Crush It! Challenge – Technical Presentation

By
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Toronto, March 3, 2019

1. Project Overview

Winning Formula

- A consortium of partners, with a project lead Georgi Doundarov, M.Sc., P.Eng., PMP, CCP, with a combined experience of **more than two centuries in mining**, environmental, **laser technology**, project and risk management, sales, financing, data analytics, and grants.
- Combination of modern technology and innovative thinking to conceptualize a creative new way to mining

Project Overview

The proposed method involves the use of high optical power output fiber lasers to cut or spall ore bearing material from the host rock in steps:

- generating and delivering a laser beam to a work surface of a geological strata having a sought after mineral to be removed from the strata;
- moving the laser beam about three perpendicular axes so that a focal point of the laser beam moves across the working surface;
- rapidly increasing the surface temperature of the working surface while providing a source of cooling media;
- delivering the cooling media to the working surface to rapidly cool the working surface subsequent to the rapid surface temperature increase generated by the laser beam in order to effect a fracturing of the working surface and to generate a plurality of chips from the working surface;
- removing the chips spalled from the working surface.

2. Project Description

Major Advantages

The proposed solution targets the following areas of the mine operations cycle:

- **Mining:** drill and blast
- **Processing:** crushing (primary, secondary, tertiary, as applicable) along with the supporting screening, material handling, etc.

Indirect positive effect

- **Environmental:** smaller footprint as less area required for mine dumps, no implications and risks surrounding the drill & blast, and crushing processes
- **Quality:** improved ore grade control
- **Social:** improved health and safety as miners not working at face, two-man crew could operate multiple mining faces, reduced manpower requirements, reduced supervision, local communities project buy-in, easier government/permitting discussions and negotiations
- **Power:** considerably reduced power requirements due to eliminating crushing process and reduced need for compressed air supply lines
- **Capital Costs:** reduced CAPEX (initial and sustaining) for drill & blast equipment, crushing equipment, general plant infrastructure, environmental & permitting associated costs
- **Operating Costs:** reduced OPEX for drill & blast explosives, materials, consumables, mine and plant manpower requirements, environmental & permitting, community relations associated costs, reduced need for compressed air supply lines.

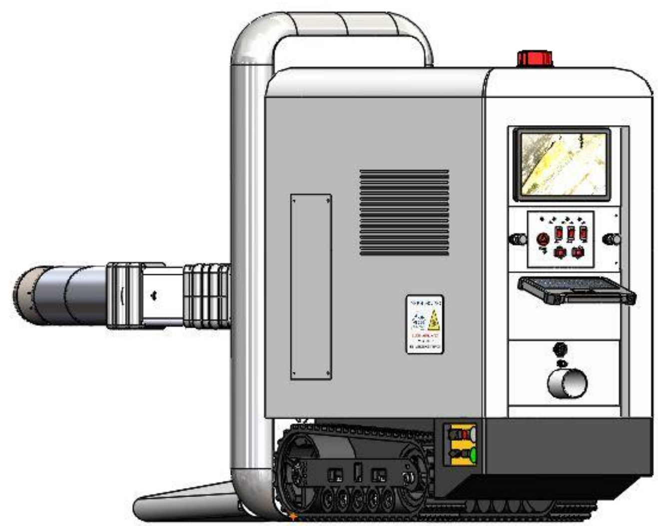
The proposed solution will reduce overall power requirements by approximately 30% and is expected to reduce projects capital and operating costs by approximately 10% and 18%, respectively.

3. Project Status – Current Status

Current Status - Technology Readiness Level (TRL) 2

Phase I: Laboratory Test Unit

- Engineering & Design – detailed engineering documentation for the scan head is 75% started, 40% complete
- Software Development – started, 20% complete
- Procurement – not started. Equipment vendors already determined and either under contract or verbal agreement.
- Integration & Calibration – not started
- Testing – not started



Phase II: Characterization Unit

- not started

Phase III: Operational Unit

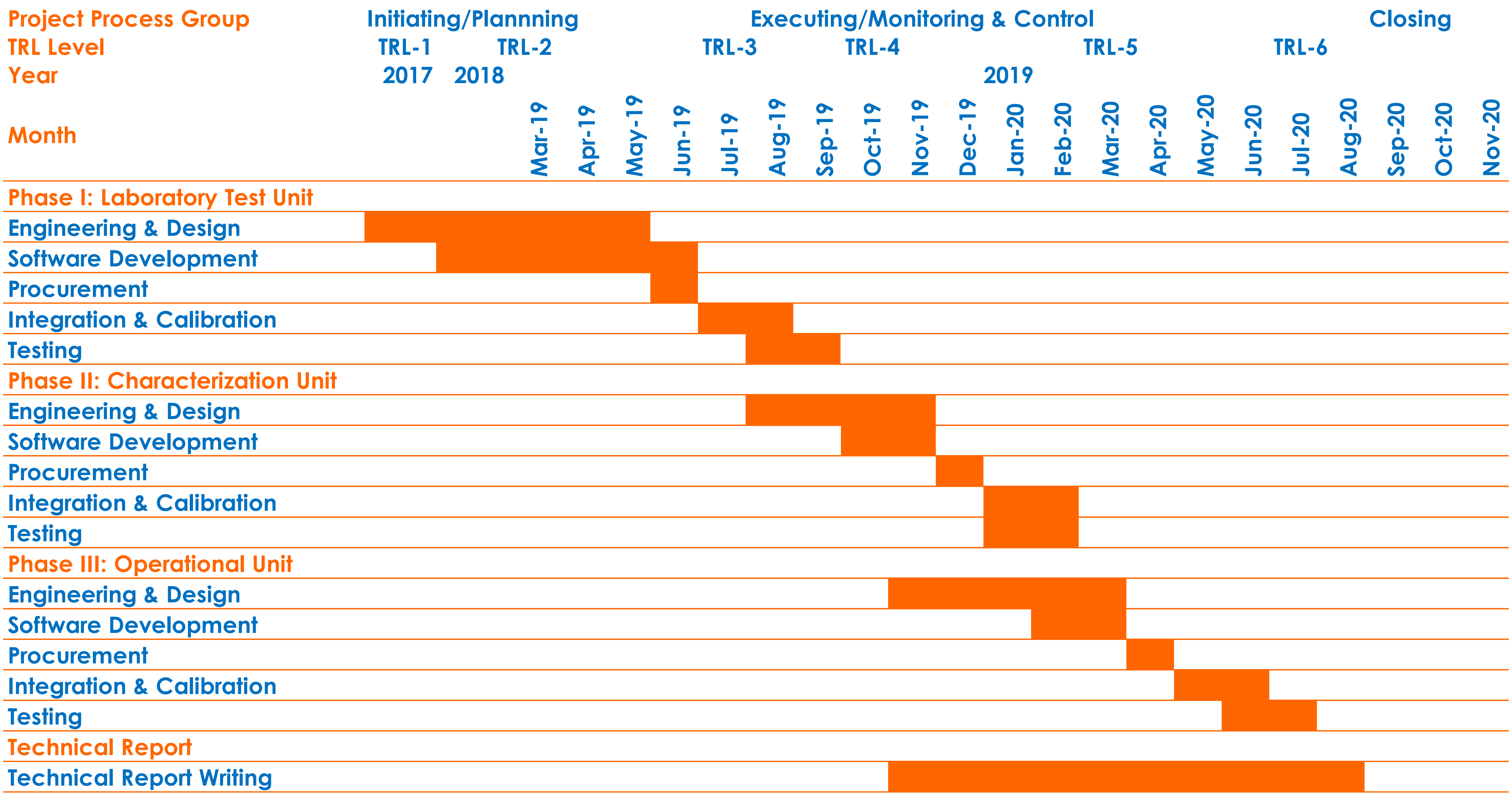
- not started

Once engineering for the Laboratory Test Unit is completed, the SolidWorks Model of the Characterization Unit (Phase II) will be updated and engineering documentation initiated. Many of the components used in the Scan Head are identical to the Test Unit and multiples will be ordered in the first release.

All the work executed to date was funded by the consortium of partners.

3. Project Status – Until TLR-6

Current Status and Project Development Plan



Thermal Fracturing of Hard Rock

P. J. Lauriello and Y. Chen
J. Appl. Mech40(4), 909-914 (Dec 01, 1973) (6 pages) doi:10.1115/1.3423186 History: Received August 01, 1972; Revised January 01, 1973; Online July 12, 2010
Abstract:
Thermal fracturing of hard crystalline in situ rock has been studied by solving the quasistatic uncoupled thermoelastic equations for a semi-infinite medium subjected to transient surface heating over a circular area by a constant flux or constant temperature convective heat source. The thermoelastic stress state is related to brittle fracture in rock according to an appropriate form of the Griffith and the modified Griffith theories. The predicted zone of weakening has been experimentally investigated by lasing samples of Barre granite. Measurements of the size of the in-depth fractures correlated well with the predicted results.

PROCEEDINGS, Thirty-Ninth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 24-26, 2014SGP-TR-2021

The Geo-materials Fracture by Thermal Process

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Abstract:
Thermal spallation of the rock is promising alternative technique for rock drilling in civil engineering works and petrol industry as tunneling and wells drilling. Over the last century, many works were conducted to test and examine the functionality and the feasibility of thermal spallation to remove the rocky materials. Recently the radiation is the most examined fashion to deliver heat at the rock surface where we need high heat flux to spall the rock. However, the thermal spallation is firstly described by Prestonetal. (1943). The Laboratory studies demonstrate that the required energy to produce fracture is huge due to high compression strength of the rocky materials. This energy varies between 0.5 and 14MW/m² according to rock type. In addition, the energy loss in the fibers (to deliver the laser energy) is almost 60% for a kilometer away, which poses a problem of energy delivery to the rock surface this deep according to this high energy level.
The present work offers an alternative method for generating thermal fracture of the rock. It is based on the introduction of the thermal contraction deformation. Accordingly tensile stresses potentially superior to tensile strength of the rock will be created. The tensile strength is much lower than that of compression as well known. So this is a hypothesis that supposedly reduces the required energy to fracture the rock. The proposed mechanism is a coupling of a local rapid heating followed by rapid local cooling of the treated surface. The rapid variation of the heat flow on the treated surface will suddenly reverse compressive stresses induced during the heating phase to tensile stresses during the cooling phase. Once induced tensile stresses exceed the tensile strength of the rock fracture should take place. A model of 2D axisymmetric finite element is used to demonstrate the procedure. The stone used is granite. The proposed mechanism is evaluated in several ways: (1) the thermal efficiency, (2) the possibility of fracturing the rock, (3) reducing the energy required to fracture the rock (4) and depth penetration.

4. Methodology – Academic Reference (2)

SPE Annual Technical Conference and Exhibition, 9-12 October, Dallas, Texas Publication Date 2005

Modeling of Laser Spallation Drilling of Rocks for Gas and Oil Well Drilling

Authors: Zhiyue Xu(Argonne National Lab)| Yuichiro Yamashita(Argonne National Lab)| Claude Reed(Argonne National Lab)

Abstract:

High power lasers can weaken, spall, melt and vaporize natural earth materials with thermal spallation being the most energy efficient rock removal mechanism. The most interesting focus of recent laser rock drilling research is on developing a laser rock spallation technique to drill large and deep holes in rocks, a potential application in gas and oil well drilling having a rock removal rate higher than that of conventional rotary drilling as well as that of flame-jet spallation. Research is also focused on using laser rock spallation to make perforation channels with improved permeability of the perforated rocks. However, laser rock spallation is a very complex phenomenon that depends on many factors. Fundamental understanding of this complex phenomenon is crucial to the success of its application to the petroleum industry.

In this paper, we propose a combined approach to this complex problem, that is establishing models for each of the physical phenomena based on the finite difference method (FDM), then combining them into one numerical procedure using the Combined Unified Procedure (C-CUP) method. With this approach, the transient temperature and stress distributions in dry or water- saturated rocks exposed to a laser beam have been calculated. The spallation boundary and rock removal efficiency have been determined for different laser conditions. The modeling results provide a better understanding of laser rock spallation phenomenon and most importantly, guidelines for selecting processing parameters for fast rock removal.

Proceedings of the 23rd International Congress on Applications of Lasers and Electro-Optics 2004

Laser Spallation of Rocks for Oil Well Drilling

Zhiyue Xu 1 Claude B. Reed 1, Richard Parker 2, Ramona Graves 3

1Argonne National Laboratory, Argonne, IL 60439, USA

2 Parker Geosciences, LLC

3 Department of Petroleum Engineering, Colorado School of Mines

Abstract:

Laser rock spallation is a rock removal process that utilizes laser- induced thermal stress to fracture the rock into small fragments before melting of the rock occurs. High intensity laser energy, applied on a rock that normally has very low thermal conductivity, concentrates locally on the rock surface area and causes the local temperature to increase instantaneously. The maximum temperature just below the melting temperature can be obtained by carefully controlling the laser parameters. This results in a local thermal stress in subsurface that is enough to spall the rock. This process continues on a new rock surface with the aid of the high pressure gas purging blowing away the cracked fragments. Laser parameters that affect the laser spallation efficiency will be discussed in the paper. Also reported in the paper is the multi laser beam spot spallation technique that has been developed for potentially drilling large diameter and deep gas and oil wells.

4. Methodology – Academic Reference (3)

Adeniji, A.W. (2014). The applications of laser technology in downhole operations-a review. In IPTC 2014: International Petroleum Technology Conference.

Agha, K.R., Belhaj, H.A., Mustafiz, S., Bjorndalen, N., and Islam, M.R. (2004). Numerical investigation of the prospects of high energy laser in drilling oil and gas wells. Petroleum science and technology, 22(9-10), 1173– 1186.

Chen, Y., Lauriello, P. J. (1972). Thermal Fracturing of Hard Rock. Journal of Applied Mechanics volume 40, 909-914

Damian, P., Batarseh, S., Han, Y. (2016). Numerical Modeling of Thermal and Mechanical Effects in Laser-Rock Interaction–An Overview. 50th US Rock Mechanics/Geomechanics Symposium, ARMA 142

Ezzedine, S. M., Rubenchik, A., Yamamoto, R. (2015). Laser-Enhanced Drilling and Laser Assisted Fracturing for Subsurface EGS Applications. Proceedings, Fortieth Workshop on Geothermal Reservoir Engineering

Ndeda, R., Sebusang, S.E., Marumo, R., and Ogur, E.O. (2017). On the role of laser pulses on spallation of granite. Lasers in Manufacturing and Materials Processing, 1–16.

Olaleye, M. (2010). A review of light amplification by stimulated emission of radiation in oil and gas well drilling. Mining Science and Technology (China), 20(5), 752–757.

Soleymani, M., Bakhtbidar, M., and Kazemzadeh, E. (2013). Experimental analysis of laser drilling impacts on rock properties. World Appl Sci J, 1(2), 106–114.

Walsh, S.D., Lomov, I., Kanarska, Y., and Roberts, J.J. (2012). Simulation tools for modeling thermal spallation drilling on multiple scales. Technical report, Lawrence Livermore National Laboratory (LLNL), Livermore, CA.

Xu, Z., Reed, C.B., Parker, R., and Graves, R. (2004). Laser spallation of rocks for oil well drilling. In Proceedings of the 23rd International Congress on Applications of Lasers and Electro-Optics, 1–6. Citeseer

Xu, Z., Yamashita, Y., Reed, C. (2005) Modeling of Laser Spallation Drilling of Rocks for Gas and Oil Well Drilling. SPE Annual Technical Conference and Exhibition, 9-12 October, Dallas, Texas

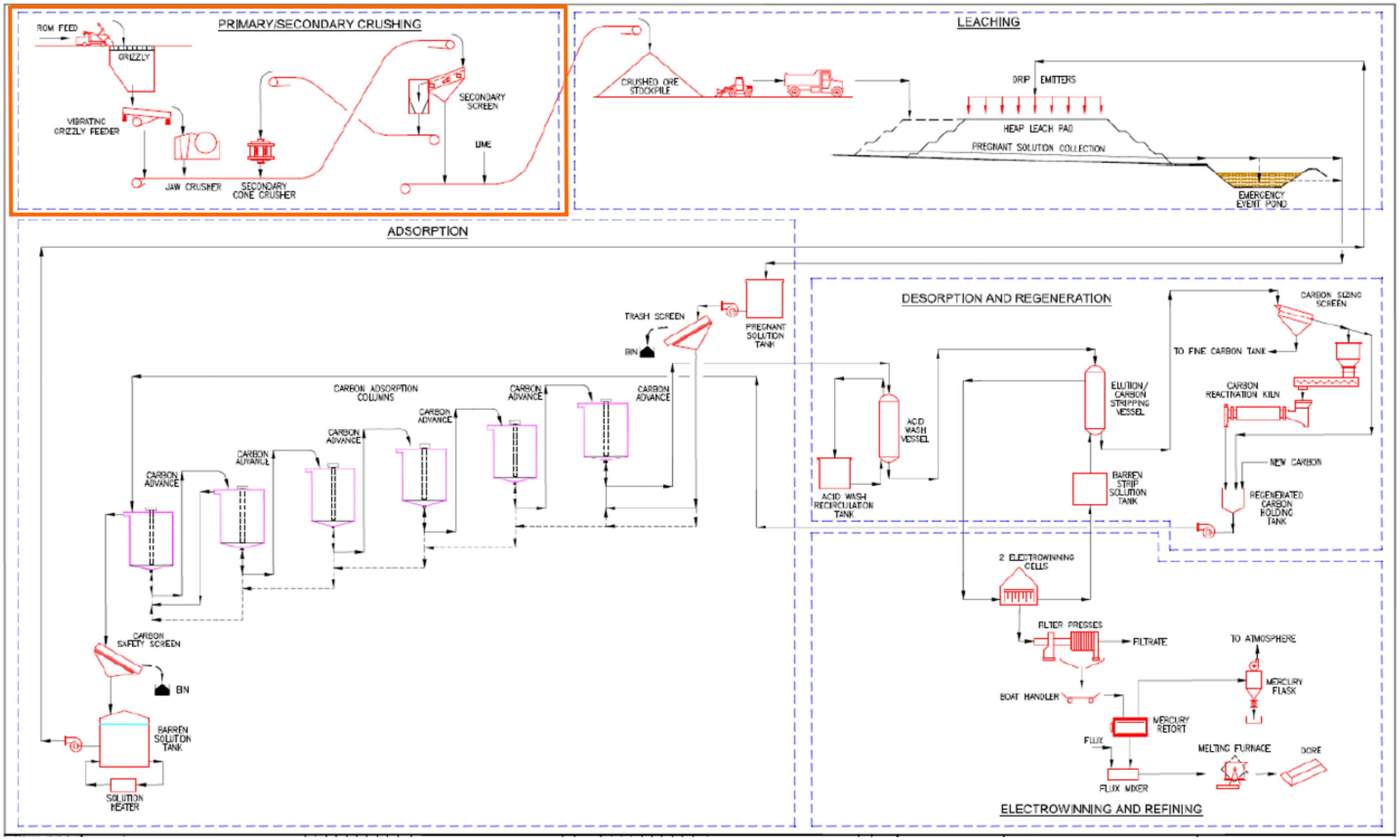
Yaseen, M., Zemmouri, J., Shahrour, I. (2014) The Geo-materials Fracture by Thermal Process. Thirty-Ninth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 24-26, 2014 SGP-TR-2021

4. METHODOLOGY – BASIS OF ESTIMATE

Calculation of Quantifiable Reduction in the Energy and Capital and Operating Costs

A current Goldcorp advanced stage development project – the NI43-101 Feasibility Study Technical Report for the Coffee Gold Project, Yukon Territory, Canada, 2016, prepared by JDS Energy & Mining Inc.

Proposed solution eliminates crushing area



4. Methodology – Direct Savings

Power

Reduction of 31%

an average annual basis or kW draw and kWh consumption (presented in the Coffee FS report Table 18.5) as a direct effect of eliminating the crushing from the process flow sheet

Area	Connected Power, kW	Average Annual, kW	Energy Annual, kWh
Crushing	1,578	669	5,860,723
Plant Total	5,525	2,178	19,075,219
Savings	**29%**	**31%**	**31%**

Capital Costs

Direct CAPEX

- Equipment costs for drill & blast and crushing
- Respective reduction in capital costs requirements for electrical supply and distribution, for general infrastructure (crushing area, drill & blast storage and distribution, etc.).
- CAPEX for the required Laser Miner units to mine the annual capacity is added to the overall costs.

Indirect CAPEX

- Reductions of 20% in indirect costs for freight and logistics, EPCM, commissioning, and contingencies.

CAPEX (MCAN$)	Feasibility Study Initial	Feasibility Study Sust.	Feasibility Study LOM	Proposed Solution Initial	Proposed Solution Sust.	Proposed Solution LOM	Savings LOM
Mining	$ 85.5	$ 47.6	$ 133.1	$ 75.5	$ 38.5	$ 114.0	$ 19.1
On-Site Development	$ 7.7	$ 0.9	$ 8.6	$ 7.7	$ 0.9	$ 8.6	$ -
Crushing & Handling	$ 16.4	$ -	$ 16.4	$ 0.6	$ -	$ 0.6	$ 15.7
Heap Leach	$ 28.2	$ 34.5	$ 62.7	$ 28.2	$ 34.5	$ 62.7	$ -
Process Plant	$ 27.6	$ 1.0	$ 28.6	$ 27.6	$ 1.0	$ 28.6	$ -
On-Site Infrastructure	$ 43.1	$ 2.8	$ 46.0	$ 38.4	$ 2.8	$ 41.2	$ 4.8
Off-Site Infrastructure	$ 24.3	$ -	$ 24.3	$ 24.3	$ -	$ 24.3	$ -
Indirects	$ 31.7	$ 4.7	$ 36.4	$ 30.1	$ 4.7	$ 34.7	$ 1.7
EPCM	$ 18.9	$ 1.5	$ 20.4	$ 15.1	$ 1.5	$ 16.6	$ 3.8
Owners Costs	$ 7.9	$ -	$ 7.9	$ 7.9	$ -	$ 7.9	$ -
Closure	$ -	$ 60.5	$ 60.5	$ -	$ 60.5	$ 60.5	$ -
Subtotal	***$ 291.4***	***$ 153.5***	***$ 444.8***	***$ 255.4***	***$ 144.4***	***$ 399.8***	**$ 45.0**
Contingency	$ 26.1	$ 7.2	$ 33.3	$ 22.3	$ 6.9	$ 29.1	$ 4.2
Working Capital	$ 23.0	$ 61.0	$ 84.0	$ 23.0	$ 61.0	$ 84.0	$ -
TOTAL (MCAN$)	**$ 340.4**	**$ 221.7**	**$ 562.1**	**$ 300.7**	**$ 212.3**	**$ 513.0**	**$ 49.2**

Operating Costs

- Drill & blast at $0.83 per tonne mined (Tables 22.4 and 22.10 from Coffee FS report)
- Respective reduction in manpower for the mill operation to account for eliminating the crushing area, the power requirements as per power table above and Section 22.4.2, and the allowances assumed for crushing maintenance calculated in accordance with Section 22.4.3 and Table 22.17
- Expected OPEX for the operations of the required capacity of the Laser Miner is added to the overall OPEX.

OPEX	Feasibility Study LOM (MCAN$)	Feasibility Study CAN$/t Processed	Proposed Solution LOM (MCAN$)	Proposed Solution CAN$/t Processed	Savings LOM (MCAN$)	Savings CAN$/t Processed
Mining	$ 707.4	$ 15.26	$ 538.1	$ 11.61	$ 169.27	$ 3.65
Processing	$ 230.3	$ 4.97	$ 195.7	$ 4.24	$ 34.62	$ 0.73
Infrastructure	$ 45.2	$ 0.97	$ 45.2	$ 0.97	$ -	$ -
G & A	$ 134.2	$ 2.89	$ 134.2	$ 2.89	$ -	$ -
TOTAL (MCAN$)	**$ 1,117.1**	**$ 24.09**	**$ 913.2**	**$ 19.70**	**$ 203.9**	**$ 4.39**

4. Methodology – Project Economics

Financials

SUMMARY	Feasibility Study		Proposed Solution		Impact	
Revenues (CAN$)	$	2,709	$	2,709	$	-
OPEX (CAN$) *	$	1,094	$	897	$	197
CAPEX (CAN$)	$	562	$	509	$	53
PRE-TAX CASH FLOW						
Cash Flow (CAN$)	**$**	**45.8**	**$**	**56.7**	**$**	**10.8**
Cumulative Undis. Cash Flow (CAN$)	**$**	**1,053.9**	**$**	**1,303.2**	**$**	**249.3**
Payback Period (Year)		**3.89**		**3.59**		**0.30**
PRE-TAX NPV						
**PRE-TAX NPV @ 5% ** **	**$**	**699.5**	**$**	**881.0**	**$**	**181.6**
IRR						
INTERNAL RATE OF RETURN (IRR)		**50.4%**		**66.4%**		**16.0%**

Notes:
*** NPV comparison has been presented on a pre-tax basis as the tax regimes presented in the Coffee FS Report would change based on the proposed solution updated costs and the project team cannot account for the changes due to insufficient public information and any calculations on an after-tax basis would be considered speculative.*

Conclusion

The Coffee project was already a viable project and the proposed solution's impact is only improving the project potential. However, in many other projects which currently are considered non-economically viable, the proposed solution can become the difference for the final "go-no go" decision. By applying the Laser Miner solution, these projects will become viable resulting in more projects in Canada (and globally) becoming profitable and being developed and reach operational stage. This will result in the creation of more jobs and better engagement of local communities – a considerable indirect effect from the solution that cannot be quantified in a single case study.

Versatility

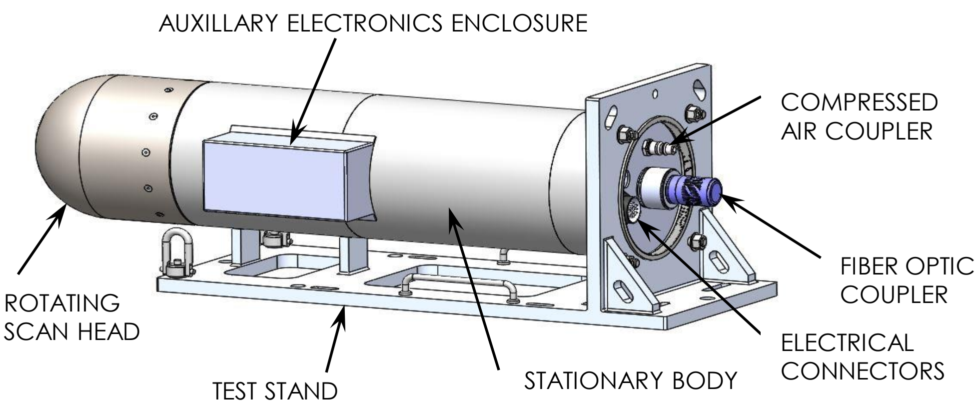
Based on the work performed by the Project team by now, the proposed solution is applicable to different commodities and mining methods. Depending on the rock type and it's physical and chemical properties specific to that type of rock laser power must be applied. Evaluation and testing of the laser requirements must be undertaken prior to developing an operational unit.

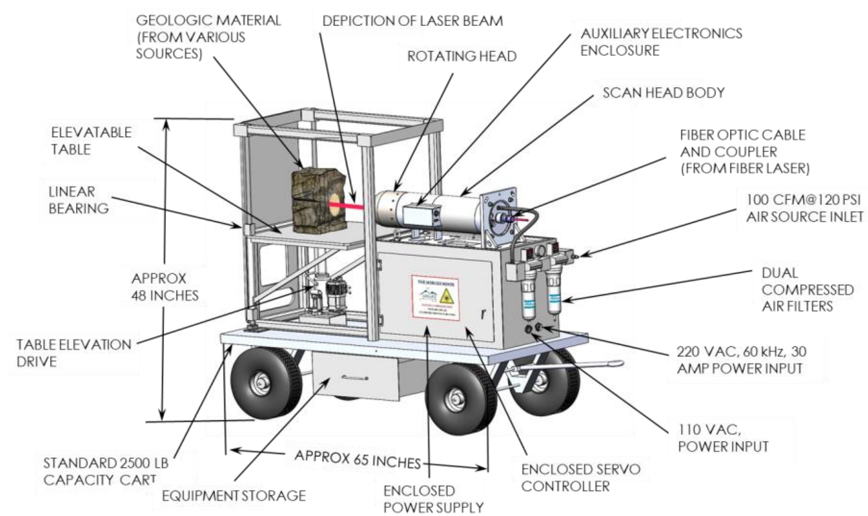
4. Methodology – Development Phases (1)

Phase I – Laboratory Test Unit

Operate a working model in a laboratory scenario to characterize operating parameters w/Single Fiber Laser and Scan Head

- **Determine Fiber Laser Power necessary for Thermal Fracturing (1 to 7 kW) (using only a 30 foot fiber optic cable)**
- **Determine that Irradiation time is actually near 1ms**
- **Determine that Optical Power is actually near 1kW/cm^2**



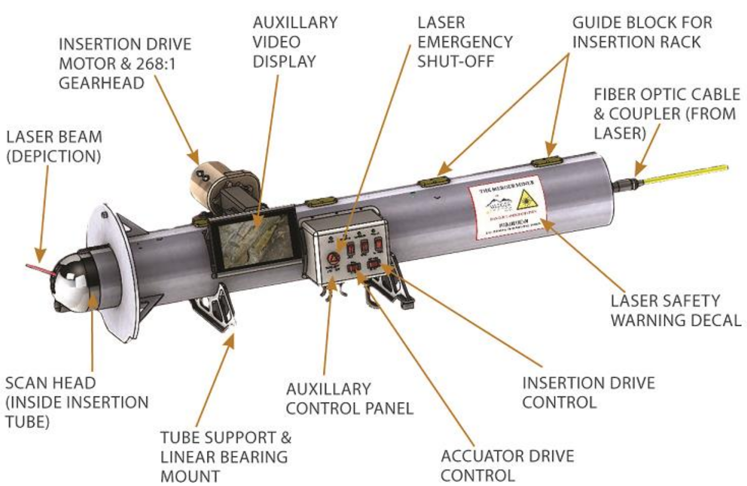


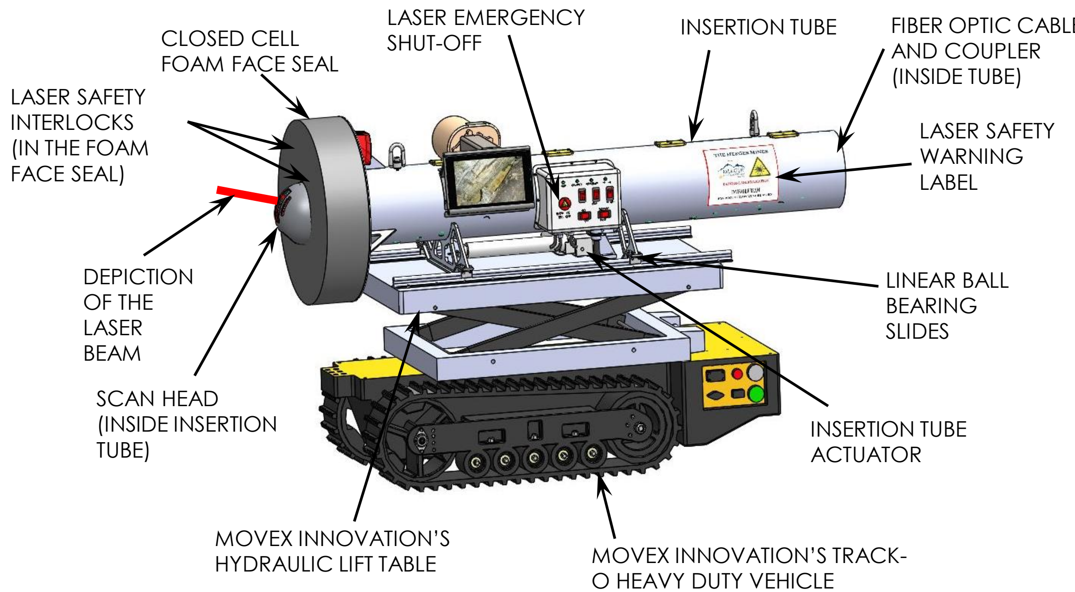
4. METHODOLOGY – DEVELOPMENT PHASES (2)

Phase II – Characterization Unit

Develop a working model in a simulated production scenario to:

- **Determine that Particle Size for Ore and Waste 0.5 cm3**
- **Refine Projected Operating Costs**
- **Determine Durability of Components in a typical Mine Environment**
- **Provide "Spalled" Material to Determine Optimal Material Handling**
- **Build a system using variable fiber laser configurations and energies to maximize efficiency.**

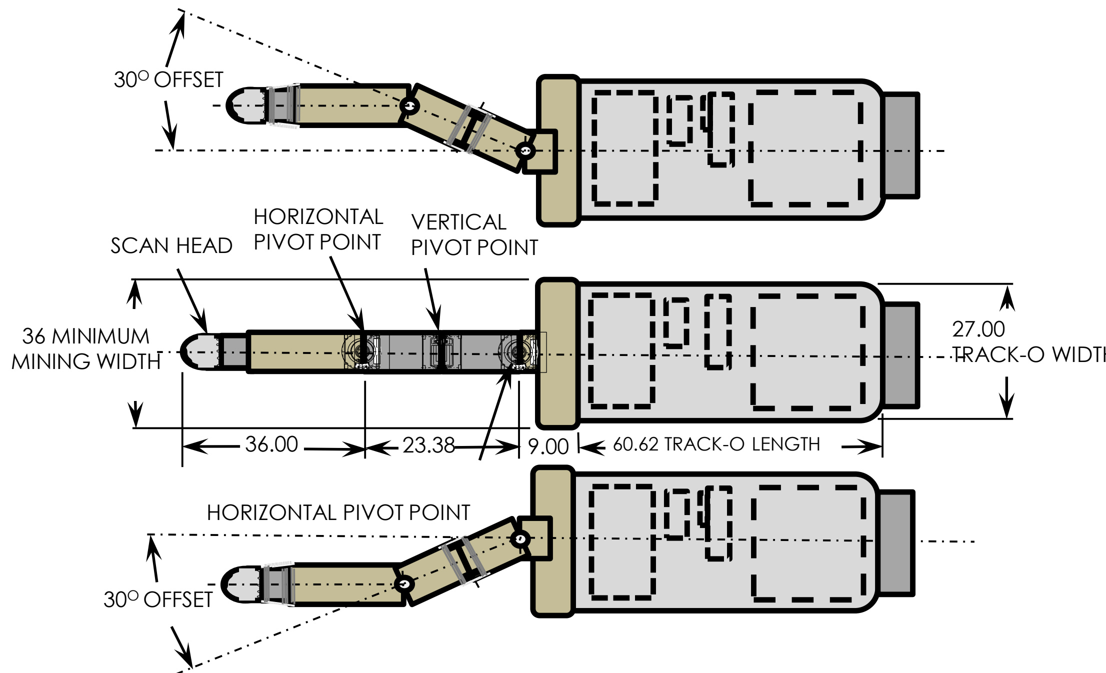


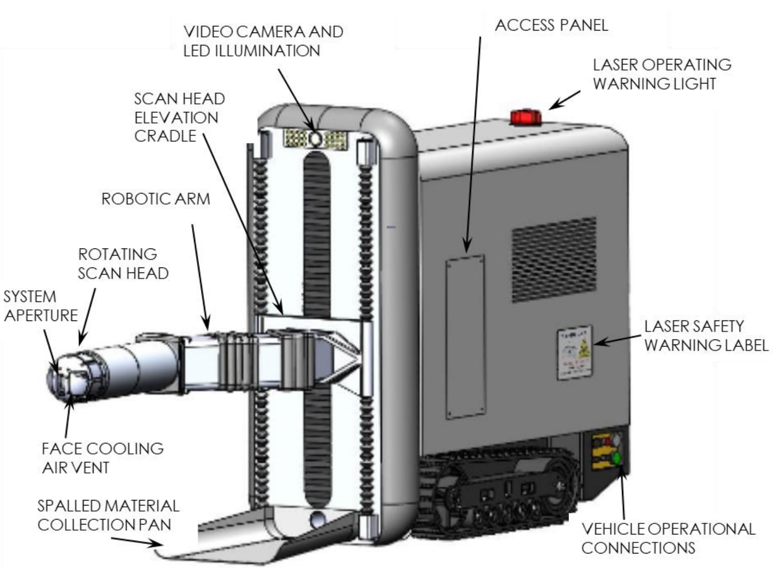


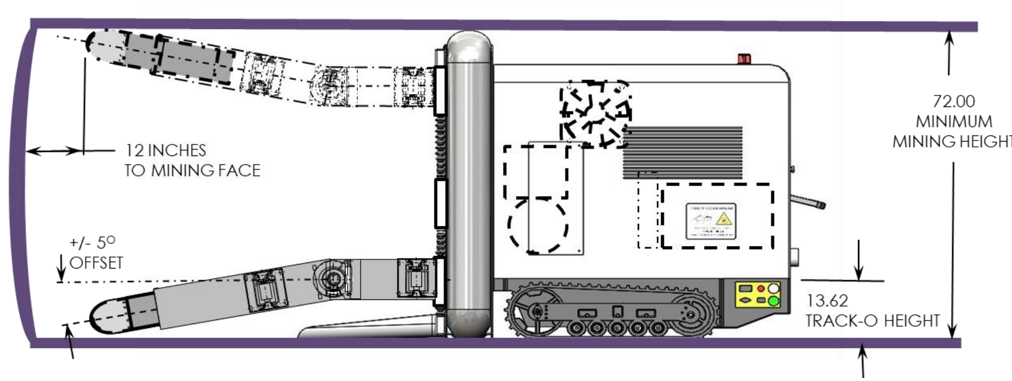
Phase III – Operational Unit

Including a software using:

- Data Analytics
- Artificial Intelligence
- Machine Learning



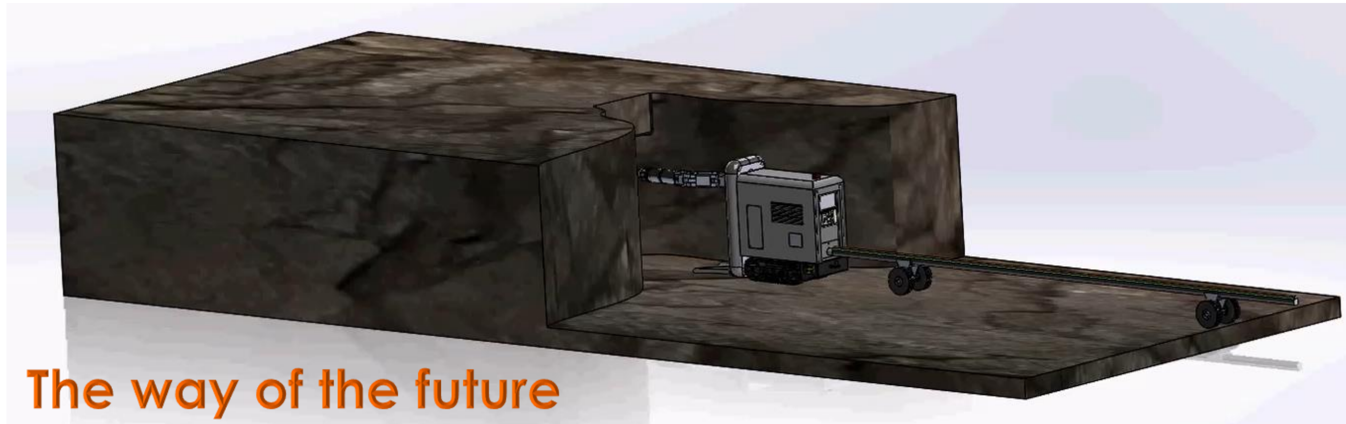




5. Environmental Impact

Drill & Blast

No more!



Crushing, Handling

No more!

Eliminating Drill & Blast - solve issues such as:

- Ground vibrations
- Air over-pressure
- Fly-rock, dust, blasting fumes
- Leaching of chemicals in the blast holes and polluting ground water,
- Health impact on animals and people

Elimination of Crushing process will have positive environmental influence on the environment surrounding the mine

- Crushing, screening, material handling and transfer operations are potential sources of particulate emissions – either process sources or fugitive dust sources. Eliminating the crushing part of the comminution process is making a tremendous difference on the overall environmental footprint of the mine.

This effect is multiplied by the fact that the proposed solution can be used for a variety of commodity types and mine conditions.

Indirect environmental benefits from the project can be summarized as follows:

- Smaller footprint, less area required for mine dumps
- Improved Health and Safety
- Miners not working at face
- Reduced need for compressed air supply lines.

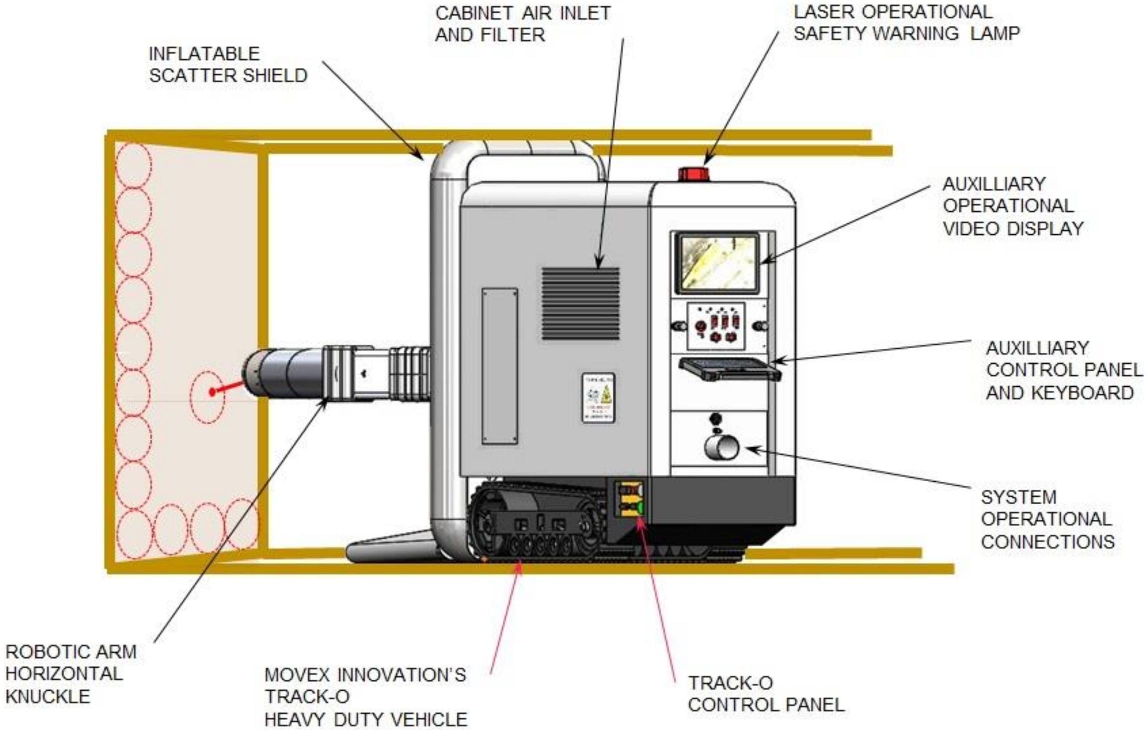
6. Downstream Impacts

There are potentially additional positive impacts on the downstream processes of grinding, flotation/leaching, etc. that have not been tested and quantified to-date, and for the purposes of the current application, they are NOT accounted for neither in the discussion nor in any of the calculations and estimations presented in Section 4 of the presentation. Instead, these impacts can be studied and quantified as the project progresses through the stages.

No negative impact

Potential Benefits

- CAPEX and OPEX reduction
- Job creation
- Artificial Intelligence
- Data Analytics
- Engineering
- Manufacturing
- Skill diversification
- Job creation during mining down cycles
- Transition to knowledge-based industries, such as data analytics and artificial intelligence



7. Uptake Potential and Scaleability

The proposed project (Phase I) will result in an operational prototype that can demonstrate all the benefits calculated above.

Key Product

The key product as a result of this project is a high optical power laser with four heads developed with specifications to satisfy the gold partnering mine in Ontario. The project team expects that the requirements of different mine projects can be fulfilled by removal or addition of scan heads ,and/or the use of fiber lasers with varying kilowatts, without changes to core specifications of the operating unit, such as width and height.

Commercialization Plan

- Incorporate the consortium in Canada and initiate the process to secure a Canadian patent to protect the intellectual property of the product.
- Collaborate with researchers from the Department of Physics, University of Toronto to quantify the results of Phase I and Phase II in a peer-reviewed academic paper, through a grant from NSERC or NRC
- Assess further the indirect benefits of the product, including the impact of energy savings and environment benefits on the health of Canadians
- Continue to engage partner mines, and assess their specification appropriateness for the development of the prototype
- Progress discussions with several mining companies towards a Letter of Intent, and purchase agreement. The mining companies that have been contacted to-date and showed interest into piloting the prototype in their operations include the following:
  - Open pit graphite mine in Quebec
  - Underground gold miner in Ontario
  - Underground gold miner in Nunavut
  - Underground gold miner in Manitoba
  - Iron ore mining company in Labrador
  - Magnesium mine in British Columbia
  - Base metal mine in Saskatchewan
- Formulate the price range of the product based on discussions with partners
- Market preliminary prototype benefits in industry events, such as PDAC, and international laser congresses.

7. Uptake Potential and Scaleability

Scalability

The successfully completed Phase I and II will result in a characterization unit that can be scaled to an operational unit (Phase III). The project team has a plan to execute Phase III and has an actual operational unit as detailed in Table 5 of this Annex F.

The product can be **scaled to different geophysical compositions** of extracted ores, commodity, and geographic location/climate by adjusting the number and strength of the fiber laser. Outside of the mining industry, product can be implemented with no or minor modifications in several other industries and scenarios.

- Drilling through rock for mine Rescue Operations
- **Oil and gas industry** already in use on offshore drilling platforms
- Drilling through debris in Disaster Rescue Operations
- Construction of by-pass tunnels in Dam Construction operations
- Vitrification of surfaces for improved ventilation flow
- Rock excavation where conditions preclude the use of explosives
- Potential for Vitrification of Fissures where explosives have been used
- Robotic surface planning on asteroids
- **Robotic mining** on Mars or other planets
- Channeling

8. Innovativeness

Unique

- The technology involving high optical power laser for mining is unique and there are no similar projects undertaken in the laser industry in Canada and/or abroad although there are a number of related patents involving mining and the oil and gas industries.
- Eliminate drill & blast, and crushing

Power and Costs Savings

The presented technology would eliminate major cost items (both capital and operating), reduce significantly requirements for power, materials and consumables.

Environmentally Friendly

Mitigate environmentally and socially risky activities such as drilling and blasting, crushing (primary, secondary, tertiary, etc.) along with the respective screening and material handling activities, supporting the crushing process.

Application for Other Industries

The Proposed solution can be used in Construction, Robotics, Safety and Rescue Operations, etc. – a major risk mitigation factor.

New Way of Mining

This would result in a completely new approach to mining – much more cost effective, using less power and consumables, and much more environmentally friendly and socially accepted. Ultimately, this product will help more mining projects become economically viable and reach an operational stage.

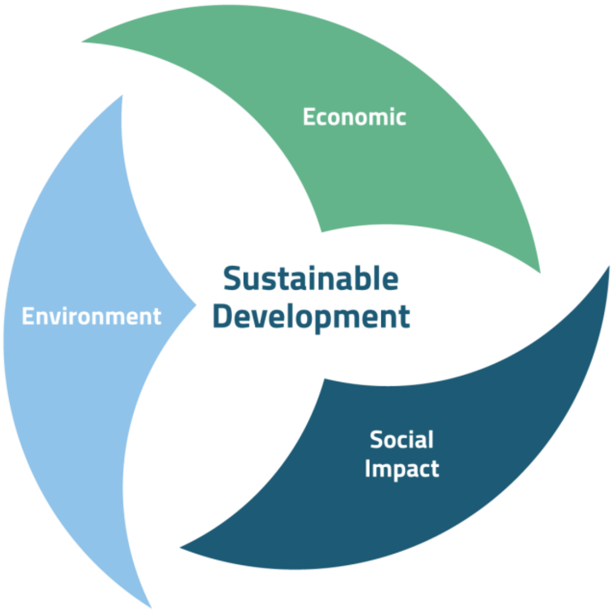
In addition, all of the above will lead to achieving **stronger social, environmental, and economic outcomes** for Canada, Canadian mining industry and Canadian citizens.

9. Economic and/or Social impact

Positive Impact

The proposed solution is expected to have a positive impact for future mining projects from economic and social point of view:

- Improved Health and Safety for miners not working at face
- Two-man crew operating multiple mining faces
- Reduced manpower requirements
- Reduced supervision
- Local communities project buy-in
- Easier government/permitting discussions and negotiations.



A successful implementation will lead to improved public confidence in mining projects operations by reducing costs, energy and emissions for mining projects and reduced risks from environmental and permitting standpoint. To reiterate, the proposed solution will help invigorate the mining industry in Canada and abroad creating more mining projects, new revenue streams, and new employment opportunities for communities.

10. Risk Assessment and Mitigation (1)

Risk Assessment Criteria

Severity (S)		Probability (P)	
4	Catastrophic	4	Likely
3	Major	3	Occasional
2	Minor	2	Rare
1	Negligible	1	Unlikely

Risk Assessment Grid

Probability (P)				
4	4	8	12	16
3	3	6	9	12
2	2	4	6	8
1	1	2	3	4
	1	2	3	4

Severity (S)

Risk Classification

12 - 16	Critical Risk
8 - 9	Major Risk
4 - 6	Medium Risk
1 - 3	Low Risk

Note: Appropriate means of mitigation must be implemented for risks quoted ≥ 8.

Risk Area	Risk Event	Impact/Consequence	S	P	Risk (S x P)	Mitigation Plan	Responsible	Residual Risk
Financial	Project budget	Over budget can potentially affect the project completion	4	2	8	Detiled Cost Management Plan and Change Management Plan and procedures developed and in place. Highly experienced Project and Cost Management team leads with multiple successful prior projects experience with much higher budgets and more complicated budget structures	Georgi Doundarov	0
	Project scope	Changes in scope can affect the project completion	3	2	6	Detiled Scope Management Plan and Change Management Plan and procedures developed and in place; Highly experienced Project Management team leads	Georgi Doundarov	0
Technical	Technical design	Technical design errors can potentially affect the overall project success	4	1	4	In depth work performed and time spent during the initiation and planning stages to ensure the proper technical design procedures and practices are followed during the execution and monitorint and control stages; Highy experienced technical leads and personnel included in the team and various consultants and specialists allocated and readily available to engage in the project; Detailed Quality Management Plan developed and in place	Gary Mladjan	0
	Software design	Software design errors can potentially affect the overall project success	3	1	3	Highly experiences software engineers included in the project with proven track record in complicated projects	Lex Smith	0
	Testing and Calibration	Improper testing and calibration may result in false results and statements	4	1	4	Proper Testing and Calibration procedure developed; Technical manegement and personnel highly experienced with many projects successfully completed involving tests and calibrations	Gary Mladjan	0

10. Risk Assessment and Mitigation (2)

Risk Assessment Criteria

Severity (S)		Probability (P)	
4	Catastrophic	4	Likely
3	Major	3	Occasional
2	Minor	2	Rare
1	Negligible	1	Unlikely

Risk Assessment Grid

Probability (P)				
4	4	8	12	16
3	3	6	9	12
2	2	4	6	8
1	1	2	3	4
	1	2	3	4

Severity (S)

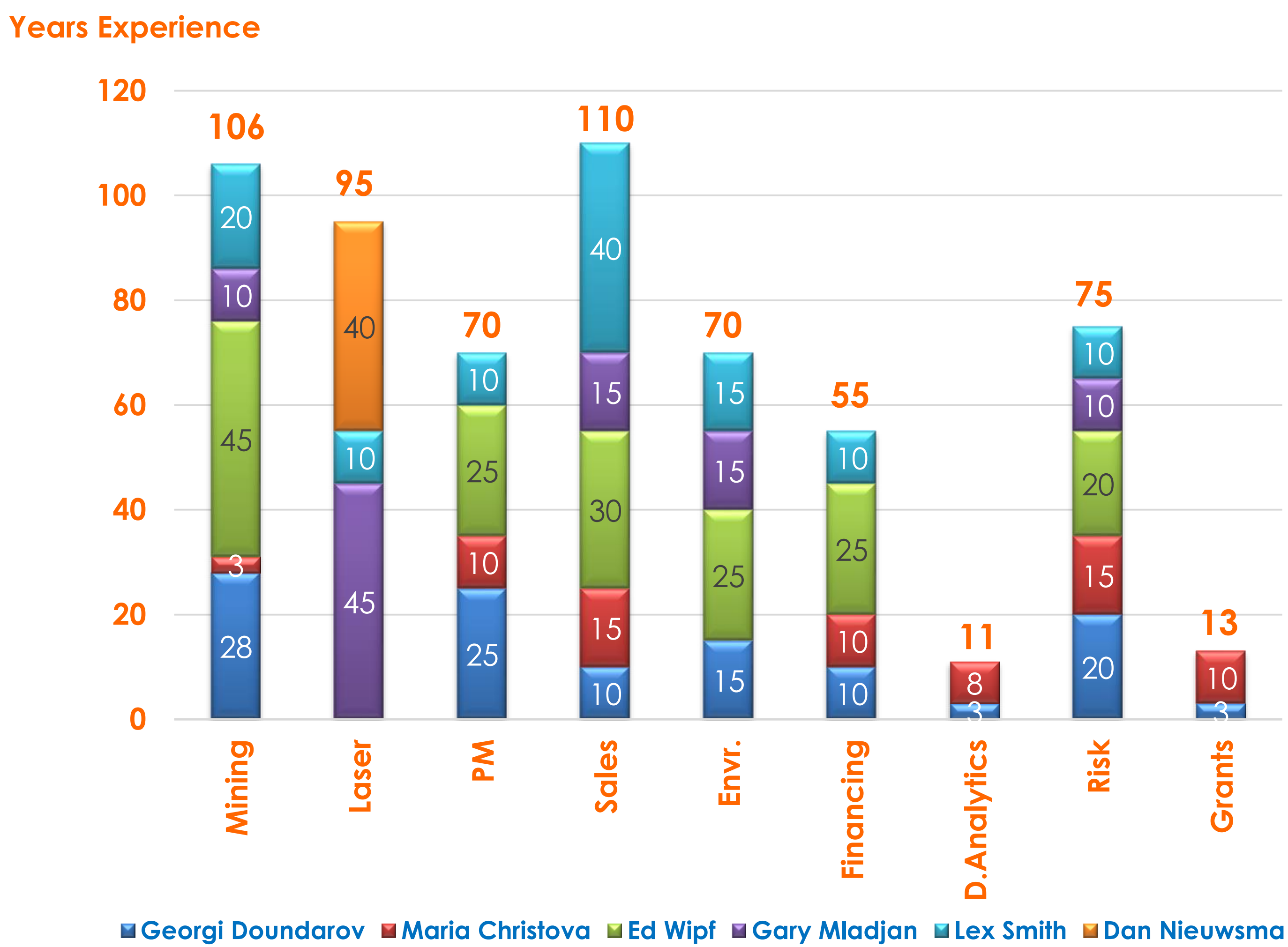
Risk Classification

12 - 16	Critical Risk
8 - 9	Major Risk
4 - 6	Medium Risk
1 - 3	Low Risk

Note: Appropriate means of mitigation must be implemented for risks quoted ≥ 8.

Risk Area	Risk Event	Impact/Consequence	S	P	Risk (S x P)	Mitigation Plan	Responsible	Residual Risk
Organizational	Consortium of partners	Current team of individuals not part of one company. If an important team member decides to leave the consortium this may jeopardize the successful project completion	2	1	2	Detailed plans in place to incorporate the current team federally in Canada and involve any additional team members as contractors or as permanent employees. Strict authority level and future company executive and technical position levels agreed upon.	Georgi Doundarov	0
	Project schedule	Delays in schedule can potentially affect the project completion	3	1	3	Detailed Schedule Management Plan developed and mitigation strategy in place to involve additional team members and/or fast track the project	Maria Christova	0
	Consultants, vendors, contractors selection	Potential mistakes in selecting consultants, vendors and contractors can affect the project success from technical point of view	2	1	2	Consultants, experts, suppliers for all aspects of the Laboratory Test Unit, such as fiber optic lasers and heavy-duty equipment, are selected based on detailed search and reviews and either under contract or verbal agreement.	Lex Smith	0
	Consultants, vendors, contractors management	Improper consultants, vendors and contractors management can affect the project completion	2	1	2	Detiled Staffing and Contracts Management Plan procedures developed and in place.	Georgi Doundarov	0
	Partners and buyers allocation	Not allocating partners to test the proposed solution may jeopardize the project success and completion	4	2	8	Early deiscussions with various mining companies in Canada were undertaken with real interest in testing the product in different operations in terms of commodities and type of mining methods. Main partner already selected and several LOIs in place	Georgi Doundarov	0
Environmental	Proposed solution environmental concerns	May result in causing environmental issues and not receive buy-in from various stakeholders	1	1	1	Detailed research of the proposed solution from Environmental stand point was completed with no concerns defined	Ed Wipf	0

10. Risk Assessment - Team Experience



10. Risk Assessment Versatile Combination of Experience

Georgi Doundarov, M.Sc., P.Eng., PMP, CCP – Project Lead

28 years of extensive managerial, operations, technical, project and financial experience in Canada, Europe and Asia, covering the whole life cycle of a mine from studies, engineering, construction, commissioning and operations to closure. Indebt technical expertise in process engineering, plant design, construction, commissioning, operations management, plant evaluation and optimization, NI43-101 compliant feasibility studies, metallurgical testing, for base, precious, and ferrous metals and industrial minerals. Solid track in project management, project cost management and financial operations including M&A deals involvement. Professional Engineer of Ontario, certified as a Project Management Professional under the PMI, and a Certified Cost Professional under the AACEI. Qualified Person under the NI43-101 Standards.

Maria Christova, MA, CFA, PMP, FRM, CSC, MEDA – Financials

With over 14 years in technology and finance in Canada, Europe and Asia, Maria has held executive positions at small and large size companies spanning responsibilities including budget management, risk management, sales, product & project management, resource & vendor management. With unwavering focus on superior customer experience, she has designed and delivered innovative products and processes that delight stakeholders. Certified as a Project Management Professional under the PMI, Chartered Financial Analyst under the CFA Institute, Financial Risk Manager under GARP and in process of becoming a Chartered Professional Accountant with CPA. Holds Canadian Securities Course certification from Canadian Securities Institute and Management of Enterprise Data Analytics certifications from University of Toronto.

Gary Mladjan – Opto-Mechanical and Laser Technology Expert

Over 50 years of opto-mechanical engineering experience with various defense contractors, most recently with Raytheon Corporation. Mr. Mladjan was a responsible team member in the development of a number of electro-optical night vision and laser devices and is the primary holder of a number of International Patents for those devices. He was the lead engineer in the advanced conceptual design, engineering costing, product design and manufacturing on many projects at Raytheon, Hughes Aircraft, Ernst Leitz, Canada (ELCAN), Northrop's Electronics Div. and Aerojet ElectroSystems' Astrionics and Research Divisions. Designated Raytheon corporate expert for Investment Castings and for Single Point Diamond Machining as well as a developer in the use of exotic materials and technologies for defense products.Mr. Mladjan has authored several published papers on New and Innovative Technology and Detail Design in Exotic Materials.

Lex Smith - Operations Lead

Mr. Smith entered the mining business in 1993 as the field manager and owner of multiple mining claims in Montana. Mr. Smith served as President and Director of Shoshone Silver/Gold Mining Company from 2003 to 2012, President and Director of the Silver Valley Mining Association from its inception in 2003 until 2009, and President and Director of Natural Resources Education Outreach (NREO). Additionally, in 2013, Mr. Smith served as a foreign legal consultant and mining law consultant for the LEHMAN, LEE & XU Law Firm in Beijing, China.

Edward Wipf – Comminution Expert

45 years of experience in comminution circuits, Mr. Wipf specializes in acquisitions and strategic alignment of new product lines for the company. He occupied various senior technical positions at Allis Chalmers, Koppers, MPSI/Svedala, Aerosion, Metso Minerals, Weir Minerals. He is the author of numerous technical papers related to mining and comminution, and has taught comminution classes at such schools as McGill University and the Colorado School of Mines. He was involved in the development of the Metso Vertimill in the late 1970s, and he developed the Vertimill slaker. He later started and sold the largest lime slaking system in the world. Mr. Wipf has a bachelor's degree in both Chemical Engineering and Energetics, and has attended Rauma's Business School for Senior Management and Product Management.

Thank You

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