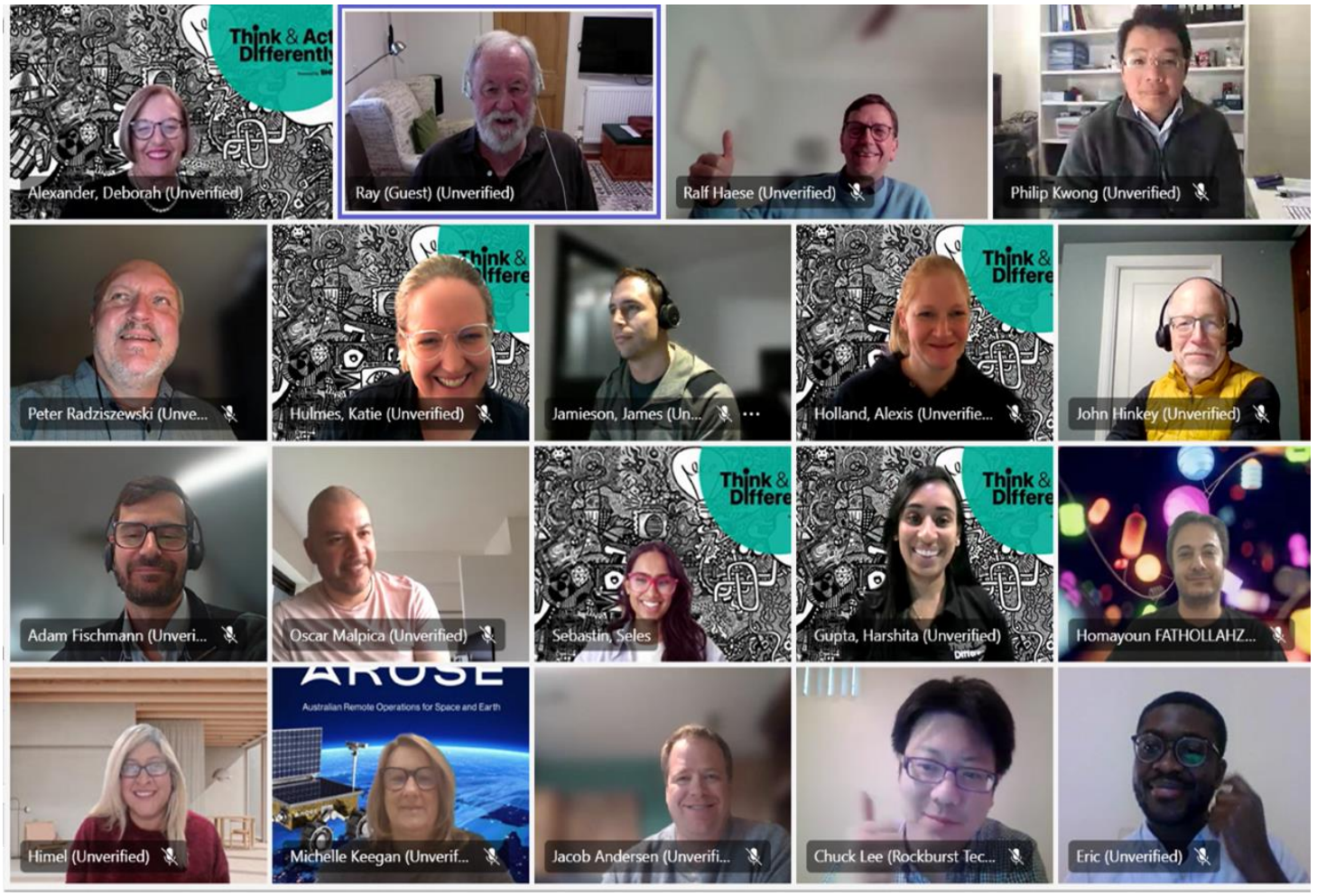
Think & Act Differently

Powered by BHP

Essential Minerals Cohort

Think & Act Differently

Think & Act Differently (TAD), Powered by BHP, finds and accelerates the best technology solutions to support BHP's ambitions to deliver resources the world needs in new ways. TAD uses a systems approach to foster a continuous flow of new technologies and capabilities that empower BHP to meet today's needs and build a roadmap for future value. Using the TAD and partner innovation ecosystems, collaboration is encouraged with a range of individuals and organisations to accelerate technologies at scale, promoting optionality, speed, and diversity.



This diverse and talented cohort has capability that covers many separate parts of the mining process. Through collaboration with experts from Think & Act Differently, BHP, and cohort members, we've collectively garnered invaluable insights. As a result, this cohort is now well-positioned to further propel their ideas towards commercialisation – Katie Hulmes, Head of Ecosystem TAD.

Think & Act Differently

Empowering innovation through collaboration

We are excited to share the learnings from of our Essential Minerals Cohort program, which concluded in October 2024. The final selected group of early-stage innovators have been formed together in the Essential Minerals Cohort, which blends capabilities from several innovation open calls. As part of this cohort, ten innovators joined forces with Think & Act Differently, Powered by BHP, to tackle three challenges:

- Carbon Economy: Exploring solutions for managing and potentially storing emissions and carbon
- Preconditioning Rock: Developing ideas, technologies, and processes to pre-condition rock.
- Mineral Extraction: Extracting cobalt, rare-earth elements (REE), and molybdenum from copper or nickel deposits

This Learning Snapshot provides an overview of the learnings and potential value which the innovators' technologies are striving to unlock.

We are incredibly proud of the progress made by the innovators and are excited about the future possibilities these innovations bring. The work done in this cohort a is milestone that underscores our commitment to fostering innovation and driving sustainable solutions in the mining industry. A huge thank you to everyone involved for their hard work and dedication.

The ecosystem approach to acceleration

Accelerating aspirational future systems requires bringing together diverse innovators across the entire value chain. This collaborative approach is aimed at understanding the capabilities of various segments within the ecosystem and envisioning what future operations could look like.

Our approach is committed to unlocking value for BHP and our partners through an innovation and technology portfolio designed to deliver benefits today, tomorrow, and beyond.

We seek to accelerate technologies that can be implemented in current operations as step-change improvements, as well as innovative combinations that form new value chains or systems that integrate multiple technologies.

We aim to cast a wide net, engaging not only traditional mining and engineering specialists, but also exploring ideas from other disciplines and industries. This inclusive approach accelerates the injection of new learnings into the innovation ecosystem.

A collaborative environment allows innovators to learn from each other, identify how their systems complement one another and pinpoint opportunities for creating value through integrated innovations. The comminution systems of the future will likely be a synthesis of various innovations spanning the entire value chain, driven by the collective expertise and creativity of the global innovation community.

Essential Minerals Cohort

Summary highlights

The Essential Minerals Cohort has made some great progress in accelerating our understanding of critical challenges and opportunities along the mining value chain, particularly in the areas of carbon economy, rock preconditioning, and mineral extraction.

The TAD cohort environment aims to create a space where subject matter experts and innovators can collaborate to analyse the competitive landscape and assess the viability of their technologies.

This cohort brought together a diverse group of experts and innovators who were able to refine their development pathways through collaboration. Both BHP and the participating innovators gained valuable insights and formed strong relationships that will continue to promote innovation within the industry. We are incredibly proud of the innovators' progress and the potential of their technologies. Every member of the cohort accelerated their knowledge in some way.

Among the achievements of the cohort were the identification and refinement of several capabilities and technologies. For example, the ore characterisation work conducted by UNI SA was recognised as a valuable capability for the industry. Additionally, Clean TeQ Water's ATA tailings dewatering technology has the potential for some near-term use cases. ATA® is a novel rapid dewatering technology designed for improving tailings management, particularly by creating a pathway for dry-stacked tailings.

The progress made by the innovators, coupled with the insights gained and partnerships formed, contributes to the industry's journey towards sustainability. Moving forward, there is great anticipation for building on this momentum, exploring new opportunities for growth, and continuing to support the development of cutting-edge technologies.

The Essential Minerals Cohort has proven to be a valuable initiative, showcasing the importance of collaboration, innovation, and learning in addressing the critical challenges faced by the mining industry. Their advancements and achievements set a strong foundation for continued progress and creative solutions for the future.

Essential Minerals Cohort

Summary highlights

Innovators involved in the Essential Minerals Cohort

The final ten groups received a blend of financial and technical support, along with some receiving samples for test work. Unearthed were our open innovation challenge partner and the following innovators participated in the Essential Minerals Cohort program:

The innovative teams in this cohort include:

- University of South Australia (Australia): *Characterisation of materials for Critical Mineral Extraction*
- Naturafrac Inc. (USA): *Pulsed Explosive Gas Preconditioning*
- Rockburst Technologies (Canada): *Transcritical CO2 Comminution*
- Edith Cowman University (Australia): *Saline Water Bio Copper Sulphide Leach*
- Mine to Metal (Australia): *Roast and Ammonia REE Leaching*
- University of Adelaide (Australia): *Biodegradable NiOx Lixiviant*
- The University of Melbourne (Australia/Canada): *Aluminum Chloride and Ferric Copper Sulphide Leach*
- Ekion (Australia): *Electrokinetic Enhanced Leaching*
- Rampart Detection Systems (Canada): *Novel treatment of acidic mine waste*
- Future Element & Clean TeQ Water (Australia): *Advanced Dewatering ATA*

A forward work plan is being established to support further experimentation and advance some technologies to pilot demonstrations.

Essential Minerals Innovators

GreenLixiviant

GreenLixiviant, developed by the University of Adelaide, is an innovative, biomass-derived lixiviant designed for sustainable metal extraction as an alternative to conventional acids like sulfuric and hydrochloric acid, commonly used in mineral processing. The goal is to reduce waste and environmental impact while maintaining the efficiency of metal extraction, particularly for nickel (Ni) and cobalt (Co).

The primary aim of this experiment was to investigate the effectiveness of GreenLixiviant on extraction of essential metals such as Ni and Co from the provided nickel ore sample. The performance of GreenLixiviant was compared with the conventional lixiviants to elucidate the potential leaching mechanisms of the metals present in the ore. Additionally, optimization of critical operating conditions, involving time and temperature, were conducted to support a brief operating cost analysis associated with the metal extraction process using the green lixiviant.

Outcomes of this project can demonstrate the green lixiviant's feasibility as a sustainable alternative to commonly used lixiviants and preliminarily indicate the potential economic and non-economic benefits associated with its application.

What we learned

GreenLixiviant demonstrated higher leaching efficiencies for Ni and Co compared to conventional lixiviants like sulphuric acid, hydrochloric acid and citric acid, considering controlled operating conditions (pH = 1.8, temp = 70℃ and time = 2 h).

GreenLixiviant offers faster kinetics, operates under milder pH conditions (1.8), and requires less costly, corrosion-resistant infrastructure. The highest leaching efficiency of Ni achieved by the green lixiviant was experimentally found to be ~70 %, attained at 80 ℃ and in 8 h. Kinetic studies suggest that the leaching efficiency of Ni could potentially reach 90% after 17 hours. Simultaneously, it is anticipated that over 90% of cobalt (Co) could also be leached out.

The lixiviant is 100% biodegradable with the potential to generate positive carbon credits via biochar production during biomass pyrolysis.

GreenLixiviant, noted that while they have not confirmed its applicability for leaching sulfides or chalcopyrite, the pyrolysis conditions, feedstock, and lixiviant concentration could be adjusted to presenting a possible opportunity to modify it for sulfide ore applications.

Essential Minerals Cohort

MINETOMETAL

MINETOMETAL

Many mineral deposits have unrecovered essential minerals and/or problem impurities that interfere with their mining and processing. MINETOMETAL joined the Essential Minerals Cohort to explore the potential of a sulphation roasting-leaching process for recovering critical metals such as cobalt, rare-earth elements (REEs), and molybdenum from copper and nickel concentrates.

This study examined the technical and economic feasibility of this technology by developing conceptual flowsheets for metal recovery based on known chemistry.

What we learned

This short study confirmed that a sulphation roast process should be technically feasible; however, the economics are challenging for the likely BHP feedstocks. Extensive development is still needed, which would need to be for a defined target material.

Essential Minerals Cohort

Ekion

Ekion Pty Ltd is developing Electrokinetic In Situ Recovery (EK-ISR), a novel mining technology designed to extract metals from low-permeability environments like hard rock, tailings, and clays. By applying electric fields to subsurface media, EK-ISR induces the migration of charged elements, facilitating the dissolution and extraction of target metals. The technology has the potential to operate in conditions where conventional hydraulic ISR methods are ineffective.

During the Essential Minerals cohort, Ekion conducted experiments to understand if EK-ISR can induce rising temperatures within the orebody and the impact of temperature on copper extraction, utilizing ferric chloride as the lixiviant. These tests explored both laboratory-based experiments and simulations to model EK-ISR performance under field-scale conditions.

What we learned

The experiments demonstrated that copper extraction rates improved significantly with increasing temperatures, showing that even modest temperature increases (e.g., from 20°C to 40°C) could enhance metal recovery under EK-ISR conditions.

Simulations indicated that heat generated by the electric fields could propagate efficiently throughout the ore body, promoting enhanced metal extraction without the need for hydraulic fracturing.

Eventually, Ek-ISR could provide access to stranded assets that are currently not economically mineable with conventional mining technologies. EK-ISR could unlock early value by targeting metals in tailings, which are typically difficult to process using traditional methods.

Ekion is currently conducting test work on tailings material to validate the scalability and energy efficiency of EK-ISR in a controlled setting. If these trials are successful, the next steps in development will be determined.

Essential Minerals Cohort

UniSA

The University of South Australia (UniSA) carried out a project focusing on the characterization of complex low-grade copper ore for the recovery of rare earth elements (REEs). The focus was on Gawler Craton IOCG deposits. The objective was to investigate how REEs could be recovered as a by-product of copper extraction through effective beneficiation techniques, aiming to produce REE-rich concentrates for further processing.

The project focused on detailed characterization of the ore to determine the concentration of REE and gangue minerals in the ore, and their mineralogical characteristics to inform developing prudent beneficiation and/or pretreatment processes.

What we learned

- UniSA characterized the ore at multiple scales, providing a detailed understanding of the distribution of REE and gangue minerals. Their analysis revealed that REE minerals, primarily bastnäsite, are finely disseminated and poorly liberated, making conventional beneficiation techniques such as magnetic separation, gravity separation, and froth flotation ineffective for selective recovery.
- Copper occurs as chalcopyrite, which is not associated with REE minerals, meaning that REE recovery as a by-product of copper extraction is feasible without significant REE losses.
- Despite achieving up to 81% recovery of REEs through magnetic separation, the REE concentrate grade was lower than the head ore grade, indicating that these conventional methods are not suitable for effectively upgrading REEs.

UniSA's characterization work provides valuable insights into the orebody's mineralogical and geometallurgical properties. This can serve as a foundation for future projects that require deep ore knowledge and understanding of geometallurgical behavior to develop new extraction and processing technologies.

We were exposed to innovative technologies from cohort members. I expanded my knowledge and met other researchers with whom I could collaborate and learn from. George Abaka-Wood, University of South Australia

Essential Minerals Cohort

NaturaFrac

NaturaFrac has developed a downhole energetics technology that utilizes high-energy pulsed combustion to create controlled fractures in rock formations, focusing on preconditioning rock masses before blasting. The goal is to improve blasting efficiency, reduce energy consumption, and increase resource recovery. The technology offers a cost-effective and environmentally friendly alternative to hydraulic fracturing with a smaller surface footprint and lower emissions.

What we learned

- NaturaFrac's simulations demonstrated improved fragmentation size and uniformity, potentially reducing energy requirements for crushing and grinding in post-blasting processes.
- The simulations indicate a 25x smaller surface footprint and 3x lower Scope 1 emissions compared to conventional hydraulic fracturing
- Enhanced fragmentation could lead to significant reductions in energy consumption, potentially reducing CO_2 emissions by up to 30 million tonnes annually.

The results in this project were derived from simulation-based tests. The technology is now ready for lab scale test work or field trials.

We honestly wouldn't have this application of the technology without the push from TAD and Unearthed. We have pushed a great and valuable application forward and have some really exciting additional applications we think we can create value for BHP with soon. BHP is building a great innovation ecosystem and I love how I personally have been able to watch it improve already - Jacob Andersen, NaturaFrac.

Essential Minerals Cohort

Future Element / Clean TeQ Water: ATA

ATA® is a novel rapid dewatering technology designed for improving tailings management, particularly by creating a pathway for dry-stacked tailings. Traditional wet tailings management has significant environmental and safety risks, while dry-stacked tailings offer a more sustainable solution. However, dry stacking is often capital-intensive. ATA® offers a solution by treating tailings with complementary polymeric reagents, creating an agglomerate structure that rapidly dewaters tailings. The technology is positioned to lower capital costs while still achieving dry-stacked tailings.

The experiments in this project focused on assessing the feasibility of ATA® technology for dry-stacking through a combination of lab-based dewatering tests and techno-economic modelling on tailings samples.

What we learned

- ATA® technology achieved rapid dewatering of tailings, with solids concentrations increasing to 60% within seconds of deposition and further dewatering over time.
- Improved filtration and handling: The ATA®-treated tailings had enhanced filtration properties and higher shear yield stress, making them easier to handle and less prone to fluidization. This resulted in better geotechnical stability for dry-stacking.
- The treatment cost of ATA® compares favourably to traditional methods of tailings management. Additionally, the capital cost for ATA®-based solutions was significantly lower than that of conventional thickening and filtration systems.

"The Think and Act Differently program has been a fantastic platform for innovation and collaboration, and we're proud to have been part of it. We look forward to building on this momentum and exploring new opportunities to drive meaningful change with BHP in the future." - Adam Fischmann – Clean TeQ Water

Essential Minerals Cohort

Rockburst Technologies

Rockburst Technologies has developed CO2 Pulverization, an innovative comminution technology that uses supercritical CO2 to fracture mineral ores through tensile breaking mechanisms. This process reduces energy consumption and sequesters carbon, making it a potentially carbon-negative solution. The technology has been evaluated through a desktop study, which included a Techno-Economic Assessment (TEA) and Life Cycle Assessment (LCA), focusing on its application at a BHP operation.

What we learned

- The technology's tensile breaking mechanism significantly reduces energy consumption in comminution, achieving up to 50.97% energy savings in total primary feed and 45.49% in pebble crushing based on small-scale tests.
- CO2 Pulverization sequesters approximately 17 kg of CO2 per tonne of ore, potentially generating carbon credits that further reduce operational costs.
- The technology operates without water, offering a sustainable solution for water-scarce mining environments.

This assessment was primarily conducted through simulations and a desktop study as a follow up to multi-year test work performed prior to the study.

Essential Minerals Cohort

The University of Melbourne

The University of Melbourne, explored the use of $AlCl_3$-rich lixiviant in combination with $FeCl_3$ and an undisclosed electrolyte for enhanced metal recovery. Initially aimed at improving copper, cobalt, gold, silver, uranium, and REE recovery from low-grade polymetallic ores, the study's findings suggest that the improvements in leaching are primarily driven by the interaction between $FeCl_3$, $AlCl_3$, and the electrolyte, rather than $AlCl_3$ alone.

What we learned

- $AlCl_3$ alone did not show significant leaching improvements when compared to $FeCl_3$. The enhanced leaching performance was observed only when a combination of $FeCl_3$ + $AlCl_3$ and the undisclosed electrolyte was used.
- Most of the experiments showed 5-50% higher metal extraction using the $AlCl_3$-rich lixiviant compared to $FeCl_3$-only and acid-only within 24-48 hours of leaching coarse materials.
- The $AlCl_3$-rich lixiviant technology was successful even for ore particle size of 1-2 mm as-received, without further grinding. Additionally, for the $AlCl_3$-rich lixiviant tests, no acid was added over the leaching period. $AlCl_3$ is used in water processing, and costs less than acid and $FeCl_3$.
- The $AlCl_3$-rich lixiviant leaching tests used BHP's process water for metal extraction, thereby creating a sustainable circular economy for mining waste materials.

The electrolyte was not tested independently with $FeCl_3$ or $AlCl_3$ alone, therefore this test did not analyse specific contributions of each component in the system. The combination of $FeCl_3$ and the electrolyte presents a potential opportunity for improving metal recovery rates. This could be valuable in scenarios where traditional lixiviants underperform.

Rampart

Rampart Detection Systems Ltd participated in the Essential Minerals Cohort to test the hypothesis that an electrochemical cell could neutralize acid mine drainage (AMD) and that an electric sieve could concentrate ions from that effluent.

The Rampart solution aims to address this problem by capturing the value that an acid mine generated electrolyte provides using an electrochemical cell and an electric sieve.

This work leveraged concepts from the Stiller patent (1985) and focused on designing and testing innovative prototypes to explore these objectives. The experiments targeted potential advancements in neutralizing AMD and enhancing ion separation for improved metal recovery.

What we learned

- The electrochemical cell effectively neutralized a sulphuric acid solution independent of the acidity level and the metal content.
- Precipitation of metals in solution start at 3 pH and continue as pH increases.
- The flow through prototype with linear array of droppers and electrode located above them produced noticeable and repeatable ion separation as measured by a change in pH. This repeatability occurred whether the electrode had a positive 15kV charge or a negative 15 kV charge.

The electrochemical cell produces electricity and hydrogen during operation. These outputs hold particular value where electricity could offset operational energy costs and hydrogen could serve as a smelting fuel, supporting decarbonization efforts.

The BHP TAD program is motivating and we enjoyed the roundtable, interactions, and feedback on our experiments. Peter Radziszewski, Rampart Detection Systems.

Essential Minerals Cohort

Edith Cowan University

Acidophilic (acid-loving) biomining microorganisms are generally sensitive to salt however the cost of desalinating process waters is expensive and creates a challenge to biomining operations in regions like Western Australia where high levels of salts are present in both process waters and the minerals. Edith Cowan University (ECU) participated in the Essential Minerals Cohort to test the hypothesis that a combination of acidophilic, halophilic iron- and sulfur-oxidizing microorganisms (AHMs) with phosphate-solubilizing microorganisms (PSMs) could enhance the release of base metals and rare earth elements (REEs) from ores under saline conditions. This study builds on ECU's previous work with bioleaching experiments using PSMs for phosphate-bearing minerals like monazite. The team focused on evaluating the effectiveness of two-step and single-step bioleaching processes on provided ore samples.

What we learned

- Reduction of pH and increase of redox potential (ORP) indicated active sulfur and iron oxidation in the experimental flasks, respectively.
- ICP-OES results indicated that metals and REEs were successfully leached from the provided ore during the experiments.
- The percentage of metals leached using only AHM strain 1 on the ore was higher in comparison to the control or when it was tested in conjunction with PSMs. This suggests that it may be possible to use just this strain for future bioleaching tests.
- Unexpected activity of the native microorganisms on the ore suggests the presence of potential bioleaching bacteria.

The use of bioleaching processes under saline conditions aligns with operational constraints at sites where freshwater availability is limited. Recovery of REEs and base metals from ores using bioleaching offers a lower environmental impact compared to conventional methods. The observed oxidation-reduction potential (ORP) buffering around 330-400 mV suggests that the process could prevent chalcopyrite passivation, supporting efficient leaching under saline conditions. This potential is currently being tested further as part of the TAD Creative Copper Cohort.

BHP TAD & Cohort Takeaways

Key takeaways

The Essential Minerals cohort has made some great progress in accelerating our understanding of critical challenges and opportunities along the mining value chain,.

Both BHP and the participating innovators gained valuable insights and formed strong relationships that will continue to promote innovation within the industry. Every member of the cohort accelerated their knowledge.

Among the achievements of the cohort were the identification and refinement of several capabilities and technologies

Collaboration with internal and external technical experts has assisted innovators to direct their future efforts to maximise value generation and technology development.

The Essential Minerals cohort has proven to be a valuable initiative, showcasing the importance of collaboration, innovation, and learning in addressing the critical challenges faced by the mining industry.

Collaboration, thought leadership and an overarching systems approach will enable fast-tracked fundamental changes to our industry.

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