NOVEL SOLUTION FOR MINING MINERALS: ¡VAMOS!

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ABSTRACT

Resources are becoming a scarce commodity. Either by depletion of deposits or by strategic cornering of the market by foreign suppliers. Increasing prices are a driver for exploring alternative origins. Higher prices allow for more effort to extract the material. Materials range from ordinary construction sand to highly valuable minerals. In both cases, hydraulic transport of a slurry reduces the cost of delivery to the destination. What increases the price of hydraulic transport is the auxiliary equipment to make it happen. Think of the supporting construction, mechanical handling of sub-assemblies, drive trains, control and automation.

To prove that hydraulic mining can be competitive to more traditional extraction methods, the ¡VAMOS! consortium started a research project to develop a Viable Alternative Mining Operating System. This comprises a submersible Mining Vehicle, a Launch and Recovery Vessel and a Position and Navigation Awareness system. All components are assembled from readily available products within the consortium. The challenge was to bring together the various industries, that would never meet under normal circumstances and still assemble an innovative fully functional system. Two submerged abandoned inland mines were chosen to test and demonstrate the effectivity of the total system in prototype scale experiments. The initial results are now in and look promising in increased resource recovery and cost reduction. Additionally, as the submerged system is operated remotely from a safe distance on shore, there are further benefits for safety and for environmental issues as there is no dust, noise or mining traffic. This innovation plots a course to a future for a resilient supply of marine resources.

Keywords: Submerged mining, aggregates, minerals, resource supply, dredging method.

INTRODUCTION

With Europe having been mined over many centuries, and in certain localities, millennia, many easy-to-access mineral deposits are depleted. Major opportunities to extract raw materials within the EU lie at greater depths, in remote areas, abandoned mines, and in smaller deposits (European Commission 2013). It is estimated that the value of unexploited EU mineral resources at 500-1,000 meters depth approximates to 100 Billion Euros (European Commission 2012). Currently accounting for only 3% of the world’s ore production whilst consuming approximately 30% of the world’s metals production, the European Union has a high reliance on imports of many common and strategically important minerals. As an example, EU mineral use includes an import dependence on ~90% of copper ore to up to 100% of certain rare earth elements and platinum-group metals (European Commission 2014). In response to more technically challenging EU deposits being abandoned and EU mineral needs being met by imports, the H2020 program calls the industry to bring forward solutions for a more cost-effective exploitation of EU resources, thereby increasing their attractiveness and ultimately reducing EU dependence on minerals and metals imports.

Recently the United States took similar measures for material independence (Trump 2017). In the meantime, there is now already a draft list established by the Department of the Interior of the 35 most critical minerals (US DOI 2018). On the list are mostly little used materials, but also more common materials as helium, tin and aluminium are present. Most of the needed minerals are produced domestically, but in small quantities (Desjardins 2018). This is rarely by a poor mineral endowment, but more often by an economic situation, that makes it an unviable business to produce these minerals against foreign competition. The new strategy of the executive order (Trump 2017) concentrates on:

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1. Finding new sources of critical materials domestically
2. Increase activity on all levels of the supply chain
3. Know where each of the critical materials can be found
4. Easing the administrative process on exploiting these reserves

As especially the first two focal points are very much in line with the European objectives, it will be interesting to see, whether similar solutions might be applicable in the American situation. Basically,¡VAMOS! is an initiative to investigate the viability of applying alternative solutions to the resource problems. In this manuscript, we will explore the involved operational parameters and provide results from a desk study and an actual trial.

RESOURCE AVAILABILITY

The critical materials as defined by the administration are either essential for the US economy and the national security, or of which the supply chain is vulnerable to disruption. e.g. Especially materials, that are required for a clean energy transition fall under this category. When essential materials are plotted against the risk of disruption, the critical materials are identified (Figure 1, US DOE 2011). Usually, these surveys result in lists with several rarely used material.

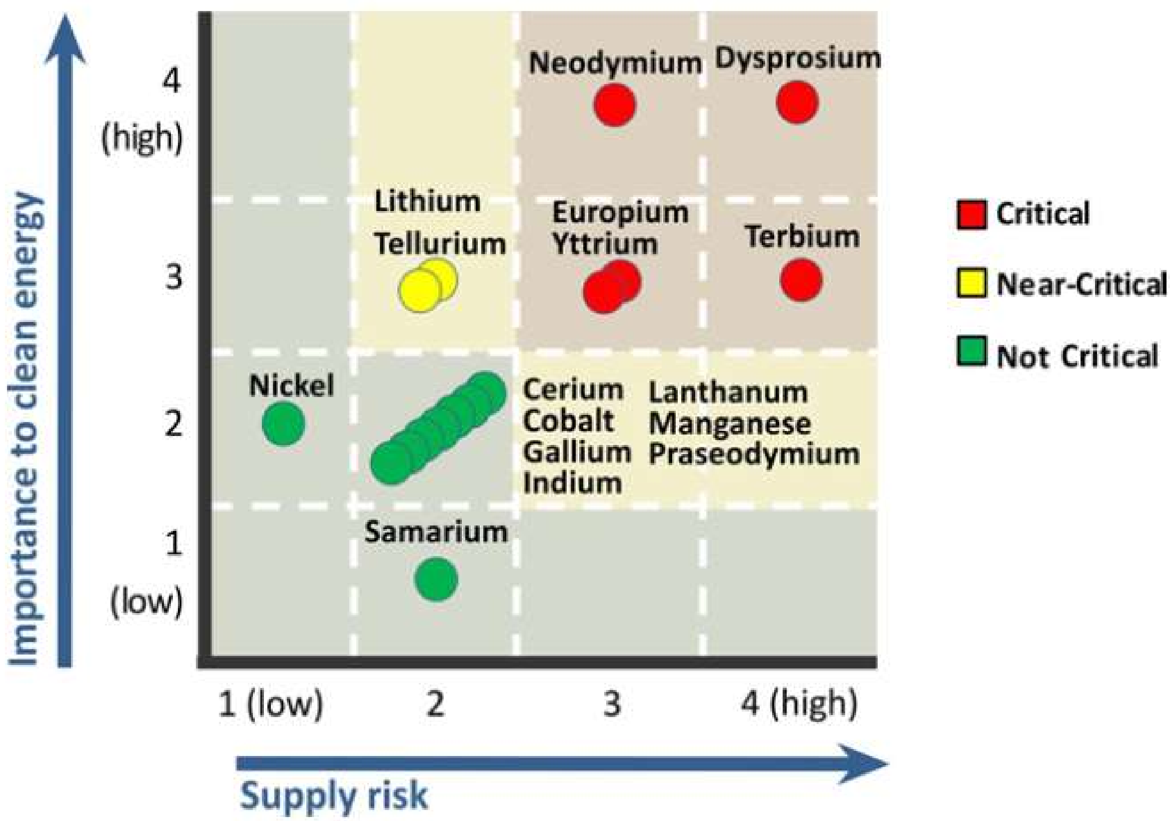

Figure 1. Medium-Term (2015–2025) Criticality Matrix (US DOE 2011)

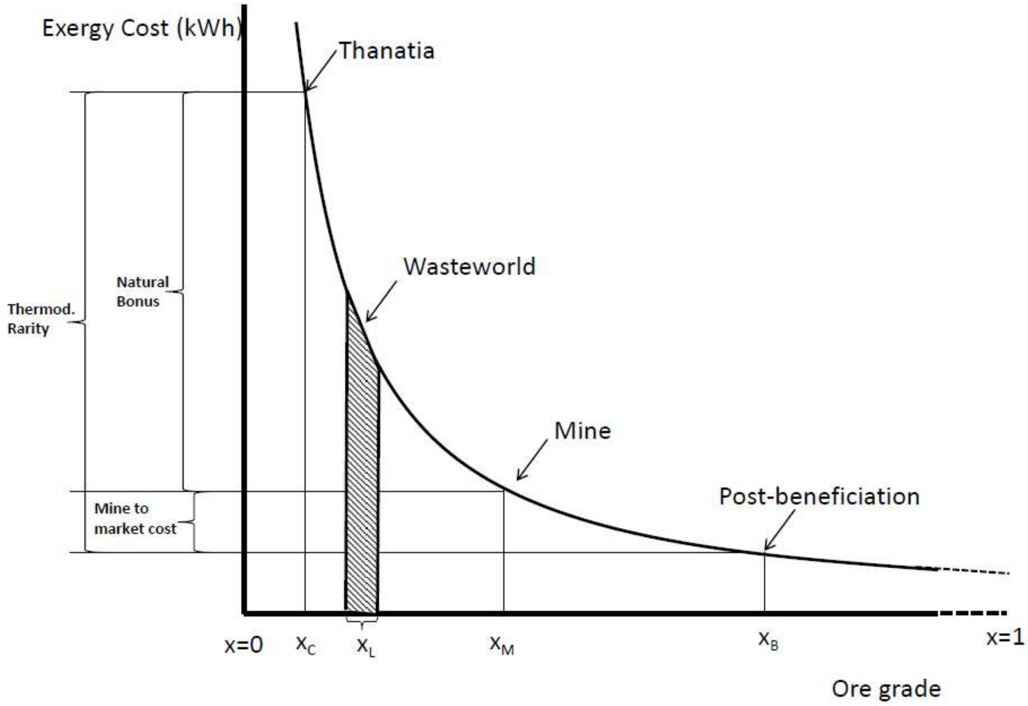

Figure 2. Exergy cost (kWh) needed for producing a given mineral from bare rock to market. (Valero 2015)

As the exergy, and consequently the costs, are quite steep at the low grade ores, the risks are high. Risk coverage is expressed in the margin, that is acceptable in the market. The margin is usually a percentage of the price. The critical minerals usually are high price, low volume. A viable business is possible from the profit (Equation 1).

$$profit = margin \times volume \tag{1}$$

In this manuscript, minerals with a high margin, but are low in volume are considered high end minerals.

HIGH END MINERALS: ¡VAMOS!

High end minerals are usually recovered in mines, either open pit mines or underground mines. Typically, all transport is dry and involving a lot of different equipment to carry out the operation. A lot of effort goes in unprofitable moving: overburden, empty trucks, trains or elevators. Due to the number of vehicles and equipment necessary, there is a lot of personnel active. This is both a burden on the costs and poses a risk for the operation. Any innovation that will be able to reduce the costs and risks, will open up resources with an even lower ore grade.

Another problem is, that these open pit mines are not very environmental friendly. They claim large areas of real estate, make noise and dust and draw ground water from the surroundings. If there is an innovation, that does not have these drawbacks, resources, that are close to urban areas or nature reserves, will be able to contribute to the supply chain.

With this set of issues with traditional mining and the experience from offshore mining, a consortium of companies set together to offer a solution. (¡VAMOS! 2015)

Description

¡VAMOS! (Viable Alternative Mine Operating System) is a 42-month international project which began in February 2015 and is part-funded through Horizon 2020 (Grant Agreement 642477), the European ninth framework programme for research and innovation. The project consortium is developing a multi-component mining robotics system to test the technological and economic viability of the underwater mining of inland mineral deposits located in flooded open-cut mines. If the technique is proven viable, ¡VAMOS! will enable access to deposits whose excavation has been historically limited by stripping ratio and hydrological and geotechnical factors (Figure 3, Kapusniak 2013).

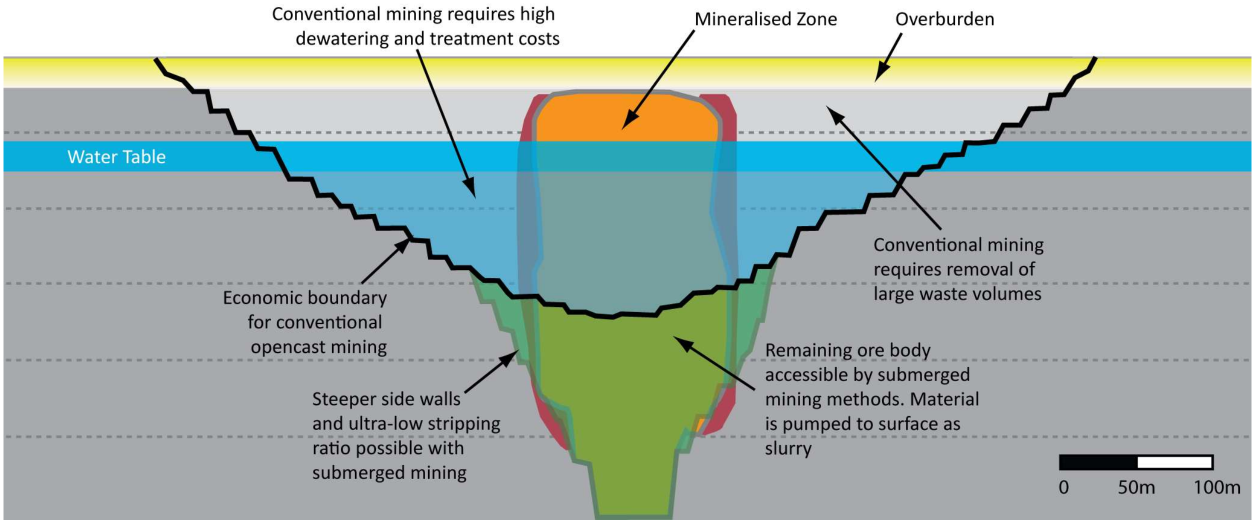

Figure 3. Schematic of typical vertical ore body in an opencast or submerged setting. (Kapusniak 2013)

Advantages of the ¡VAMOS! solution include:

- Simple transportation: The LARV, the largest system component, is modular and can be disassembled into multiple sections which can be transported by road together with the other system components.
- Quick implementation: Its self-contained power generation system and road-transportable modules mean that ¡VAMOS! can be used in disused remote mines with poor infrastructure, without needing to commission significant preliminary civil engineering works.
- Potentially cheaper mining operations: The transition to an underground mining strategy can lead to high capital expenditure and downtime, and in addition, in areas of high tectonic stresses, it might not be possible to open an underground mine. ¡VAMOS! could offer another way for open-cut mines to remain in production as they approach their economic limit.
- Safer mining operations: Less personnel will be exposed to high risks in the pit such as sidewall collapse and blasting.
- Mitigation of hydrological limitations: As the water level within the pit should remain constant and the system operates underwater, there will be no aquifer drawdown and no need to remove water ingress. ¡VAMOS! therefore offers a cheaper solution for mines with high dewatering costs and environmental penalties and restrictions.
- Less environmental and social impact: With ¡VAMOS!, the environmental footprint of the mine is significantly reduced by the absence of blasting noise and vibrations and equipment noise, in addition to the preservation of high air quality due to rock dust being contained within the pit.

By demonstration of a safe, silent, clean and low-visibility system, the ¡VAMOS! project hopes to encourage investment in disused and prospective EU mines by providing an alternative and more cost-effective excavation technique, ultimately aiming to reduce the EU's reliance on strategically important raw materials imports. Following a design freeze in October 2016, work was completed on all system components and software by July 2017, shortly before the first European field trial in 2017 in England. Post-trial microeconomic, environmental and strategic foresight analyses will guide the future development of the technology vision.

The consortium consists of seventeen parties, each experienced in offshore engineering or mining or both. There are two major components: the Launch And Recovery Vessel as a platform to power and deploy the Mining Vehicle (Figure 4 and 5). Additionally there was also EVA (Exploration VAMOS AUV) for reconnaissance and a Control Cabin where the whole system could be operated by two pilots.

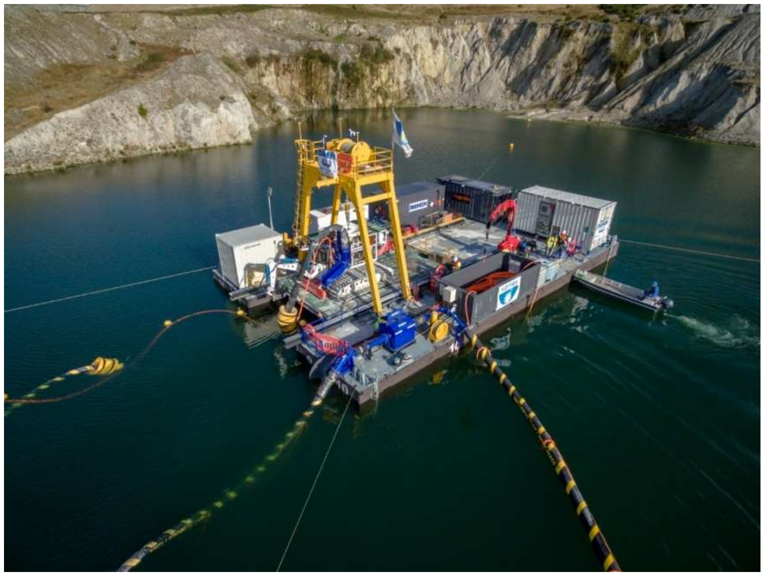

Figure 4. Overview of LARV and MV at Lee Moor test site in Devon, UK.

Figure 5. MV handling on LARV at Lee Moor test site in Devon, UK.

Project

The project scope was divided over several work packages, mostly along the various phases and components of the work. The main components and their supplying partners are listed in table 1.

Most components were available commercially of the shelf, but their novel integration was a major driver to investigate their cooperation. Each component was known to be able to work in the expected environment and the project was intended to bring the Technology Readiness Level from TRL5 (technology validated in relevant environment) to TRL7 (system prototype demonstration in operational environment).

Table 1. Main components of the ¡VAMOS! system.

ID	Abr.	Component	Supplier	Purpose
1	CU	Cutter Unit	Sandvik	The actual cutting tool, to excavate the mineral. Integral part of the body of the Mining Vehicle
2	MV	Mining Vehicle	SMD	Central body to which most submerged components are attached.
3	SC	Slurry Circuit	Damen	Transporting the slurry from suction mouth to DeWatering Facility. Double stage slurry pump attached on Mining Vehicle
4	PNA	Positioning and Navigation Awareness	Inesc	Separate hybrid ROV with instruments to monitor cut face and environment. Some instruments also on MV.
5	RH	Riser Hose	Trelleborg	Part of the Slurry Circuit for vertical transport to LARV.
6	LARV	Launch And Recovery Vessel	Damen	Platform to support MV in power, operations and maintenance.
7	FH	Floating Hose	Trelleborg	Part of the Slurry Circuit for horizontal transport to DWF.
8	DWF	Dewatering Facility	Damen	Diked area for settling of minerals and overflow of clean water.
9	CC	Control Cabin	SMD	Control centre to monitor and control operations from shore.

For the integration of all components and specifically each sub-system, the manufacturing parties used an integration register to exchange essential data. An example below (table 2) illustrates the interfaces between the major component, the real register consisted of more than 50 sub-systems, resulting in more than 1200 interfaces to be evaluated.

Table 2. Interface register on main component level for ¡VAMOS! deliveries.

Cutter Unit								
Mechanical	**Mining Vehicle**							
Slurry	Structure	**Slurry Circuit**						
#N/A	Structure	#N/A	**PNA**					
#N/A	Mechancial	Slurry	#N/A	**Riser Hose**				
#N/A	Hoisting	Mechancial	Electrical	Mechancial	**LARV**			
#N/A	#N/A	Slurry	#N/A	Slurry	Mechancial	**Floating Hose**		
#N/A	#N/A	Mechancial	#N/A	Slurry	#N/A	Mechancial	**Dewatering Facility**	
Electrical	Electrical	Electrical	Electrical	#N/A	Electrical	#N/A	Electrical	**Control Cabin**

If there was a valid interface node, the exchange of information had to be described in an interface document. This could be either a drawing or a spec sheet, or an elaborate engineering report. This also assisted in a smooth assembly and commissioning.

Trials

An extensive testing schedule is planned in which ¡VAMOS! has been tested at a granite-kaolin quarry in England in the autumn of 2017 and will be at an iron mine in Bosnia-Herzegovina in the summer of 2018. These two separate trials will allow the consortium to test the limits of all system components on a range of rock types and underwater operation conditions. Specifically, the aim is to collect data on turbidity build-up, water chemistry and ecotoxicology, and water level before, during and after operation; basic system functionality, sensory system robustness, cuttability, energy consumption, equipment wear and other operational data will also be recorded. The environmental field data will be used to conduct an environmental impact analysis of ¡VAMOS! to prove the environmental integrity of the system in comparison with conventional methods, and the operational data will be used to conduct a microeconomic analysis to prove the viability of the system and its comparison to conventional methods.

The baptism of fire for the complete ¡VAMOS! system was in an old disused mine site at Lee Moor in Devon, UK. The mine has been used for mining kaolinite, a mineral used in various applications needing gleaming and shining. The specific site ceased operation in 2008 in an otherwise operational mine. So, all infrastructure, logistics and procedures were still in place. Preparation of the site included some civil works to assemble the Launch And Recovery Vessel and as a De-Watering Facility, a reclamation area to collect the mined material.

Results

One important result, was the effect of the test of time on an inoperative mine. Erosion or rehabilitation alters the geology, which can increase the initial effort to revive the submerged mine floor for operation. Especially in Lee Moor, the surrounding hills had eroded their clay into the low lying pit. This had a serious impact on the mining trials. It was very difficult to make an estimation of the current bathymetry and survey the condition of the pit bottom. We were not able to actually follow a mining plan, but had to limit the tests to two locations that we only found suitable by actually having the machine on the bottom.

Still, the most important tests at Lee Moor result in a positive expectation on the viability of the ¡VAMOS! approach and provide a good background that can be validated with the next tests in Bosnia.

Most notable results from the actual testing at Lee Moor were:

Mining Vehicle Operation

All systems on the mining vehicle have been tested. Functionally, everything passed the tests. As the bottom of the pit was covered with silt from the runoff from the surrounding area, there was not much to be tested as a free roving vehicle. Some track tests were performed, but all other tests were done stationary. e.g. Cutter movement, auger collection, backhoe operation.

The MV was essentially a scaled down prototype version of a bigger production model, yet it was still within an industrial size, to be able to engage in a hard rock face. In the test site, this was hard to find, but some samples were collected that proved the capability to perform the required cutting hardness (Figure 6).

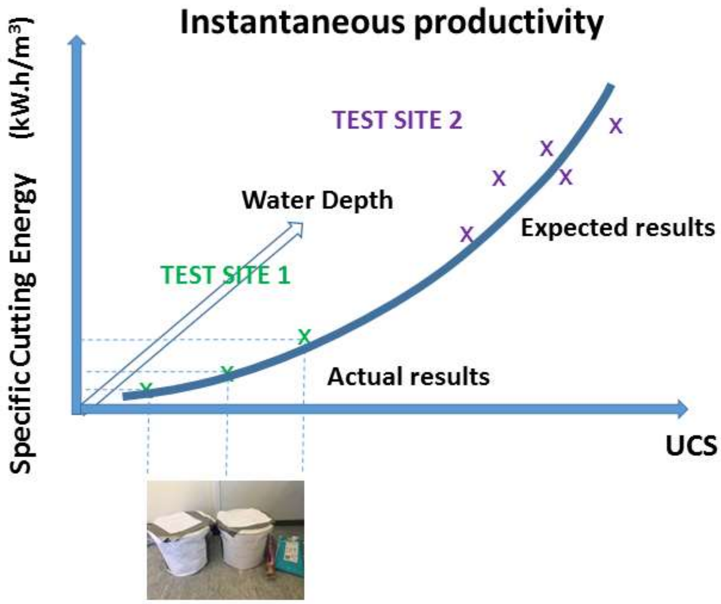

Figure 6. Tested and expected rock hardness and specific cutting energy for the trials.

Launch And Recovery Vessel Operation

The LARV was assembled and was the main platform for power supply and MV support. It also carried a workshop and an electrical cabin. The main purpose of the LARV is the launch and recovery of the mining vehicle. This has been tested in lifting the vehicle, but also exactly locating the MV and accurately positioning the LARV over the MV to lower the bullet in the catcher. The tolerance for catching the bullet is within 0.20 m, which was easily achieved, even under windy conditions. (Figure 7) The wind speed only influenced the time necessary.

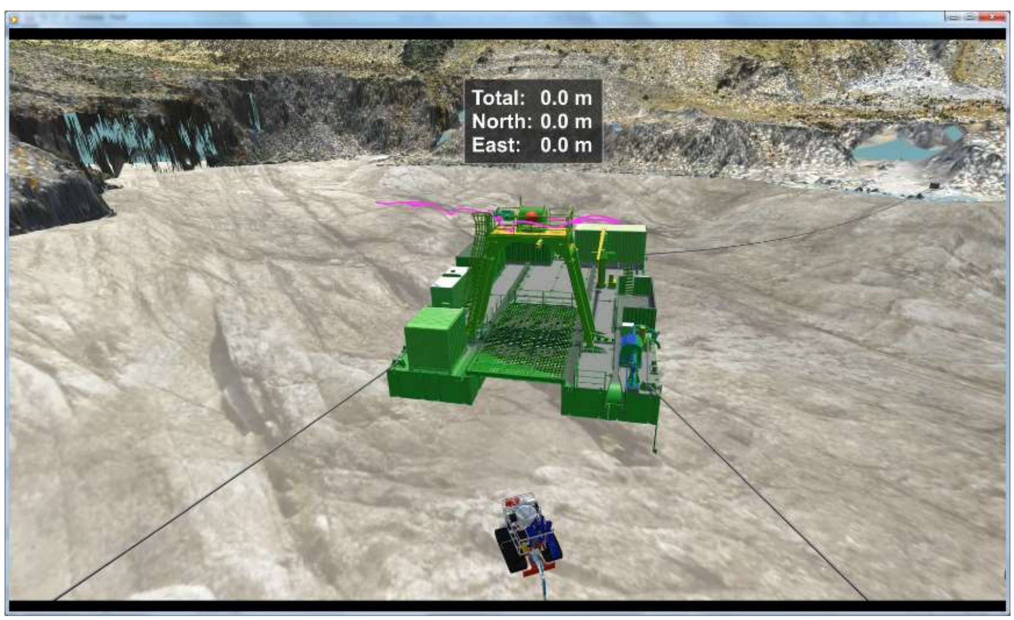

Figure 7. Positioning accuracy of LARV and MV in a fusion of LIDAR, bathymetry and real time models.

Slurry Circuit Performance

The slurry circuit is a system, that conveys the slurry from the intake on the mining vehicle all the way to the dewatering facility, in this case a reclamation pond. An innovative feature of the slurry circuit was the application of a dual stage dredge pump. This pump combines a high discharge pressure with a compact design. The performance of the dual stage dredge pump has been evaluated on the normal performance curves (Figure 8), but also on blockage of the individual stages and a novel drive mechanism. Within the power restriction of the on-board power pack of the MV, there was a normal low speed, high torque phase for low density high velocity mixtures in the vertical riser and a high speed, low torque phase when the vertical riser had to cope with a high density mixture.

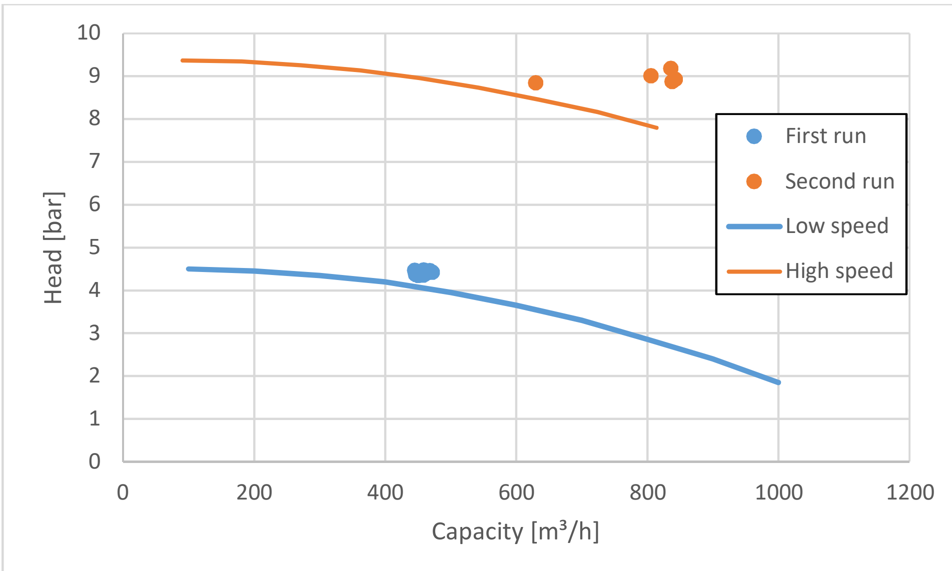

Figure 8. Dual stage dredge pump performance.

Positioning and Navigation Awareness System Performance

For the PNA system, it is important, that all different information models as bathymetry, geology and other environmental geometries on one side and MV, LARV and AUV on the other side are merged in one system. On top of that, they have to be accessible and updated real time. On a global scale for the navigation of the LARV and MV an example can be seen in figure 7. The UAV and the scanning sensors on the MV establish a local visual for the actual cutting face. The information concerning the geology can be included, to substitute the view, that the mining operator usually has as a visual clue from the rock face on the ore grade of the minerals. (Figure 9)

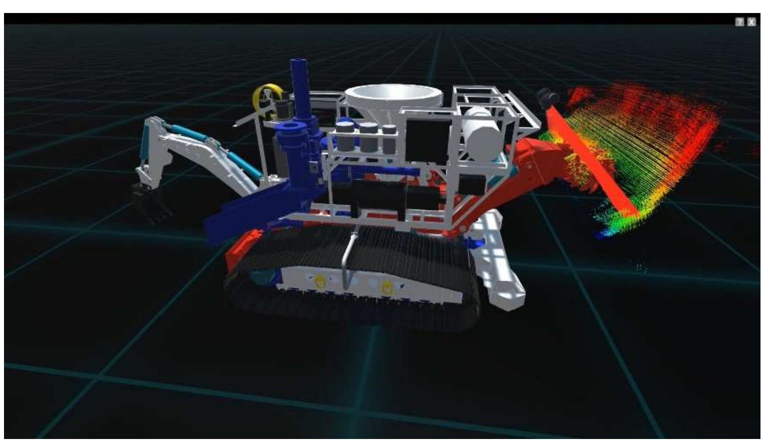

Figure 9. Fusion of LIDAR, sonar and real time model of MV and cut face.

CONCLUSIONS

On a global scale, governments are recognising the increasing demand for critical materials. Various programs and initiatives are in place to reduce the reliance and prohibitive costs for alternative sources.

Experiences and design tooling from the dredging industry in various disciplines proves to be a valuable asset to provide the solutions needed in inland mining.

The ¡VAMOS! tests at Lee Moor provide confidence in the operability of the system, further tests in Bosnia will show the results on the economic viability.

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NOMENCLATURE

CC	Control Cabin
CU	Cutter Unit
DOE	Department of Energy
DOI	Department of the Interior
DWF	De-Watering Facility
EU	European Union
EVA	Exploration VAMOS AUV
FH	Floating Hose
H2020	Horizons 2020
LARV	Launch And Recovery Vessel
MV	Mining Vehicle
RH	Riser Hose
TRL	Technology Readiness Level
USGS	United States Geological Survey
¡VAMOS!	Viable Alternative Mining Operating System