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Viable Alternative Mine Operating System: A novel underwater robotic excavation system for flooded open-cut mines.

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Abstract

The ¡VAMOS! Project (**V**iable **A**lternative **M**ine **O**perating **S**ystem) is developing a novel underwater excavation system to test the technological and economic viability of the mining of inland mineral deposits in flooded open-cut mines, currently uneconomic using conventional methods. A floating launch and recovery vessel has been built, and in July 2017, work will be completed on a remotely-operated underwater roadheader and robotic assistance vehicle. After completion, the first of two European trials will commence. During these trials, the road-transportable system will be tested on a range of rock-types and its technological and economic viability and socio-environmental impact will be analysed.

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Keywords: Horizon 2020; Flooded Mines; Minerals; Mines; Mining; Raw Materials; Robotics; Subsea; Technology; VAMOS.

1. Introduction

¡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 Union's 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.

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.

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- *Quick implementation:* Its self-contained power generation system and road-transportable modules mean that ¡VAMOS! can be used in abandoned 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 abandoned 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 is set to be 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.

2. Background

2.1. Horizon 2020 (H2020) Application

The original 18-member ¡VAMOS! Consortium applied for a Horizon 2020 Research and Innovation Grant to address 2014-2015 H2020 Work Programme no. 12, entitled 'Climate action, environment, resource efficiency and raw materials.' Under Work Programme 12, the consortium was granted 9.2 Million Euros in European funding to address Societal Challenge 5-11a (SC5-11a-2014), 'Mining of small and complex deposits and alternative mining', a sub-category of Societal Challenge 5-11 'New solutions for sustainable production of raw materials' [1].

2.2. Motivation

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 [2]. It is estimated that the value of unexploited EU mineral resources at 500-1,000 metres depth approximates to 100 Billion Euros [3]. 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 [4]. In response to more technically challenging EU deposits being abandoned and EU mineral needs being met by imports, H2020 funds were awarded to ¡VAMOS! to develop a novel inland mining solution that could more cost-effectively exploit EU resources, thereby increasing their attractiveness and ultimately reducing EU dependence on minerals and metals imports.

3. System configuration

3.1. The mining process

The ¡VAMOS! approach centres on the remote-operation of an underwater roadheader which has been adapted from existing subsea mining technology. As this mining vehicle cuts the underwater mine face, it creates small rock fragments which can be easily transported. At the front of the mining vehicle, underneath the boom, a rotating auger feeds the mined slurry material into a dredge intake. A sieve over the dredge intake limits rock particle sizes to 50 mm. Next, a built-in dual-stage pump draws the crushed mixture through a custom-built onboard pipe network and into a flexible riser. The slurry is then transported upward to an anchored launch and recovery vessel (LARV), which also acts as a moveable floating deployment platform for the mining vehicle. From the LARV, the slurry is pumped through a floating hose to an onshore dual-stage dewatering pit. The dewatering process filters sediment from the slurry and then returns the excess water to the open-cut mine.

3.2. Underwater positioning, navigation and power

This underwater mining vehicle operates in tandem with a custom-made hybrid remotely operated vehicle (HROV) which provides underwater sensory assistance. Illuminated by onboard lights on the mining vehicle and HROV, real-time digital images taken by both vehicles can be relayed to an onshore control cabin. A digital visualisation of each flooded mine environment can be created from bathymetric geophysical data and then processed using proprietary algorithms. The resulting digital visualisation can then be updated using real-time structured-light data gathered by the HROV's structured-light sensor array. The entire system including the HROV, mining vehicle and control cabin is powered and charged by the electrical output from a diesel generator.

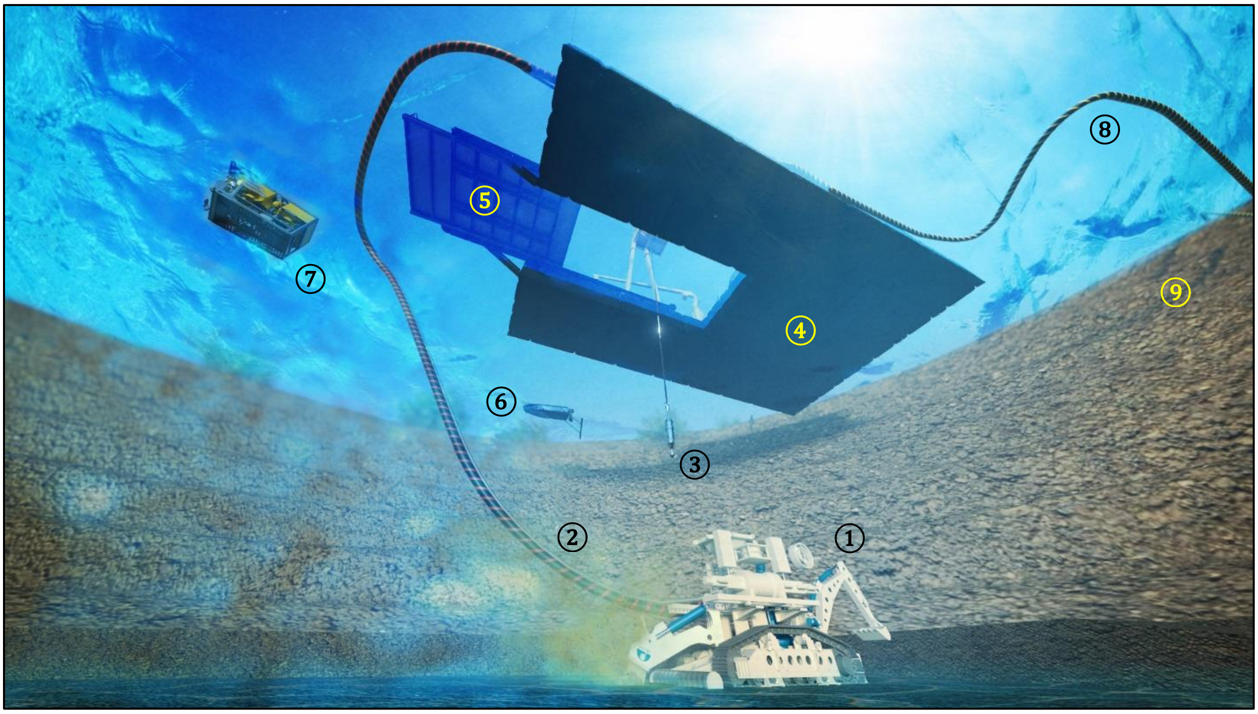

Figure 1. A render of ¡VAMOS! operating in a flooded open-cut mine.

1 – Mining vehicle; 2 – Riser and umbilical; 3 – Bullet-style lifting attachment; 4 – Launch and recovery vessel; 5 – Retractable deployment platform; 6 – Tender vessel; 7 – Remotely operated vehicle; 8 – Floating pipe, leading to dewatering pit; 9 – Pre-existing sidewall benches.

3.3. Production monitoring

On the LARV, a slurry bypass system has been designed that connects to a production measurement unit (PMU) and a laser-induced breakdown spectroscopy (LIBS) system. The PMU can measure the density and flow rate of the slurry, and the innovative LIBS system will test the technological feasibility of real-time ore grade control.

4. Current progress

Since the launch of the project in February 2015, the consortium has finalised design specifications on all components of the system architecture. Preparatory work has been carried out to assess the regulatory compliance of the project, its likely social and environmental impact, and the steps which need to be taken to reduce and quantify these during testing. During the research period, the consortium found that there is a gap in regulatory coverage of underwater inland mining activities and that the likely social and environmental impact of ¡VAMOS! would be less significant than mine excavation by conventional methods [5]. Two community stakeholder workshops took place in England and Portugal which suggest that the public is receptive to the ¡VAMOS! concept [6]. By July 2017, the build phase of all remaining hardware will be completed and the prototype will be ready for its first test later in the year.

5. Field trials

An extensive testing schedule is planned for autumn 2017 and summer 2018 in which ¡VAMOS! will be tested at a granite-kaolin quarry in England and at an iron mine in Bosnia-Herzegovina. 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.

5.1. Site selection

The confirmed test sites were selected from numerous mines from Europe, mostly in England, Portugal and Bosnia-Herzegovina. In a field test suitability assessment, the consortium ranked eight mines based on the four characteristics 'Site access', 'Environmental restrictions', 'Miscellaneous' and 'Scientific value.' Of the eight mines, two test sites proved to offer a suitably extensive variety of pit conditions and rock types for the pilot tests. The first test site is in England, and contains mechanically weak kaolin interspersed with competent granite pillars; the second site is in Bosnia-Herzegovina and is composed of a tilted succession of highly metamorphosed carbonates and metapelites, with interspersed siderite- and haematite-rich metasomatic veins.

Table 1. ¡VAMOS! European field trial information.

Trial location	Trial date	Duration	Work days	Mine type
England	2017	21 days	18	Kaolin; Granite
Bosnia-Herzegovina	2018	21 days	18	Metamorphic Limestone; Metamorphic Clastics; Fe-rich mineralisations

5.2. Post-trial analysis

After the first trial is complete, data gathered during the three-week test phase will be used to conduct a shortened Environmental Impact Assessment. Project Partners will study water chemistry, ecotoxicology and open-pit water levels to understand the effect of ¡VAMOS! on the water within the pit, using this as a proxy for changes in adjacent aquifers which might be undetectable during the project period. The results from this analysis will help us to understand the environmental implications of the ¡VAMOS! technique. In concurrence with the environmental data analysis, predefined proprietary microeconomic models will be used to calculate OPEX costs based on the productivity and equipment-wear data from the test. With this analysis, the consortium hopes to prove a cost-effective excavation solution for open-cut mines that are approaching their economic limit, those which have been abandoned and are currently too expensive to be reopened, and prospective mines in areas with high groundwater levels. Environmental and productivity data from the second site test will supplement the data from the first trial. Final environmental and economic analyses will coincide with a future research roadmap and policy recommendations report which will be completed by the end-date of the project in August 2018.

6. Summary

¡VAMOS! (Viable Alternative Mine Operating System) is a part-funded EU project which is developing a novel underwater mining excavation system for use in flooded inland open-cut mines. The project is part of a broader European Commission initiative to create a more 'sustainable production of raw materials' [1] and reduce the EU's dependence on imports of strategically important raw materials. In autumn 2017, the multi-component mining robotics system will be tested at the first of two sites, a granite-kaolin quarry in England, and in 2018 it will be tested later at an iron mine in Bosnia-Herzegovina. In August 2018, after a successful testing phase and upon reporting a positive socio-environmental and microeconomic analysis, the ¡VAMOS! Consortium hopes to prove the technological and economic viability of the underwater extraction of minerals in flooded inland open-cut mines.

7. Future research planning

As part of our efforts to engender effective research by enabling the European Commission to create an impactful scientific funding strategy, we invite the research community to complete a 5-minute survey on the project. In this document, you will also be able to apply to receive important project updates and to register your interest for an open-day in 2018. Find the survey online here: https://goo.gl/forms/fBUqvNZjx35Jf06k2. Keep informed on project developments by joining the ¡VAMOS! Sustainable Mining Forum at https://www.linkedin.com/groups/8272350, and by visiting the project website at www.vamos-project.eu.

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