUDIES	PRE FEASABILITY	DFS	PRODUCTION
CONVENTIONAL MINING	Drilling $$$$	Desktop study $$	Desktop studies $$	Drilling for Metallurgical studies $$$$	Bulk Sampling $$$$	Production $$$$	
				equivalent activities			
COPPER & GOLD ISR	Drilling $$	Desktop study $$	Desktop Studies $$	Site Environmental Lixiviant Trials (SELT) $$	Pilot Site / Production $$$		
URANIUM ISR	Drilling $$	Desktop study $$	Desktop Studies $$	Field Recovery Trial (FRT) In ground lixiviant trials* $$$$	Trial Mining/Pilot Plant $$$$	Production $$$$	
				*EPBC Act triggered due to Radionuclides			

What Our Work Means

List of Firsts

- ✓Testing benign lixiviants in-ground that extract copper
- ✓Fracture modelling to better estimate resource accuracy
- ✓Combined Fracture & Fate modelling for environmental risk mitigation
- ✓Positive support from the Kapunda community, 500 metres from mine-site
- ✓Envirocopperscorecard.com.au a leading approach
- ✓4D MT for tracking copper extraction
- ✓Regulatory framework for Scoping ISR project

Copper ISR - Proven Recovery Method

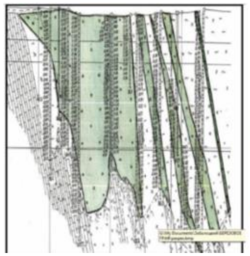
Economic Copper recovery has been proven in the US (San Manuel deposit) and in Russia (Gumeshevskoye) in low copper price environments

Gumeshevskoye

- Gumeshevskoye Copper Deposit in the Ural Mountains of Russia, was mined over nearly 300 years
- Successfully operating as a copper ISR mine since 2004 (low copper price environment)

	PLS	Capacity	Capex	Full Opex
Economics	1-4 g/l	5000 t/yr	US$20m	US$2,700/t

Source: CSA Global, M, Seredkin



Source: CSA Global, M, Seredkin

San Manuel

- ISR used to extend mining operations at the San Manuel copper owned by Magma Copper
- Successfully recovered copper from 1995 until closure of Magma Copper's North American business

"ISR Production ramped up for several years until the annual copper production reached 40 million pounds at an operational cost of 40 cents per pound. With the low capital investment required, the total costs including depreciation and amortization was still under 70 cents per pound."

Gary Sutton, Exploration Manager - https://www.mining.com/web/in-situ-copper-leaching-is-a-proven-technology/

Florence

- [insert]

ENVIRO COPPER THE INVISIBLE MINE

Kapunda

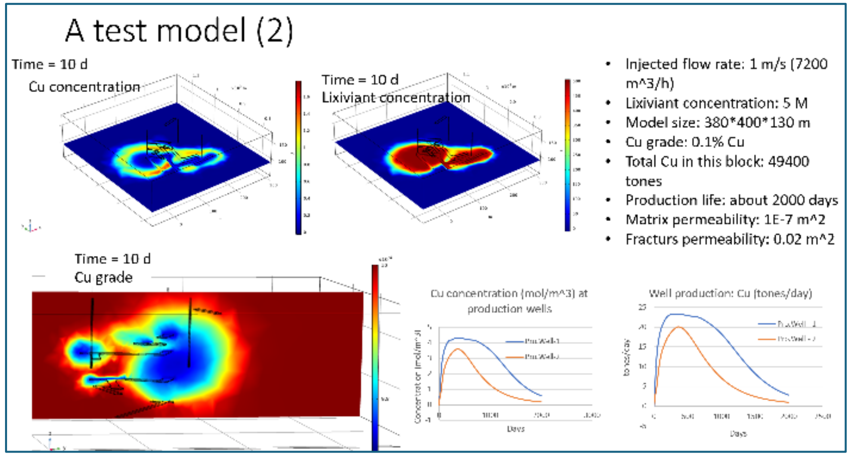
Kapunda is a near term copper/gold ISR project currently in detailed feasibility and mining lease application

- Desktop review ✓
- Resource definition ✓
- Lab Test work ✓
- Hydro Test work ✓
- Column Leaching ✓
- Scoping Study ✓
- SELT Trials & DFS
- Mining Lease Application
- Production

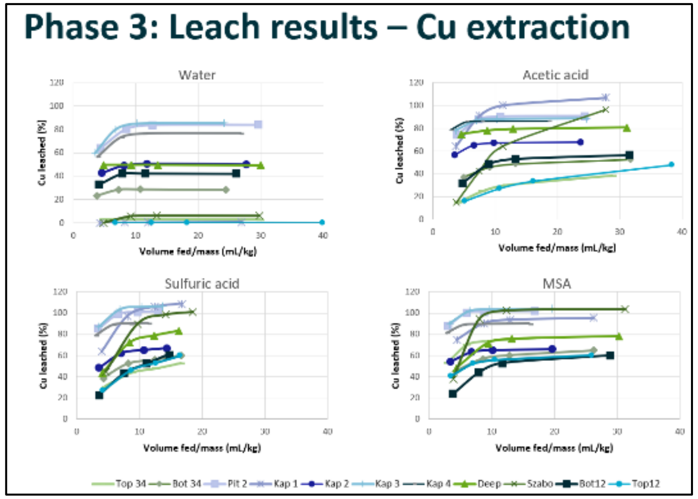
Interest	**ECL has earned 50% project interest and is earning to 75%**
Location	150 km north of Adelaide, South Australia
Infrastructure	Poximity to power, water and workforce
Resource	JORC resource 102MT @ 0.23% Cu (119,000t Cu), significant gold upside potential
Geology	Siltstone, fracture fill mineralisation
Social	Built strong research-based community support for project
ISR Characteristics	- Depth of mineralization (40-250m) - Visible core is highly weathered and fractured, likely to be permeable - Mineralisation sits under water table, right hydrogeological environment - Copper already present in water monitoring bores (suggesting readily leachable)

Kapunda is currently conducting in ground trials for definitive feasibility

Kapunda *Advancing ISR Technical Research*



ECL has worked with University of Adelaide to develop coupled hydrothermal/fluid flow model suitable for modelling and estimating metal recoveries from a fractured rock aquifer allowing accurate simulations of wellfield designs to be tested



ECL has been working with CSIRO Minerals in WA to look at the effectiveness of a range of environmentally suitable lixiviant systems

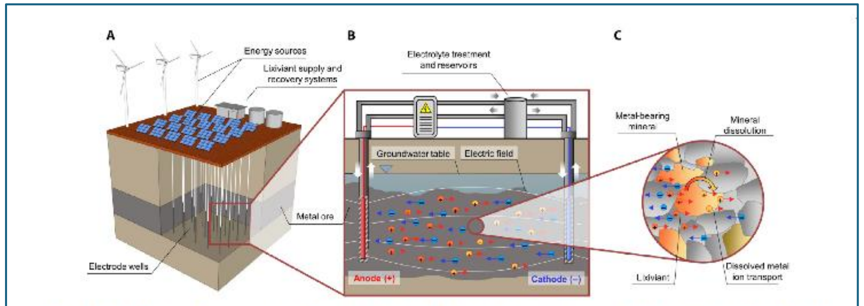


Fig. 1. Schematic illustration of metal extraction from a subsurface ore body via EK-ISL. (A) 3D isometric view of an industrial-scale EK-ISL operation, including potential electrode configuration, above-ground energy source, lixiviant supply and recovery reservoirs, and metal recovery treatment facility. (B) Cross-sectional view of the ore interface between an individual anode and cathode. (C) Conceptual illustration of principal hydrogeochemical reactions between the lixiviant and the ore material when subjected to EK-driven electromigration.

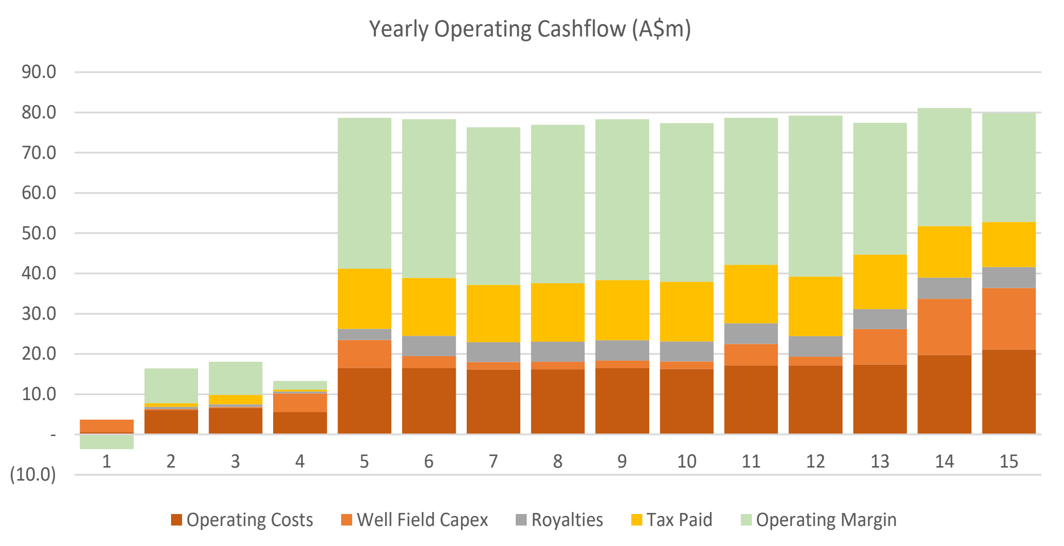
ECL is working with CSIRO to research the emerging Electrokinetics area – potential to mine primary, unfractured hard rock copper ore bodies

ENVIRO COPPER THE INVISIBLE MINE

Kapunda

Scoping Study has demonstrated compelling economic returns, now moving to in ground trials and mining lease

Economic Outcomes*	Targeted Lixiviant	Groundwater as Lixiviant
NPV	$243m	$174m
Life of Mine Free Cash	$505m (Real)	$320m (Real)
Capex to Production (Cu Cement)	$10.1m	$10.1m
Stage 2 Capex (Cu Sulphate)	$49.0m	$49.0
IRR	66%	65%
Total Cu Sold	82,389 tonnes Cu	52,408 tonnes Cu
Avg Cu LOM Production	3,923 tonne Cu pa	3,494 tonne Cu pa
Mine Life	22 years	16 years



Additional Upside Potential

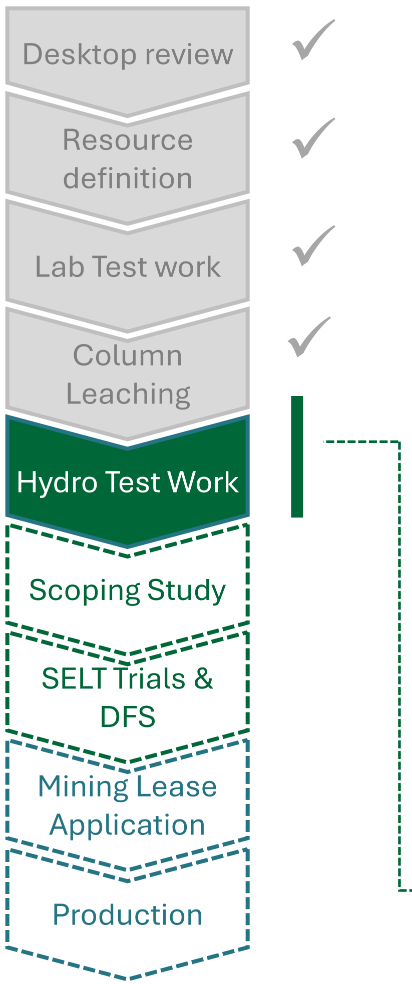
- Potential for additional copper through adjacent mining lease (PM10), and nearby exploration targets with similar IP anomalies
- Gold and other metals also leach into solution. Gold potential is significant and needs to be investigated at DFS stage
- Potential to reduce well capex through directional/horizontal

DFS

- Next stage of work is moving to representational field trials in parallel with mining lease application

York Peninsula

Alford West trough is a significant geological structure with the potential to become a large scale ISR project

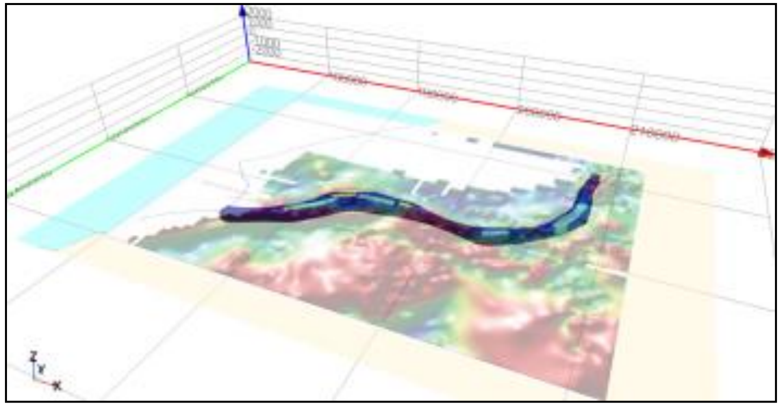


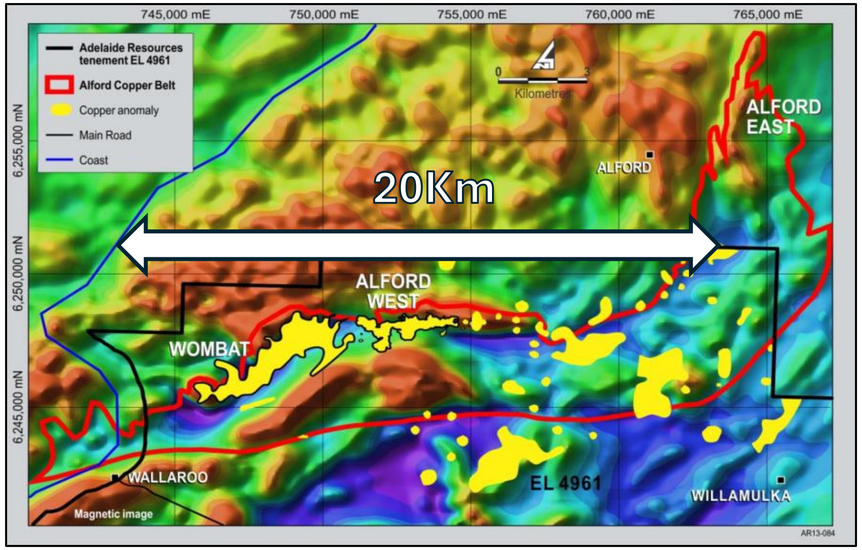
Interest	**ECL 100%**
Location	180 km northeast of Adelaide, South Australia
Infrastructure	Proximity to power, water and workforce
Resource	JORC resource 66MT @ 0.17% Cu (114,000t Cu, 20,000Oz Au), substantial exploration potential of 700kt+ Cu along strike in same trough. Further projects and copper resources on broader tenement.
Geology	Deeply weathered troughs hosting oxidized copper with impermeable boundary rock
ISR Characteristics	- Depth of mineralization (40-300m+) - Visible core is highly weathered and fractured, likely to be permeable - Mineralisation sits under water table, right hydrogeological environment

Alford is undergoing hydrogeological and leaching test work

Alford West

Alford West is a significant geological structure with the potential to become a large scale ISR project



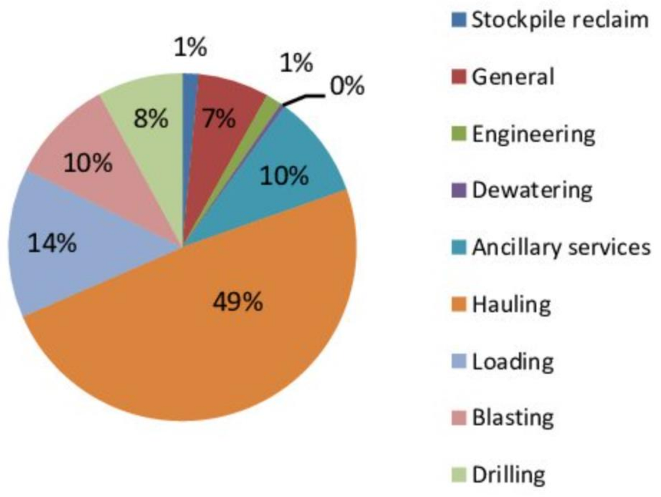


- 30km contact zone
- JORC compliant exploration target of 428 – 713kt Cu
- JORC compliant resource of 114kt Cu defined across the Wombat and Alford sub zones (limited to 100m)
- THOR Mining Alford East JORC resource 177kt of Copper and 71,500 Oz Au
- EnviroCopper believe that the weathered contact zone has the potential to host > 1Mt Cu

Removing Cost Base…

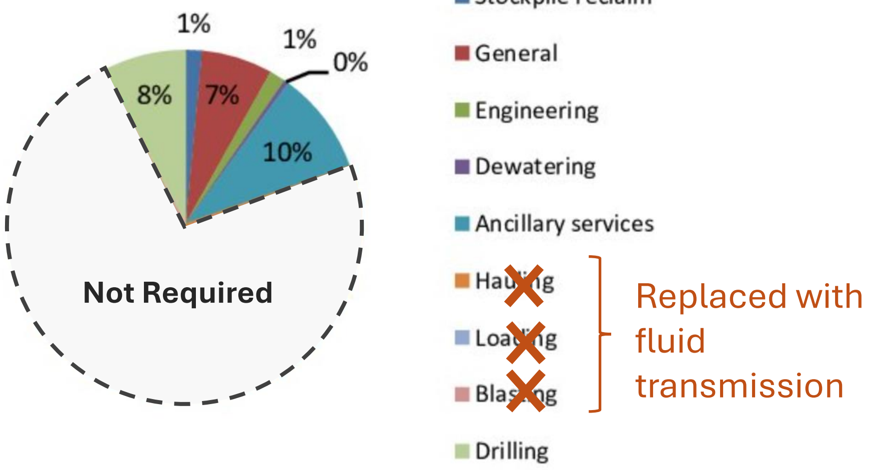
ISR can remove 75% of the cost base of a conventional mining project – it can handle lower grade, it just needs the right geology & application

Conventional Mining Cost Distribution



Morteza Paricheh, Oct 2016 Determination of the optimum in-pit crusher location in open-pit mining under

ISR removes cost and adds margin (no smelter)



ISR - a path to quickly and sustainably meet the future market demand for copper

Flexible Development Economics

- ✓ Targeting conventionally low value (or stranded) resources
- ✓ Removes significant cost base of conventional mining
- ✓ Ability to start small and ramp up over time (reduced development timeframe)
- ✓ Ability to adjust production to suit market dynamics
- ✓ Copper cathode output selling directly into market (the mine is the smelter)

ESG Benefits

- ✓ Low carbon intensity development
- ✓ Significant reduction in community (reduced noise, dust and visual amenity)
- ✓ Reduced long term impact (no tailings dams, open pits)
- ✓ Ability to return land back to its original use after development
- ✓ More likely to get support of local community and reduce approval time (what is current industry standard?)

EnviroCopper

Building an ISR network of technical excellence

Core Team

EnviroCopper – The Invisible Mine

Research Network

- Curtin University
- The University of Adelaide
- CSIRO
- mining3 – Transforming Mining

Industry Network

- Adelaide Control Engineering
- InnovEco Australia
- GPA Engineering
- BHP
- Alligator Energy
- LWC Land & Water Consulting

Professional Network

- South Australian and overseas
- Engineering & Hydrogeology
- Uranium ISR operations

EnviroCopper's Business

Laying the groundwork to build successful copper projects

Appraisal

Kapunda and Alford Geology

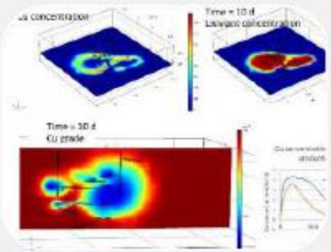
Finding the right geology

Leach Recovery

Lab recovery trials

Testing in lab recovery

In-ground testing & simulation



In ground recovery trials at Kapunda

Validating in ground recovery

Community

ECL Office in Kapunda

Engaging with community early

ENVIRO COPPER
THE INVISIBLE MINE

In Summary

- ✓ the ECL team has made significant advances in identifying and developing copper ISR projects
- ✓ ISR has significant ESG benefits to conventional mining as well as substantial potential to transform the value of stranded copper assets
- ✓ ECL has developed significant knowledge and IP in Cu ISR technologies by leading and participating in key research projects over the last 8 years.
- ✓ >220,0000 tonnes of JORC Cu resources in existing projects
- ✓ Exploration Potential for >1,000,000 tonnes Cu in current projects
- ✓ Identified significant further Cu ISR potential in Australia and elsewhere

Further information www.envirocopper.com.au

Enviro Copper

The invisible mine

Anya Hart

Principal Co-Design

BHP

Mining...but not as we know it

Mining…but not as we know it

Mining the Gap Innovation Forum

September 2024

Think & Act Differently's role is to find and accelerate the best technology solutions to support BHP's ambitions to deliver resources the world needs in new ways.

Think & Act Differently
Powered by BHP

We **help innovators mature their technology** and ideas to accelerate new options to provide the resources the world needs.

We use a **value chain approach** to fostering a continuous flow of new technologies and capabilities that empower BHP to meet today's needs and build a roadmap for future value.

We use our superpower, the innovation ecosystem, to collaborate with a range of individuals and organisations to accelerate technologies at scale, fostering optionality, speed, and diversity.

The world needs the commodities we produce to support the energy transition...

...and there are global challenges and opportunities to be able to develop these resources in new and innovative ways.

Mines are getting deeper, lower grade and requiring more energy, resulting in more waste.

Industry wide cost inflation.

Societies ESG expectations are changing.

New deposits are not easy to find

Discovery to production averages 16 years.

We see our biggest opportunities to support BHP in delivering the resources the world needs in new ways by focusing on these four key areas to maximise value

Think & Act Differently
Powered by BHP

DISCOVERY SUCCESS & ADVANCED CHARACTERISATION

Accelerate tools for discovering orebodies and understanding the characteristics of those minerals for effective mining

ACCELERATED MINE DEVELOPMENT

Reduce timeframe to first product through data insight, new decision-making processes, alternative mine design and mining methods.

OPTIMAL ACCESS TO ORE

Economically mine low grade, complex orebodies, addressing capital intensity through initiatives such as Intelligent mass movement, effective comminution, preconditioning.

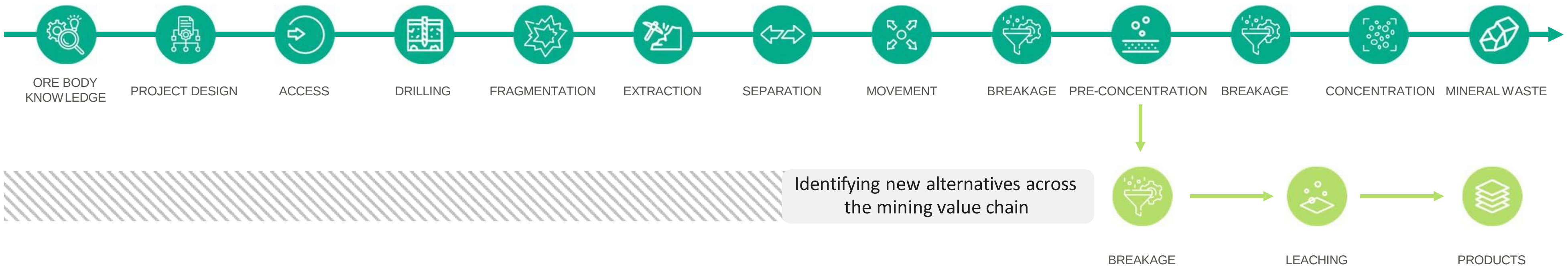
MAXIMISE MINERALS RECOVERY

Economic recovery of low grade, complex mineralogy, at high throughput; future flowsheets, whole orebody recovery

MAXIMISE VALUE

Optimising existing value chains and create innovative revenue streams. Increase social value

Our systems approach allows us to explore new alternatives to the traditional mining value chain



Think & Act Differently
Powered by BHP

TAD Open House

Open House enables us to communicate our opportunities and attract people to work with us to bring novel thinking and ideas.

Collaboration at the heart of Open House is collaboration and sharing of knowledge.

BHP provide mentoring, access to subject matter experts, test sites and funding.

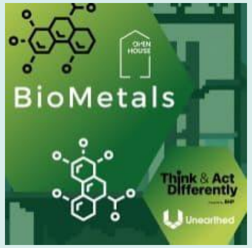
Think & Act Differently
Powered by BHP

TAD open house challenges we have run and are running to date

Think differently about storing carbon in mining

Preconditioning solutions to reduce grinding energy

Efficient Comminution would save significant energy



Biotech solutions have the potential to enhance the efficiency, sustainability, and mitigate environmental impact

Drying potash while reducing emissions intensity

Low carbon heap leach options

Collaborate with us.

Please get in touch to unlock growth through innovation.

We can create greater value when we work together.

Think & Act Differently

Powered by BHP

WE ARE A CONNECTOR & GET TO KNOW THE PEOPLE BEHIND THE IDEAS

WE ARE AN END-CUSTOMER & ACTIVE INVESTOR

WE ARE AN ENABLER & ACCELERATOR

Contact Think & Act Differently – TAD@bhp.com

Jayde Webb

Practice Lead Mining Technology

SOUTH32

A Miner’s Perspective on In-Place Mining Challenges

IN-PLACE MINING CHALLENGES

Unlocking value through academic collaboration

September 2024

OUR COMPANY

South32 is a globally diversified mining and metals company.

We **produce** commodities including bauxite, alumina, aluminium, copper, silver, lead, zinc, nickel and manganese from our operations in Australia, Southern Africa and South America.

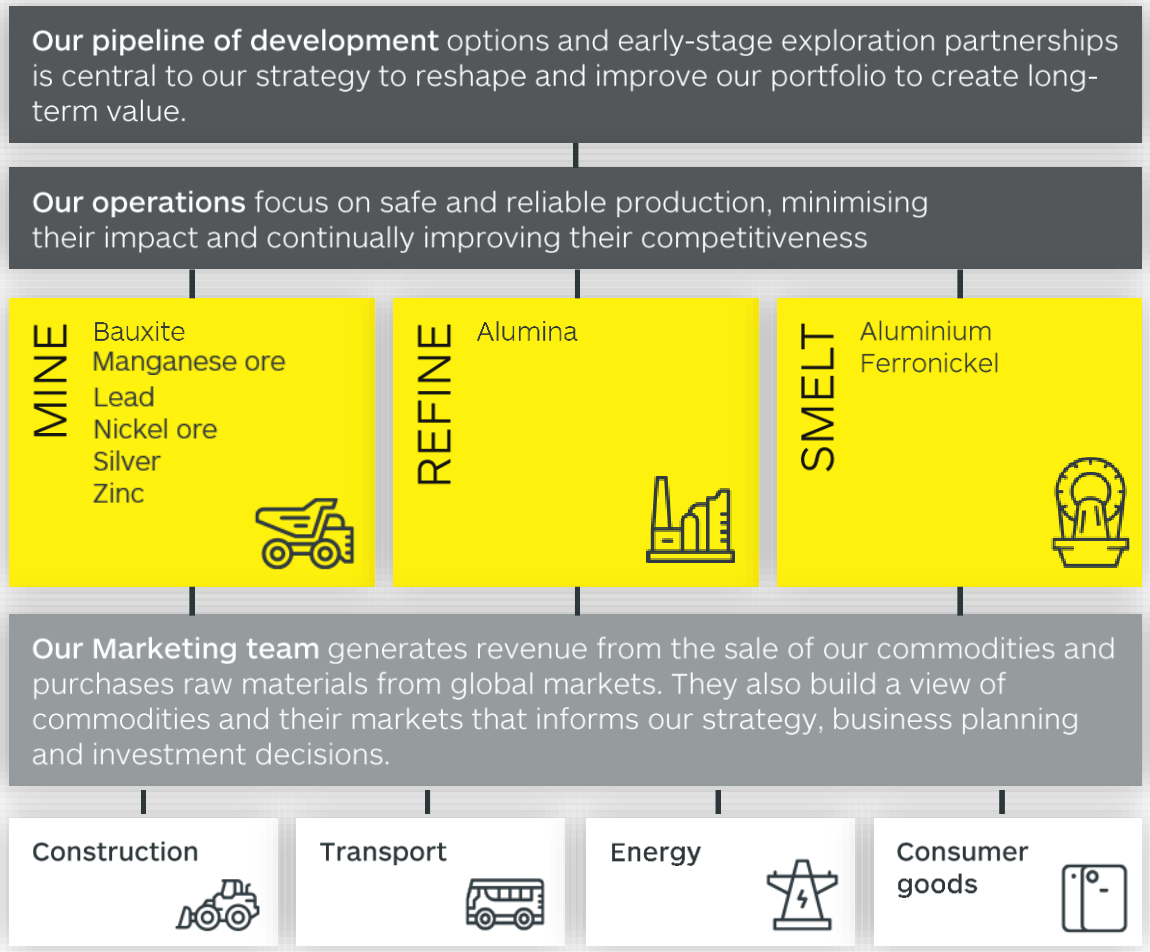
We also have a portfolio of high-quality development projects and options, and exploration prospects, consistent with our **strategy** to reshape our portfolio toward commodities that are critical for a **low-carbon future**.

Our **purpose** is to make a difference by developing natural resources, improving people's lives now and for generations to come. We are trusted by our owners and partners to realise the potential of their resources.

SOUTH32

OUR BUSINESS MODEL

South32 mines, refines and smelts and this is important in the context of in-place mining because the product that we sell, and the market is key factor of how we create value and produce commodities that are used in all aspects of modern life



OUR OPERATIONS

Worsley Alumina

Worsley Alumina is one of the largest and lowest-cost alumina refineries in the world which mines, refines and exports alumina.

South Africa Manganese

Our South African manganese mines are found in the Kalahari Basin, in the country's northern cape, which is home to 80 per cent of the world's manganese ore body. **Underground** and surface mining.

Cerro Matoso

Cerro Matoso is an integrated nickel laterite mine and smelter located in the Cordoba area of northern Colombia. Cerro Matoso is a major producer of nickel contained in ferronickel which is used to make stainless steel.

GEMCO

GEMCO is one of the world's largest and lowest-cost manganese ore producers.

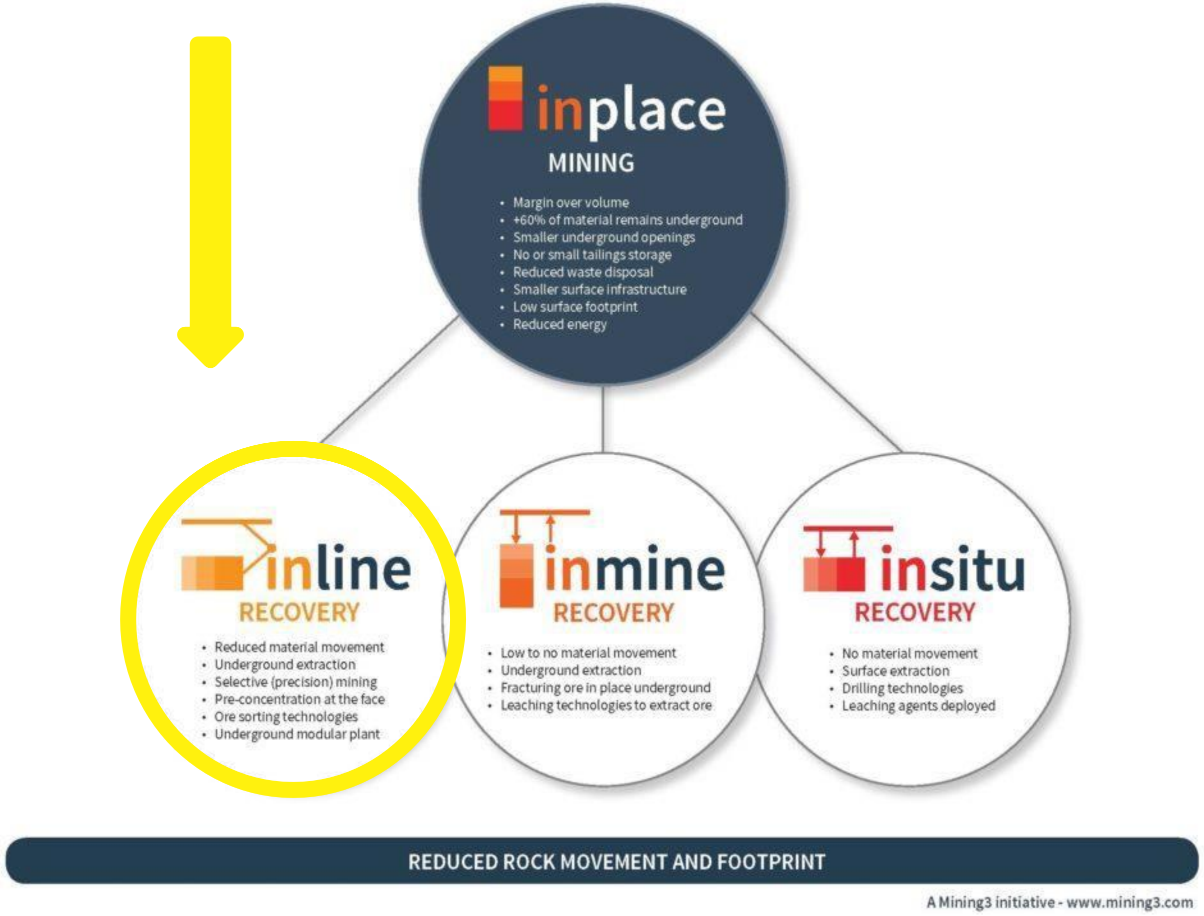
Cannington

Located in north-west Queensland, Cannington is an **underground** base metal mine (Zn) and is one of the world's largest producers of silver and lead.

SELECTIVE MINING TECHNOLOGY STRATEGY – IN LINE

Overview of the core technologies involved in in-line mining:

- **Autonomous systems** - foundational infrastructure, communications systems and sensors are required to make it safe and repeatable.
- **Advanced drilling techniques** to be more selective - mechanical rock cutting technology suitable to the orebody, and impact from a changing orebody blend over multiple decades.
- **Real-time data analytics** – desire to make decisions closer to the face.



Source: IN PLACE MINING - A TRANSFORMATIONAL SHIFT IN METAL EXTRACTION - MINING3

CHALLENGES WITH IN-LINE MINING

In-Line Mining Technical Challenges:

- **Orebody characterisation** – predicting the match of in-place mining technique from exploration drill samples and to mining.
- **Geotechnical suitability** – how do we measure the long-term geotechnical benefit in traditional NPV calculations.
- **Safe, efficient & reliable resource extraction (underground mining)** – keep it simple, please remember the dishwasher rather than the robot at the sink.

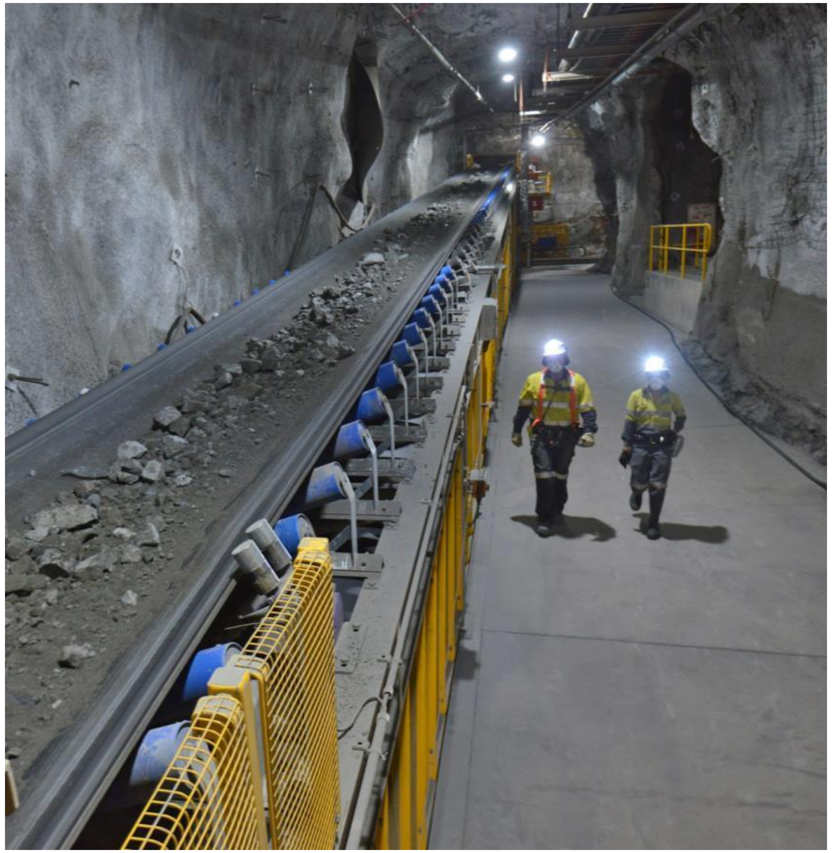
In-Place Mining Environmental Challenges:

- **Water management** – there must be non-toxic lixiviants (beyond copper), and a range of strategies are required to contain any leaching underground that don't overly complicate a mining system.

ROLE OF ACADEMIA

Key research areas where academic modelling is crucial:

- **Advanced material science** – modelling opportunity is predicting the match of in-place mining technique from exploration drill samples and how representative the correlation is when mining.
- **Breaking the traditional NPV mould** – financial modelling opportunity is how do we financial value the long-term geotechnical benefit in traditional short term NPV calculations.
- **Environmental impact studies** – involving the regulators in your jurisdiction to address concerns. They are a fundamental enabler of the transformation journey.



CONCLUSION & THANK YOU

Key takeaways:

We need to be able to predict earlier in our mine design and mining studies, what in-place mining application could be included to increase the orebody value and modelled with clever ways to represent this value financially.

Call to Action:

Encouragement for research and academic collaboration and innovation with Mining3, that is where South32 is investing our innovation budget for transforming sustainable mining success.

Jayde Webb
Practice Lead Mining Technology
Innovation & Technology Development
Jayde.Webb@south32.net

SOUTH32

Session 2

Unlocking the challenges of In-place mining through innovation, research & development.

DR ERIK ISOKANGAS

Research Director – Mining3

Dr Niko Suenderhauf

QCR Deputy Director

QUT

Robots that learn from humans and understand the world.

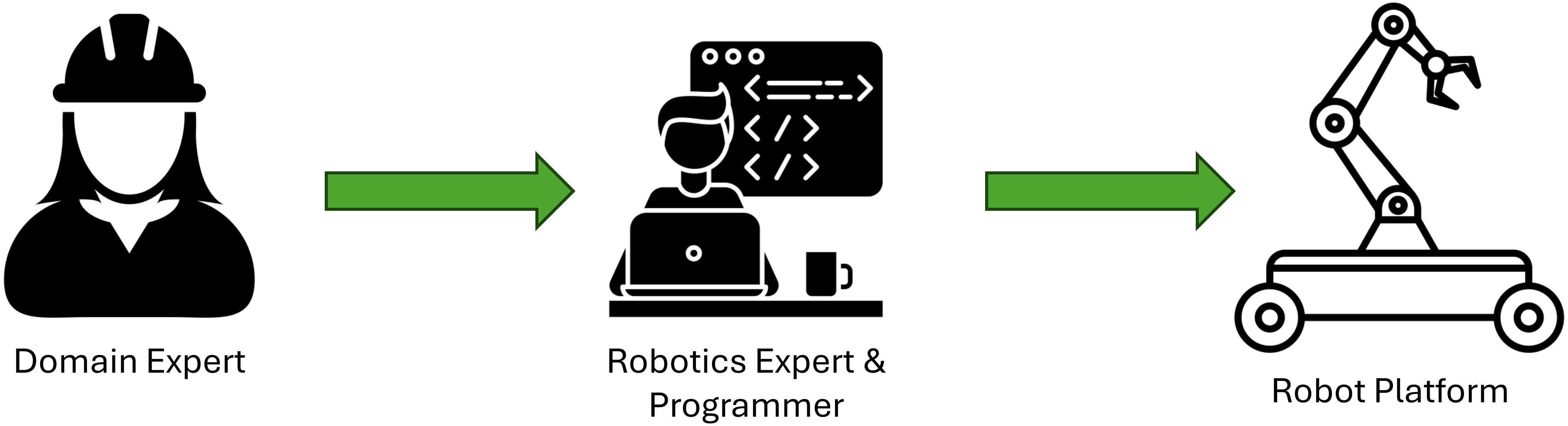
QUT Centre for Robotics

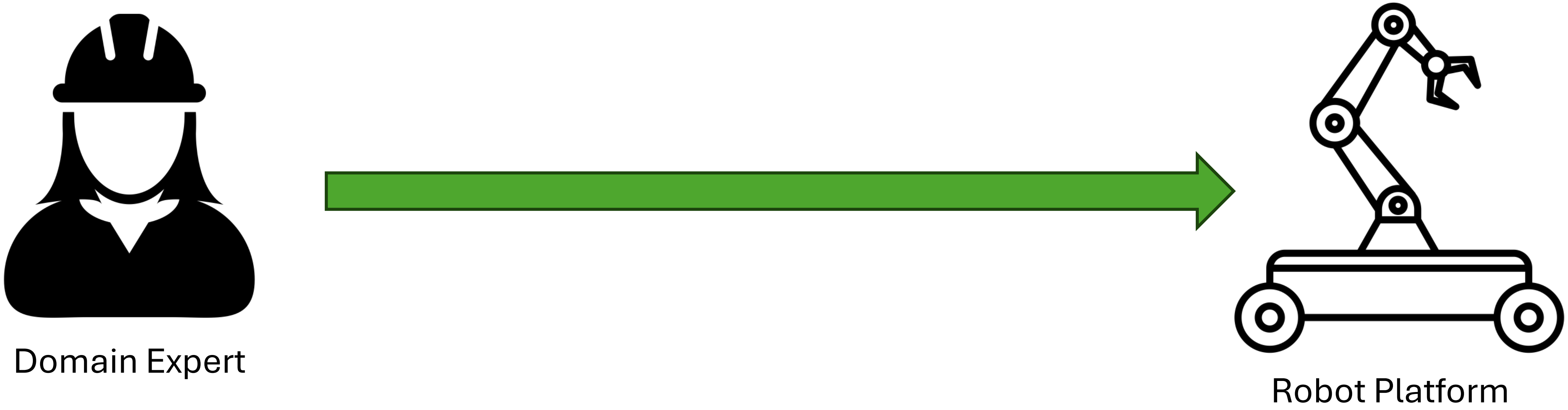
Robots that learn from Humans and Understand the World

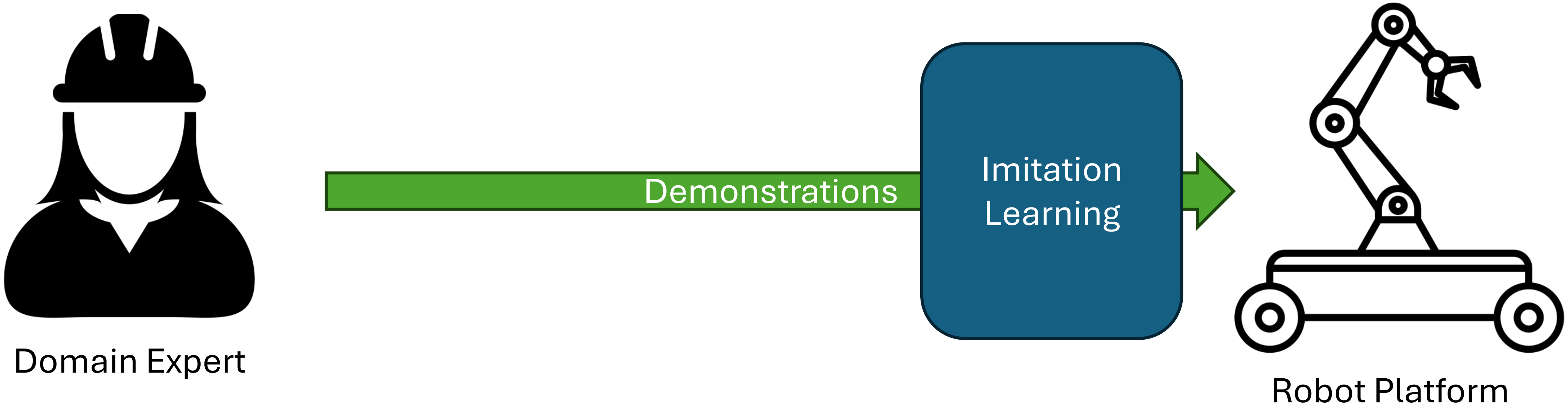
Prof Niko Suenderhauf

Deputy Director, QUT Centre for Robotics

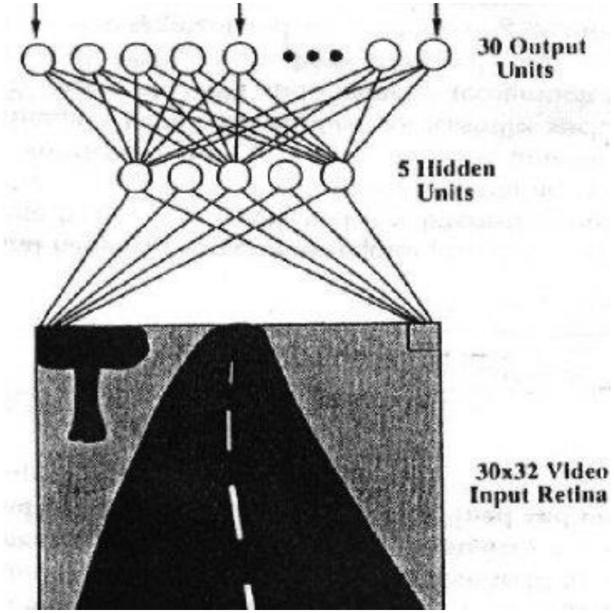
Robots that Learn from Humans

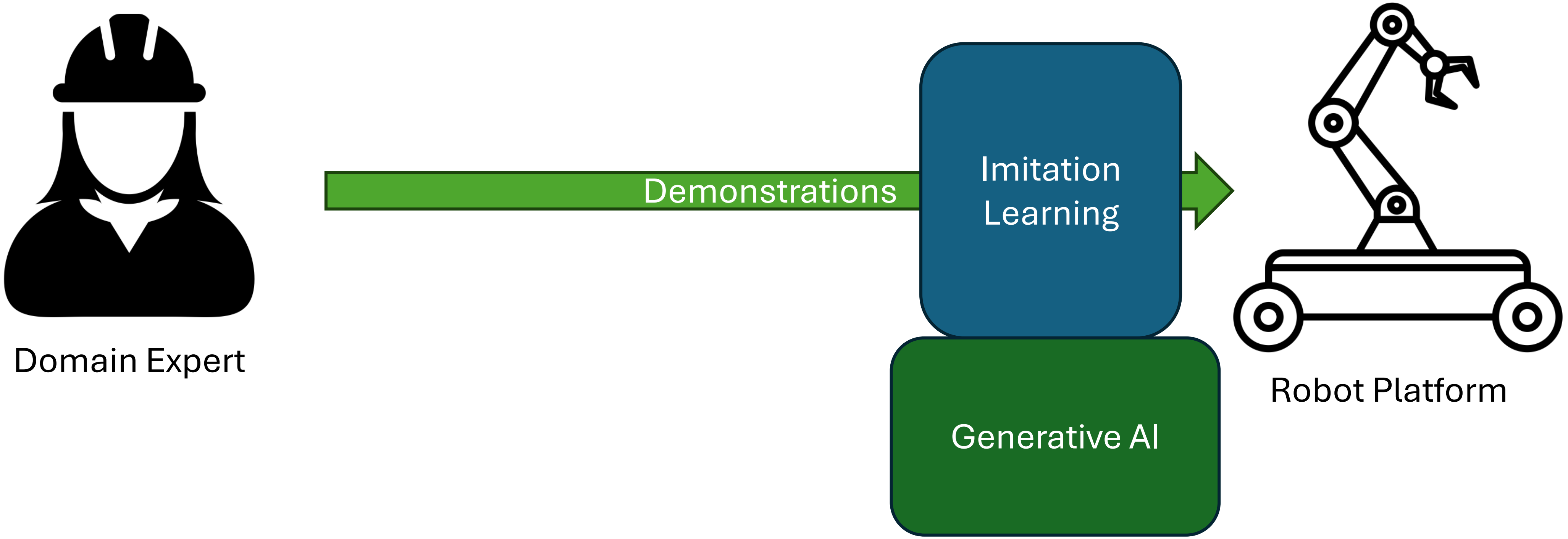

Domain Expert
Robotics Expert & Programmer
Robot Platform


Domain Expert
Robot Platform

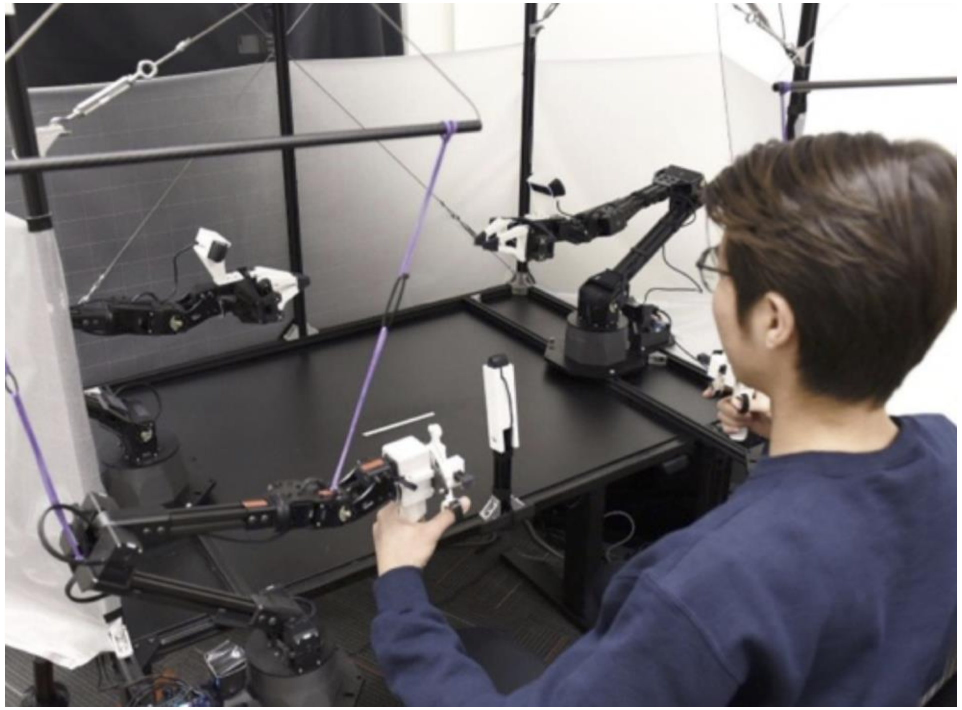

Domain Expert
Demonstrations
Imitation Learning
Robot Platform

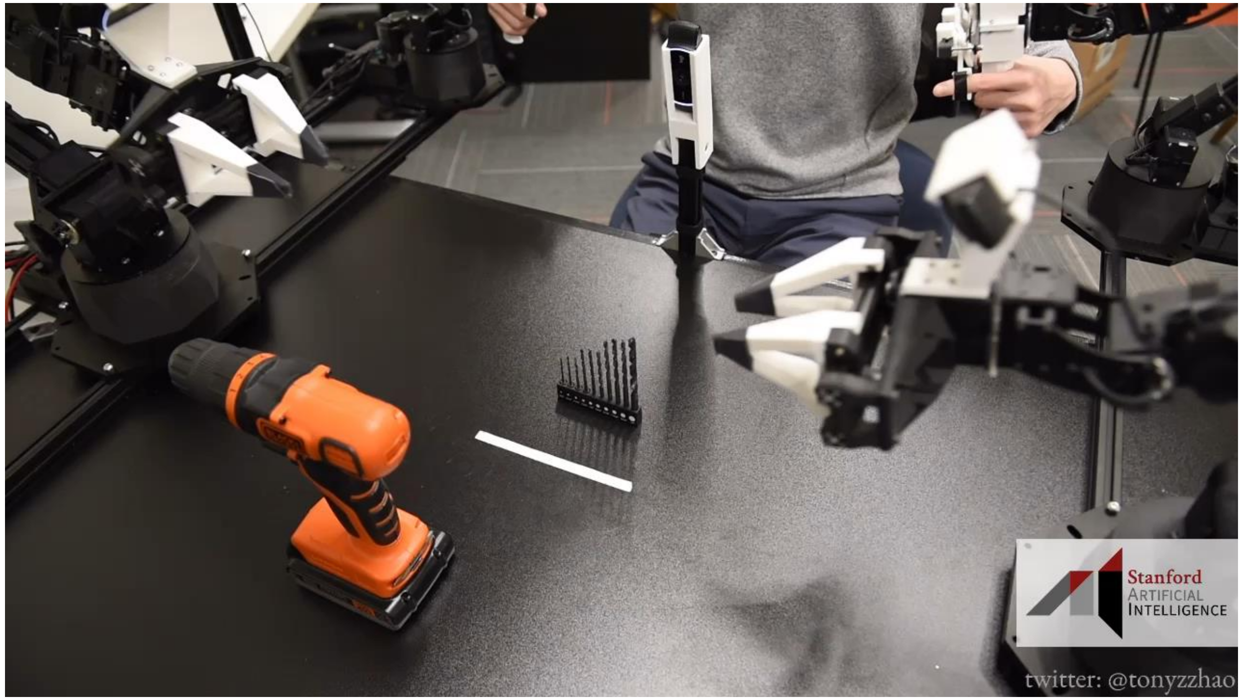
Not a New Idea (ALVINN: 1989)




Demonstrations
Imitation Learning
Generative AI
Domain Expert
Robot Platform

How to Collect Demonstrations?

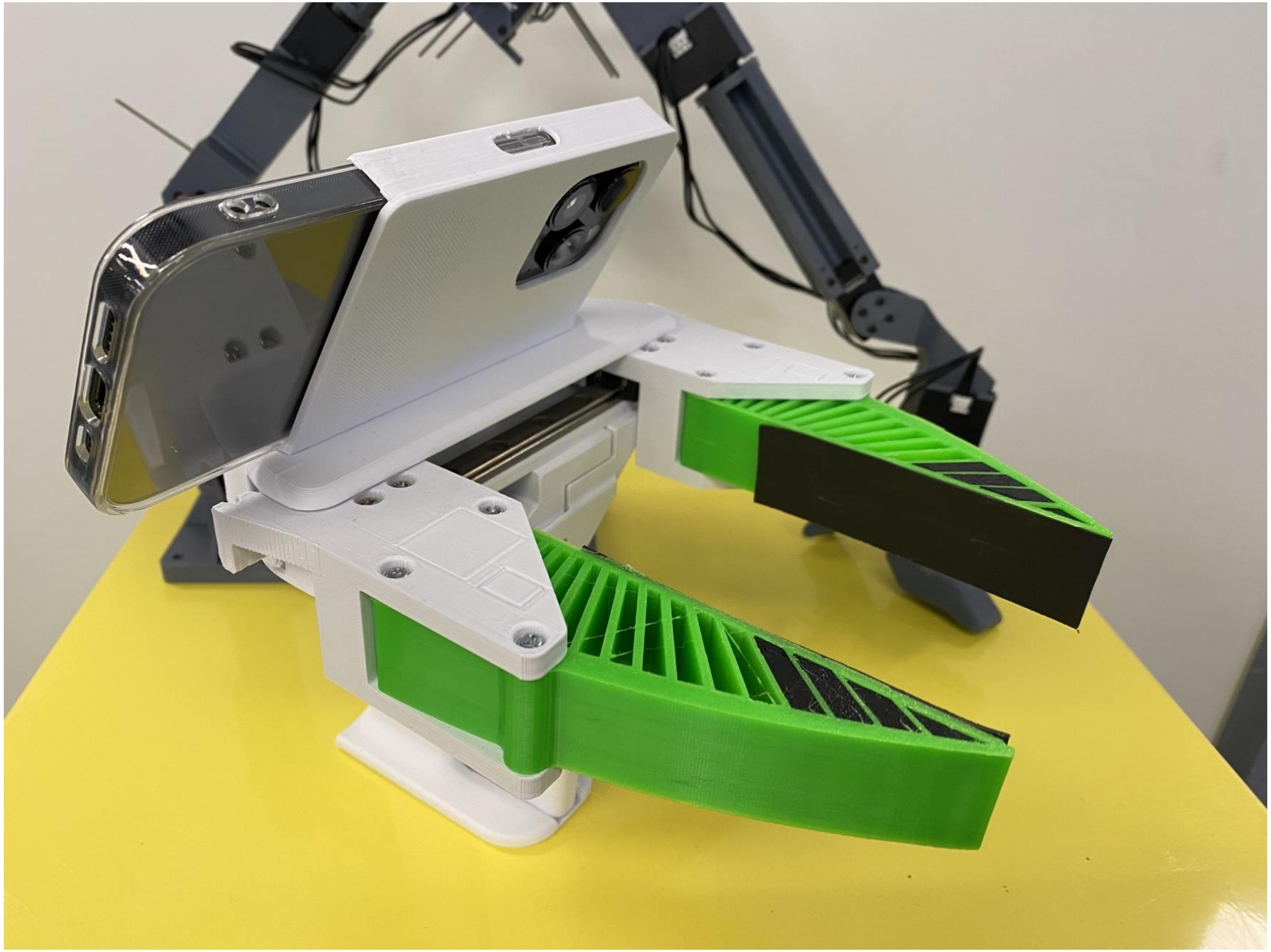




Learning Fine-Grained Bimanual Manipulation with Low-Cost Hardware https://tonyzhaozh.github.io/aloha/

Stanford University UC Berkeley Meta

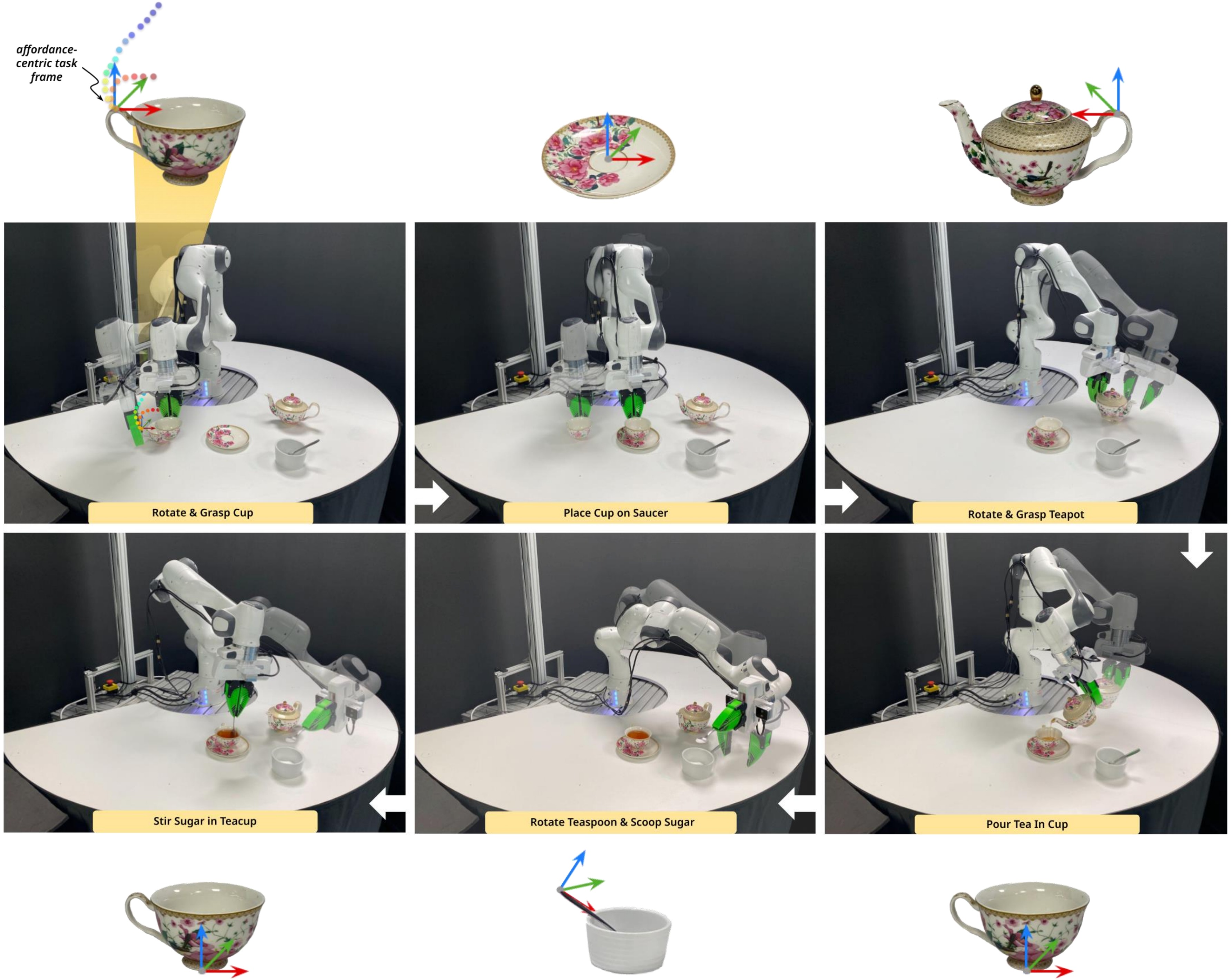
How to Collect Demonstrations?



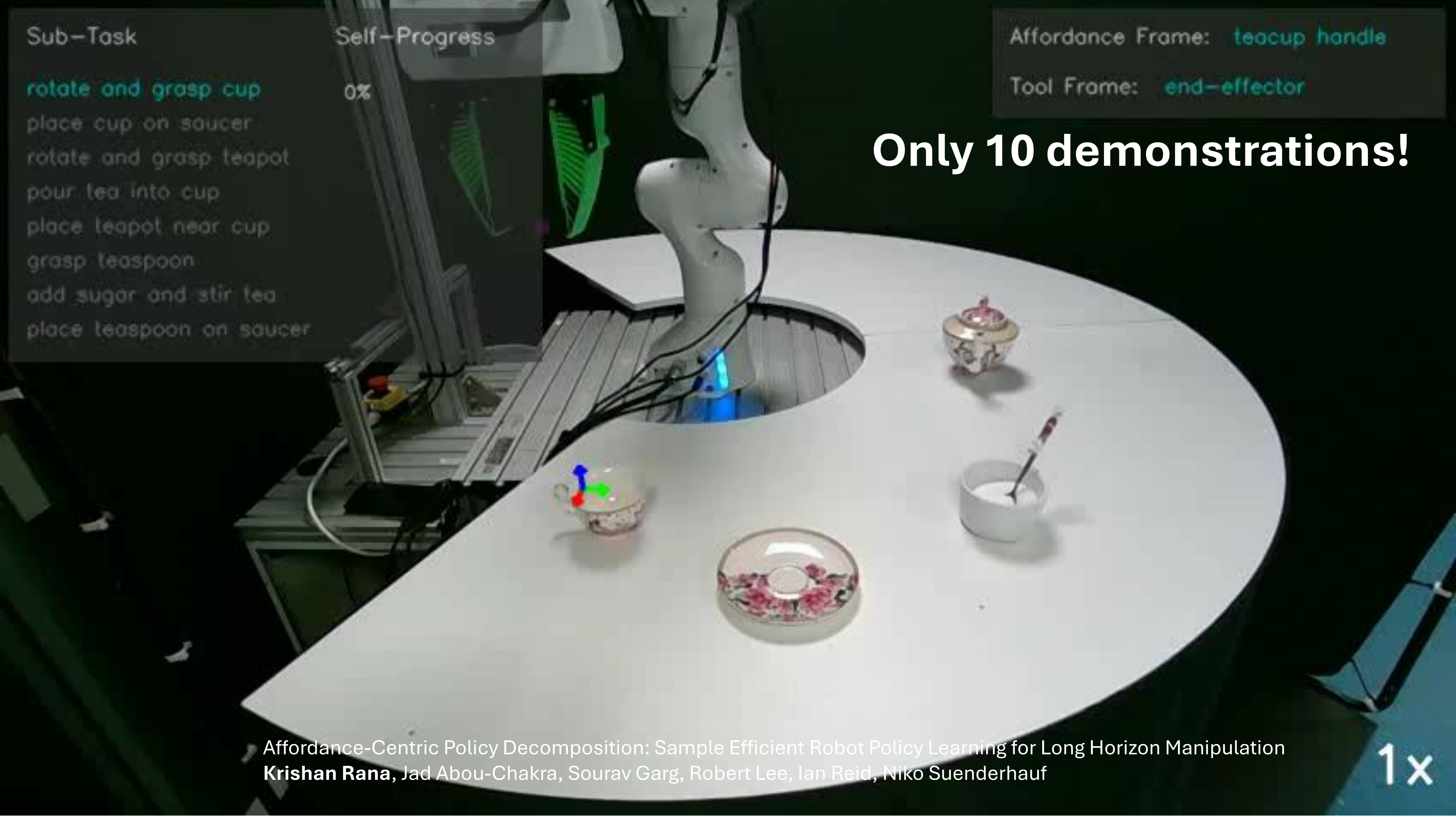

Cook Shrimp
(autonomous)
6x speed
Mobile ALOHA
Learning Bimanual Mobile Manipulation with Low-Cost Whole-Body Teleoperation
Stanford University

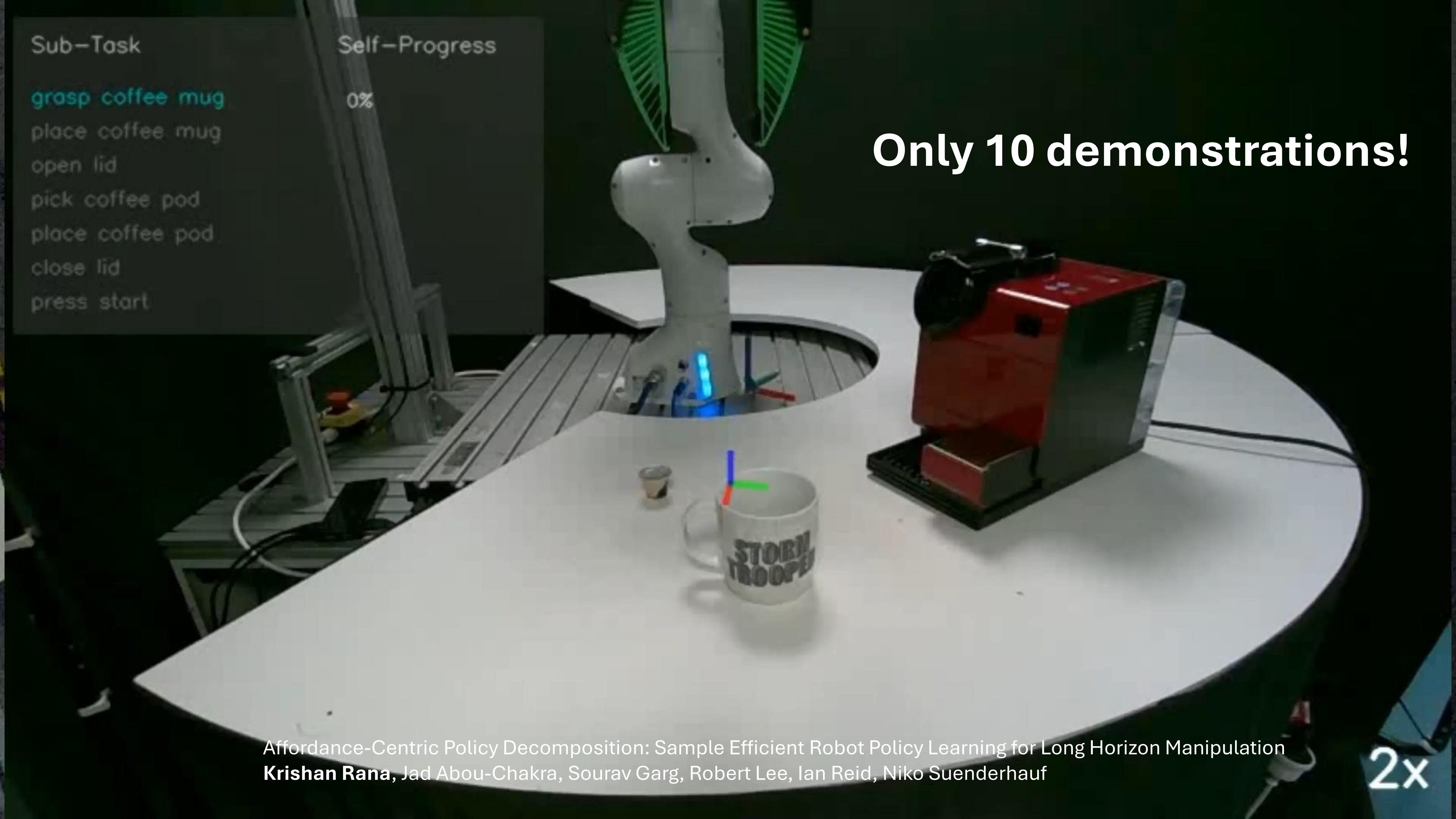
Weaknesses of Current Systems

- Need dozens to **hundreds of demonstrations**
- Can’t deal with **multiple steps** and **sub-goals**
- Can’t deal with **variations**



affordance-centric task frame
Rotate & Grasp Cup
Place Cup on Saucer
Rotate & Grasp Teapot
Stir Sugar in Teacup
Rotate Teaspoon & Scoop Sugar
Pour Tea In Cup


Sub-Task
Self-Progress
rotate and grasp cup
0%
place cup on saucer
rotate and grasp teapot
pour tea into cup
place teapot near cup
grasp teaspoon
add sugar and stir tea
place teaspoon on saucer
Affordance Frame: teacup handle
Tool Frame: end-effector
Only 10 demonstrations!
Affordance-Centric Policy Decomposition: Sample Efficient Robot Policy Learning for Long Horizon Manipulation
Krishan Rana, Jad Abou-Chakra, Sourav Garg, Robert Lee, Ian Reid, Niko Suenderhauf
1x

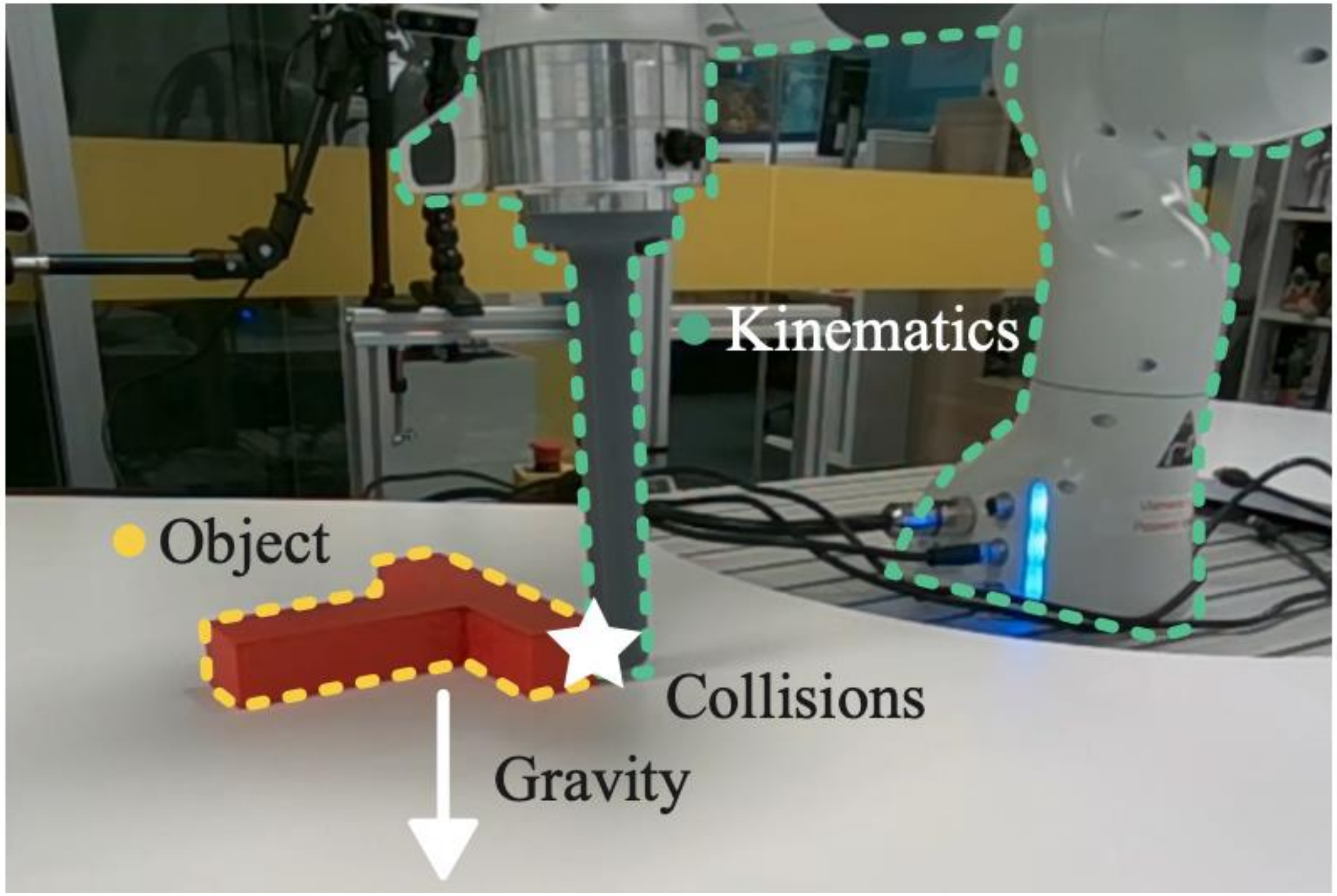

Sub−Task
Self−Progress
grasp coffee mug
0%
place coffee mug
open lid
pick coffee pod
place coffee pod
close lid
press start
Only 10 demonstrations!
STORM TROOPER
Affordance-Centric Policy Decomposition: Sample Efficient Robot Policy Learning for Long Horizon Manipulation
Krishan Rana, Jad Abou-Chakra, Sourav Garg, Robert Lee, Ian Reid, Niko Suenderhauf
2x

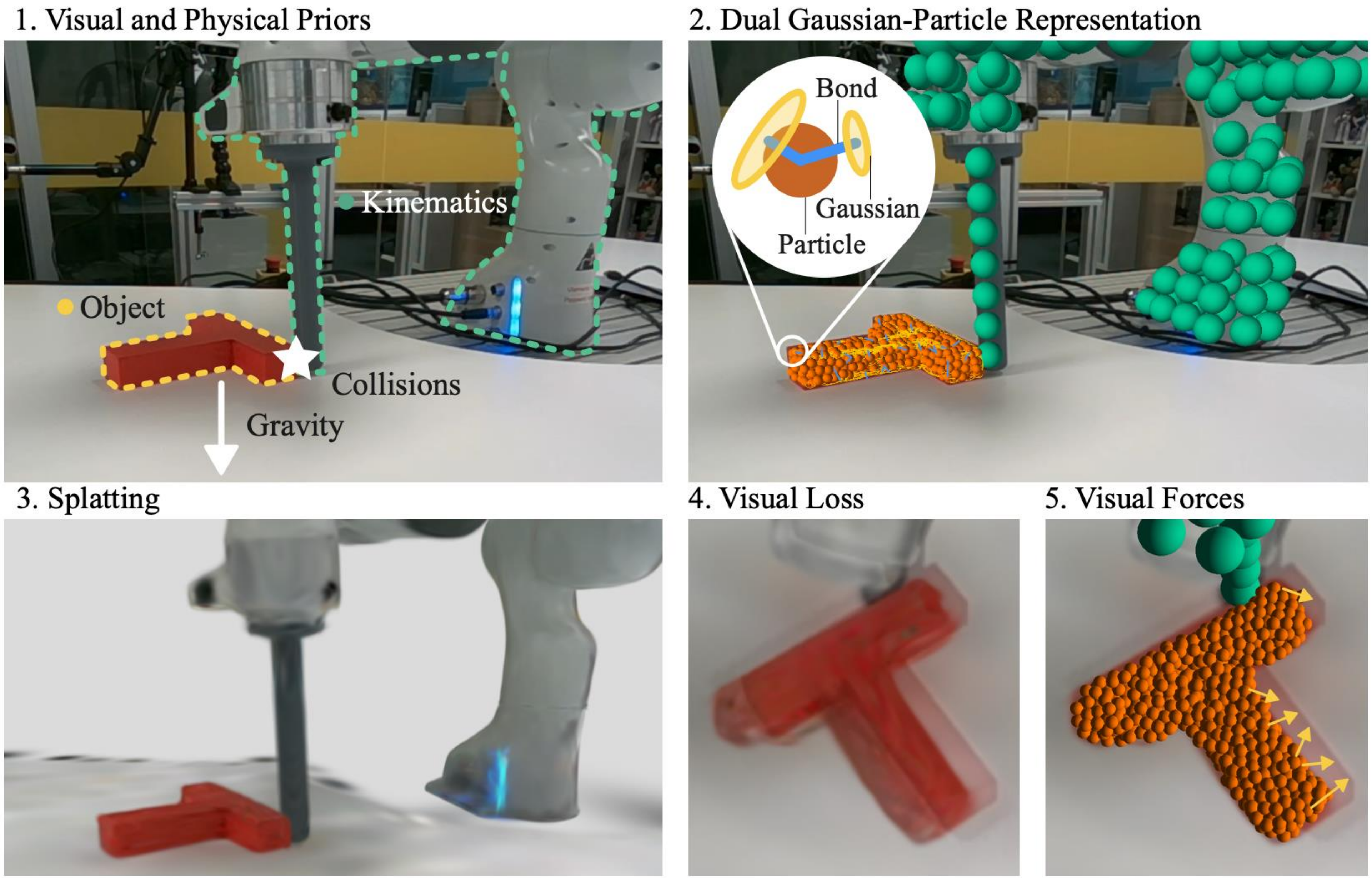
How would your business change if you could teach a robot anything within minutes?

Robots that Understand their World

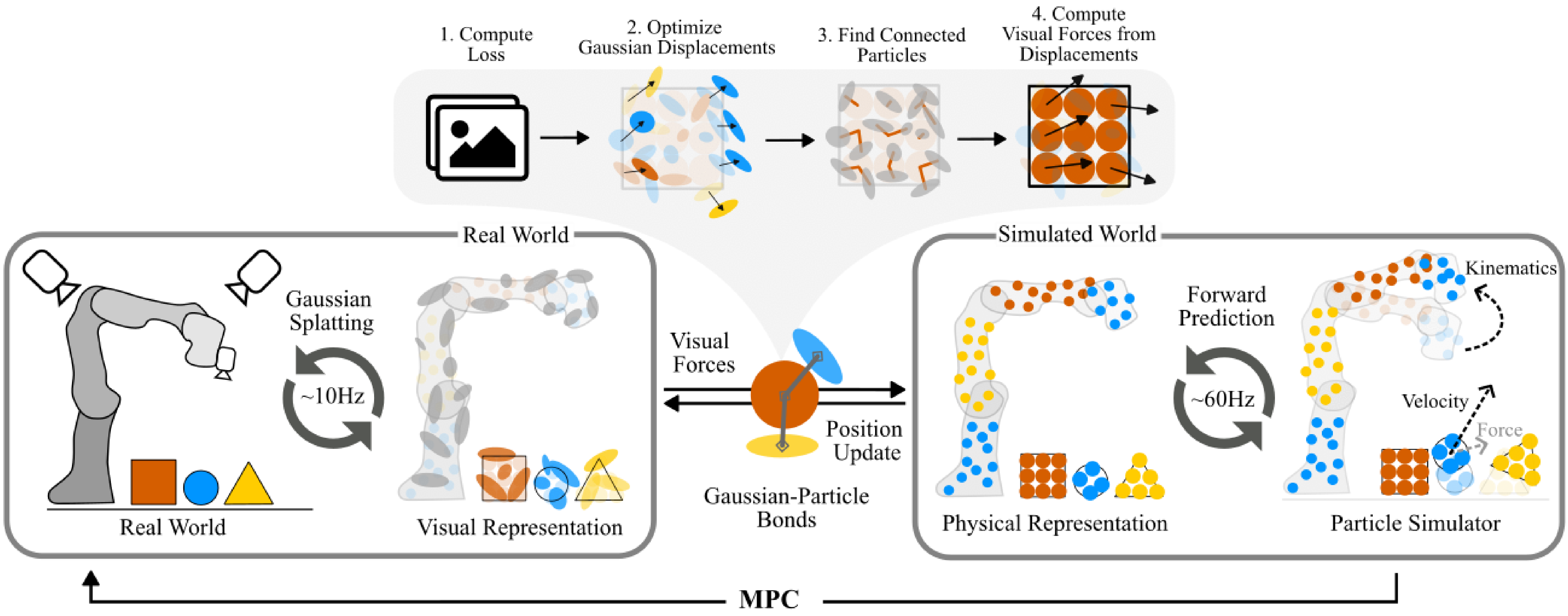
Wishlist for a "good" Representation

- "Simulate-able"
- From few images
- Multiple objects
- Deformable objects
- Physics (collisions, friction, ...)
- Priors (gravity, kinematics, ...)
- Update & initialise via vision
- Real-time

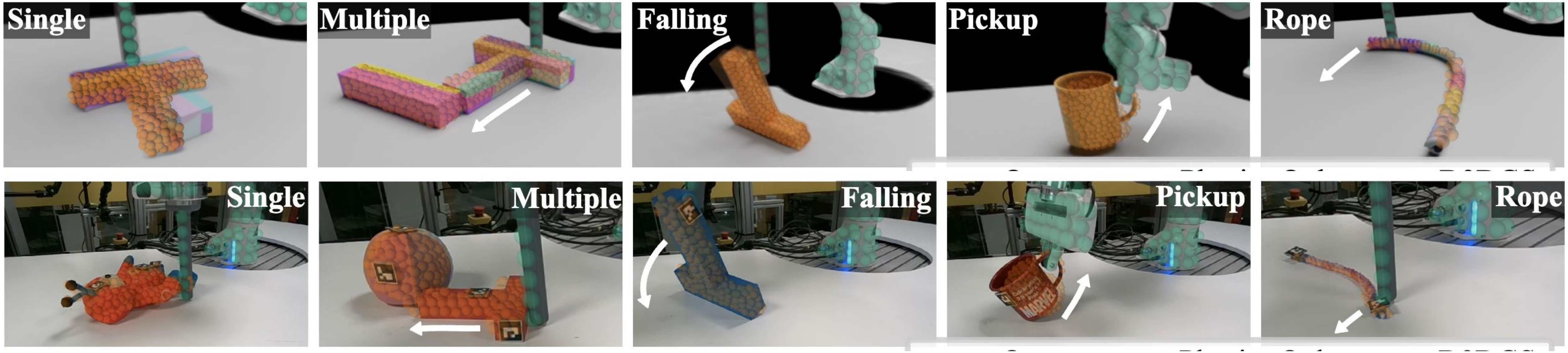


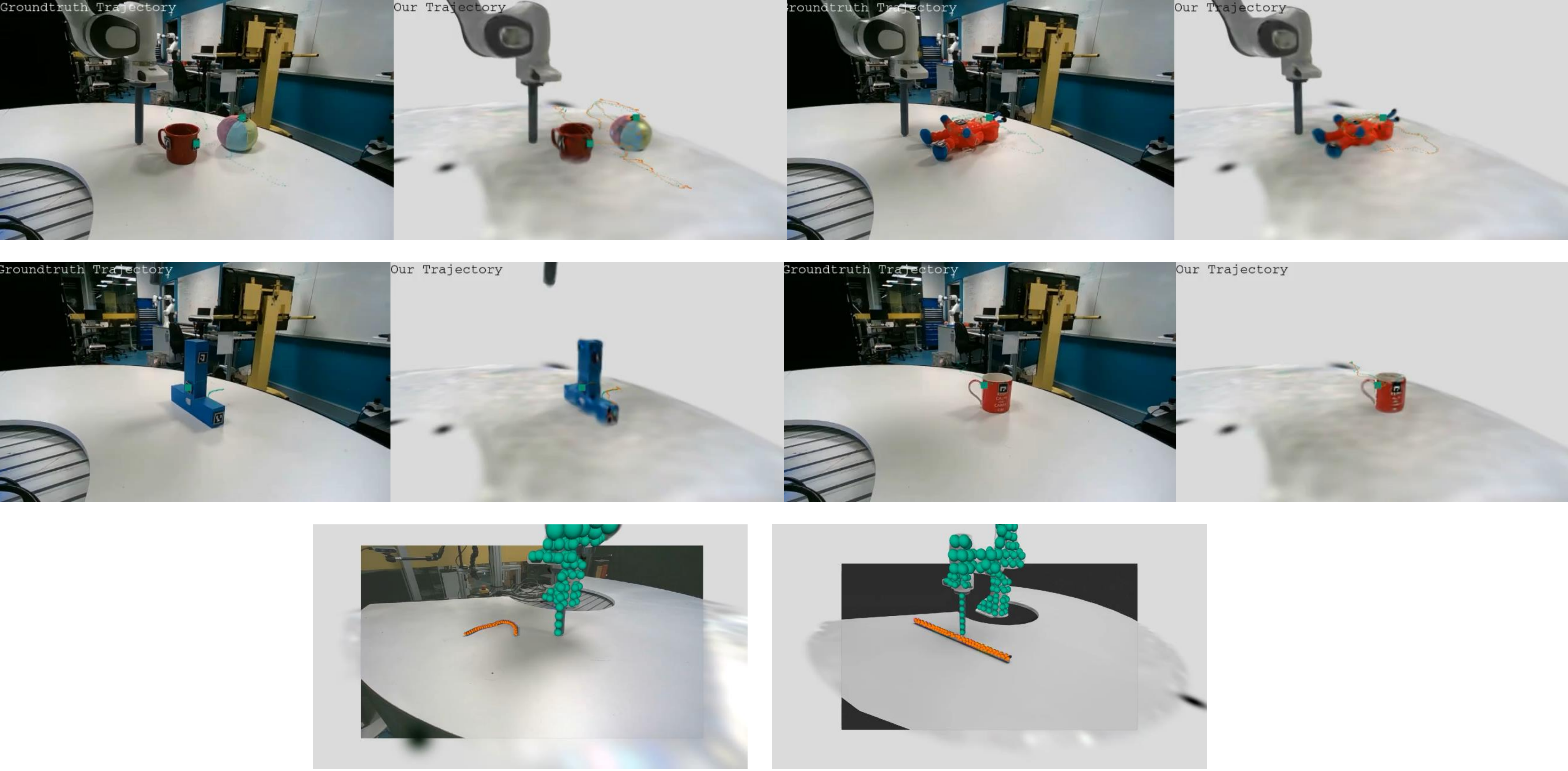

1. Visual and Physical Priors
Kinematics
Object
Collisions
Gravity
2. Dual Gaussian-Particle Representation
Bond
Gaussian
Particle
3. Splatting
4. Visual Loss
5. Visual Forces

Physically Embodied Gaussian Splatting



Physically Embodied Gaussian Splatting




Groundtruth Trajectory
Our Trajectory
Groundtruth Trajectory
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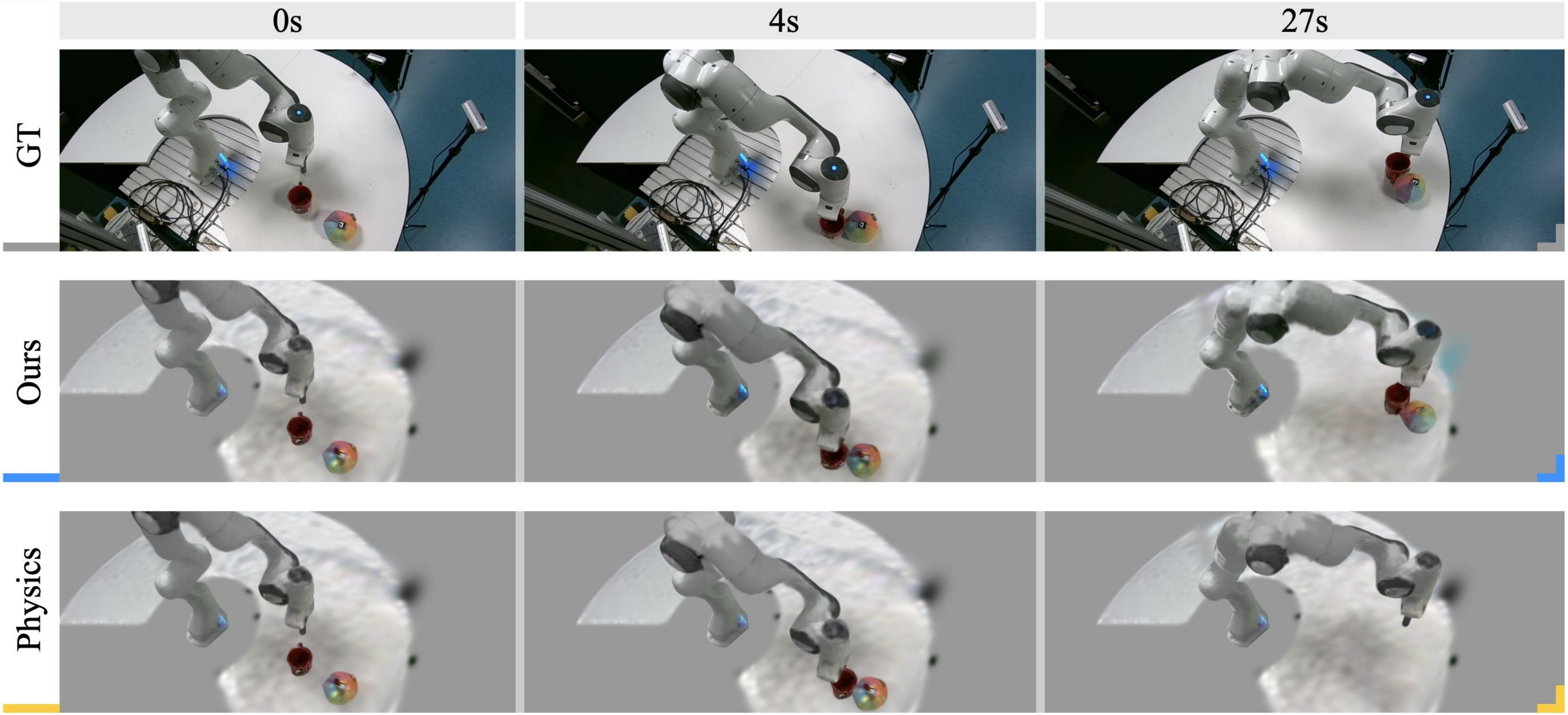
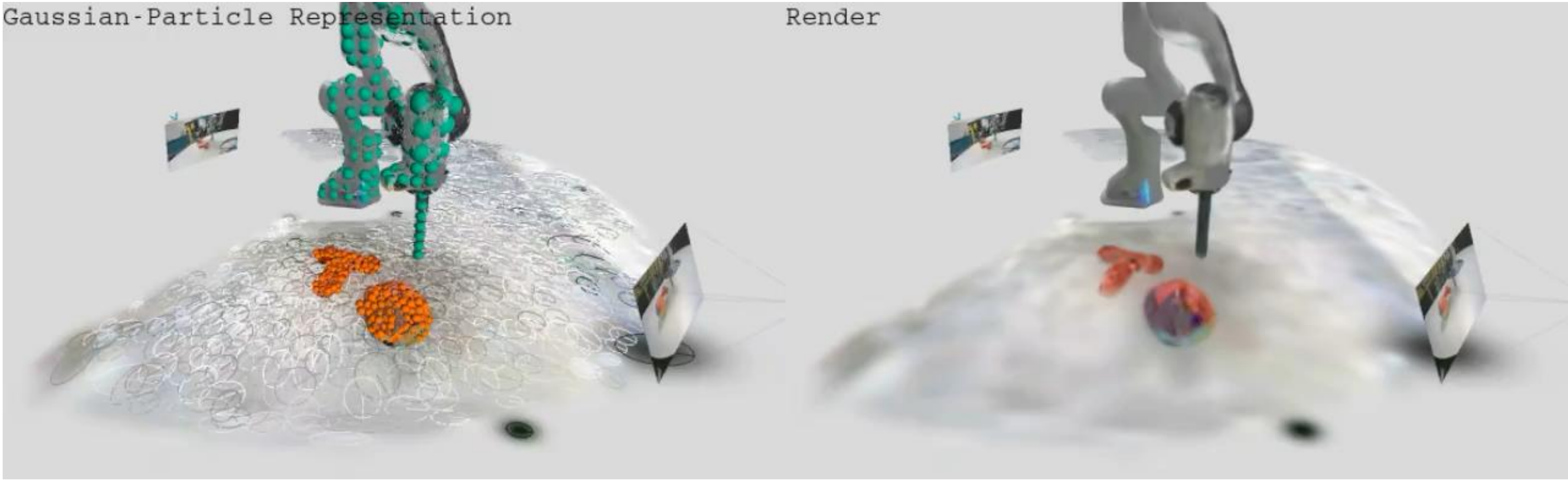
Groundtruth Trajectory
Our Trajectory


0s
4s
27s
GT
Ours
Physics

Physically Embodied Gaussian Splatting



Acknowledgements

Physically Embodied Gaussian Splatting: A Realtime Correctable World Model for Robotics
Jad Abou-Chakra, Krishan Rana, Feras Dayoub, Niko Suenderhauf. arXiv:2406.1078
https://embodied-gaussians.github.io/ (under review)

Affordance-Centric Policy Decomposition: Sample Efficient Robot Policy Learning for Long Horizon Manipulation
Krishan Rana, Jad Abou-Chakra, Sourav Garg, Robert Lee, Ian Reid, Niko Suenderhauf.
https://policy-decomposition.github.io/ (under review)

Dr Kym Runge

Julius Kruttschnitt Mineral Research Centre

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

New Generation Modelling

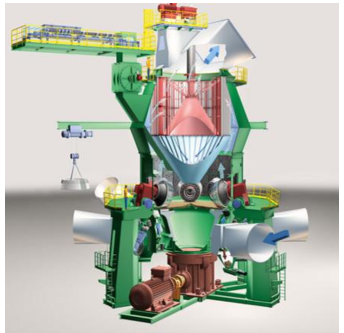
New Generation Modelling

Associate Professor Kym Runge

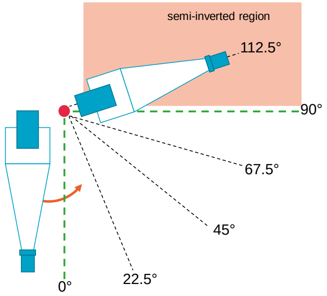
Collaboration between SMI-JKMRC and Mining3

Advancements in separation technology is set to change circuits…

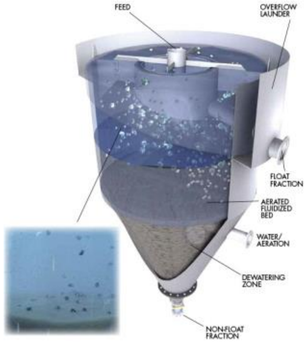
Preconcentration
- High Voltage Pulse, Sensor based sorting



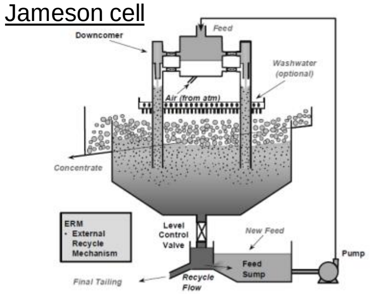
Novel Comminution
- VRM



Novel Classification
- Inverted cyclones, Hybrid classification, Magnetised cyclones



Coarse Particle Flotation
- HydroFloat®, Novacell, CoarseAir®



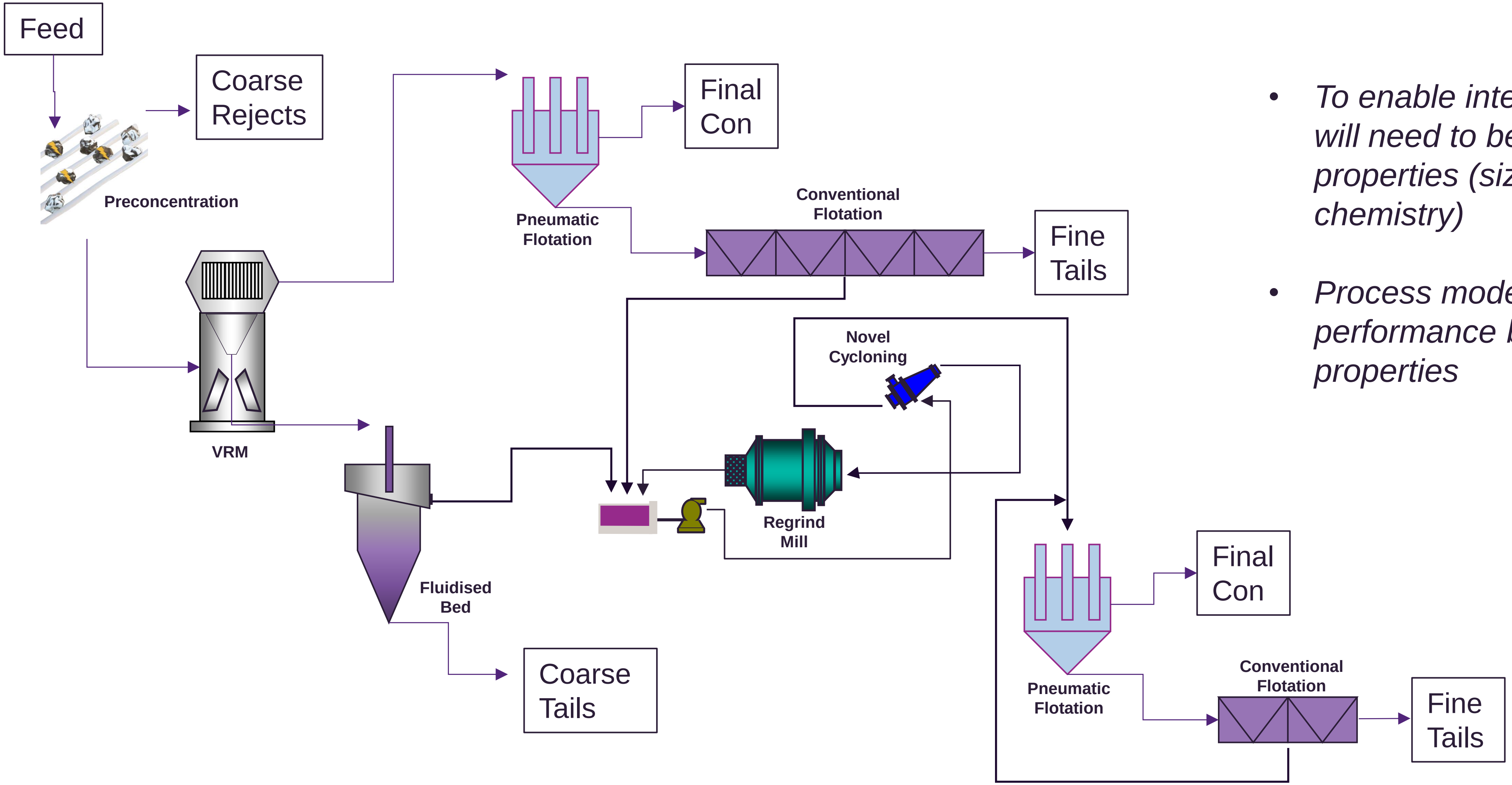
Fine Particle Flotation
- Jameson Cell, Concorde, StackCell

…however process modelling techniques are yet to be developed

Importance of Modelling & Flowsheet Simulation

- Provides an understanding of key process drivers
- Enables assessment/feasibility of different process operations
- Determine optimum flowsheet & size of equipment required
- Geometallurgical prediction of different ores
- Optimisation of existing processes
- Model-Informed Process Control

Requirements of New Generation Simulation



- *To enable interconnectivity, streams will need to be based on particle properties (size, liberation, shape, chemistry)*
- *Process models will need to predict performance based on these particle properties*

Proposing a New Approach to Model Development

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Historic

Model reliant on 100s of physical experiments and interpretation of data trends

Many Physical Experiments → Interpretation of Results → Traditional Simulation Models

Proposed

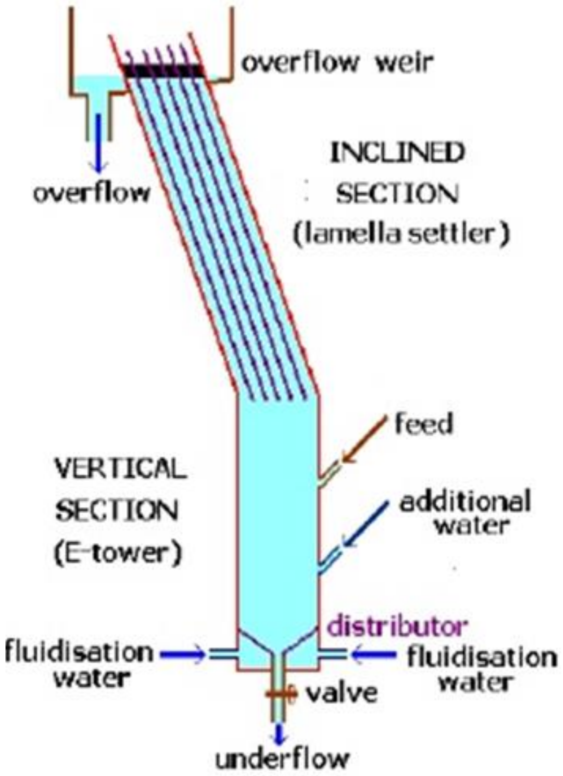
Fewer physical experiments required with CFD model running simulations to support fundamental knowledge development

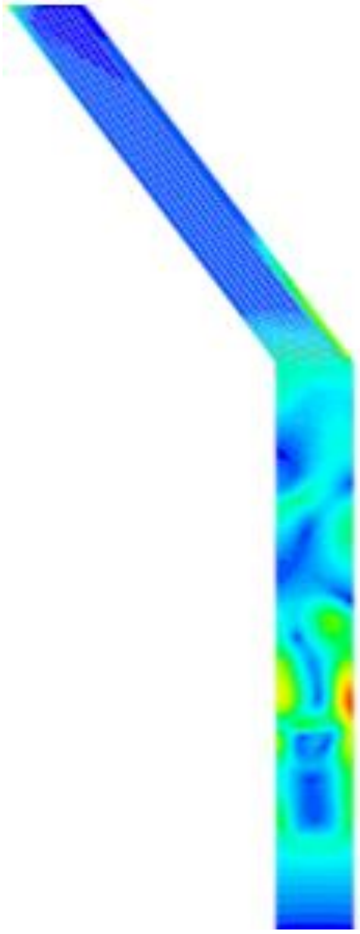
Few Physical Experiments → Build Computational Fluid Dynamics Model → More sophisticated Simulation Models

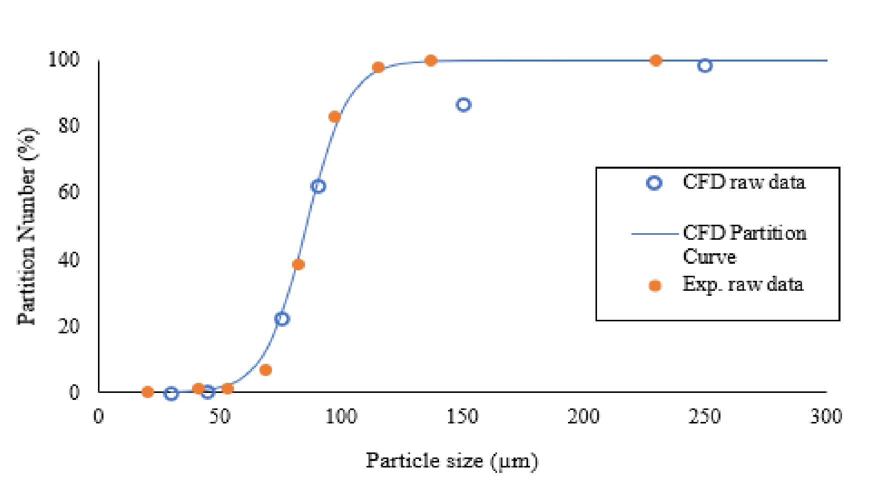
Opportunity to test different designs → Build Computational Fluid Dynamics Model

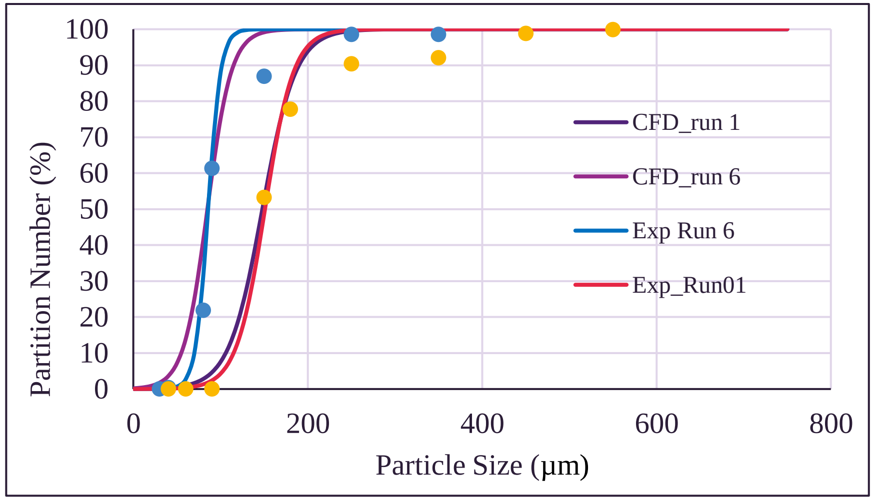
Build Computational Fluid Dynamics Model → Better understanding of fundamentals

CFD Modelling of a Reflux Classifier









Phases of Development of Capability

The University of Queensland
Australia

Completed	*Database of experimental data for a range of novel technologies (e.g. HydroFloat®, Concorde, Inverted Cyclone)* *Building of CFD capability*
Current Focus	*Case Study: Teeter Bed Separator (ACARP) HydroFloat (Trailblazer)* *Build CFD Models and develop process models from learnings*
Further Development	*Set up Collaborative Research Program with Industry Partners* *Develop a sequence of product releases using approach* *Develop a flotation simulation tool to facilitate technology transfer*

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Concluding Statements

- **New Generation Modelling** will involve developing process models of **novel processes** that can be interconnected using **particle properties**
- It will utilise emerging **computational physics-based simulation** and **artificial intelligence** techniques to minimise the need for expensive and logistically difficult experimentation
- The aim is to improve our **understanding** of novel processes and unlock an ability to better **design process flowsheets**, **forecast future performance** and **optimise and control** circuits incorporating these processes

Thank you

Dr Kym Runge Group Leader Separation

SMI-JKMRC

k.runge@uq.edu.au

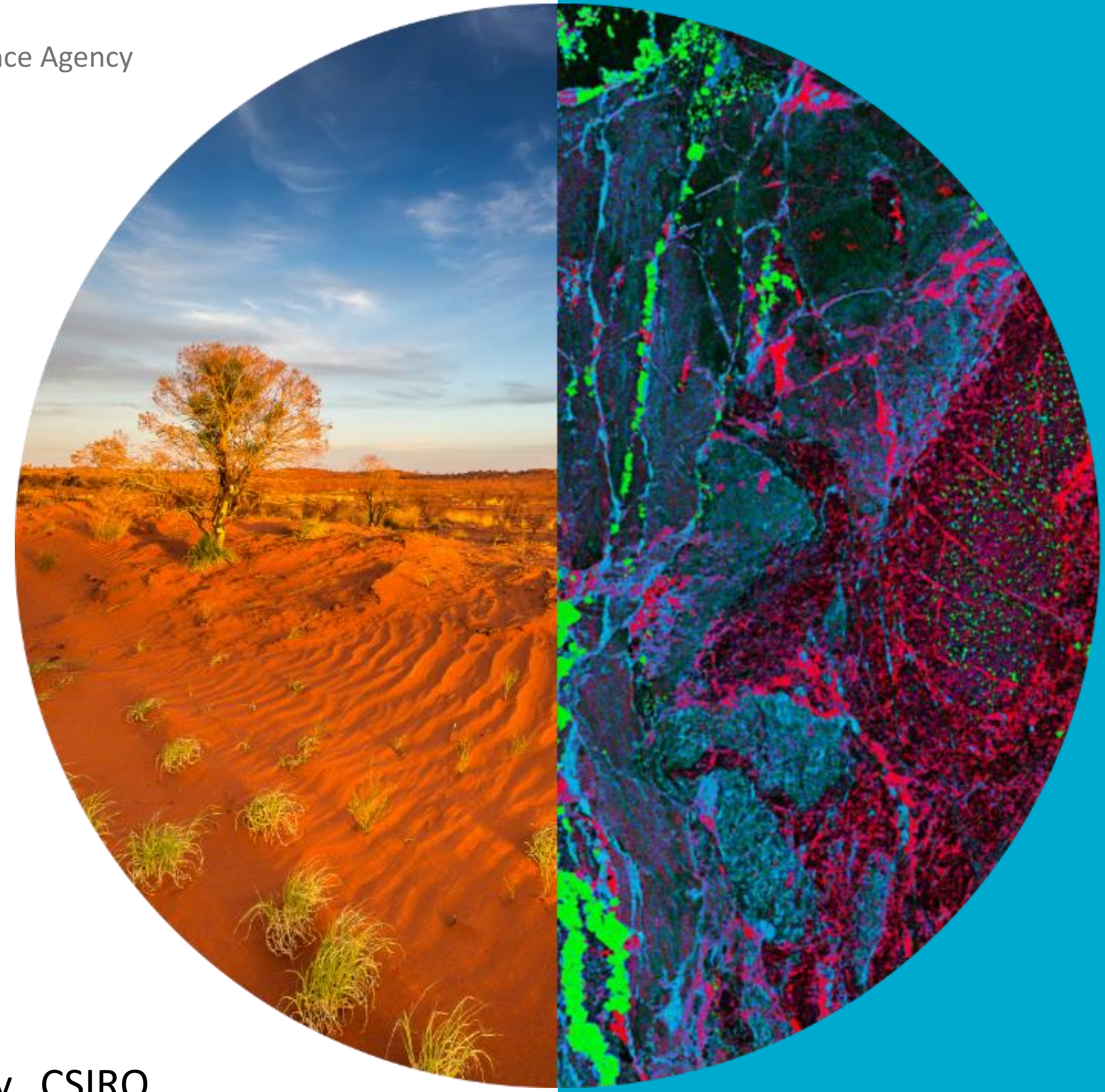
Dr Ebrahim F. Salmi

Senior Mining Mechanics Engineer

CSIRO

In-Place Mining: Refining Old Methods of Mining While Reducing Tunnels and Lining

Australia's National Science Agency



In-Place Mining: Refining Old Methods of Mining While Reducing Tunnels and Lining

Ebrahim F. Salmi
Sustainable Mining Technology, CSIRO

Outline

- A Glimpse into History I'm Keen to Share,
- My Poem to End the Presentation with Flair

My Story: A Tale of a Mine and Quarry

https://www.abc.net.au/news/2016-10-21/brazil-dam-collapse-homicide-charges/7953458

Once upon a time, a tailings dam failure occurred. Engineers wondered how they could have been better prepared.

https://en.wikipedia.org/wiki/File:Bento_Rodrigues,_Mariana,_Minas_Gerais_(22828956680).jpg

The Mariana dam failure, (also known as the Bento Rodrigues or Samarco dam disaster)

Date of Incident: 5 November 2015)

My Story

Soon after, another one occurred. Many people and animals were injured.

https://www.mindthegap.ngo/wp-content/uploads/sites/10/2020/07/Ibama-Flickr.jpg

Adopted from: https://www.worldanimalprotection.org/

Brumadinho Tailings Dam Failure

Date of Incident: 25 January 2019

My Story

https://www.e-mj.com/leading-developments/tailings-dam-fails-at-jagersfontein-diamond-mine-in-south-africa/

**It did not stop.
The rate of failures did not drop.**

And another one!

https://www.stava1985.it/wp-content/uploads/2023/04/Jagersfontein2.jpg

Jagersfontein Tailings Dam Collapse

Date of Incident: September 11, 2022

My Story

More information? Please see here:

Chronology of major tailings dam failures (from 1960)

https://www.wise-uranium.org/mdaf.html

And this will continue until -----?

Please select the Correct Answer, based on your skill

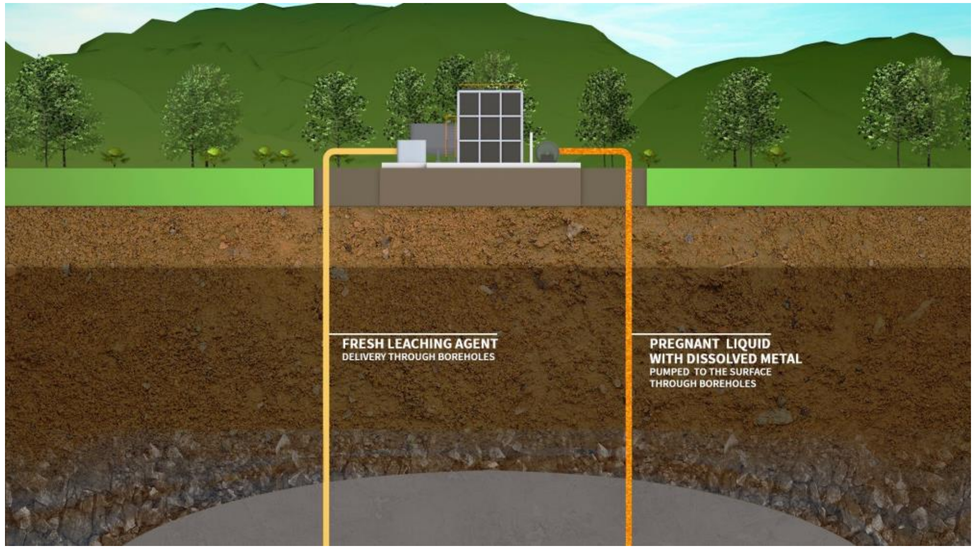
1) – We're good, still. It's no big deal. Let's stick with the same mining and mill.

2) – Dam failure brings a big bill. We will mine differently to fulfil ESG. Let’s consider in-situ mining; just a few boreholes to drill.

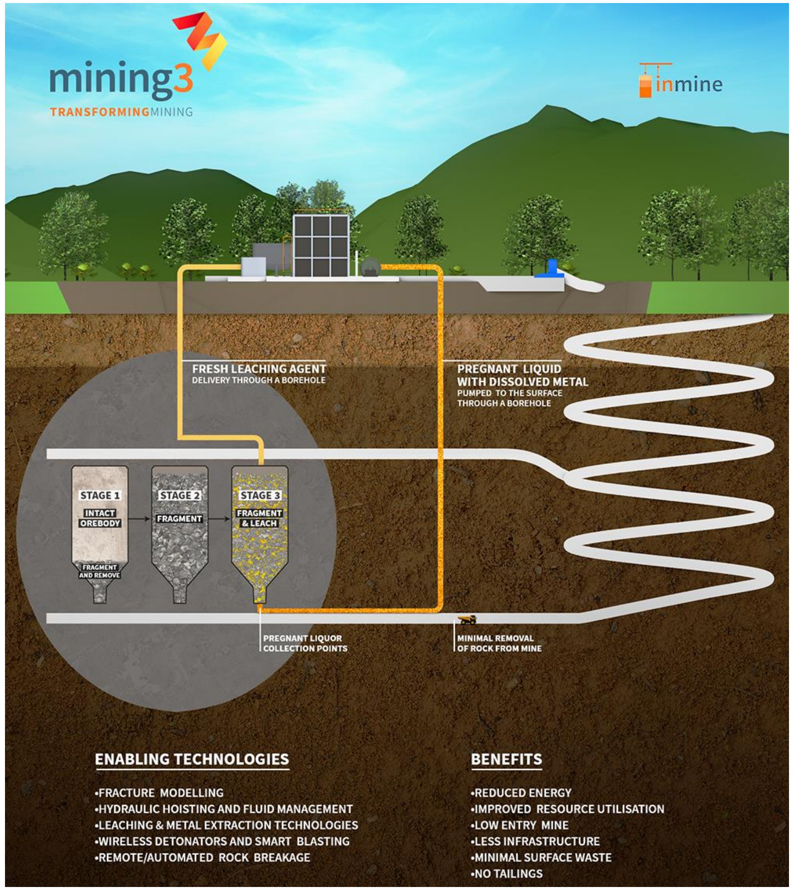
A Perspective on In-Place Mining with no Tailing - Please Pay Attention if You Think Traditional Methods are Failing

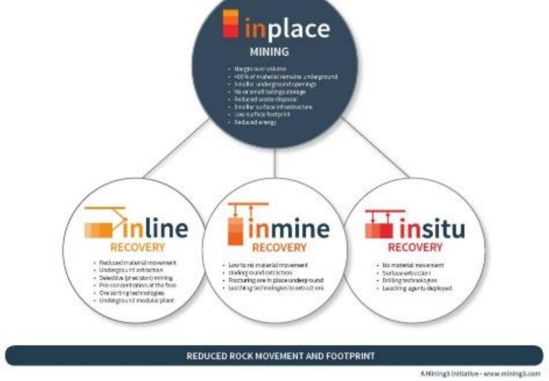
Note: The rest of the slides are for you, but only if you chose option two

In-Situ Recovery



In-Mine Recovery





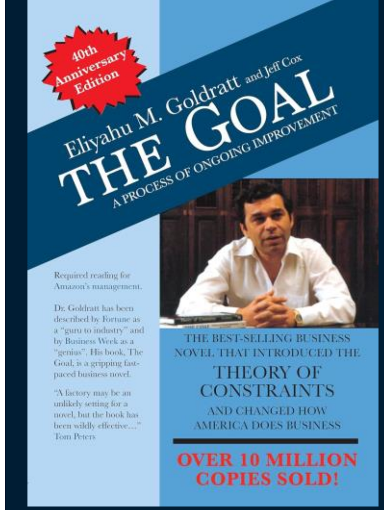
Finding Conventional Constraints for Better Mining States

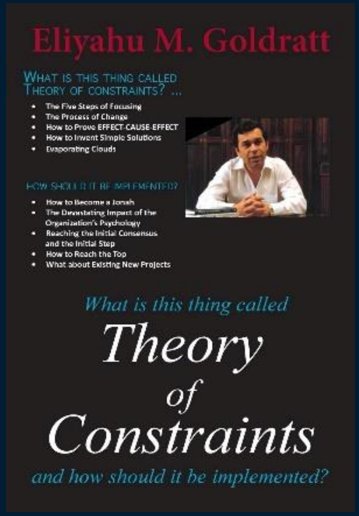
Theory of Constraints (TOC):

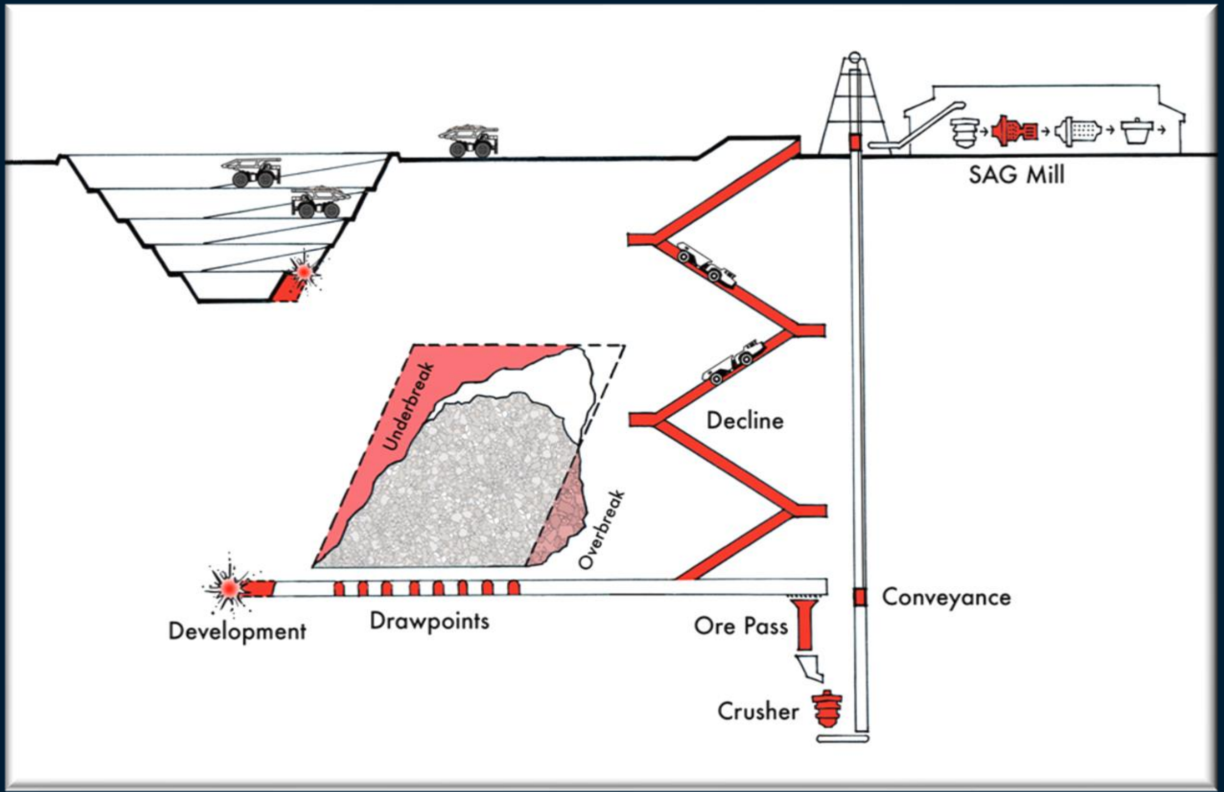
- Developed by Goldratt (1984)
- Identifies the key limiting factors (constraints) hindering goal achievement

Considerations in blasting operations:

- Downstream operations impact total value return
- In-place mining can significantly reduce initial capital and development costs while enhancing overall value by increasing access to a broader range of resources.

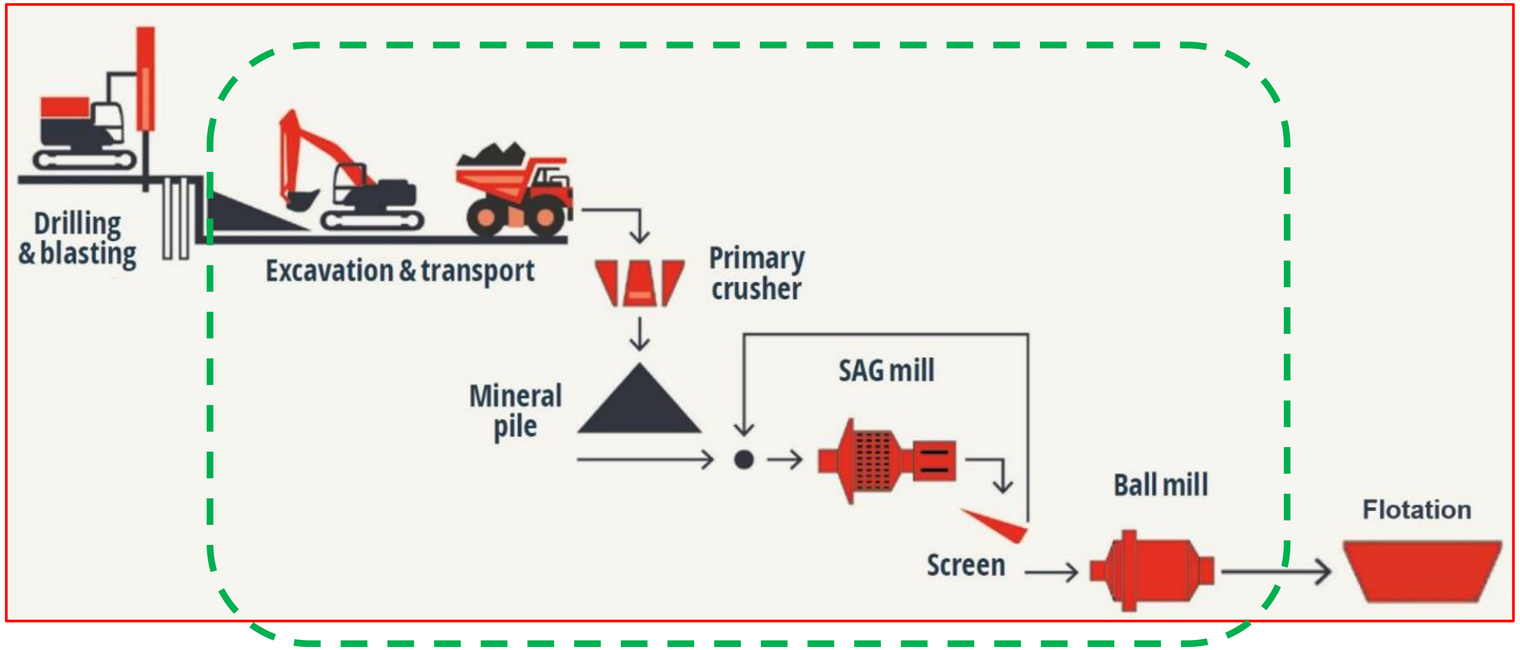




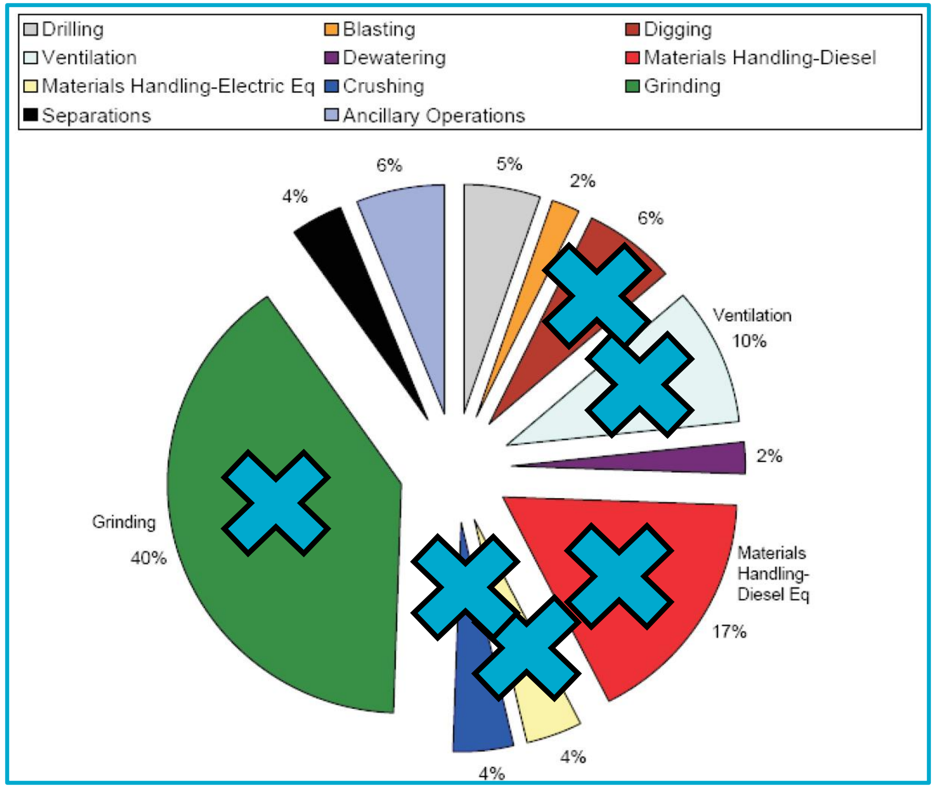


Schematic (not to scale) highlighting potential mine to mill throughput constraints (in red) in open pit and underground operations

Recovery Through In-Place Mining When It's Declining

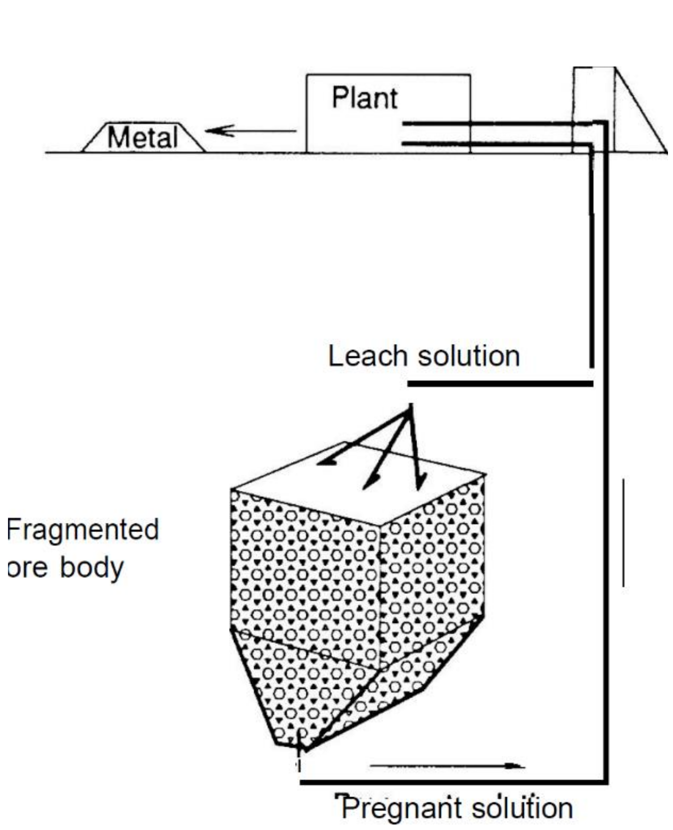


Mine to Mill Value Optimisation in Surface Mining (Couceiro 2018)

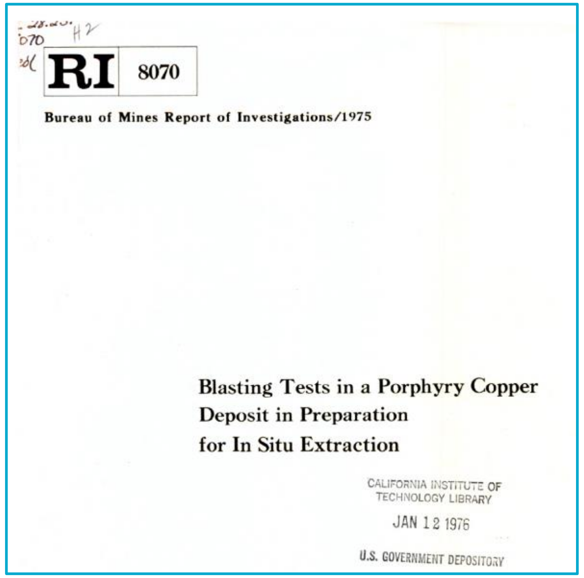


Energy use across the mining process
(Powell and Bye, 2009)

A Touch of History to Decode This Mystery



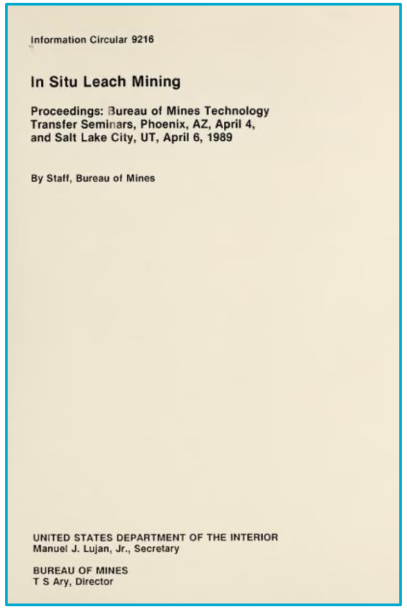
Schematic view of In-mine Recovery Proposed by USBM, (1992)



RI 8070

Bureau of Mines Report of Investigations/1975

Blasting Tests in a Porphyry Copper Deposit in Preparation for In Situ Extraction



Information Circular 9216

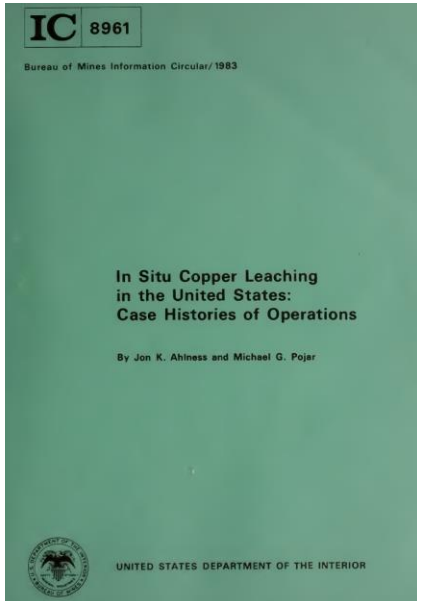
In Situ Leach Mining

Proceedings: Bureau of Mines Technology Transfer Seminars, Phoenix, AZ, April 4, and Salt Lake City, UT, April 6, 1989

By Staff, Bureau of Mines

UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel J. Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director



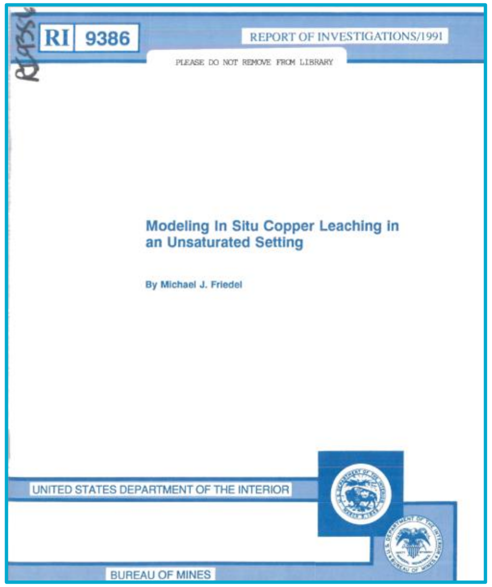
IC 8961

Bureau of Mines Information Circular/1983

In Situ Copper Leaching in the United States: Case Histories of Operations

By Jon K. Ahlness and Michael G. Pojar

UNITED STATES DEPARTMENT OF THE INTERIOR



RI 9386 REPORT OF INVESTIGATIONS/1991

Modeling In Situ Copper Leaching in an Unsaturated Setting

By Michael J. Friedel

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

The United States Bureau of Mines (USBM): A Historical Overview

Established in 1910: The USBM was created as a federal agency with the primary mission of improving safety, health, and efficiency in the mining industry.

Mid-1990s Transition: Due to budget cuts and a shift in US government priorities, the USBM was gradually phased out.

Legacy and Transition: Many of the USBM's responsibilities were transferred to agencies such as the U.S. Geological Survey (USGS) and the National Institute for Occupational Safety and Health (NIOSH).

Shift in Research Focus: However, in-situ recovery, a key area of USBM research, was deprioritised and largely removed from the research agendas of these successor agencies.

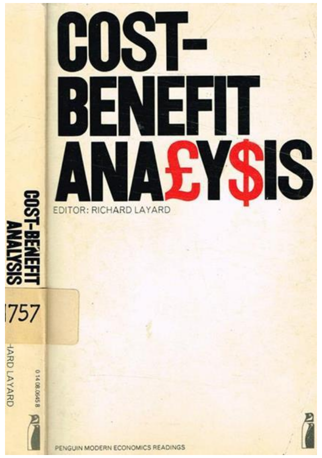
Why In-place Mining of Copper is Still Rare, While Everything is There?

Ore Body Knowledge	Recovery	Environment	Operation
Limitation of Technologies for Discovery & Characterisation	Not Suitable Lixiviant	Toxic Lixiviant for Hybrid Operations	Corrosion
Lack of Techniques for Data Fusion & Processing	Sulphide Ore & Deleterious Elements	Aquifer Contamination	Fracing for Permeability and Fragmentation

Additionally, the need for rapid access to ore resulted in several cumulative issues (the period of 1970's to 1990s).

Research Areas in In-Place Mining for Enhanced Designing

Always weigh the cost-benefit analysis; cleaning the solution is much like dialysis.



Ore Body Knowledge
- Grade
- Stresses
- Structure
- Strength

Fracing
- Measure while drilling
- Fragmentation and Particle Size Distribution
- Permeability

Lixiviant flow
- Metal (Designed for each metal and tailored to each mineralogy)
- Physical control (barriers for leaching silos)
- Physical integrity (how to leach, for how long circulate and when to process the solution)

Extraction
- Energy (quantification and optimisation)
- Recovery (improvement, heated lixiviant? additive? cost benefit analysis)

Footprint
- Surface (minimal)
- Hydrogeology

Conclusion

Let’s challenge the status quo together

and

embrace change with courage to make mining better.

This is my poem for In-place Mining as Promised :)

What's the best way to design a new mine,
Where the ground stays calm, and the vineyards shine?
Can we grab that copper, clean and bright,
Without a crusher in sight?

Forget the AG mill, ditch the SAG,
Let's think big, wave the innovation flag!
Why stick to limits? Let's explore it all,
No need to keep the reserve so small.

It's time to rethink, be smart and bold,
Change the game, break the old mould.
Leach it in place, right where it's at,
No moving ore—how about that?

This could be the golden case,
Protect the earth, and win the race.
Boost recovery, make it shine,
Science is ready, the future's fine.

Keep those pipes safe, no rust in sight,
And break the rock just right.
Maybe all we need is an SXEW plan,
Just a grant, and we're off, man!

Thank you

Dr Ebrahim Fathi Salmi
Ebrahim.FathiSalmi@csiro.au

We, Persian, Love Poems

Questions?

- When and where do you think the concept of in-situ mining was first tested?
- Can you name any operation currently testing the viability of in-situ mining for ores other than uranium?
- Which country do you think uses the ISL (In-Situ Leaching) concept the most globally?

Dr Italo Onederra

Associate Professor

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Dr Micah Nehring

Associate Lecturer

Optimising Value in Stope Leaching Systems - Insights from past research and emerging innovations

THE UNIVERSITY OF QUEENSLAND AUSTRALIA | CREATE CHANGE

Optimising Value in Stope Leaching Systems

Insights from past research and emerging innovations

A/Professor Italo Onederra
Dr Micah Nehring

Centre for Future Autonomous Systems and Technologies
School of Mechanical and Mining Engineering

Outline

- **Insights from past research:**
  - Understanding the impact of preconditioning and fragmentation on recovery

Learnings from BHP project (2019-2021)
Rock mass preconditioning and fragmentation

- **Emerging innovations**
  - Decision support systems for sustainable mine process optimisation strategies (e.g. Blast to Leach & M2M)
  - Development of strategic planning and extraction optimisation for in stope leaching systems

Current developments - Centre for Future Autonomous Systems and Technologies (FAST) (2023- 2026)

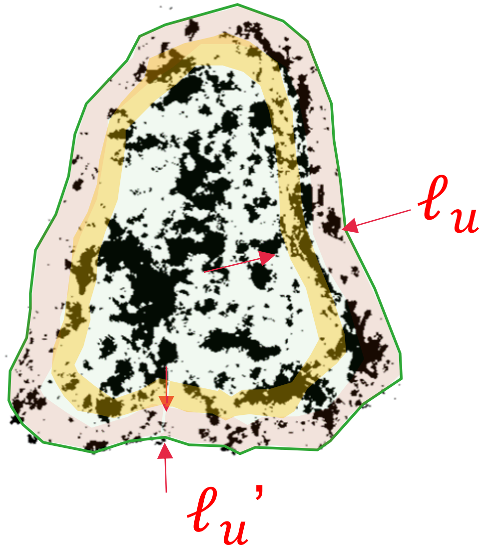
BHP sponsored project (2019-2021)

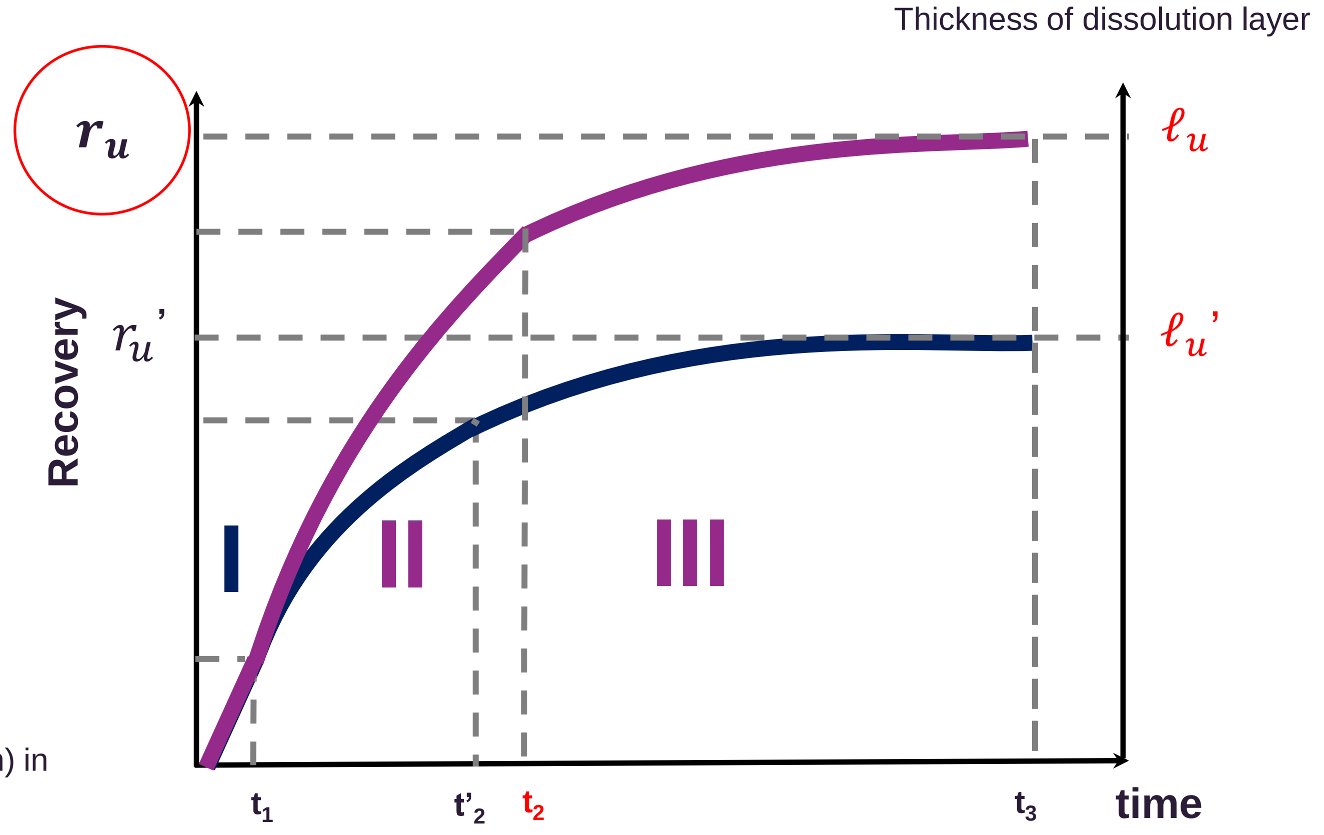
Rock mass preconditioning and fragmentation

The team

From left to right: Paulo Lopez, Zi Wang, Alexandra Roslin, Felipe Salazar, Travis Mitchell, Christopher Leonardi, Italo Onederra, Miguel Araos

On the question of recovery





Phase I leaching of grains at the surface of the ore particles

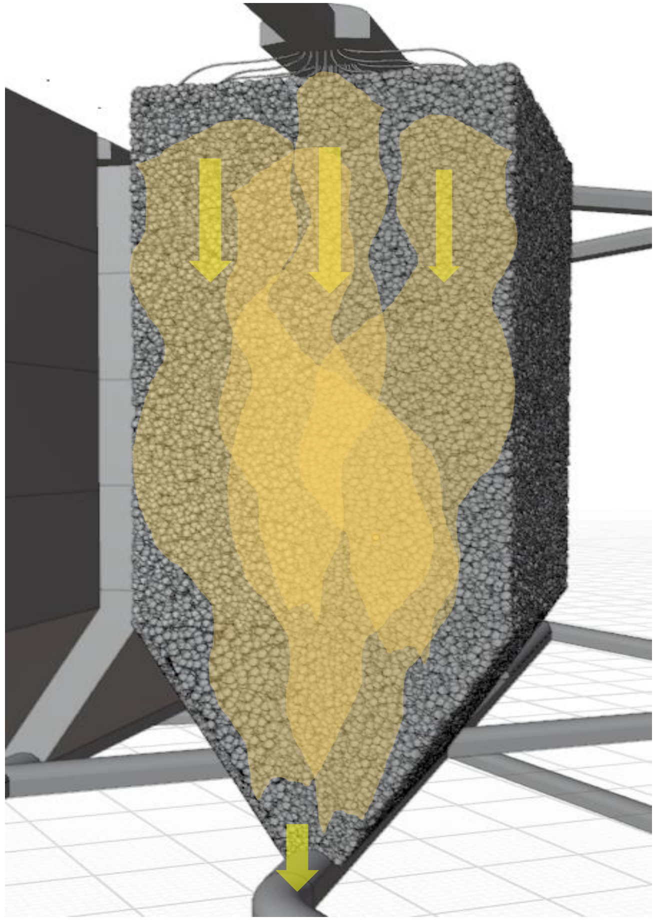
Phase II leaching of grains (a combination of diffusion and reaction) in the subsurface within the thickness of the ℓ_u

Phase III beyond the thickness of the ℓ_u the overall leaching rate decreases dramatically until there is an almost linear relationship between conversion of the target mineral grains and time.

Lopez (2022)

The link between recovery and fragmentation

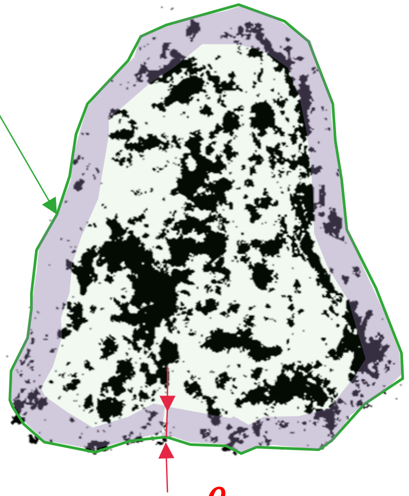
- Total surface area per volume of rock σ_λ for all the particles of size λ
- The fines content μ_λ is the fraction of the rock volume made of fragments smaller than λ



Surface driven *Volume driven*

$$r_u = \ell_u \sigma_\lambda + \mu_\lambda r_{u\lambda}$$

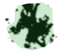
σ_λ *Total specific surface area of the coarse fraction (mm^2/mm^3)*



ℓ_u *Dissolution layer (mm) (Lixiviant accessibility)*

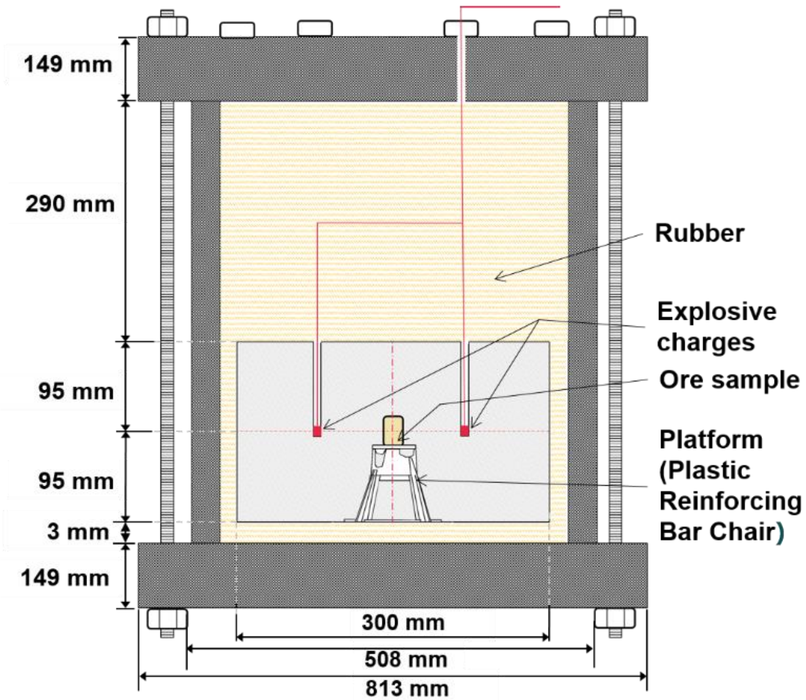
Detournay (2021)

μ_λ *% less than λ (fines)*



$r_{u\lambda}$ *Fines recovery factor*

Fragment preconditioning and dissolution layer ℓ_u

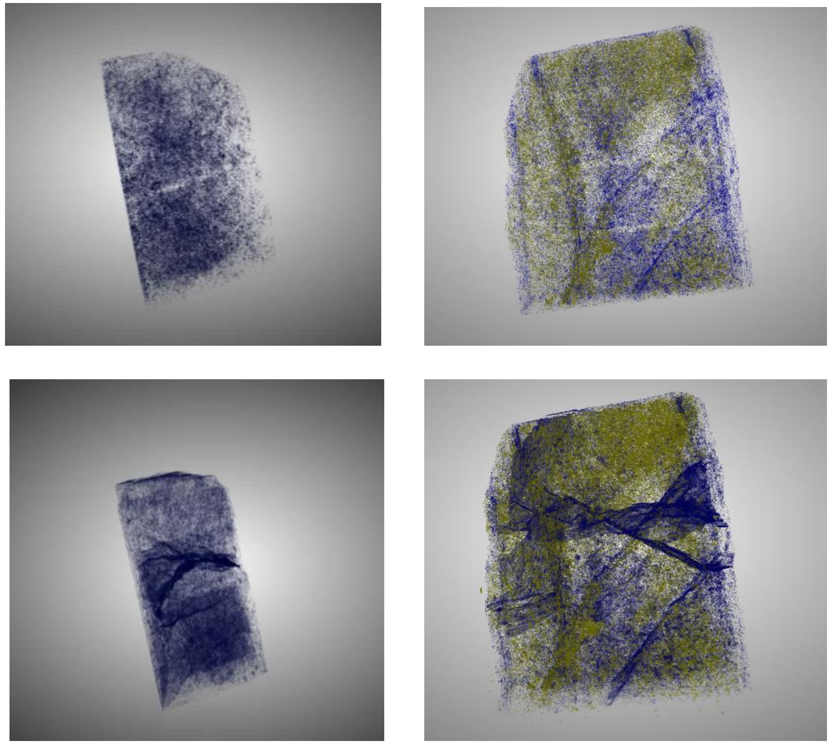


(a)

(b)

Intact vs Preconditioned Ore

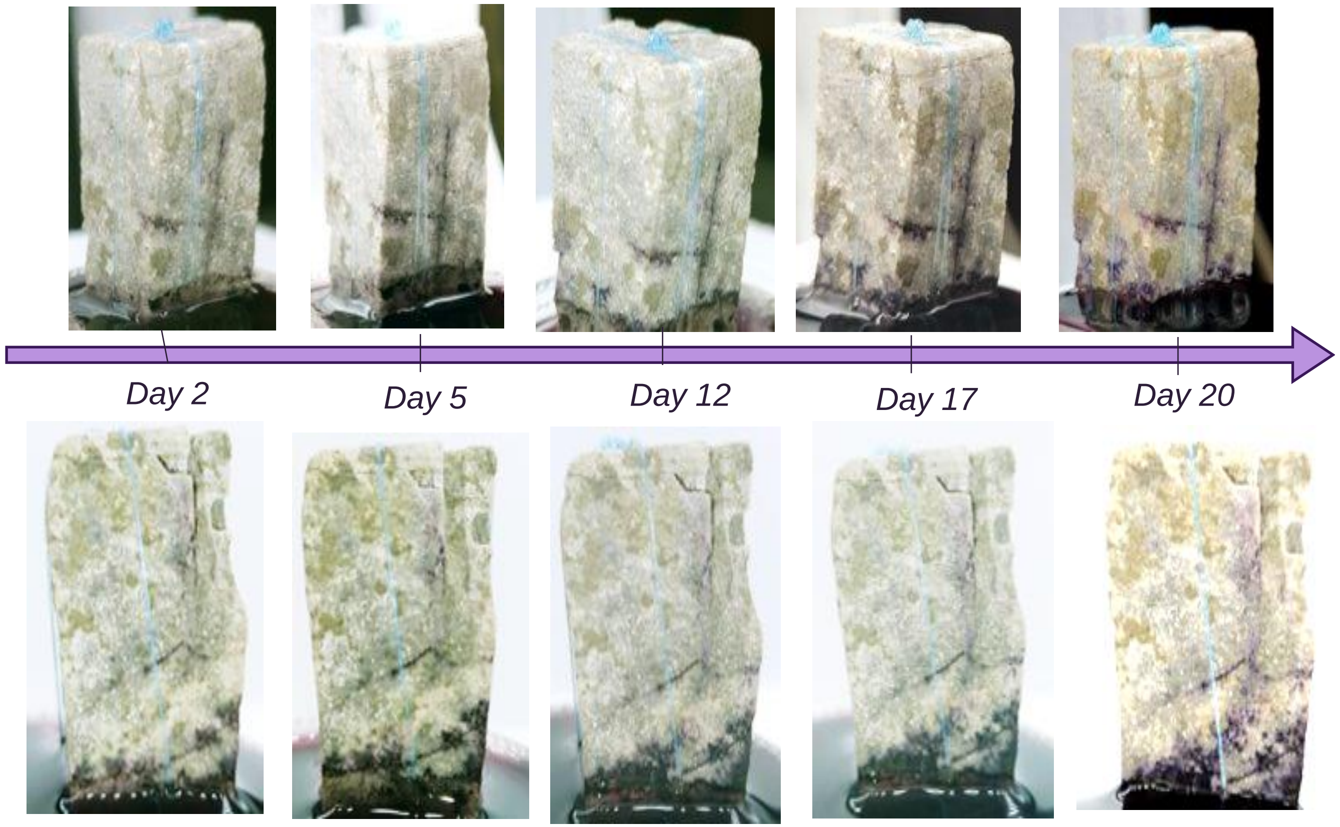
3D model of pore distribution and sulphides dissemination (blue – pores, yellow – sulphides)

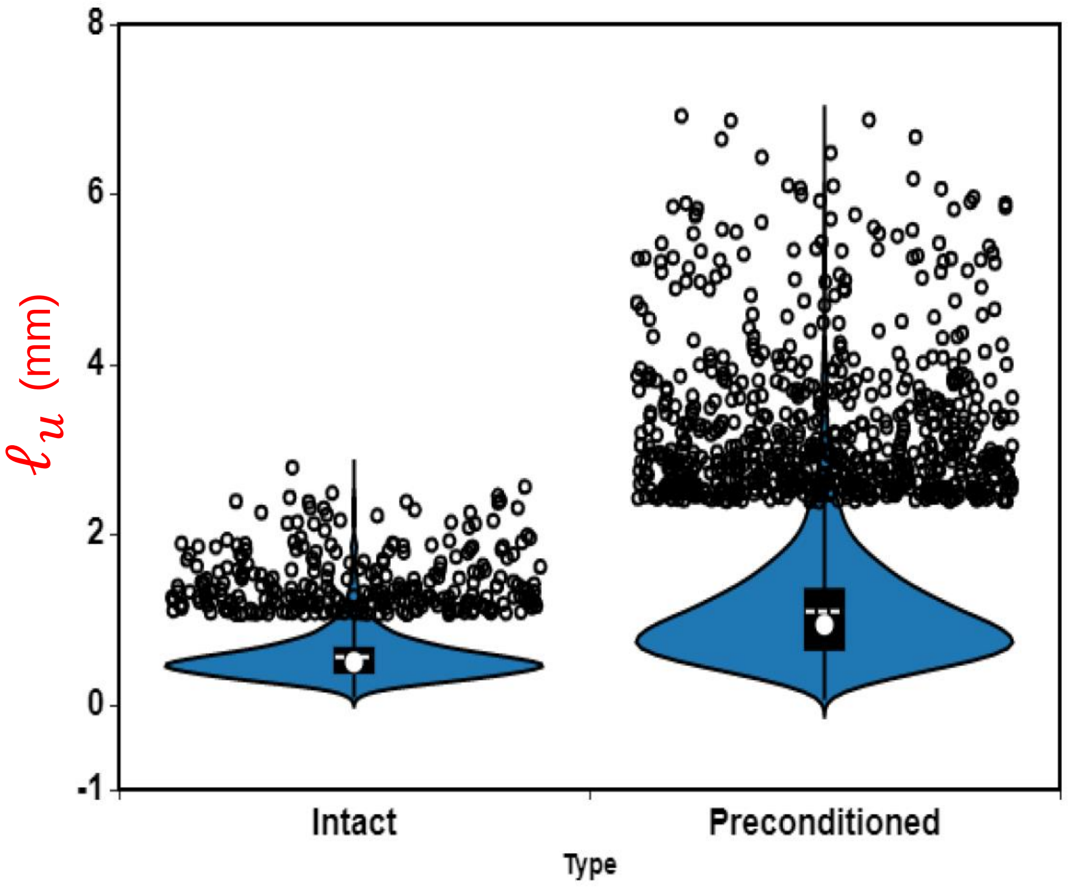


Lopez (2022)

Fragment preconditioning and dissolution layer ℓ_u

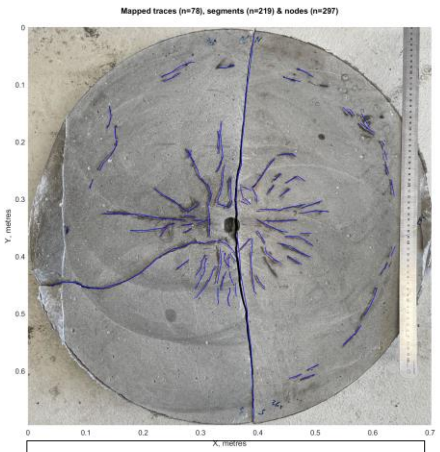
Capillary rise in Sample 1 - after blasting

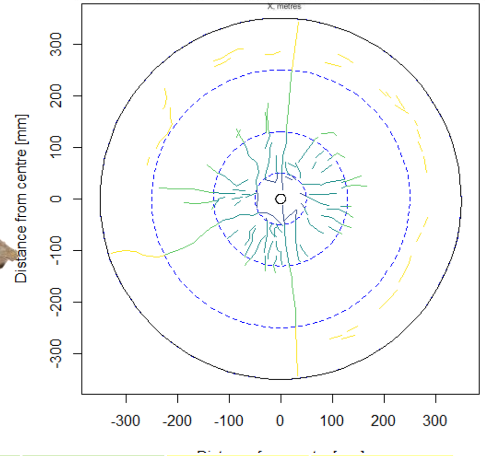




Lopez (2022)

Preconditioning experiments and SSA of fractured zones

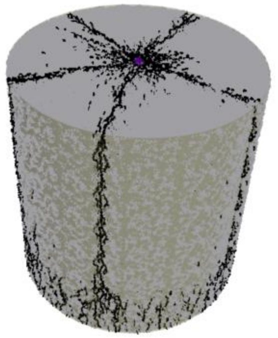


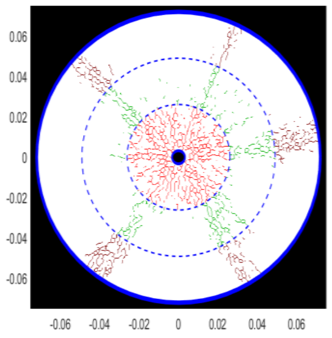


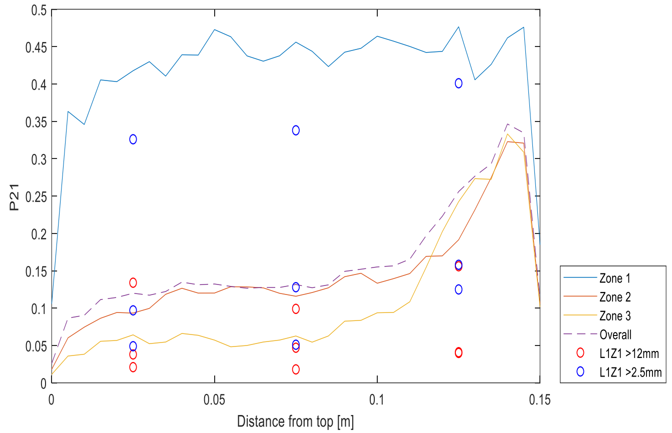
Zone 1 (0-50mm) Fracture length (mm)	**P21**	Zone 2 (50-130mm) Fracture length (mm)	**P21**	Zone 3 (130-250mm) Fracture length (mm)	**P21**	Zone 4 (250-350mm) Fracture length (mm)	**P21**
300.6	0.0398	1828.5	0.0404	934.2	0.0065	1015.1	0.0065
Total Fracture length (m)				4.08			

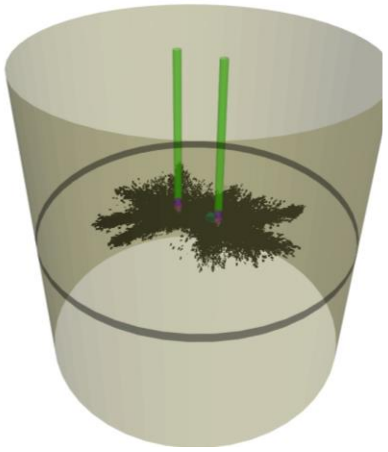
Multi-scale preconditioning modelling

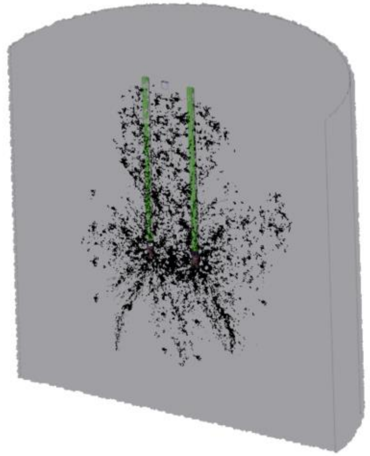
Laboratory scale – Calibration and validation





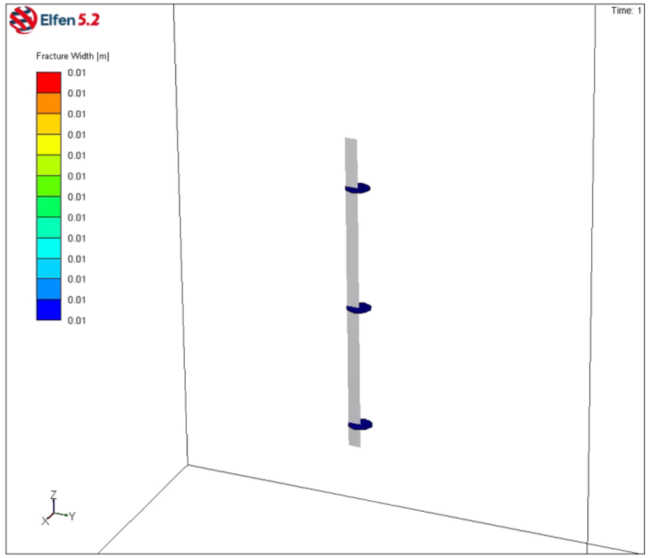


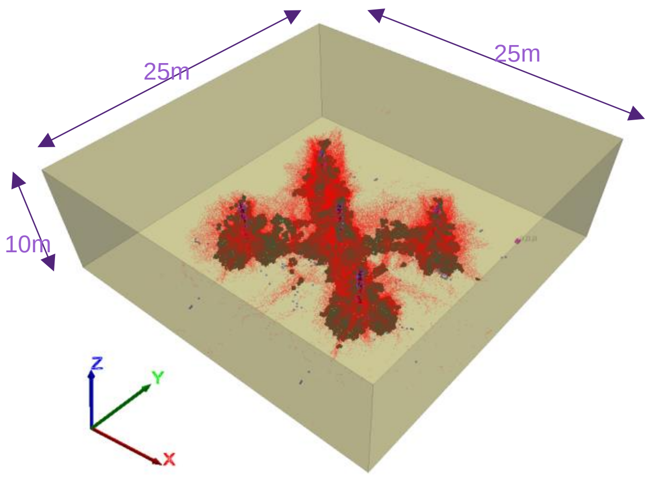




Hydraulic fracturing & Confined blasting

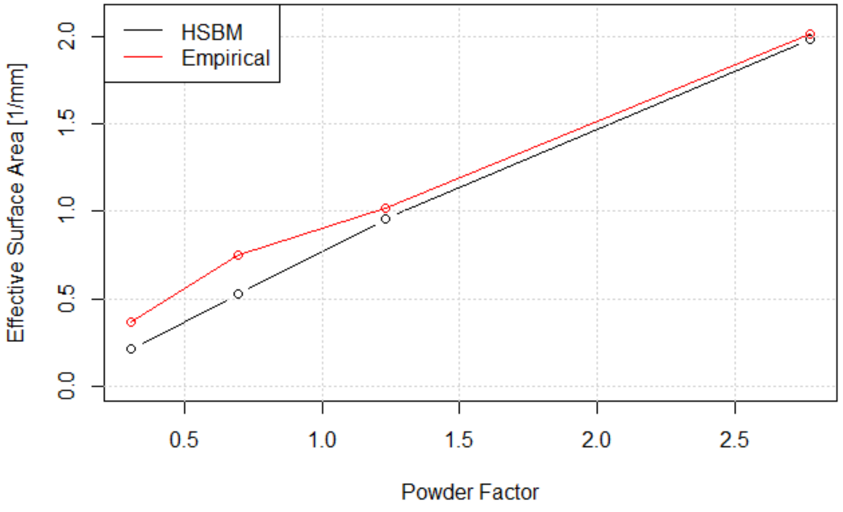
Stope layer scale





Minor increased in Total SSA

Validation and improvement of empirical models



Improving stochastic fragmentation and SSA modelling

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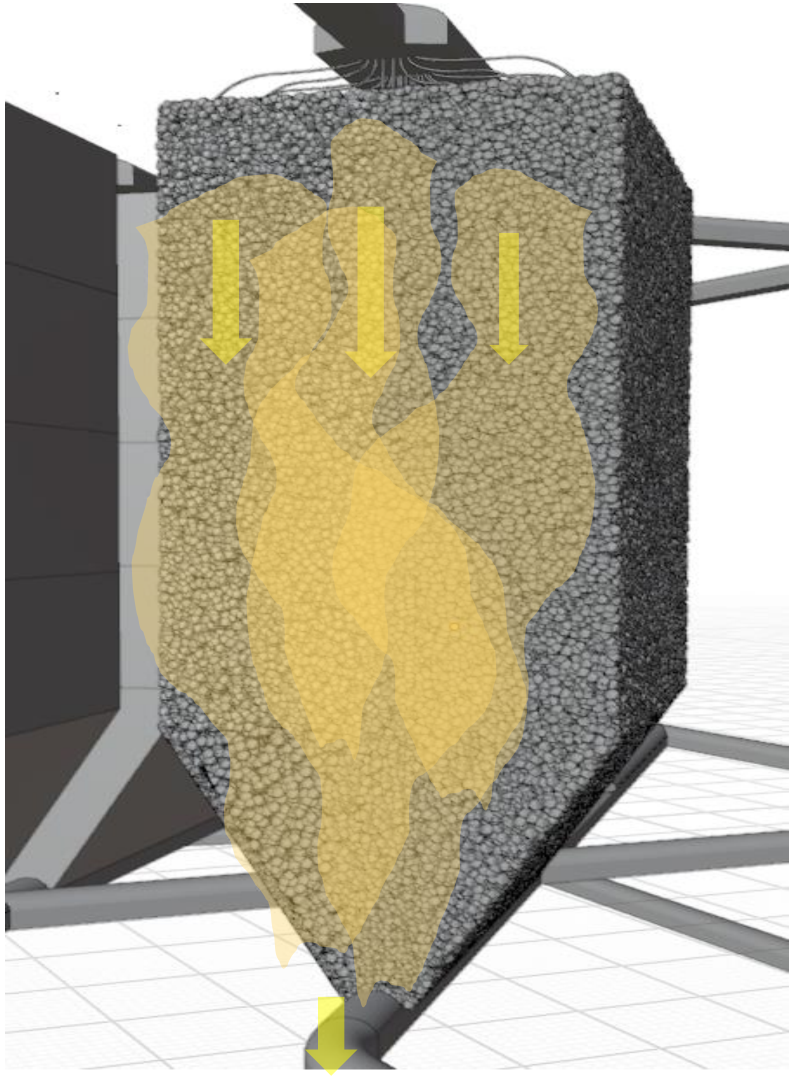
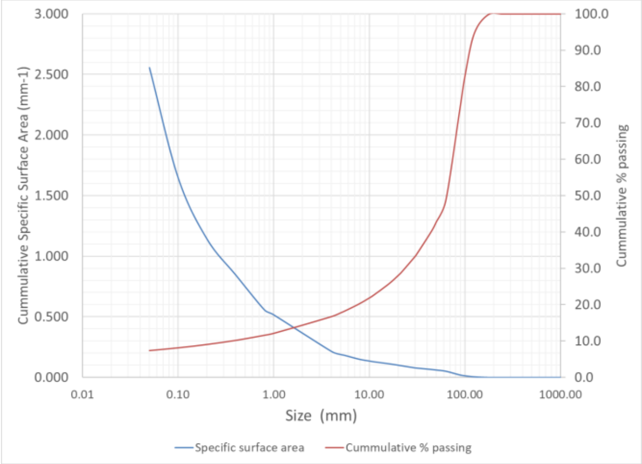


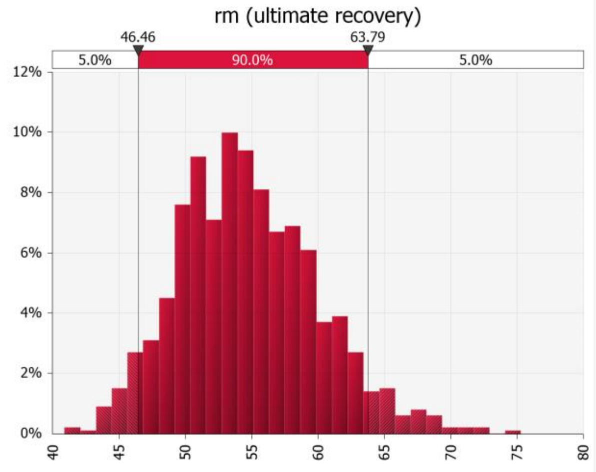
Fragmentation and cumulative specific surface

Specific surface area of coarse fraction ($\sigma\lambda$)

Dissolution layer (fines cut off)

Burden (m)	Spacing (m)	Charge diameter (mm)	Explosive type	Layer height (m)	Powder Factor (kg/m3)	Total SSA (mm-1)	% fines -4mm	Total SSA (coarse >4mm)	P50 (mm)
7	8	200	A	10	0.63	0.687	2.9	0.1	238
6	6	250	B	10	1.60	1.547	7.5	0.157	123
5	5	250	B	10	2.31	2.049	10.3	0.192	98
4	5	250	B	10	2.89	2.269	12.4	0.219	83





Centre for Future Autonomous Systems & Technologies

Decision support & Strategic Planning Tools (2023-2026)

The team

From left to right: Armando Liebenberg, Mphoentle Olorato Gadiile, Micah Nehring, Italo Onederra and

Emerging innovations: Decision support system for Mine Process Optimisation

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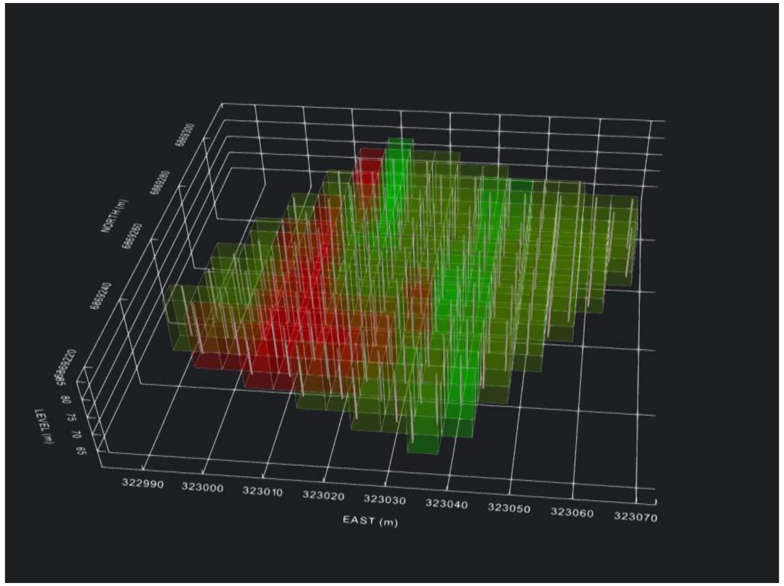
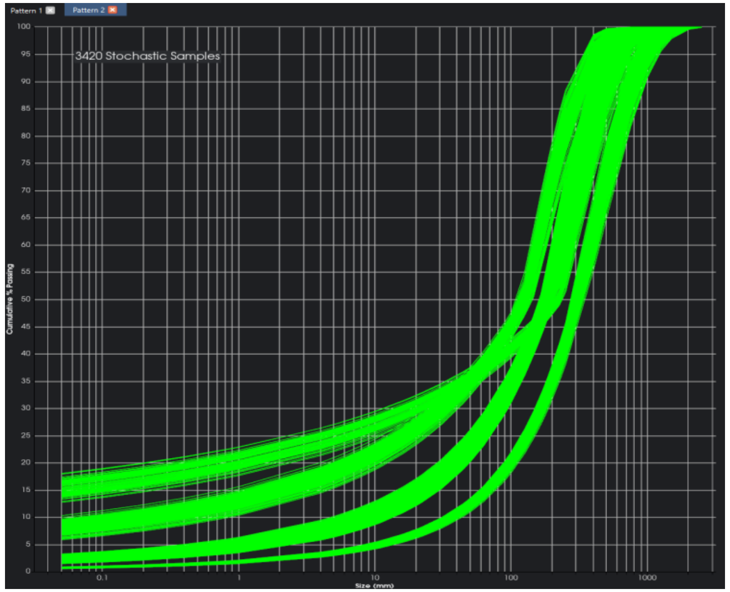
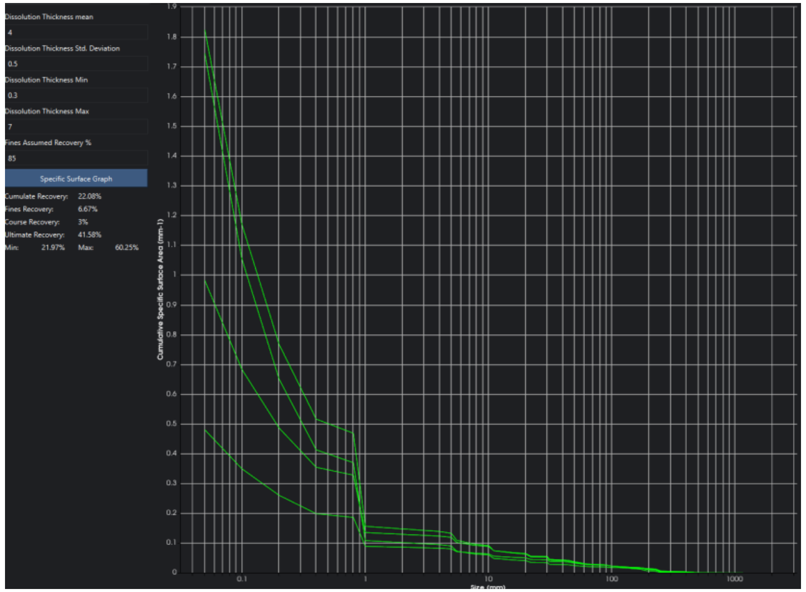
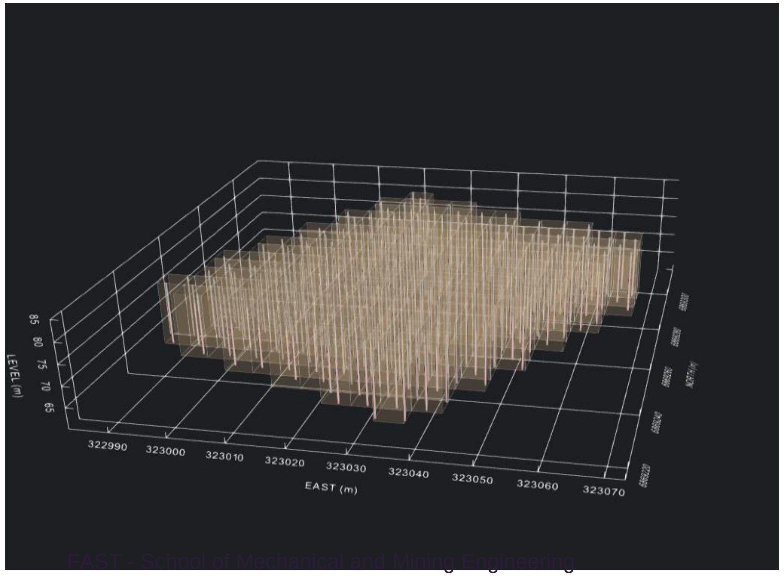
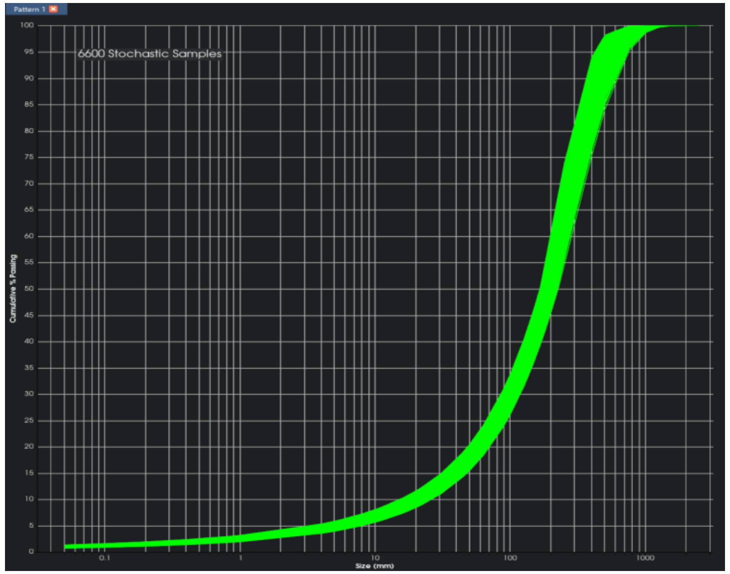
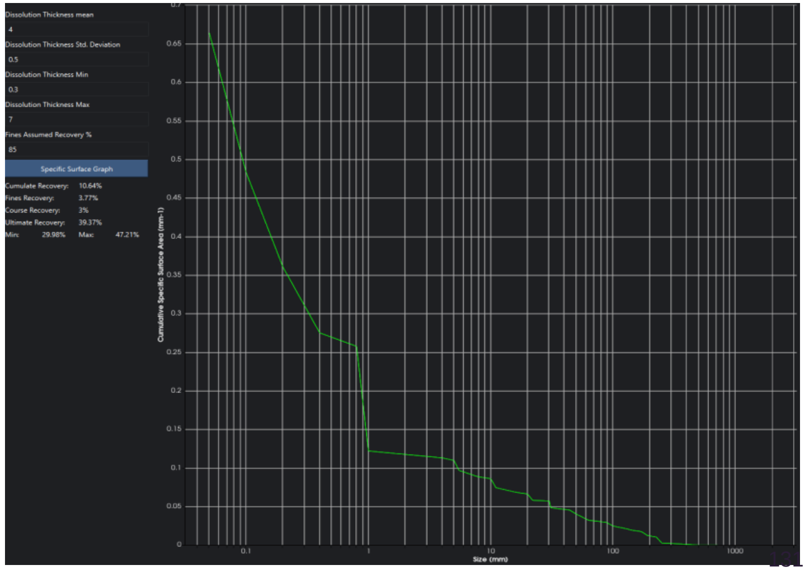






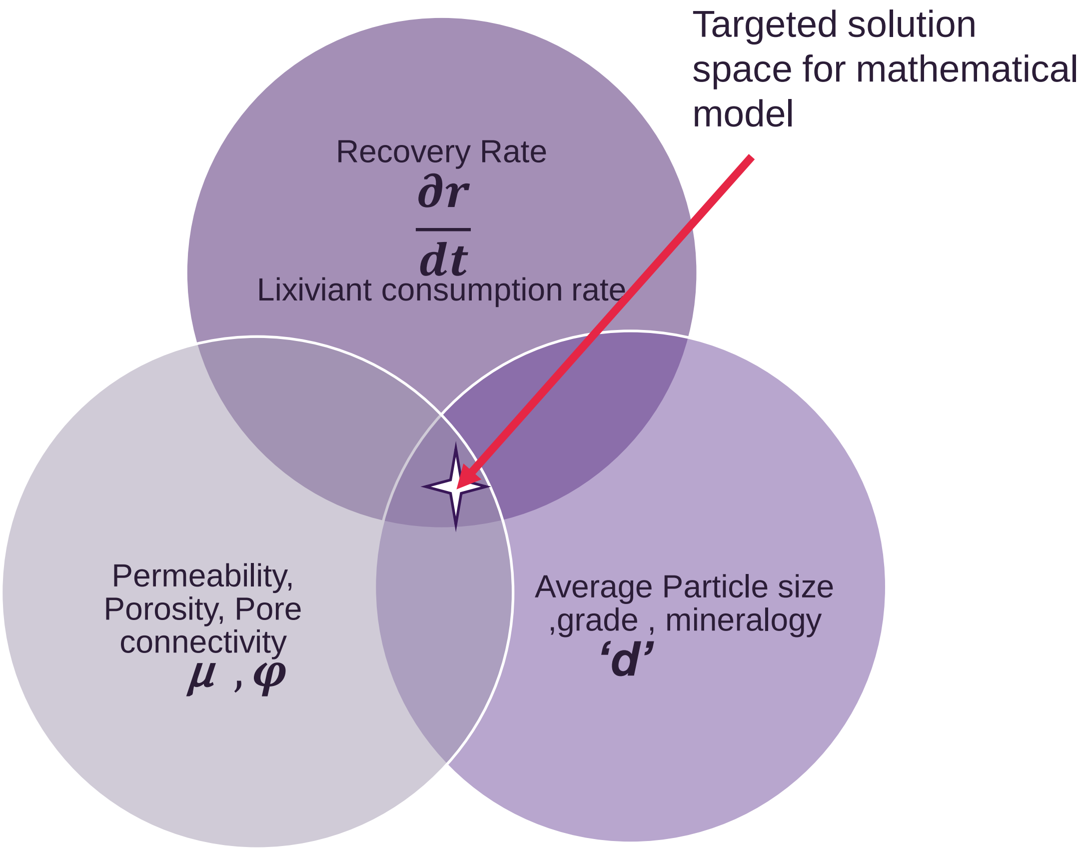


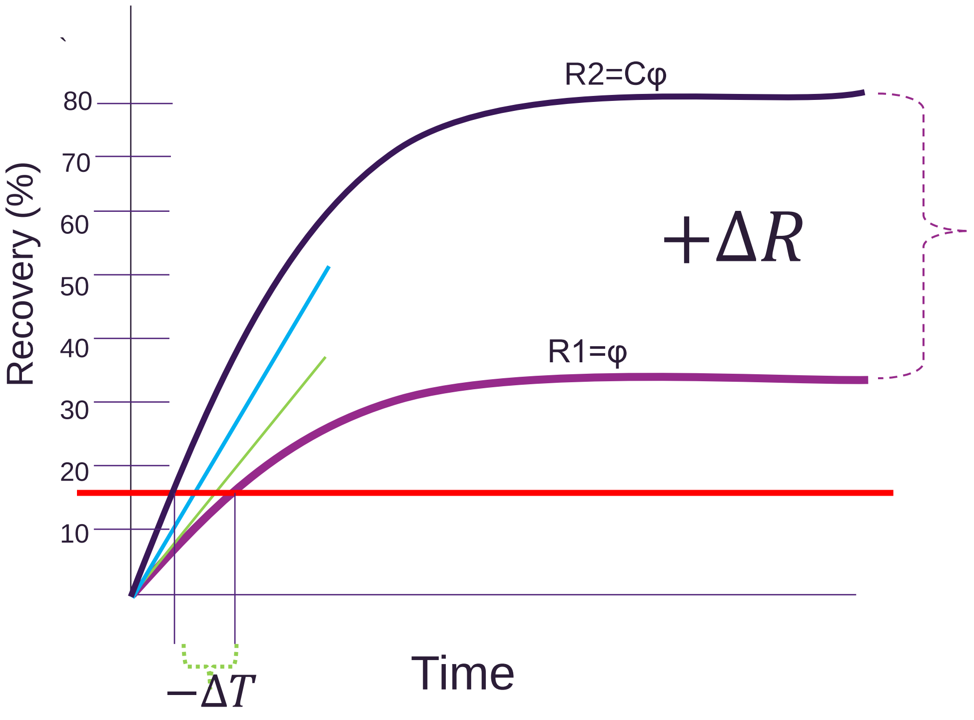




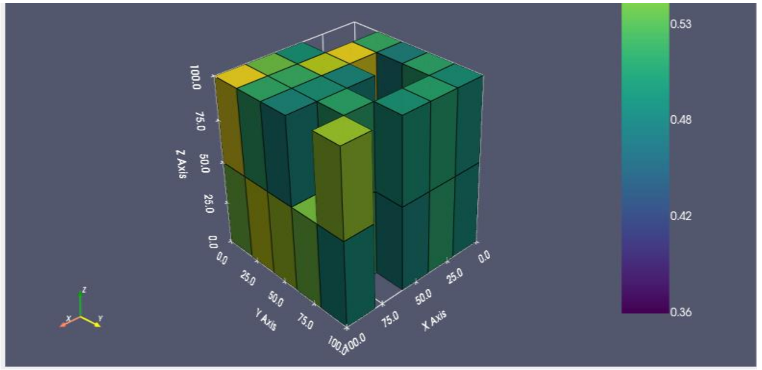
Emerging innovations: Strategic planning for stope leaching systems

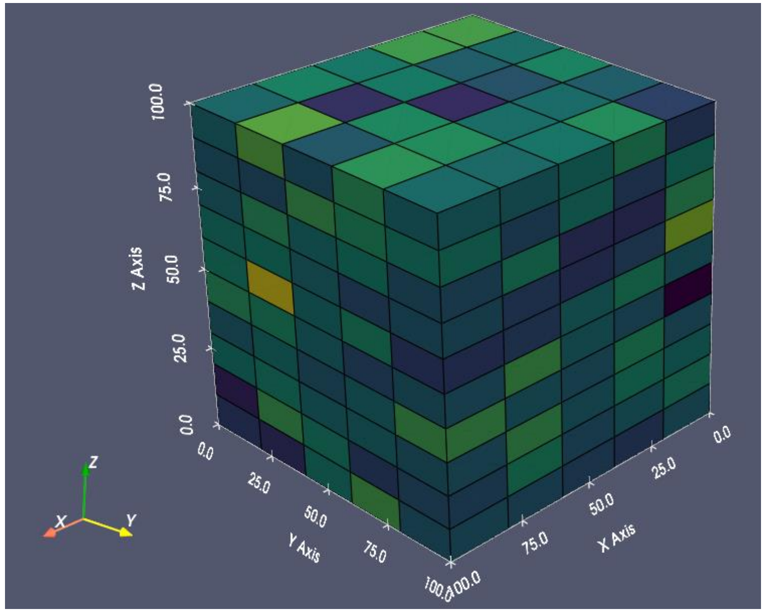
Integrating geometallurgy, geotechnical and hydro-geological aspects to long-term optimisation

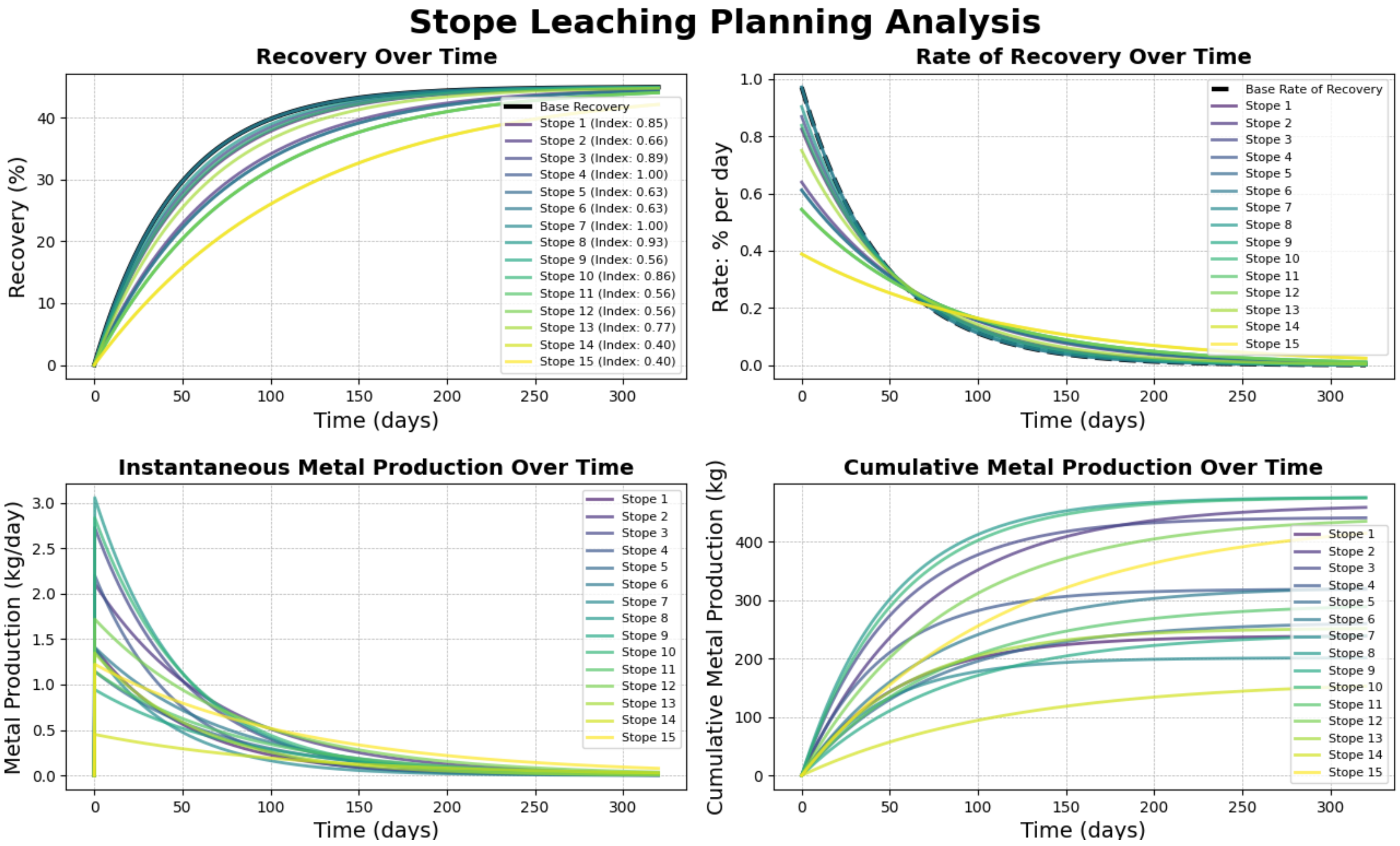




Emerging innovations: Strategic planning for stope leaching systems







Thank you

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