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canada mining innovation council


# Surface Mining: Roadmap to the Future

April 2018

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Canada Mining Innovation Council (CMIC) requested Deloitte to facilitate a collaborative workshop with participants from different surface mining companies in Canada to create a roadmap that identifies grand challenges related to surface mining and plots a pathway to tackle these challenges

# A two-day workshop was conducted with participants to identify the key challenges, to define the guiding principles and to develop new concepts and solutions for surface mining

**Objectives**

- Identify the issues and establish existing design principles and constraints
- Establish areas of opportunity and new design principles
- Envision "what might be possible" and develop new concepts and solutions
- Create opportunities for future collaborative projects

**Process**

DISCOVER

- Brainstorm the challenges experienced in surface mining
- Identify the design principles that lead to the challenges

SYNTHESIZE

- Brainstorm generalized solution areas
- Define the design principles required to develop solutions

ENVISION

- New connections
- New concepts

CO-CREATE

- New solutions
- Integrated systems design

PLAN

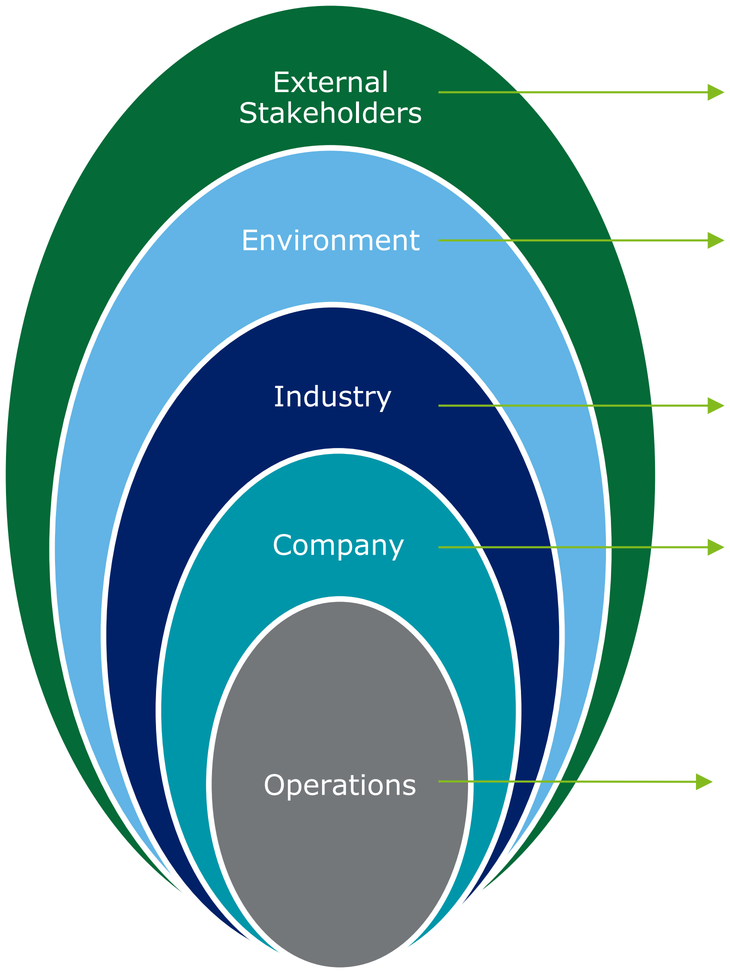
Projects

Resourcing

# Key Challenges in Surface Mining

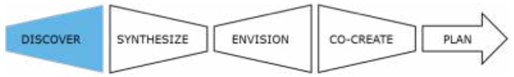
# All the surface mining issues identified during the workshop have been categorize across the following domains

**Domain** **Description**




- Issues related to the community, government and the suppliers
- Issues related to emissions, water usage and land footprint
- Issues related to mining industry as a whole
- Issues related to the corporate culture and expectations
- Issues related to the surface mine - Ore Deposit, Operations, Labor, Energy, and Capital

# Key Challenges in Surface Mining

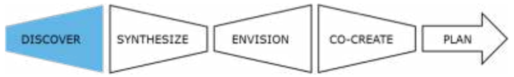



| | | |
|---|---|---|
| **External Stakeholders** | **Community** | ▪ Lack of community involvement surrounding planning and external understanding of community needs<br>▪ High community expectation on what the miners will provide during all phases of the mine life (from design to post-restoration)<br>▪ Lack of provision of opportunities for the community post-restoration; For example, sustained employment |
| | **Government** | ▪ Failure to strengthen government relationships and "partner" with them to drive policies<br>▪ Long mining process duration inhibits change of permits; firms are reluctant to go back on their original word/permits even if there is a better way to manage operations<br>▪ Low trust with government, regulations are typically "unacceptable" and regulatory uncertainty exists<br>▪ Application process for mining permits is long and cumbersome<br>▪ Uncertainty in the regulatory environment<br>▪ Misperception of governments on the economic of mining, leading to high royalty and tax demands |
| | **Suppliers** | ▪ Vendor relationships are viewed as transactional and not as partnerships with risk sharing<br>▪ Suppliers are slow to introduce new innovations<br>▪ Suppliers and miners objectives are not always aligned |

# Key Challenges in Surface Mining (cont'd)


| | | |
|---|---|---|
| Environment | Water | ▪ High water usage, availability of water, and disruption of natural water flow<br>▪ Inefficient water extraction from tailings, resulting in increased tailings footprint and limited recycling<br>▪ Disposal of tailings is harmful to the environment and surrounding communities<br>▪ Poor quality of used water due to high concentration of salts, resulting in limited reuse and recycling to the environment |
| Environment | Land Footprint | ▪ Extensive land footprint due to poor planning and execution of restoration and reclamation activities<br>▪ Large and deep holes created in the ground due to open pit mining methods, costly to restore<br>▪ High cost associated with processing and moving waste which limits options to deal with waste differently |
| Environment | Emissions | ▪ Increased cost of mining due to carbon pricing<br>▪ High emissions due to old technology used in mining (PM10 & Greenhouse gasses)<br>▪ Current infrastructure favors fossil fuels<br>▪ Lack of renewable energy sources and inefficient use of energy |
| Industry | General | ▪ Corporate cultures makes it difficult for firms to work together at the industry level<br>▪ Complexity around IP ownership and management affects collaboration and technology progress<br>▪ Industry stakeholder misalignment; Lack of connection between supply chain stakeholders<br>▪ Increased uncertainty in commodity pricing drive short term focus<br>▪ Inability of mines to achieve closure requirements, resulting in perpetual mining at uneconomic levels |

# Key Challenges in Surface Mining (cont'd)




**Company**

| | | |
|---|---|---|
| Company | **Culture and Values** | ▪ Risk-averse decision making - Aversion to change processes and technologies that have worked in the past<br>▪ Incentives are misaligned (Innovation vs Continuous Improvement; Short term vs long term)<br>▪ Shareholder returns are emphasized over society and environment |
| | **Expectations** | ▪ Immediate returns are required to meet funding requirements<br>▪ Companies go after large projects; Bigger is better. Cost of project failure becomes catastrophic<br>▪ High hurdle rate requirements drive poor long-term decision making<br>▪ Large upfront investment reduces funding available to make changes and experiment |
| | **Decision Making** | ▪ Ineffective resource allocation process due to disparate systems and siloed processes across sites<br>▪ Inaccurate planning assumptions for different commodities, including energy<br>▪ Difficult to measure improvements due to lack of integration between operations and financials<br>▪ Lack of system solutions. Too many point solutions developed independently of each other |

# Key Challenges in Surface Mining (cont’d)


## Operations

### Ore Body

- Ore grades are declining and large deposits are scarcer. Smaller and low grade ore bodies are less economic with the current technology and mining methods
- Lack of accurate upfront ore body knowledge prevents better planning and improved risk assessment
- In oil sands, government regulations exist that impose requirements for higher oil recovery

### Productivity

- Lack of integration across different processes and departments
- Lack of timely mine planning and scheduling to adjust to responses in structural ore body variations
- Lack of sufficient agility in operations to adjust to changes in mine plan and schedule
- Inefficiency and high waste due to batch process. Batch mindset is hard to change
- Drilling and blasting results in non-selective mining
- Equipment and system reliability is not optimized
- Production is not demand driven, lack of responsiveness to changes in demand
- High and growing material movement cost due to truck haul model

### Labor

- High cost of procuring labor and increasing labor inflation
- Poorly skilled labour has a low-tech mindset (due to ineffective university/trades programs) contributes to poor technology deployment
- Failure to engage diverse experts external to mining industry
- Unionized labor make some change initiatives more difficult
- Alignment of employees and corporate objectives

# Key Challenges in Surface Mining (cont'd)



**Operations**

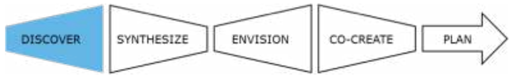
| | |
|---|---|
| **Energy** | ▪ High energy consumption due to highly inefficient technologies (haul trucks, crushing and grinding, etc.)<br>▪ High cost of energy due to lack of energy infrastructure to supply power or fossil fuels to mine sites<br>▪ Lack of visibility on energy trade-offs across the mining processes |
| **Capital** | ▪ Large upfront investment reduces optionality later in the life of mine<br>▪ Lack of dedicated funding for innovation<br>▪ Large fixed investments requires large ore bodies or long mine lives to provide sufficient returns<br>▪ Returns are not always properly risk adjusted which makes optimum capital allocation difficult |

# General Constraints in Driving Change


# General constraints to innovation and driving of change

1. Pressure from investors to deliver short term returns
2. Mines are incented to achieve planned performance targets based on assumptions of using existing technologies
3. Technology is mostly viewed as an operating issue, not a strategic issue
4. Sunk cost and regret avoidance biases reduce likelihood of changes after commitments have been made
5. Siloed functional structure creates barrier to develop system-level solutions
6. Mining companies lack of experience in system-level innovation
7. Operating mines are not step up to pilot, improve and operationalize new innovations
8. Perceived high cost of innovation
9. Safety considerations and regulations creates barriers to “test to failure”
10. Risk and opportunity cost of lack of innovation are not visible and not easy to quantify
11. High barrier of entry and long approval processes make it less attractive for new entrants to introduce radical innovations
12. Suppliers does not have an incentive to drive radical change that will erode the returns from their existing platforms
13. Infrastructure not in place to support larger degree of electrification
14. Information connectivity at sites are not sufficient
15. Cyber security concerns and lack of knowledge limit
16. Common standard related to new technologies does not exist, making it difficult for innovations to scale
17. Unionized labor force is resistant to change that could lead to employment reduction

# General Assumptions




# General assumptions that influence decision making

1. Mines have to comply with minimum standards for community and environmental wellbeing, anything more erodes financial value
2. Safety improvements are inversely proportional to productivity enhancement
3. Mines are designed around the ore body to maximize returns
4. All significant choices and large capital expenditures are fixed and financed upfront
5. Mine plans that accelerate path the revenue has higher NPV
6. 24/7 operations maximizes the return on assets and increase NPV
7. Energy and water requirements in consequence of mine design
8. Mining requires a lot of energy and water, but both are abundant and available
9. Waste is unavoidable and value-added activities should be minimized on waste
10. Tailings ponds are the most economical way to deal with processing waste
11. Shovels and trucks has to be paired optimally to streamline the batch process
12. Diesel fuel is used almost exclusively in mobile applications
13. Larger equipment drives down the unit cost and improve overall value of mine
14. Mines sell commodity products to commodity markets with little influence over the price
15. Lowest cost producer wins in commodity markets
16. Mining requires a lot of labor
17. It is the responsibility of suppliers to bring proven innovations for mining companies

# Current Orthodoxies and Design Principles

# Core orthodoxies and design principles that are implicitly used in surface mining today

**1** Bigger is better – Economies of scale lowers cost

**2** 364/24/7 mine operations maximize asset utilization and production

**3** Standardized processes and equipment at mines and across mines reduce cost

**4** Mine life is designed to maximize return on fixed investments

**5** Critical resources like labor, energy and water are readily available

**6** Waste movement and processing has to be minimized as it erodes returns

**7** License to operate requires compliance with minimum social and environmental regulations

**8** Success across each phase of the LOM requires a different focus

# Implications of current design principles have resulted in the challenges faced by surface mining

| | Current Design Principles | Description and Implications |
|---|---|---|
| 1 | Bigger is better – Economies of scale lowers cost | A large mine/plant/mining equipment is typically built/procured upfront to gain economies of scale in order to drive down the unit cost of production. Large upfront investment requires significant capital commitments and leave little option to change over the LOM. |
| 2 | 364/24/7 mine operations maximize asset utilization and production | When resources are assumed to be available, and upfront investment have been made in fixed plant and equipment, then continuous operations will maximize asset utilization and presumably value of the project. |
| 3 | Standardized processes and equipment at mines and across mines reduce cost | Mining processes are designed to followed standard sequence/method and equipment is standardized to specific size/type/life in order to gain sourcing, maintenance and training cost reductions. Less diversity in the design and equipment reduce options adjust to changes |
| 4 | Mine life is designed to maximize return on fixed investments | Fixed assets and equipment lives are tied to the live of the ore body in order to provide an acceptable return of, and return on capital to the investors. Ore bodies below a certain size for a certain type of mine will not be considered as the shorter life = uneconomical returns |
| 5 | Critical resources like labor, energy and water are readily available | Because these resources are presumed to be available at an acceptable prices, as it has been in the past decade, mine design is not constrained by it. Physical mine design leads, resources follows. When alternative and much cheaper options are available the mine cannot adjust. |
| 6 | Waste movement and processing has to be minimized as it erodes returns | Waste is treated as a necessary cost of mining and balance between lowest cost and environmental and social compliance is targeted. Non-selective mining and economies of scale to drive unit cost down leads to significant waste at the end of the mining value chain |
| 7 | License to operate requires compliance with minimum social and environmental regulations | Complying with minimum regulatory requirements from communities and environmental regulations in order to keep the upfront costs down, may result in greater longer term challenges to maintain a social license to operate and may drive longer term cost much higher |
| 8 | Success across each phase of the LOM requires a different focus | Success factors are different for each phase. Development is focused on lowering CAPEX, operations on lowering OPEX, reclamation on lowering CAPEX and OPEX. Trade-offs between CAPEX and OPEX decisions are not optimized across the entire life cycle to increase value |

# New Design Principles

# New design principles can break tradeoffs in existing orthodoxies to help overcome current surface mining challenges

| # | **Current Design Principles** | **New Design Principles** |
|---|---|---|
| 1 | Bigger is better – Economies of scale lowers cost | Modular, scalable and flexible design and equipment to increase options over LOM |
| 2 | 364/24/7 mine operations maximize asset utilization and production | Optimize mine plans and schedules to maximize value of the mine to all stakeholders |
| 3 | Standardized processes and equipment at mines and across mines reduce cost | Customize processes and equipment to optimize value from ore body |
| 4 | Mine life is designed to maximize return on fixed investments | Increase the amount of movable assets to create value from any life of mine |
| 5 | Critical resources like labor, energy and water are readily available | Minimizing the use of critical resources is a key criteria in mine design considerations |
| 6 | Waste movement and processing has to be minimized as it decreases returns | Invest to eliminate waste as early in the value chain as possible and add value to what remains |
| 7 | License to operate requires compliance with minimum social and environmental regulations | Maximize the value to society and environment subject to achieving required returns |
| 8 | Success across each phase of the LOM requires a different focus | All decisions has to take into account the value of the integrated system over the LOM |

# Solution Areas for Immediate Action

# Surface mining needs to adopt a new set of guiding principles to overcome current challenges

| # | New Design Principles | Description of solution area |
| --- | --- | --- |
| 1 | Modular, scalable and flexible design and equipment to increase options over LOM | Adoption of modular, scalable and flexible approach to mine/plant development & equipment selection greatly decreases the upfront capital investment. Build smaller mine first and scale as options become better understood. Flexibility may drive greater value than lowering costs. |
| 2 | Optimize mine plans and schedules to maximize value of the mine to all stakeholders | Mine schedule is optimize to maximize value not utilization. Better prediction of factors like commodity prices, cheap resource availability, availability and condition of equipment and ore grades can allow mine plans and schedules to be altered to increase value, not production. |
| 3 | Customize processes and equipment to optimize value from ore body | Flexible processes/equipment that utilize rich ore body data collected throughout the mining process enables real time ore control through selective and responsive processing. This flexibility allows adjustment of processes and equipment based on ore grade to meet mine plan |
| 4 | Increase the amount of movable assets to create value from any life of mine | Design mines to require minimal fixed infrastructure. When the life of the asset investments can be decoupled from the life of the ore body, assets can be redeployed to ensure the return of, and return on investments are achieved over the life of the assets. |
| 5 | Minimizing the use of critical resources is a key criteria in mine design considerations | Energy, water and labor considerations becomes critical inputs and drivers of mine design, rather than a consequence of the design. Design for minimal labor, emissions, water and waste, and design for maximum use of renewable energy and water to enhance value. |
| 6 | Invest to eliminate waste as early in the value chain as possible and add value to what remains | Consider the overall system value benefits of investments to eliminate waste as early in the process as possible, e.g. using selective mining methods like ore sorting, pre-concentration and in-situ mining. Extract value from waste products (e.g. Cobalt from bitumen waste). |
| 7 | Maximize value to society and the environment subject to achieving required returns | Consider the community and government as partners in all phases of the mining lifecycle and design the mine to incorporate the community capabilities and environmental assets (like renewables). Explicitly incorporate ongoing community needs in mine closure plans. |
| 8 | All decisions has to take into account the value of the integrated system over the LOM | Mine design, development and operating models should include all stages of mine life and is progressively optimized for entire mine life stages as opposed to individual stages. All data need to be integrated in order to maintain a whole system perspective on trade-off options |

# Key existing technology solution collaboration areas

# Various solutions become enablers of the proposed new design principles to address the challenges of surface mining in a meaningful way

## 1. Improve ore body knowledge

- Reduce core sampling requirement. Analyze the hole not the core
- Coil drill techniques
- Real-time analyses
- Blast hole analyses
- Ore sensing technologies at the face
- Multi-disciplinary analyses
- AI based ore body models

## 2. Integrated mine design, planning and scheduling

- Integrate all ore body data into one common platform like MineRP
- Integrate common database of all resources and capabilities
- Integrate operational planning and scheduling with financial systems to model system value

## 3. Selective Mining

- Continuous cutting machines
- High intensity blasting
- Ore sorting at the face
- Pre-concentration
- Integrated mine planning to adjust mining dynamically

## 4. Alternative hauling technologies

- Decouple truck and shovel interface with buffer like MMD surge loader to maximize productivity of truck and fleet.
- Electric modular truck/truck train
- Autonomous hauling
- Alternative technologies like Railveyor and Ropecon
- Multi-modal system

## 5. Modular mining

- Use equipment that can be assembled and disassembled on-site
- Hybrid air vehicles to transport equipment modules to sites
- Avoid road infrastructure where possible
- Removable equipment decouples equipment life from ore body lifer

## 6. Integrated operations with intelligent work environment

- Fully digitalized operations
- Digital twins of all equipment as well as full mine operations to track deviations to plan
- Predictive platforms like Predix

## 7. Automation

- Link to intelligent work place
- Remote centres to operate remote equipment. No people on site for most of the mining tasts
- Full autonomous parts of the operations
- Automate the management of renewable energy integration

## 8. Electrification & re-newable resources

- Electrification of all mining processes
- Digitally intelligent grid to enable full load control and orchestration at mine level
- Maximum penetration of renewable energy
- Use cheap energy to recycle water
- Standards required to catalyze innovation

## 9. Transact more efficiently

- Use BlockChain to track ore mined throughout the value chain
- Rewards employees and partners with instant payments
- Track warranties on parts with BC individually
- Sell metals and minerals directly to end customer with BC
- Track, recycle and resell

## 10. Improve Water Treatment & Management

- Advanced purification and recycling technology like Axine.
- Digital water monitoring
- BlockChain logging of water quality
- Vacuum assisted evaporation with renewables to reduce tailing requirement

# A number of different solutions are required to enable the new guiding principles to successfully address key surface mining challenges

Solutions

| **New Design Principles** | 1. Improve ore body characterization | 2. Integrated mine design, planning and scheduling | 3. Selective Mining | 4. Alternative hauling technologies | 5. Modular mining | 6. Integrated operations & Intelligent workplace | 7. Automation | 8. Electrification & renewable resources | 9. Transact more efficiently | 10. Improve Water Treatment & Management |
|---|---|---|---|---|---|---|---|---|---|---|
| Modular, scalable and flexible design and equipment to increase options over LOM | x | x | | x | x | x | | | | |
| Optimize mine plans and schedules to maximize value of the mine to all stakeholders | x | x | x | x | x | x | x | x | x | |
| Customize processes and equipment to optimize value from ore body | x | x | x | x | | x | x | | | |
| Increase the amount of movable assets to create value from any life of mine | x | x | | x | x | x | x | x | x | x |
| Minimizing the use of critical resources is a key criteria in mine design considerations | x | x | | x | x | x | x | x | | x |
| Invest to eliminate waste as early in the value chain as possible and add value to what remains | x | x | x | x | | x | x | | x | |
| Maximize value to society and the environment subject to achieving required returns | | x | | | | | x | x | x | x |
| All decisions has to take into account the value of the integrated system over the LOM | x | x | | | | | | | x | x |

# CMIC surface mining roadmap

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **1. Improve ore body knowledge** | Adopt coil drill techniques | Improve real time data analyses | Improve blast hole analyses | Reduce core sampling requirements | Integrate ore sensing at the face | Implement multi-disciplinary analyses | Develop AI based ore models |
| **2. Integrated mine design, planning and scheduling** | Integrate all ore body data into one common spatial database & planning pltfrm | Integrate common database of all resources and capabilities | Integrate operational planning and scheduling with financial systems to model system value | Stochastic dynamic model of mining process based on plan and schedule | | | |
| **3. Selective mining** | Explore continuous cutting machines for bulk mining | Develop high intensity blasting techniques for fragmentation control | Engineer ore sorting at the face and along the mining process to eliminate waste | Pre-concentration of ore inside the pit | Dedicated ore streams to selective processing to reduce/eliminate blending | | |
| **4. Alternative hauling technologies** | Decouple truck and shovel interface with loading buffer (surge loader) | Electric, modular truck/truck train (trolley assist/Battery hybrid) | Remote operation integrated with autonomous hauling | Explore application of alternative technologies (Rail-veyor/RopeCon, other) | Multi-modal system to optimize the flexibility and cost advantage of different technologies | | |
| **5. Modular mining** | Develop modular equipment that can be containerized for easy transport and on-site assembly | Use hybrid air vehicles to transport equipment modules to remote sites | Avoid building road/rail infrastructure to remote sites where viable | Decouple equipment life from life of the ore body. Relocate equipment | Mine smaller, richer ore bodies with small footprint | | |
| **6. Integrated operations with intelligent work environment** | Establish digital twins of all equipment as well as full mine and operations | Improve predictive analytics of equipment and mining process performance | Integrate wearables to create the performance augmented worker | Fully digitalized operations with integrated performance feedback loop | | | |
| **7. Automation** | Automate back-office processes | Link intelligent work place to integrated planning, scheduling and dynamic simulation | Remote centers to operate remote equipment | Full autonomous parts of the operations | Automate the integration and management of renewable energy integration | | |
| **8. Electrification & renewable resources** | Electrification of all mining processes | Digitally intelligent grid to enable full load control and orchestration at mine level | Maximum penetration of renewable energy | Use cheap renewable energy to clean and recycle water | Zero emissions fully electrified mining operation | | |
| **9. Transact more efficiently** | Use Block-chain (BC) to track ore mined throughout the value chain | Reward employees and partners with instant payments | Track warranties on parts with BC individually | Sell metals and minerals directly to end customer with BC (Track, recycle and resell) | Fully transparent mining – operations, supply chain and all external stakeholders | | |
| **10. Improve Water Treatment & Management** | Implement digital water monitoring and automated management | Establish Block-chain logging of water quality | Introduce advanced purification and recycling technology to reduce/eliminate tailing | Extract valuable minerals from waste streams | Zero water environmental impact mining | | |

# Risk Mitigation

# The six major risks associated with implementation of a digital mine roadmap are described below with the associated management strategy

| # | Risk | Profile | Mitigation Plan |
|---|---|---|---|
| 1 | Inaction due to risk aversion and resistance to change | High | • Separate the budget associated innovation from the operating budget and dedicate innovation teams to de-risk innovation projects in an environment that minimizes production risk.<br>• Create projects that present a benefit to all parties involved: Demonstrate tangible progress early on in the project, even if this is only a small progress, can be utilized and presented in impactful manners to diminish resistance to change within the industry by showing beneficial outcomes. |
| 2 | Managing ownership of IP | Medium | • Develop and IP management framework to support organizational innovation ambitions. |
| 3 | Missing key enablers and technologies within "windows" of opportunity | Medium | • Create a collaboration framework within which mining companies can share resources and expertise. |
| 4 | Limited funding for innovation | High | • Develop strategic innovation ambitions that are grounded in the business strategy.<br>• Dedicate funds to innovation to ensure that overall innovation ambitions are met. |
| 5 | Poor communications and stakeholder engagement | High | • Define the accountability for innovation within each organization. |
| 6 | Lack of industry support on key initiatives | Medium | • Identify common issues across the industry to develop an understanding of the focus for key initiatives.<br>• Define measurable success factors for initiatives to foster increased engagement and desire to collaborate. |

# Next Steps to Achieve Short-term Progress

# Next Steps

- Align on the content for the surface mining roadmap
- Decide on the best collaborative structure to explore the solution theme
- Develop agile solution development approach that is focused on achieving results within 6 months
- Determine resource requirements for successful development and piloting efforts
- Identify where pilots will be conducted and who would lead it
- Developed detailed plan (timing, specific solutions, resources etc.) for each proposed solution using the IRL framework below

Innovation Readiness Level (iRL) provides a method for tracking an initiative's development