BioMinE

Project	NMP2-CT-2005-500329
Acronym	BioMinE
Project Title	Biotechnology for Metal bearing materials in Europe
Instrument	Integrated Project
Thematic Priority	Priority 3 – NMP Nanotechnologies and nanosciences, knowledge-based multifunctional materials, and new production processes and devices

Publishable Activity Report

Period M_0 – M_{48} / November 04 - October 08

Due date of report:	**November 01, 2004**
Actual submission date:	**October 29, 2008**
Start date of project:	**1 November, 2004**
Duration:	**48 months**
Lead contractor for this Report:	**BRGM**
Version:	**N°1**
Revised version submission date:	

BioMinE
Publishable Activity Report

November 04 / Octobre 08 **Period $M_0 – M_{48}$**

INDEX

N°	**Participant Name and Short Name**	
1	Bureau de Recherches Géologiques et Minières	BRGM
3	Tampere University of Technology	TUT
4	Technische Universitaet Berlin	Tu Berlin
5	Universitaet Duisburg	UDE
6	Institute of Geology and Mineral Exploration	IGME
7	National Technical University of Athens	NTUA
8	Bioclear b.v.	Bioclear
9	Paques B.V.	Paques
10	Wageningen University	WU
11	Instityt Metali Niezelaznych	IMN
12	Instituto National De Engeharia	INETI
14	De Beers Consolidated	DBCM
15	MINTEK	MINTEK
16	University of Cape Town	UCT
17	University of Stellenbosch	Stellenbosch
18	Universidad Autonoma de Madrid	UAM
19	Luleå Univiversity of Technology	Ltu
20	MEAB Metallextraktion AB	MEAB

21	Umeå University	Umeå
22	CellFacts Instruments Ltd	CIL
24	Imperial College of Science and Technology	Imperial
25	Rio Tinto	Rio Tinto
26	University of Wales, Bangor	UWB
27	University of Warwick	Warwick
28	Tecnicas Reunidas	TR
29	Outokumpu	ORC
30	Umicore	Umicore
31	Skeria Untvecklung, Skellefteå	Skeria
32	CNRS	CNRS
33	Stuttgart Univ	USTUTT
34	PE Europe	PE Europe
35	Institute for nonferrous and rare metals	IMNR
36	Milton Roy Mixing	MRM
37	Boliden	Boliden
38	Copper Institute Bor	CIB
39	KGHM	KGHM
40	University of Seville	US

Table of contents

General scope of the project

BioMinE is aimed at "the production of tomorrow" and encompasses biotechnological research to provide "radical changes in the Basic Materials industry for cleaner, safer and more eco-efficient production".

Biohydrometallurgy, as explored in BioMinE, is a recent technical area that is based on specific interactions between microorganisms and minerals to extract metals from raw materials. The field of the applications of biohydrometallurgy that want to tackle low-grade complex resources is quite pertinent within the European geological context.

The challenges of the BioMinE Integrated Project are to go beyond the limits of our fundamental understanding of bio-hydrometallurgy and to develop, improve, and / or better integrate biotechnological processes for recovery of metals from primary and secondary metal bearing materials. The technological breakthroughs resulting from BioMinE must allow the integration of innovative biotechnology-based processes for recovery and/or removal of metals from primary materials such as ores and concentrates, secondary materials such as mining wastes, metallurgical slags, and combustion/power plant ashes. The developed processes give consideration for eco-design and a reduced impact on environment.

The investigated biotechnologies, which cover almost all the aspects of the application of biohydrometallurgy, have included bioleaching, biooxidation, biosorption, bioreduction, bioaccumulation, bioprecipitation, bioflotation, bioflocculation, and biosensors. The main ultimate objective has been to determine the specifications of environmentally friendly biotechnologies that are economically attractive particularly at a small scale, especially suitable for the European situation. They will in some circumstances provide an alternative to current technologies such as roasting and smelting for difficult-to-treat resources and often in a complementary way of processing materials to extend the feed of metal sources for Europe.

The breakthroughs under the RTD programme have been commercially evaluated by integrated piloting of the new, or improved, processes together with preliminary economic assessments of European resources. This will provide a sound basis for decisions by industrial companies on whether to then proceed to commercial demonstration. The competition of biohydrometallurgical treatments with conventional processes can only be successful if this would eventually lead to substantial improvements for metal production by increased recovery, reduced costs, reduced energy demands, increased revenue, access to new resources, better compliance with the environmental regulations and/or better acceptance from the public of the mining activities in Europe.

The Consortium of partners of BioMinE

BioMinE has been based on a multi-disciplinary approach involving universities and research organisations, mining companies, waste treatment facilitators and equipment and instrument suppliers. From geology and microbiology to industrial process sustainability assessment, the expertise of the consortium of partners encompasses all the special fields required for an investigation of biohydrometallurgy in horizontal and vertical directions. The vertical direction means that BioMinE has aimed at the emergence of technological breakthroughs for an improved exploitation of the European mineral resources. And the horizontal direction wants to stress that the project has significantly contributed to the progress of fundamental knowledge in microbiology reinforcing the confidence in the basics of biohydrometallurgy.

Figure 1: A multidisciplinary partnership composes BioMinE Consortium.

Organization and work programme

Seven workpackages cover the technical rationale and the management of the project.

The figure 2 below illustrates the workflow between the technical workpackages from the screening of European geological resources to the exploitation of the outputs of the project.

It can be noticed that a side organization of the partnership in clusters managed in WP5 has aimed at focussing the efforts of the Consortium on the technical results with the highest potential of exploitation after the project.

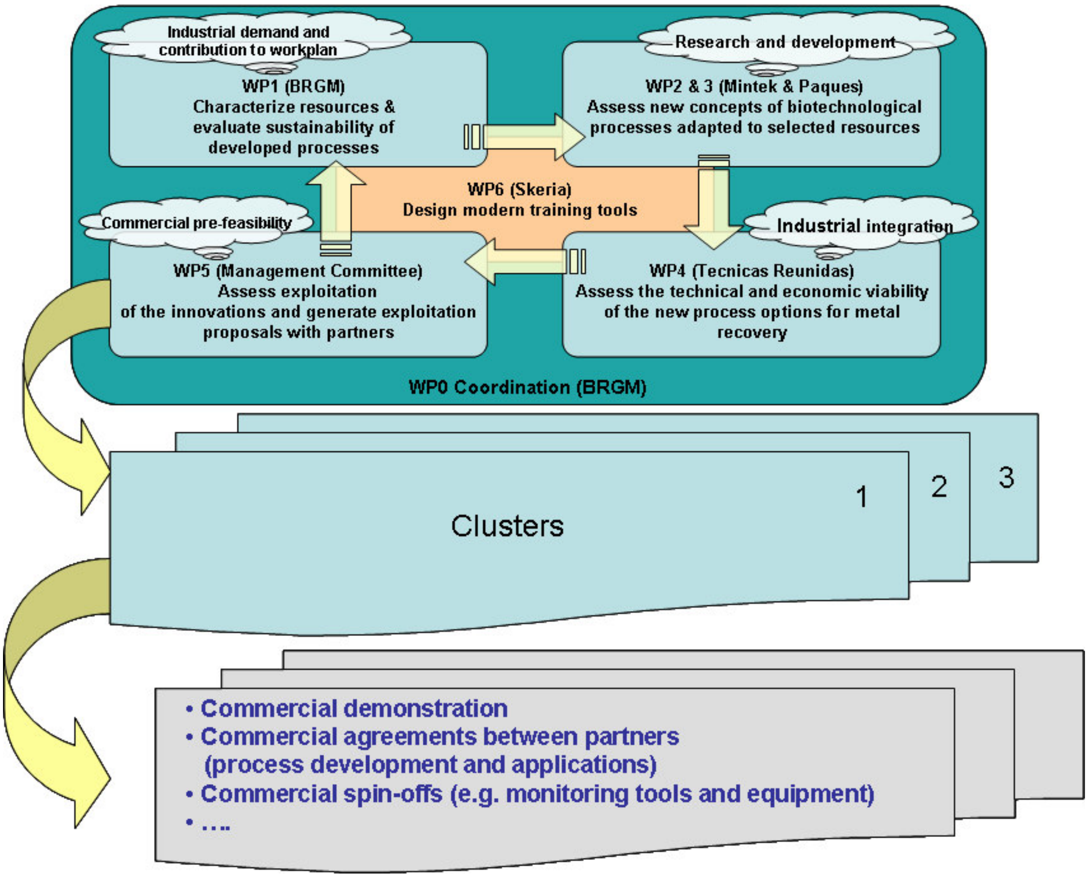


Figure 2: Schematic view of the structure and workflow of BioMinE project

In particular, the thinking about the selection of targets of the applied research and the work plan to conduct the work up to demonstration scale in the frame of WP5, fostered the process of establishing the match between developed technology and potential application sites thus giving rise to “Exploitable Technologies” and “Benchmark Resources”.

Exploitable Technologies

Exploitable Technologies encompassed:

- Integrated Processes, ie novel biotechnology-based technologies incorporated into conventional technology to constitute an integrated process package that can be applied to identified EU resources in an economically-, environmentally- and technically feasible manner.
- Specific items of equipment and devices with a commercial potential in the field of minerals bio-processing.
- Methodologies and procedures that can be furnished as a commercial service in the field of minerals bio-processing

Scientific results that, while not necessarily having direct commercial application in the short-term, enhance understanding in the field and provide a basis for further research aimed at improving mineral bio-processing technology.

As such, exploitable results can range from tangible processes and devices to intangible knowledge. Ultimately, the intent was to translate as much as possible of the scientific learning into tangible innovation, ie improved technology applied on an industrial scale. Minerals biotechnology is, however, an immensely complicated field and final innovation depends on solid fundamental research – an important component of BioMinE. The long term value of the pure research outputs should thus not be underestimated.

Benchmark Resources

After extensive consideration of the economic importance, the resource prevalence and biotechnology opportunities, the following target opportunities for application of the technologies were selected:

- Copper and copper polymetallics (which covers everything from a predominantly copper to a predominantly nickel resource)
- Zinc and zinc polymetallics (which covers everything from a predominantly zinc to a predominantly lead resource)
- Metal recovery from solutions (both primary and secondary) by bio-absorption, flocculation and precipitation

In each of these areas, a specific commercial operation was selected to be used as a real site for demonstrating the technology and evaluating both the technical and economic viability. These sites were termed “Benchmark Resources”. For commercial reasons these specific sites cannot be identified.

Evaluation and demonstration of the technologies

After further analysis, five technologies were evaluated with materials originating from five specific sites. These sites represented not only potential commercial applications, but also served as reference applications for broader marketing efforts.
These efforts will be conducted outside the auspices of BioMinE by the participants that own each of the developed technologies.

Integrated Process	Pilot Plant leader	Pilot Plant location
Direct bioleaching of nickel/ copper concentrates	Mintek	Mintek, South Africa
Direct bioleaching of copper concentrates	Mintek	Mintek, South Africa
Indirect bioleaching of zinc/lead concentrates	Tecnicas Reunidas	Technicas Reunidas, Spain
Low Cost Bio Reactor (LCBR)	BRGM	BRGM, France
Bio-precipitation of metals from effluent streams	Paques	Umicore, Netherlands

The results of the pilot plant campaigns were used as a basis for detailed process design, capital and operating cost estimation and techno-economic evaluation.

Mineral resources and sustainability assessments (WP1)

The main objectives of the European resources assessment can be summarized as follows:

- To identify primary and secondary sources in Europe for metal extraction by integrated biotechnologies and provide subjects and appropriate samples for testing bio-hydrometallurgical metal recovery process during the research phases of the project.
- To apply Life Cycle Sustainability (LCS) methodology to assess the potential impacts on human welfare and on the environment of biotechnological versus conventional metal recovery in Europe
- To put forward "benchmark resources" based on the detailed socio-economic and environmental LCS evaluation with best practices for optimised recovery and minimisation of future wastes

Resource identification and macro-economic analysis

The work started with the preparation of a first inventory of metal bearing resources (primary resources and secondary resources) and a presentation of the geographic distribution of these metal bearing resources. A database comprising an exhaustive list of European mineral deposits (based on in-house capitalization in conjunction with the ESF GEODE programme) had been largely extended and updated by BRGM and now lists over 9,000 deposits and occurrences of all commodities (metallic and non-metallic) across Europe. Information extracted from databases on European mining wastes as possible secondary resources complete the overview of the European landscape.

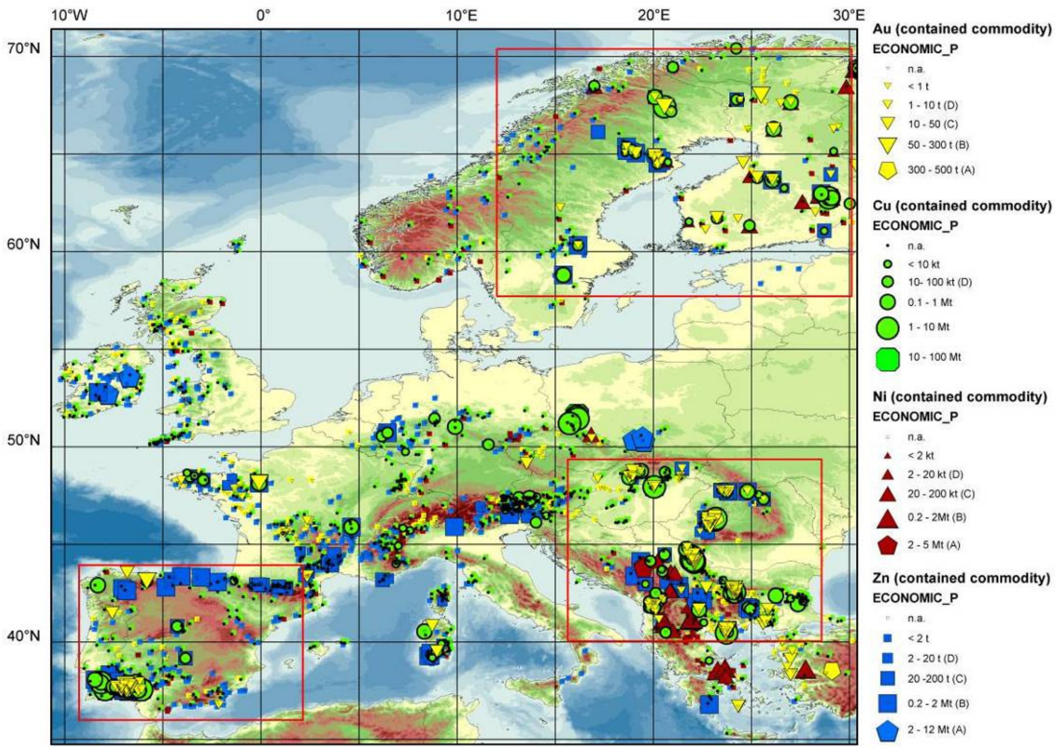


Figure 3: Past and present mineral deposits and occurrences in Europe compiled to serve BioMinE resource identification. Three areas selected for further focus (Iberia, Scandinavia, Balkans) are indicated.

A resource selection and prioritisation by economic filtering and by general assessment of the potential technical, environmental and socio-economic effects and benefits was then carried out. It was followed by an additional characterisation of metal bearing resources made accessible by industrial BioMinE partners or associated organisations, focusing on both a mineralogical characterisation and an infrastructure characterisation.

The target resource types identified under WP1 can be metallurgically classified as follows:

- Primary Materials:
    - Polymetallic sulphide ores and concentrates in which the metal values are combinations of Cu, Ni, Zn, Pb, Ag and Au;
    - Refractory gold ores and concentrates in which the gold is locked in sulphide minerals - usually pyrite and/or arsenopyrite;
    - Lead sulphide concentrates (contain significant Au and Ag);
    - Low-grade copper sulphide ores and concentrates (some high-Ag);
    - Low-grade zinc sulphide ores and concentrates.
- Secondary Materials:
    - Flotation tailings (Cu, Ni, Zn);
    - Refinery slimes and slags (Pb, Zn, Cu);
    - Ashes and dusts, which will be co-processed in other bioleaching processes or require pre-treatments (bio-processing) prior to bioleaching.

This approach led to the definition of primary and secondary resources that could be tested for metal extraction through biotechnologies within the frame of the subsequent project workpackages.

In parallel, a market macroeconomic study of several metals (copper, zinc, gold, silver, nickel) was conducted, to draw up the macro-economic environment and global market sentiment in which the biohydrometallurgical technological development is positioned. Indeed, BioMinE aims at evaluating the applicability of biotechnologies in the exploitation of European mineral resources. Indeed, Europe continues to grow and to consume more and more minerals: recycling has allowed a significant internal secondary supply of metal but it is unfortunately limited whereas external primary resources have been preferred to internal ones for long. Reasons are geological for a part but also social and environmental for another.

The aim of BioMinE is to reconsider the exploitability of European resources taking into account progresses of biotechnologies that could provide for an environmental-friendly means of treating resources and an innovative way to recover metal in Europe.

The scope and the stakes of such a question have to be outlined. Indeed resources are being more and more costly and it is time to look for ways to better play on the international market. The macroeconomic study describes international demand and supply before giving elements on the European case and concluding on major facts to consider. It clearly shows the price soar and the global demand increase with possible shortage in mineral supply on the short term.

The figures 4 & 5 hereafter illustrate the market analysis on zinc. The same approach has been conducted for copper, gold, silver, lead and nickel.

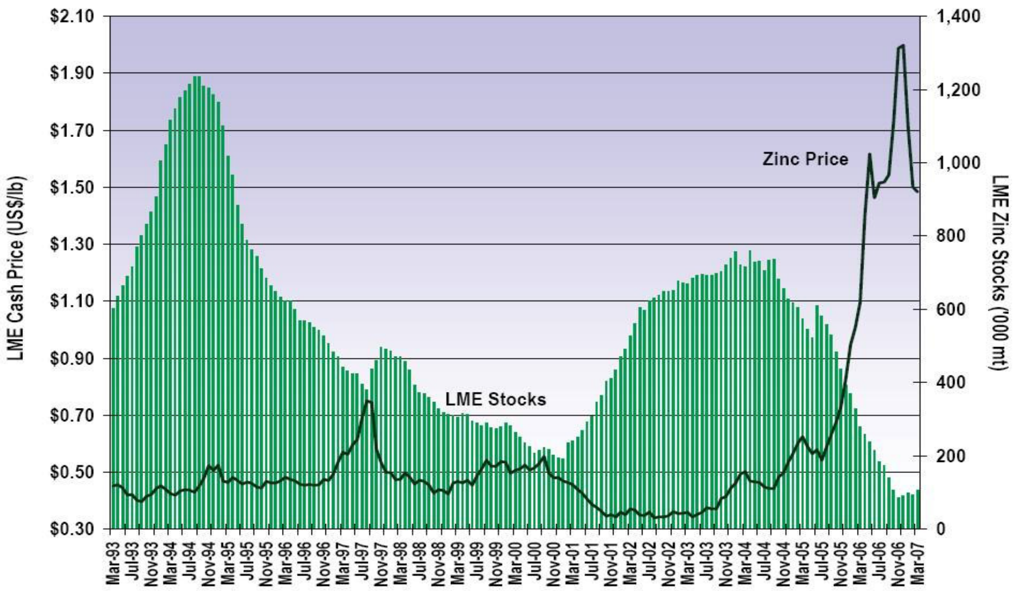


Figure 4: Average Monthly LME Zinc Prices and Stocks, March 1993-March 2007.

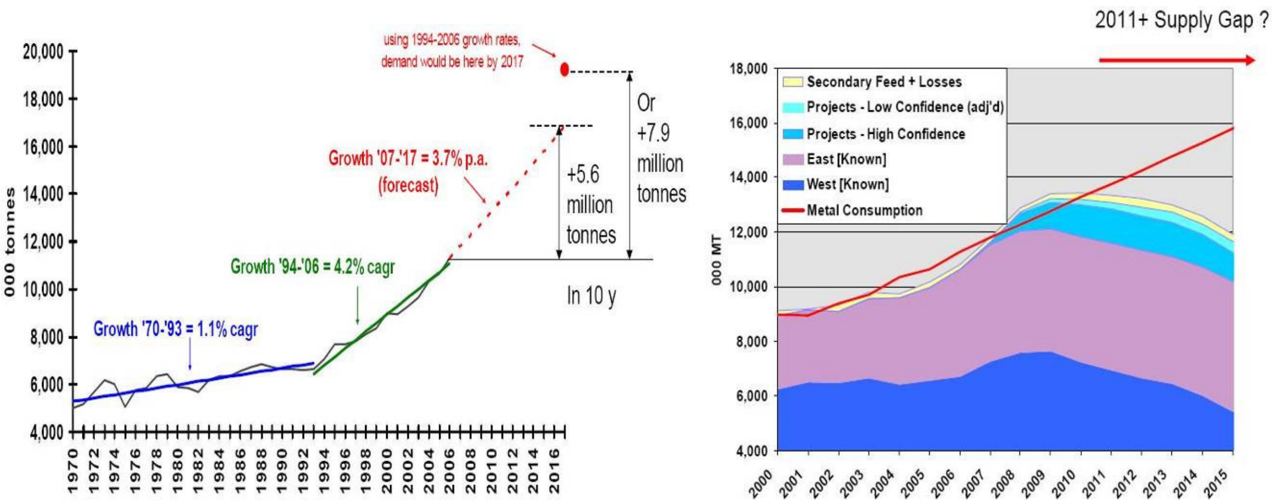


Figure 5: Zn reserves versus demand growth.

Biohydrometallurgy sustainability assessment

A procedure for the general sustainability evaluation within BioMinE has been developed. The boundary conditions, model setup, data sources and general difficulties were discussed with the experts in the field of metal extraction during the first period of the project and the base for the subsequent Life Cycle Sustainability (LCS) modelling of the biotechnologies was laid. The conventional technologies have been assessed in order to estimate the potential improvements in terms of reduced environmental impacts when the newly developed technologies are employed. A main problem persists in obtaining Life Cycle Inventory data of processes which are to be developed/under development.

In summary, the work carried out under LCS approaches the following objectives:

- Definition of the general sustainability evaluation approach in view of goal and scope of the BioMinE project (methodological approach, inclusion of sustainability dimensions, and way of addressing results).
- Highlighting potential of BioMinE project with respect to sustainability performance
- Focus on conventional technologies (pyrometallurgical processes) as starting point for assessment of biotechnological metal recovery,
- Identification of key parameters in view of the sustainability assessment of biotechnologies,
- Conduction of a first environmental assessment of biotechnology processes, and
- Development of a qualitative evaluation matrix (characterisation).
- Specification of data need (quantitative and qualitative), start of data collection and compilation.

The methodology is schematically illustrated in the figure 6.

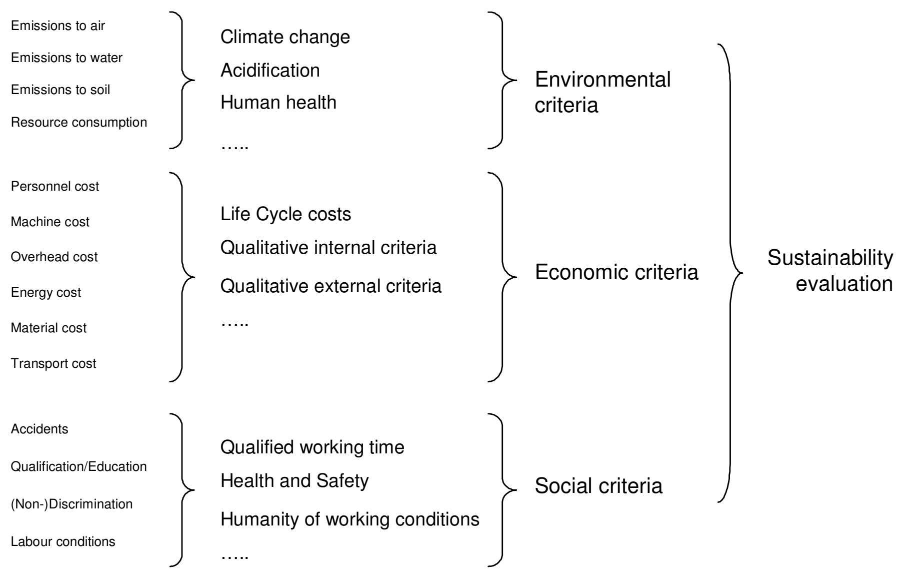


Figure 6: Sustainability assessment aspects and methodology rationale.

The LCS has been conducted for both the Aquablanca (Spain) and Bor (Serbia) concentrates. The work performed by USTUTT and PE consisted in modelling the different conventional and bioleaching routes under consideration, applying the LCA expert tool software GaBi 4, including several scenarios and sensitivity analysis.

Regarded as a whole, the bioleaching route performs better in most selected result parameters than the conventional route. In particular, the acidification potential which is mainly influenced by SO_2 emissions is significantly lower for the bioleaching route.

The report of the work on the LCS however stresses the fact that the conventional route relies on consistent data since the technology has been applied for many years and on large scale. On the contrary, in the case of biotechnologies, data are much less reliable as they have been used at industrial scale on a limited number of sites and for a short period of time only.

Mining activities and regional development

A case-study report comparing mining activities in the context of regional development (Iberia vs Balkans vs Scandinavia, as shown on previous map) was elaborated. It was aimed at drawing up the different socio-economic climate and sentiments towards mining and metal winning across Europe.

It was initiated by sending a lay-out of appropriate items to be filled in by the relevant partners that included:

- Brief history of precious & base metal mining in the region,
- running mining operations and future perspectives,
- Limits and opportunities of the mining law vis-à-vis European legislation,
- Perception / opposition of government to the mineral industry over the last 10 years,
- Perception / opposition of regional community to the mineral industry (in this particular region) over the last 10 years,
- Regional employment (mineral industry compared to other professional activities),
- Other regional attractions and land-surface occupation activities competing with mining and mineral processing,
- Opportunities for mining and mineral processing (primary AND secondary resources) in the region,
- Potential effects of introducing bio-hydrometallurgy in the region, remaining problems and anticipated solutions.

Although information provided by the partners was not always comprehensive, it appeared that situations largely vary according to local regional contexts:

The mining sector is important for the economy in Sweden, especially for the northern regions of Sweden and discovery of new resources is very favourable to introducing bio-hydrometallurgy.

For Spain, developing any industrial plant (biohydrometallurgy process applied on Aguablanca concentrate) is regarded as an opportunity to decrease unemployment rate in the area of Ossa Morena Region.

Mining and metallurgy are essential for the economical development of Serbia and bio-hydrometallurgy is considered as a way to modernise old, poorly efficient metal recovery facilities while developing new skills and employment.

Greece, on its side, has to face local communities and authorities to develop the mining activities in the Kassandra mines in Chalkidiki, northern Greece.

The conclusions of the regional comparison are presented in the deliverable D1.6.

Management of wastewater and tailings in processes relevant to BioMinE

A review of the state-of-the-art of management of wastewater and tailings in processes relevant to BioMinE has been carried out (deliverable D1.8). With regard to objectives, it is clear that mineral dumps and dams remain the best available technology for managing mine and process waste. 'Waste' continues to be largely a 'pipe end' matter rather than an interdependent part of an overall combined process, or indeed of an overall life cycle, although there is increasing evidence of improved sustainability through different forms of containment and re-use.

The work confirms that mineral dumps and tailings dams continue to represent the best available waste management technology under regulation, when employed with optimum water recycle and void backfill. Additionally, combined uses of mineral wastes with wastes from other industries, yielding practical products, increasingly indicate the potential of integrated routes towards sustainability in mineral and metal production. In particular, tailings might be re-used with ash from power stations or incinerators for controlled low strength materials in the construction industry and with sewage products from the water

Bioleaching (WP2)

Status of the bioleaching technologies and directions taken by BioMinE

Bioleaching as the process of dissolving minerals by the action of biological phenomena is the main field of applications in biohydrometallurgy. The major part of the activity of RTD of BioMinE was about bioleaching.

Bioleaching is a process that employs the unique capabilities of a number of types of naturally occurring micro-organisms to transform minerals. This microbial process is often perceived in a negative light through its contribution to acidic water run-off and related pollution associated with old mining areas. However, scientific and engineering endeavours over a number of decades have been able to harness this process so that today it is an established technology in the mining industry that offers lower cost and lower environmental-impact extraction methods applicable to a number of major metal resources. Most recent examples include the commissioning by BHP Billiton of their USD 1,270 million copper bio-extraction (heap bioleaching) operation at the Escondida mine in Chile in 2006, and the commissioning by Talvivara Mining plc of the world's first nickel heap bioleaching operation in Finland in 2008. The Kasese bioleaching plant commissioned in Uganda in 2000 is a tank bioleaching processes that is successfully treating pyrite tailings produced from old mining operations to recover cobalt (figure 7). Also, to date, there are six bioleaching plants operating world-wide treating refractory sulphidic gold ores as well as a number of newer plants that will soon be reaching the commissioning stage.

Figure 7: Bioleaching plant at the Kasese mine, Uganda, for extraction of cobalt from pyrite tailings.

While there are a number of large mining operations in Europe, such as the KGHM Polska Miedź S.A. copper mining operation in Poland and the New Boliden copper and zinc operations in Sweden, most of the remaining mineral deposits tend to be small and in many cases are relatively low-grade and complex. Other realizable metal resources in Europe occur as historical mining or metallurgical industry wastes and in some cases these are accompanied by chronic environmental impact problems.

As already discussed, the benchmark metal resources chosen were based on industry interest and support, coupled to economic screening criteria indicating that bioleaching technology applications may provide cost, environmental and socio-economic advantages. The bioleaching technologies are categorized as follows:

The Conventional tank bioleaching process (as employed at the Kasese plant mentioned above) would generally be used to treat higher grade metal sulphide concentrates. In this process the bioleaching microbial culture is contacted with the sulphide concentrate in a single-step process comprising a train of leach reactors. Currently all commercial scale bioleaching processes have employed this technology.

The Indirect tank bioleaching process being further developed under BioMinE is intended to be a simpler and more versatile technology aimed more at lower grade metal sulphide resources. This is a two-step process in which the bio-oxidation step (iron oxidation) is separated from the sulphide leaching step. This technology is particularly suited for treatment of complex sulphide ores and concentrates which contain mineral components that could be inhibitory to the microbial culture.

Heap bioleaching processes are normally considered for low-grade resources, where for cost or technical reasons upgrading to produce a concentrate is not justified. As mentioned above, this is established technology for treating low-grade copper sulphide ores and more recently in Europe, low-grade nickel ores.

Microbiology and molecular biology

One of the important objectives of BioMinE has been to accelerate the application of modern biotechnology techniques, which have been successfully applied to other areas of industrial biotechnology such as pharmaceuticals and fine chemicals, to bioleaching processes. A key area here has been Bioprospecting research involving the application of established and new molecular methods to detect, characterise and isolate new microbial cultures from mining-related areas in Europe and to assess their potential to improve the efficiency of bioleaching processes (illustration figure 8). A register of bioleaching cultures, which is available to the participating partners in BioMinE, was a very important output from this research. Bioleaching cultures generally exist as mixtures (consortia) of different microbial types that oxidize iron and sulphur compounds and exhibit different tolerances to acidity and metal concentration. They also exhibit different optimum temperatures for growth ranging from as low as 4°C (psychrotolerant types) to 80 °C (thermophilic types). It is suggested, for example, that the psychrotolerant microbes may prove to be important for start-up of heap bioleaching processes under cold climatic conditions. Thermophilic bioleaching consortia have received particular attention in BioMinE since the ability to operate bioleaching processes at high temperatures is often required to successfully treat important but refractory copper sulphide minerals such as chalcopyrite.

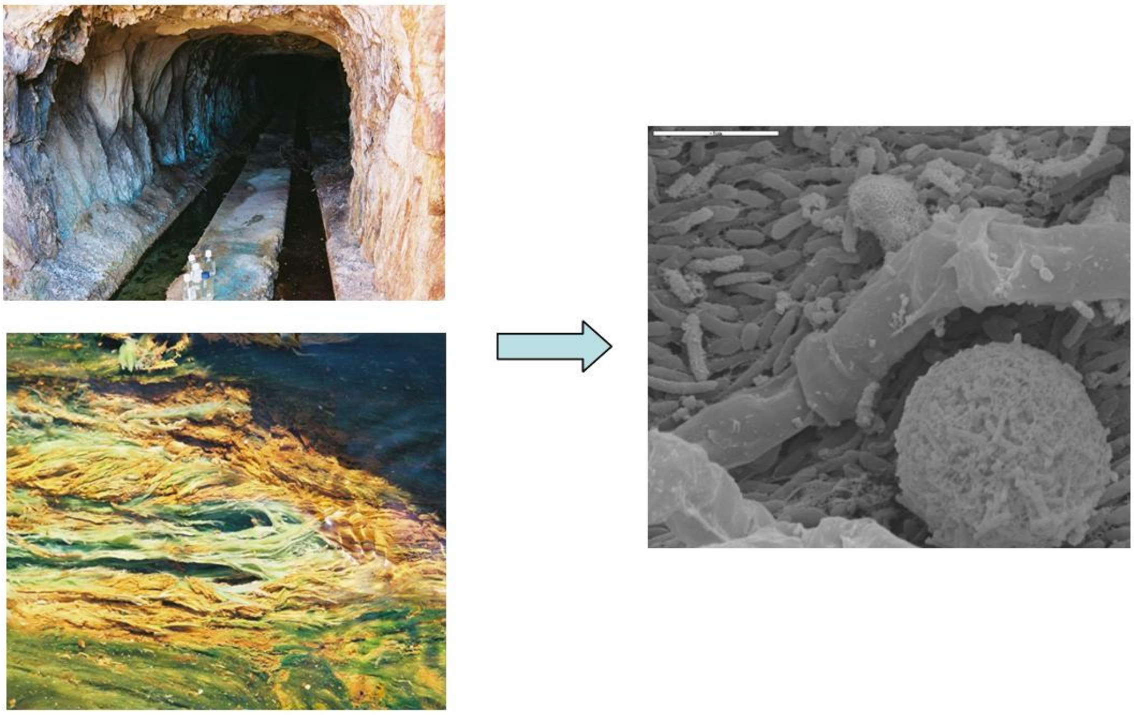


Figure 8: Tharsis copper mine Spain – bioprospecting reveals a highly complex community of microorganisms.

Major advances have also been made in extending the use of biomolecular tools, which provide the ability to more closely monitor the type, number and activity of microorganisms in the consortia being used in bioleaching systems. These monitoring tools depend on the ability to extract microbial DNA from highly contaminated mineral systems and to use to this to construct specific probes to identify the type and numbers of specific bioleaching microbes present. The progress made in understanding the mechanisms whereby microbial cells directly contact and attach to mineral surfaces may have considerable future potential for intensifying bioleaching systems. A number of new techniques were further developed to help facilitate this research as illustrated below in figure 9.

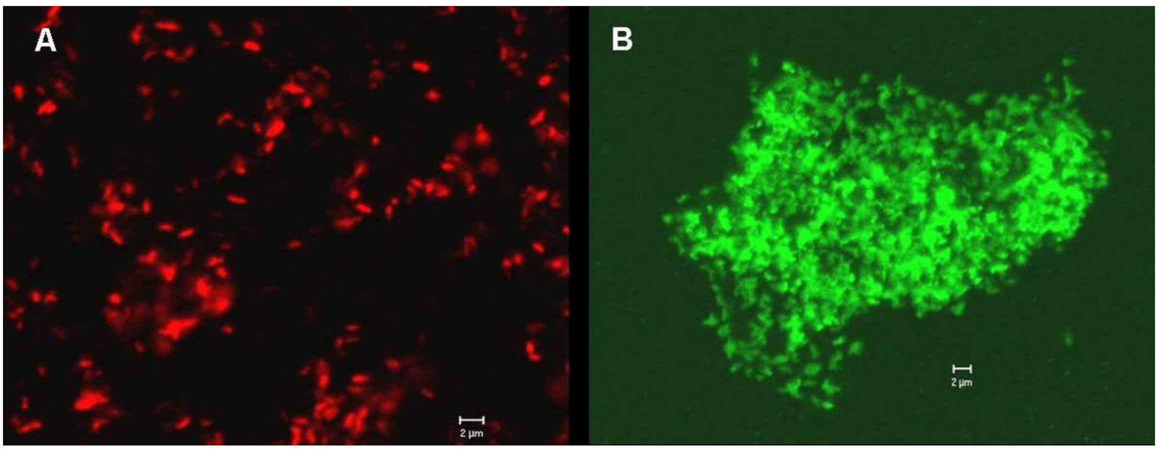


Figure 9: The use of new novel fluorescence in situ hybridization techniques to view bioleaching microbes attached to mineral surfaces.

A major success of the research completed under BioMinE project was to advance the development and application of modern biomolecular techniques to bioleaching processes. For example, there has been very little information available in the scientific literature on the composition of bioleaching microbial consortia in pilot- or commercial-scale tank bioleaching processes. Most of the bench-scale and pilot-scale bioleaching processes studied under BioMinE were fully characterized in terms of the bioleaching consortia present and this will provide a significantly improved basis for further process development and scale-up. Other important research results indicated that process improvements can be achieved by careful choice and optimization of the microbial consortium used for process start-up. Access to bioleaching samples from the Kasese commercial bioleaching plant mentioned above, and a comparison of the plant consortia with newly constructed laboratory consortia, provided valuable insights in this respect. Another objective was to better define the complex enzyme systems responsible for iron and sulphur oxidation in bioleaching microorganisms and how these might be regulated to improve the efficiency of bioleaching processes. This has encompassed research to better understand which genes are responsible for controlling these oxidative cellular functions and the conditions under which the expression of these genes are regulated. In many bioleaching processes the stability and efficiency of the process depends on microbial consortia being able to adapt to tolerate high concentrations of toxic metals such as arsenic and copper. Significant progress was made in the development of genetic systems for a range of the most important bioleaching microorganisms, one achievement being further elucidation of how arsenic resistance may be acquired in bioleaching consortia. This research has important spin-offs for bioleaching processes applied to sulphide gold-containing concentrates that usually contain high quantities of arsenic minerals. It should be stressed, however, that no attempt was made to genetically modify the bioleaching microorganisms since this is unnecessary and would be legislatively and socially unacceptable.

Bioleaching of the European copper ores

At the beginning of the BioMinE project a range of preliminary bioleaching studies were completed on a range of primary sulphide ores and sulphide ore concentrates. Eventually a number of benchmark resources were identified and the major focus of the research activities was then directed to these. Early on, one of the major challenges identified was the poor response to bioleaching of the copper mineral, chalcopyrite (figure 10). Chalcopyrite is present in many of the primary mineral resources studied under BioMinE. These include Aguablanca mine, Spain, the RTB-Bor copper mines, Serbia, the Boliden Aitik copper mine Sweden, and the Somincor mine, Portugal. The importance of chalcopyrite as a copper source can be appreciated from the fact that it is currently estimated that 80% of the world copper reserves now occur in low-grade chalcopyrite deposits.

Figure 10: Chalcopyrite ($CuFeS_2$) ore sample

A number of research approaches were taken to address bioleaching of chalcopyrite. It was shown that elemental sulphur and iron hydroxide layers form on the surface of chalcopyrite and this may be one of the contributory factors inhibiting the bioleaching reactions. This conclusion was supported by research which showed that biological oxidation or chemical treatment to remove the sulphur layers could restore bioleaching activity. Evidence was also provided that certain microbial types isolated during the bioprospecting research were more efficient for chalcopyrite bioleaching than other consortia. The use of thermophilic cultures operating at up to 70°C were shown to be the most successful for achieving the optimum bioleaching of chalcopyrite concentrates by conventional tank bioleaching. Further research showed that the process could be improved further through additional control of the bioleaching chemical environment, to the extent that leaching times could be approximately halved. These results represent a major achievement for BioMinE.

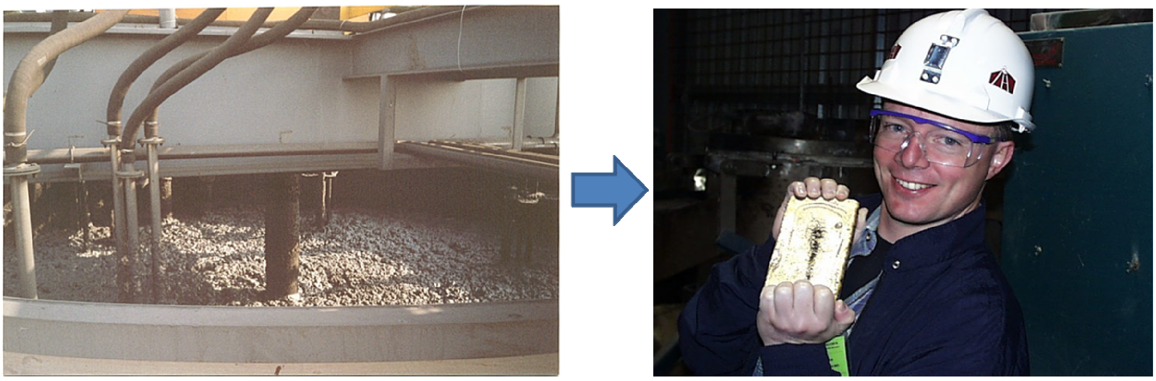
The advances in the bioleaching of chalcopyrite-containing concentrates were encompassed by the broad based research programmes applied to two of the benchmark resources studied under BioMinE. The nickel-copper concentrate from the Aguablanca mine, Spain, is a polymetallic concentrate containing copper as chalcopyrite and nickel as the mineral pentlandite. The challenge for this concentrate was to develop a bioleaching process that maximizes the extraction of both copper and nickel. This was achieved initially in research carried out in “bench-scale” bioleaching facilities (figure 11), which allowed continuous operation of the bioleaching process under conditions that closely simulate those encountered in real large-scale operations. These test results were then also used to define the operating conditions to be used in the integrated piloting using Aguablanca concentrate.

Figure 11: Bench-scale facilities used to optimize conventional tank bioleaching processes to treat Aguablanca nickel-copper concentrate and RTB-Bor copper concentrates.

Bench-scale bioleaching development work was also carried out on two low-grade copper concentrates obtained from the Majdanpek and the Veliki Krivelj mines in the Bor district, Serbia. Again, chalcopyrite is the main copper mineral in both concentrates. The concentrates are categorized as “low-grade” due to their high content of the iron sulphide mineral, pyrite. Pyrite is very difficult to separate from chalcopyrite when the ore is processed to produce a sulphide concentrate. For the RTB-Bor concentrates, two processing requirements needed to be achieved, namely, to minimize processing costs due to the low-grade and to minimize environmental impact from waste products produced. It was shown that both of these requirements could be met by careful control of the bioleaching conditions. The bioleaching process developed achieved selective and high-rate leaching of the copper present as chalcopyrite, leaving a final bioleach residue composed almost entirely of pyrite. This product could be handled or disposed of with minimal environmental impact, or, potentially it might be saleable for the manufacture of sulphuric acid. A key advantage of the process developed is that the bioleaching process costs are minimized since the pyrite sulphur was not oxidized. A further advantage realized was that a copper concentrate prepared from waste smelter slag at RTB-Bor site could be successfully bioleached by blending with the Majdanpek and Veliki Krivelj, thereby helping to increase copper production and also serving to alleviate environmental issues by removal of the smelter wastes.

New approaches of bioleaching

With respect to the use of cyanide, it is known that elevated cyanide consumption for gold recovery results from the reaction between cyanide and sulphur remaining in the bioleaching residues. For this reason a major research effort was focused on ways to reduce this sulphur level in the residues. In a first approach, it was demonstrated that the use of thermophilic bioleaching microbial consortia considerably reduces the amount of residual sulphur compared to that observed using the lower temperature (mesophilic) bioleaching, which is the process currently used in commercial operations. This showed that the thermophilic microbial consortia exhibit a higher affinity for sulphur and can reduce sulphur to very low levels in the residues. Another approach to this problem was to employ a post-bioleaching processing step to further reduce residual sulphur. It was shown that this could be successfully accomplished using either bio-oxidation or chemical extraction. Both of the above approaches were shown to decrease subsequent cyanide consumption up to ten-fold.



Conventional tank bioleaching

Final gold production

Figure 12: Tank bioleaching of refractory sulphide gold ores

In addition to copper and nickel, other base metal resources looked at were zinc and lead. A range of lead, zinc and polymetallic lead-zinc resources derived from deposits in Rumania, Portugal, Sweden and Ireland were subjected to bioleaching testing. Since the values of lead and zinc are significantly less than copper and nickel the specific focus of bioleaching research applied to these metals was on ways to minimize the processing costs. The major cost in conventional tank bioleaching processes is associated with the energy requirement to promote the transfer of oxygen from air injected into the bioleaching tanks. This oxygen is mostly used by the microbial consortium to oxidize sulphur to sulphate (sulphuric acid). As already noted, a broad scope of research under BioMinE was carried out to improve our understanding of how the sulphur and iron oxidation mechanisms in bioleaching microorganisms are regulated. In the longer term, it is anticipated that this research may allow the operation of conventional tank bioleaching processes, where the degree of sulphur oxidation can be controlled to achieve the best process economics.

One of the advantages of "indirect" bioleaching processes is that sulphur, rather than sulphate, is generally the final product when treating base metal sulphides. In indirect bioleaching processes the bio-oxidation step is used only to oxidize iron which generates an acid-ferric sulphate solution. This is the leaching "reagent" that is then used to separately leach the metal sulphides, with solubilised metals and sulphur being the products. A major research objective was therefore to develop a high-rate iron bio-oxidation process through the development of improved reactor types and iron oxidizing microbial consortia capable of high oxidative performance at high metal concentrations. This provided an important contribution to the integrated piloting programme carried out under BioMinE for treatment of zinc and lead sulphide concentrates employing indirect bioleaching technology (see figure 13).

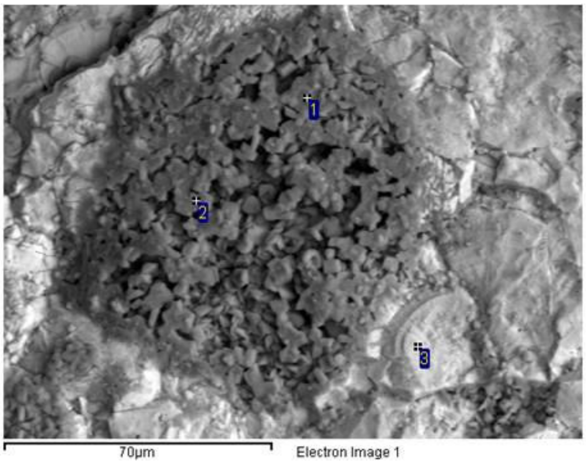
Figure 13: Indirect bioleaching process – bench-scale development of a high rate iron bio-oxidation reactor.

Conventional tank bioleaching of lead sulphide concentrates was also investigated as a possible technology to replace older smelter-based technology used in parts of Eastern Europe. The feasibility of using bioleaching technology was successfully demonstrated in bench-scale testing coupled to modern lead hydrometallurgical refining processes. Economic analyses indicated that this could be a viable treatment route for lead sulphide concentrates. Indirect bioleaching of lead sulphide concentrates was also successfully demonstrated and this was subject to larger scale integrated piloting as discussed further below.

Heap bioleaching has historically been applied for treatment of low-grade copper ores in major copper producing regions such as northern Chile and Australia, although, as already noted, the latest application is for nickel sulphide ores at the Talvivara mine in Finland. Research under BioMinE has focused on specific technical areas where improvements to heap bioleaching are needed and on assessing potential areas for application of this technology relevant to European mining.

Figure 14: Copper heap bioleaching operation showing mining pit and heap bioleaching pads.

As already discussed, the leaching of copper from chalcopyrite is normally slow, but with careful control of the leach conditions, as is possible in tank bioleaching processes, it has been shown that the rate of leaching can be accelerated to high levels. Heap bioleaching are open stacks of crushed ore and this is a far less controllable process. Consequently, the heap bioleaching of chalcopyrite-containing ores is a far more challenging technology to develop. A key issue addressed in support of this objective was improvements to the way heaps are engineered to ensure that rock distribution and the related issue of liquor percolation is improved. In other research, intensively monitored laboratory column (heap) bioleaching facilities were used to improve our understanding of the changes in a range of physical, chemical and microbiological conditions within the columns of ore as leaching progressed. A chalcopyrite ore from a mine in northern Sweden was used for this purpose. This showed, for example, that interfering layers of precipitation, surface changes and mineral interactions can have a major influence on the copper leaching rate. As illustrated in the scanning electron micrograph in figure 15, one example of this can be the formation of precipitated iron hydroxide layers on the chalcopyrite surface. It is anticipated that the results from these types of studies will eventually allow monitoring techniques and control philosophies to be developed so that heap bioleaching technology for low-grade chalcopyrite ores can be successfully implemented. Heap bioleaching of other low-grade resources such as old dumps of copper- or nickel-containing tailings were also considered, where economic screening showed that they contained sufficient metal value to justify processing. In the majority of cases this material is finely ground and heap leaching cannot be applied successfully due to the low permeability of leaching liquors through the finely ground solids . However, it was shown that this could be overcome by agglomerating the tailings to produce larger solids pellets, but generally the cost of cement or other reagents to achieve this is too high. Alternative lower cost agglomerating reagents will need to be found for this application to move forward.



s

Figure 15: Scanning electron micrograph showing interfering layers of iron hydroxide on the surface of bioleached chalcopyrite.

One other novel application of heap bioleaching that was successfully demonstrated at laboratory scale was for the accelerated weathering of diamond-hosting kimberlite ores. Exploration studies have identified possible economic deposits of these ores in north-eastern Finland. After accelerated weathering kimberlite ore is easier to process, but the major advantages anticipated from this novel processing method are a significant reduction in the amounts of water and electric power required.

Bioleaching of secondary resources of metals

A range of secondary waste resources from mining and other industrial sources were also considered. These included sulphidic mine wastes, smelter slags and other industrial waste solids that are commonly found across Europe. The primary objective of BioMinE was application of bioleaching for the economic recovery of metal resources. While this remained the objective when considering secondary waste resources, treatment of these materials may often also serve the purposes of environmental remediation.

Probably the major metal-containing waste resource occurring in Europe is tailings dumps produced from old or current ore-processing plants. An example of these types of resources considered under BioMinE is the gold-containing tailings dumps at the Stratoni and Olympias gold mines in northern Greece. It was the need to process low-value resources that motivated the research under BioMinE to investigate lower cost bioleaching processes such as heap bioleaching, indirect bioleaching and the low-duty bioreactor. As already noted, heap bioleaching will generally be uneconomic for treating tailings and other studies suggested that indirect bioleaching would also be uneconomic. The application of the low-duty bioreactor technology was the most promising technology to emerge from BioMinE for possible treatment of tailings. The piloting and cost studies associated with this technology are discussed further below.

Copper smelter slags are the waste solids produced from traditional smelting processes, which often still contain significant amounts of potentially recoverable copper sulphide. A range of different types of copper slags from Spanish smelters and from the RTB-Bor smelter in Serbia were tested for their amenability to both conventional tank and indirect bioleaching. Application of both bioleaching processes was successfully demonstrated. For the RTB-Bor copper slag, it was also shown that concentrate prepared from the slag could be successfully co-processed with the Veliki Krivelj copper sulphide concentrate using conventional tank bioleaching. Costs analyses for both tank and indirect bioleaching processes indicated that favourable process economics may be achievable.

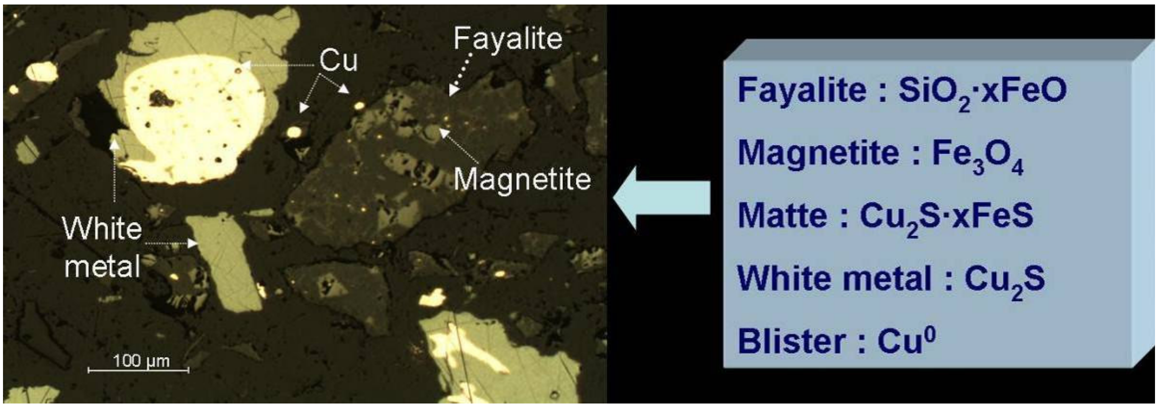


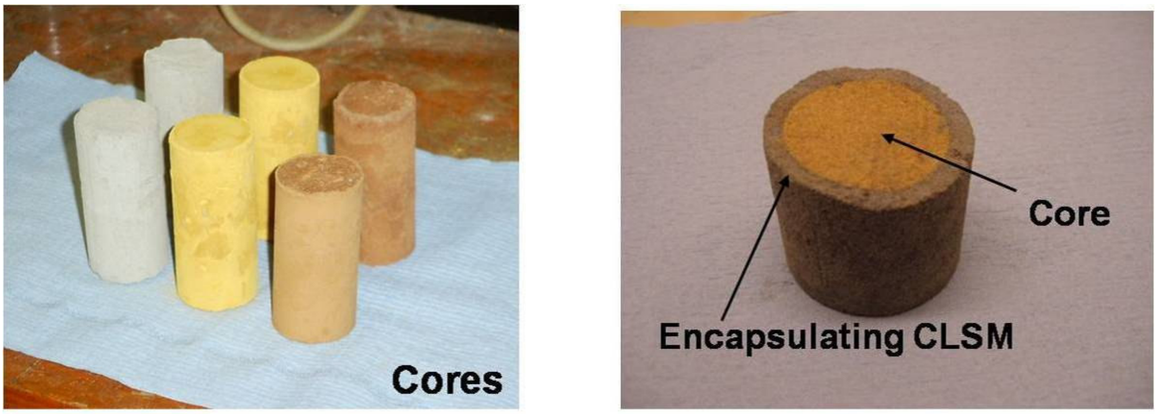
Figure 16: Mineralogical composition of copper converting slag produced at a Spanish smelter.

Another waste smelter product was lead slimes contained in old waste dumps near the Glogow and Legnica smelters, Poland. In this case the initial challenge was to use a bio-extractive or related processing step to remove high levels of hydrocarbon contaminants associated with this waste material. This was achieved successfully and subsequently pyrometallurgical or hydrometallurgical processing of the “upgraded” product resulted in significant improvements in the levels of lead that could be recovered.

Improvement of the sustainability in bioleaching

Conventional tank bioleaching is now the industry-preferred process for treatment of sulphidic gold ores in Australia, Africa and Asia. However, opportunities to apply this technology to gold deposits in Europe have been constrained partly by worries of environmental impact related to waste containment (such as arsenic-containing wastes) and the need to employ cyanide as the reagent for final gold extraction.

A number of research approaches were taken to address the issue of arsenic-and other contaminant-containing wastes from bioleaching. The first sought to identify sustainable industrial uses for these wastes. In support of this objective, research was carried out that was able to demonstrate that the use of modified “controlled low strength material” technology might be successfully employed to contain bioleach wastes so they could be considered for applications such as foundation building rather than disposal in mine waste dams. The principles of this technology are illustrated in the figure 17 below.



Before encapsulation **After encapsulation**

Figure 17: The use of controlled low strength material (CSLM) technology to contain bioleach waste solids allowing alternative sustainable industrial uses of the wastes to be considered.

It was also recognized that waste arsenic-containing bioleach residues could be further stabilized if the arsenic was present predominantly in the oxidized and less soluble arsenate state. Research was carried out using specific bacterial isolates and consortia that are able to promote this oxidation reaction. The results indicated that this process could provide an additional means for improved stability for these residues.

Another important objective of BioMinE was to identify possible ways of using bioleaching technologies to facilitate alternate and sustainable uses of industrial waste products. One category of wastes studied were alkaline (oxidic) wastes, which can include slags, dusts and ashes commonly generated by industries across Europe. For example, ashes include fly ashes derived from coal-tyres combustion and wood chips and municipal waste combustion operations. Samples of these types of wastes were derived from various sources in Sweden and tested with the objective of assessing whether these materials might replace high-cost lime or limestone for neutralization purposes in bioleaching processes. It was demonstrated that this substitution would not negatively impact technical performance and might indeed result in significant costs saving in bioleaching processes. There would also be positive financial and environmental spin-offs by finding sustainable industrial uses for these types of wastes.

Other applications of biotechnologies to the recovery of metals (WP3)

Additionally to the aforementioned aspects of bioleaching that is the most well-known application of biological treatment to minerals, other biotechnologies have been investigated in the frame of the workpackage 3 with the aim of improving the sustainability of the mineral industry.

Based on other specifities of the relationship between microbiology and minerals than in the case of bioleaching, the studies in this workpackage targeted an improved eco-efficient & economic production of metals through the various objectives that follows:

- Better efficiency of metal recovery both upstream & downstream of the (bio-)leaching operation,
- Better overall leach performance,
- Selective recovery from bleeds,
- Economic benefits by recovering more metal values,
- Reduction of wastes,
- Reduce toxicity of unavoidable wastes,
- Minimal potential future liabilities and
- Higher effluents standards requested both chemically & toxicologically.

Figure 18 graphically highlights the different tasks of WP3 in a schematic view of a general process flow diagram of the metal recovery industry including the interactions with the other workpackages. The following topics have been covered:

- Integrated innovative biohydrometallurgical process with minimal toxic effect on environment & society,
- Maximise resource recovery and at the same time minimise waste generation and
- Understand the fundamentals of new bio-based separation techniques

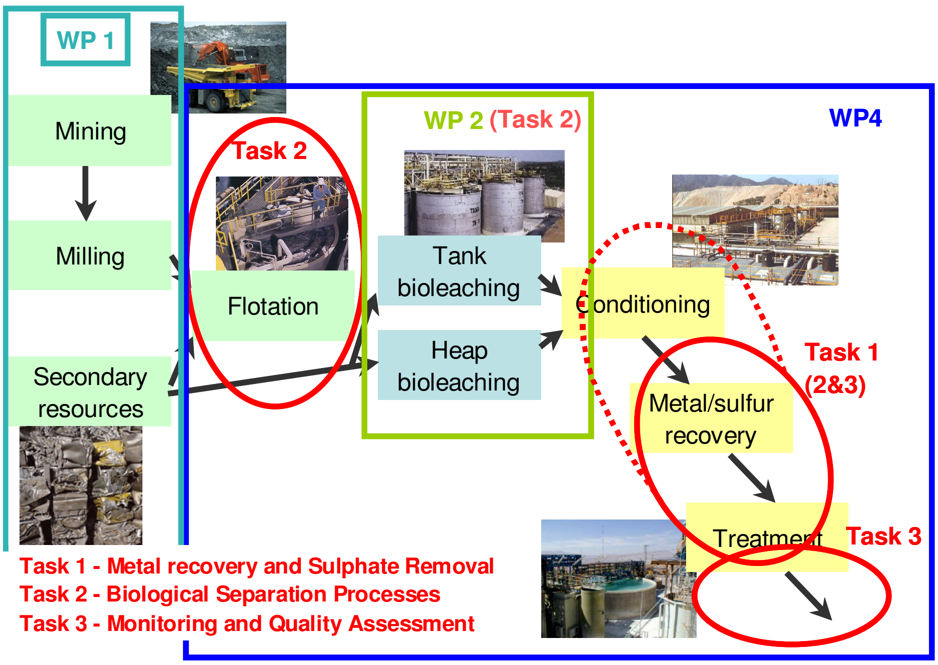


Figure 18: Schematic view of the main steps of a general process flowsheet in the metal recovery industry showing the interactions between the workpackages and the main tasks of WP3.

The topics and the results of the three tasks of WP3 have been summarised as follows.

Sulfate reduction and dissolved metal recovery

Biological sulfate reduction for the removal of sulfate from liquids and combined with the recovery of metals is attractive. Typical applications are the recovery of metals from wastes and tailings treatment, recovery of metals from naturally leached streams or the recovery of metals secondary metals from (bio)leach stream. 'Secondary metals' are for example nickel from a Cu/Ni concentrate or copper and zinc from a gold leaching operation.

The focus in the BioMinE project was on the one hand on finding and characterising bacteria than can conduct sulfate reduction under more extreme conditions, especially related to pH (acidic conditions) and temperature (low and higher than ambient conditions, on the other hand the recovery of metal sulfides was improved.

Good progress has been made during the course of the BioMinE project. New sulfate reducing bacteria were found that can operate at pH less than 3 and or a temperature higher than 65°C. Furthermore, it could be shown that sulfate reducing bacteria that have an optimum pH of about 7 could be applied as low as at pH 4. Although in the latter case, the growth rate would become very low. It could also be shown that sulfate reduction under acidic conditions can be used to selectively precipitate for example zinc from nickel. An interesting was also that arsenic could be removed in a column reactor at pH 3 (figure 17).

Figure 19: Bioprecipitation of arsenic sulfide in a laboratory column test.

Elemental metal separation & recovery

The blue-sky research in WP3 is the development of separation technology using the properties of bacteria and yeast cells to adhere to surface whereby the hydrophobic of the combined particle changes. The aim is to use this characteristic for the separation of sulfide minerals of base metals.

The research was strongly aimed at increasing the basic understanding of the interactions between microorganisms and particles. The focus of the three research groups that were involved was on different aspects related to the EPS (Extracellular Polymeric Substances) that microbial cells create to 'glue' themselves to the surface of minerals. The basic idea is that material recognises the mineral surface and understanding of these interactions holds the key to an effective separation.

Interesting results could be obtained. On the most practical level, yeast cells have been investigated as a scavenger for sulfide minerals. The loaded cells could be easily separated via floatation. These results were obtained under laboratory conditions but further research could lead to interesting applications. Furthermore, measurements have been done and models have been developed to determine the interaction between cells and minerals on a physicochemical level. It could be shown that this interaction is clearly different depending on cell and mineral properties and on water phase conditions. Finally, on a microbial level the characteristics of the EPS material have been investigated. This resulted in new insights in how cells bond to the mineral surface.

Water purification, recovery & reuse

The metal and mining industry is well known (and criticised) for its large impact on local water conditions in the widest sense. Effects on groundwater levels, consumption of water for processing plant, acid mine drainage and the release of water with a quality that is often insufficient to allow reuse, are the main issues.

Consequently, developing technology based on biotechnology to purify water before the final release into the environment has also been an important aspect in BioMinE. In the beginning of the project we could already show that biologically-treated water had a lower ecotoxicity than physico-chemically treated water.

A packed column applying sulfate reducing bacteria on a carrier material gave very good results on bench scale. Another technology, the moving bed bioreactor, was selected as a technology to test on a pilot scale. This technology aims to remove residual dissolved and colloidal metal and metal salts so that the final discharged water is environmentally benign. It applies active bacteria that convert dissolved metals present with concentrations < 50 mg/l into a precipitate that is trapped and separated from the liquid. Depending on the metal this is through a direct metal reduction (like for example for selenium or via sulfide precipitation) is based on active bacteria. In addition, the usage of membrane technology has been investigated.

Technological demonstrations and process integration (WP4)

After the screening of the European resources, amenability studies carried out at lab-scale have shown which technologies should be assessed on selected benchmark resources. The design criteria and specifications of equipment have been determined for the most promising technologies applied to the most representative metal-bearing materials available. Technical demonstration operations could then be undertaken.

The four technologies around which BioMinE partners clustered for the demonstration operations were the following:

- Direct bioleaching in stirred tanks of copper and copper polymetallics concentrates
- Indirect bioleaching of zinc and zinc polymetallics concentrates
- Low cost bioreactor: aimed at the design and development of a new concept of equipment for bioleaching
- Biotreatment of effluents for metal recovery and purification

Cu & Cu polymetallics

The main challenge in this case lies in the development of an integrated process capable of extracting all the valuable metals in an environmentally friendly and cost-effective way.

The integration of bio- and hydro-metallurgical techniques to simultaneously recover copper and nickel was successfully demonstrated during the pilot-scale campaign on the bulk nickel-copper flotation concentrate of Aguablanca (figure 20), which was operated during seven months. Both copper and nickel overall recoveries exceeded 90%. A cost estimation showed good economic results and that the investment return rate is very sensitive to nickel price.

Figure 20: The integrated bioleaching pilot plant treating Aguablanca Cu/Ni concentrate.

Zn & Zn polymetallics

Indirect bioleaching is a biotechnology that presents important assets when applied to treatment of zinc & zinc polymetallic concentrates such as: high metals recovery, fast kinetic of 4-5 hours to get full metals extraction, sulphur oxidation to elemental sulphur (avoiding sulphuric acid generation, while pyrite mineral remains untouched), and use of conventional reactors (aeration is not required) and unsophisticated process equipment. This technology is especially attractive to process Zn/Pb polymetallic ores that are abundant in Europe (Sweden and Iberian Peninsula particularly) and in other mining areas of the world.

Therefore, this innovative bioprocess can open the way to benefit difficult-to-treat mineral deposits or to extend the life of open mines by treating the remaining lower grade ores and complex minerals.

For the first time in biohydrometallurgical field, indirect bioleaching technology applied to Zn/Pb concentrates has been demonstrated in an integrated pilot plant (figure 21) producing electrolytic SHG zinc plates. In addition, the integrated pilot plant operations have confirmed the efficient combination in between chemical and biological steps, resulting in Zn and Pb recoveries above 97%. Bioreactor response has been very stable and the performances of the ferrous iron oxidizing bacteria have been very satisfactory, producing all the ferric iron required at the leaching stage. Very promising economic figures were obtained in the prefeasibility study that exploited the data of the pilot-scale campaign.

Figure 21: Flooded packed-bed bioreactor of the TR pilot plant unit using indirect bioleaching for treating a Zn/Pb concentrate.

Low Duty Bioreactor

The work carried out was devoted to the assessment of the technical feasibility of a bioleaching route based on the use of a new bioreactor that would require less investment and operating costs than the conventional stirred tank technology. A preliminary step of assessment was to identify the benchmark resources that could be used for testing the concept. The pilot-scale testwork campaign aimed at defining design criteria and specifications of an installation incorporating the low duty bioreactor concept for a preliminary cost estimate.

The lab-scale test work realised on four representative samples of European resources led the partners involved in the LDB development to select copper flotation middlings as the best candidate to carry out the design of this new technology. It also appeared that from a process engineering point of view, a decoupled system was needed. A first stage ensuring perfect mixing will allow acidification and heating-up of the slurry to obtain the adapted conditions for bacterial development in the second stage (figure 22). The latter will be dedicated to bioleaching and will be a plug flow reactor characterised by lower duty mixing. Some interactions between both systems could be implemented.

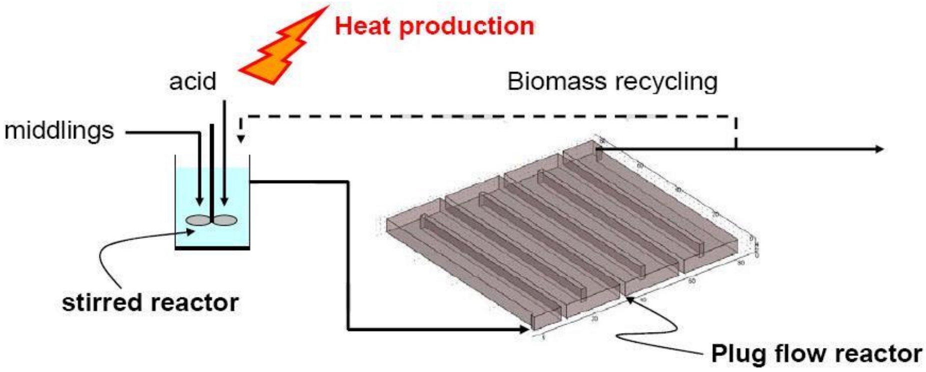


Figure 22: Schematic representation of the LBD pilot installation.

Metal Biorecovery

During the (bio)leaching both wanted and unwanted metals are dissolved. The metals of interest are recovered and further processed into usable metal half products like bars, sheets etc. However, often a (waste) stream with dissolved residual metals and high salt concentrations remains that must be treated in order to reuse the water or release into the environment.

Traditionally, the combined waste of the mines result is results in large basins with high concentrations of metals remaining in a more or less unstable form. These so-called tailings dam can be an environmental time bomb, posing a considerable liability risk for mining companies.

A major activity of the cluster of partners involved in this field is the execution of a pilot plant trial for removal of toxic metals from an effluent. Most of the cluster members have shown a keen interest to participate in this pilot trial.

From February to July 2008, a pilot study was thus carried out at Umicore's Hoboken site for treatment of the final aqueous effluent of the site, primarily aimed at removal of several mg/l of selenate and thallium, but also removal of cadmium, cobalt, antimony, arsenic and beryllium was relevant. In the BIOMETEQ® process, such heavy metals are biologically precipitated and separated in a moving bed bioreactor (see pilot unit figure 23). An additional aim of the study was to remove nitrate from the Hoboken effluent. Ethanol was used as growth substrate for the bioprecipitating bacteria.

The results showed that the process operates stably at temperatures between 20-30 ºC at filtration rates from 3 to 10 m/h.

On average, Selenium was removed from 1.24 down to 0.15 mg/l (88% efficiency). Both selenite and selenate were removed. Thallium removal is very effective; it is removed from 1 mg/l down to below 0,02 mg/l. Nitrate is completely removed; from 30-110 mg/l in the feed down to <1 mg/l in the effluent.

The few available data for Cadmium indicate a removal from 0.2 mg/l to values below 0,01 mg/l. The few data for Cobalt indicate a removal from 0.4 mg/l to values of below 0.005 mg/l.

Arsenic, present between 0.02-0.30 mg/l, is not removed. Antimony, present between 0.02-0.25 mg/l, is also not removed. Beryllium was always below the detection limit in the pilot feed.

In the pilot a small increase of, on the average, 35 mg/l COD was found, due to incomplete degradation of the dosed ethanol. TOC increased with on average 5 mg/l. It is expected that the increase in COD and TOC can be further reduced by implementing a controlled ethanol dosage in the process.

The treatment costs for this type of installation are estimated at 0.08 Euro/m^3.

Figure 23: Installed pilot plant at the Umicore Hoboken site in Belgium.

Training and dissemination through internet (WP6)

The main focus of the BioMinE project in matter of training has been to make learning tools in the form of so called digital learning objects, suitable for distance learning, blended /hybrid learning in ordinary courses at universities and for in-house training at the workplace – but also as stand-alone objects for self-directed and spontaneous informal learning. In this configuration, the objectives of the activities in this area were:

- To establish cross-disciplinary understanding around the project issues
- To produce flexible, web-based teaching materials (“learning objects”) for use in- and outside the project
- To serve the partners with a web-based distance course (containing learning objects) for training in biohydrometallurgy
- To prepare for future exploitation by elaborating an international masters education

Nine partners worked with training – besides the WP coordinator, an education developer from a municipal organisation in a mining area in North Sweden; 4 universities, 1 research institute and two technology companies. After a mapping-up of teaching experience, content expertise, IT-tools-skills, local IT and application support and self-experienced training content needs in own organisation, a training plan was made up, assigning content areas to partners and advising tools to use. The mix of partners’ content expertise was quite lucky to work with the cross-disciplinary subject biohydrometallurgy, and the work started with first more basic content learning objects, but mostly at a masters’ level (that can also be an interdisciplinary taught master, less specialised).

As early as at the time when the first object could be showed it became clear that biohydrometallurgy contained an uncontroversial body of basic and established knowledge and experience suitable as course content, not dangerously close to cutting-edge R&D.

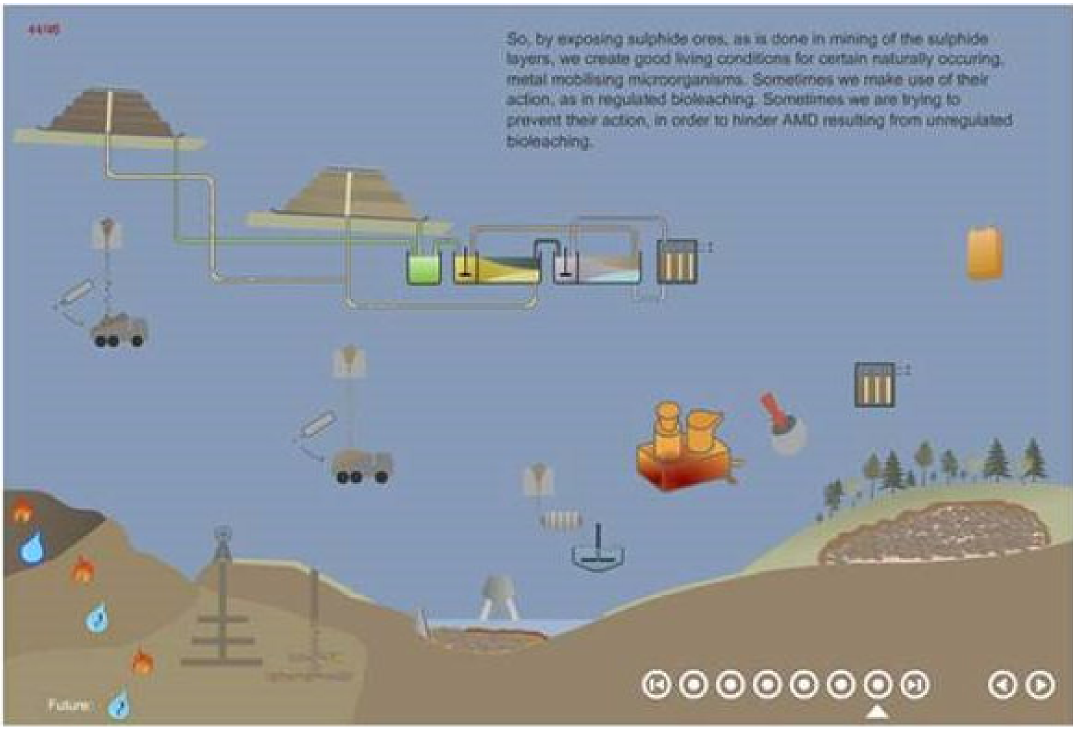


Figure 24: Scene from Mining Landscape.

Many partner-produced objects were made with easy-to-use tools that were already mastered by researchers and engineers: Word and PowerPoint. Word files could then be processed with CourseGenie into very functional and nice web tutorials (or converted into PDF files), and PowerPoint files could be Flash-converted for smaller file size and for an add-on of lecturer voice, and for automatic playing on a web site. The learning object designer did the more complicated objects as Flash animations and the BioMineWiki.

Soon the pattern for what WP6 was doing became clearer. We produced classical fixed objects, web 1.0 objects, as teaching texts and tutorials on the net, which were not meant to be changed, easy to handle in courses, to make tests on etc. But this was later developed into web 2.0, user-community created material and an experiment with web 3.0 material, participation in a web based 3D world.

Web 1.0 learning objects

Web 1.0 objects produced include:

- 1 web book in Hydrometallurgy (10 chapters, CourseGenie and pdf),
- 4 bioleaching tutorials (CourseGenie objects),
- 4 tutorials on mining and hydrometallurgical technology and economy (4 CourseGenie objects), Geochemistry tutorials (4 pdf files),
- 1 object on how to make use of simulation software (Interactive ppt),
- 10 slide series in Microbiology for bioleaching, in ppt, lecture audio and flash player version.
- 3 other slide series in different subjects, mostly microbiology
- 5 explanatory and interactive Flash animations mainly on bioleaching mechanisms,

…and many files uploaded to the Wiki also are of this kind, ranging from pdf with case-examples to small presentations, animations and images, and made specially for learning or donated to this purpose by BioMinE and bioleaching people (totally about 400 files of this kind, besides the 650 wiki articles.)

Web 2.0 and 3.0 objects

A smaller definition wiki for basic terms was begun early in the work, as well as a layered mindmap object made in Inspiration explaining which concepts and terminology that were coherent, what the relation of terms were, etc. These two were later merged into a bigger object on the Media Wiki platform (same platform as Wikipedia). The combination of clickable concept mindmaps and a wiki is an innovation in itself. This creation was called the BioMineWiki, and is our biggest success so far, as a growing content-creation community, consisting of not only BioMinE experts in-or outside WP6, but also of experts from other universities and businesses with interest in the field. BioMineWiki has at the end of the project about 260 000 page views, 9000 edits and about 180 registered contributors from about 25 countries all over the world. There are about 650 articles and 400 uploaded files. It has been linked from or mentioned in about 650 external web sites and used at organised university projects also outside the Consortium.

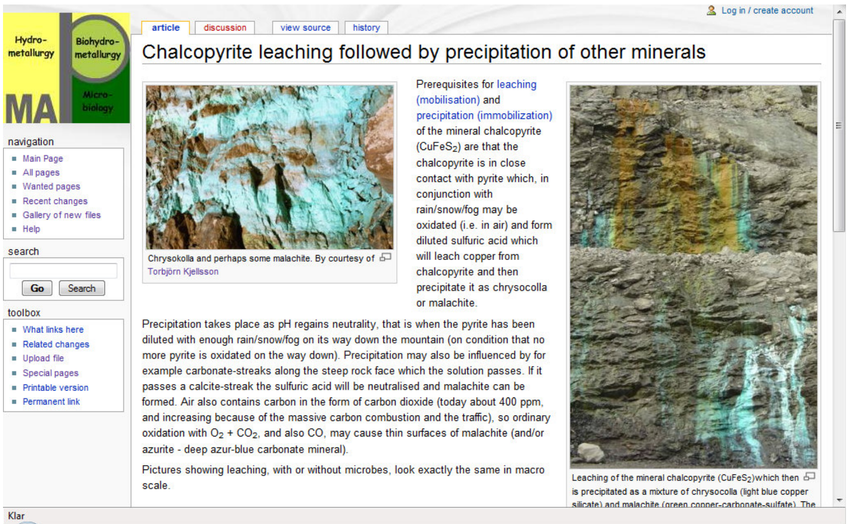


Figure 25: Page from BioMineWiki.

In a user-driven collaborative community Web 2.0 environment, the BioMineWiki displays a platform for writing understandable scientific texts and getting feedback from other users as a way to communicate, to test ideas, etc

The thought of a Web 3.0 object became also very attractive in this learning content development endeavour. Web 3.0 is not any fully established term – but some mean with it the 3D worlds like "Second Life". In this kind of environment, people can interact in virtual worlds in the form of avatars, and among other activities they can use many university-generated tools as a flexible way of learning. Many big multinational companies build their own Second Life 3D environments for interacting with their customers. BioMinE has made two virtual bioleaching demo plants in the "Second Life" environment. This can be found on the Lulea Technical University island, and it is also meant to work as a 3D-window in connection with our other learning materials.

HDTV documentary, "Invisible Miners"

A WP5 dissemination action, the HDTV Documentary "Invisible Miners", will also be connected to the learning content by being cut up in modules that can be downloaded from YouTube (but embedded in own site). The documentary will be free to use for all education, EU and partner organisations purposes worldwide. The sub-contracted TV company in charge of the production of the documentary manages the distribution to documentary and education channels in Europe and worldwide.

All objects are linked from the BioMinE Learning Hub, http://tinyurl/biominelearninghub or the real address http://biomine.skelleftea.se/html/HUB/biomineguide.htm where also other relevant resources for teaching and learning biohydrometallurgy are linked up. A process of integrating all learning objects into the BioMineWiki is ongoing as another possibility. The learning resources are also registered at major learning object repositories and referatories. A BioMineWiki Internet browser toolbar makes also access easier.

A subject area earlier with very little teaching and learning material, biohydrometallurgy, now has been equipped with a rather rich flora of useful learning objects and tools, objects and tools that are already in use. The work has also been interesting as such, how to develop digital learning material from a rising niche area of knowledge, taking researchers as a help.

Even if the personal focuses on research questions have been very obvious, and work with training came in second, it has been an opportunity among researchers and technicians to examine the question about the usefulness of cyber infrastructure for teaching and learning now and in the future. It has also been a work strongly connected to the WP5 exploitation work, as public dissemination of research matters has obvious connections to learning processes.

We have a reasonable hope that the BioMineWiki will live on an be used for several years to come, while the learning objects are more like fresh meat, and needs that the developer modernizes them now and then – and that somebody uses them of course. This last thing depends of the development of bioleaching in Europe and elsewhere.

Exploitation of the results (WP5)

The activity focussed on the exploitation of the results of the BioMinE Project was established and structured to coordinate the commercialisation of the developed technology and the dissemination of the scientific findings amongst the scientific community at large.

In order to attain these objectives, WP5 was tasked to:

- Define sets of exploitable research results
- Define a practical strategy for exploiting the results of the project
- Assess the market potential and specific opportunities for the technology packages, products and services
- Assist the partners and clusters in their exploitation of project results

Methodology employed for the exploitation of the results

The BioMinE Project is large and complex – it brought together 37 diverse participants, including universities, research institutes, mining companies, engineering companies and equipment suppliers. It encompassed aspects of both technology push and market pull, without having a clear definition from the outset of either of these drivers. The objective was, in short, to develop bio-technologies suitable for applying to European metal resources. The considerable early part of the project was spent in identifying a match between the technology opportunities and suitable resources. Only after this was complete could work begin on developing specific technologies appropriate to the identified resource opportunities.

Normally, commercial applications for technology are identified either on the basis of “market pull” or “technology push”. Success is dependent on whether there is a match between the two drivers. In the case of the BioMinE Project, the following two activities were conducted concurrently:

Potential technologies, specifically appropriate to European resources, were identified and conceptualised.

European resources, potentially appropriate to biotechnological processing, were identified.

Once this had been done, possible matches between the identified technologies and identified resources were established. Exhaustive, structured processes were followed in order to systematically establish these matches.

The “Cluster Concept” was formulated and developed. This was adopted to facilitate the interaction between participants with common interest in the various exploitable technologies. These clusters, under the guidance of “cluster leaders”, gave extensive consideration to the market analysis and the technology packages. This cluster concept proved to be very effective and served well as a basis for advancing the identified commercial opportunities to the benefit of all interested participants.

The results of all the studies, together with the consolidated plan for promoting the application of the technologies, were reported in a detailed Technology Implementation Plan. This plan provides the “technology roadmap” for the partners in their respective future commercial and academic endeavours.

The European minerals industry and commercial drivers

This analysis took place in the context of EU-specific mineral economics. The metals of particular importance to the EU are illustrated in Figure 26.

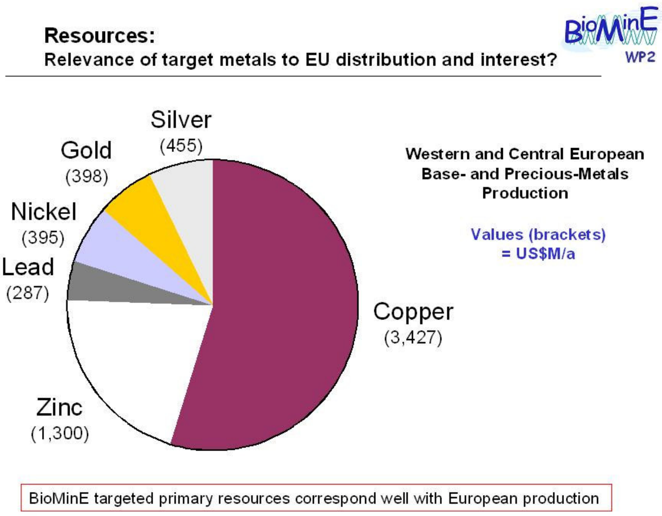


Figure 26: The most important metals in the EU

The European imbalance between mining, smelting and consumption, drawing on copper as an example, is well illustrated in Figure 27. The situation is very similar in the other strategic metal industries.

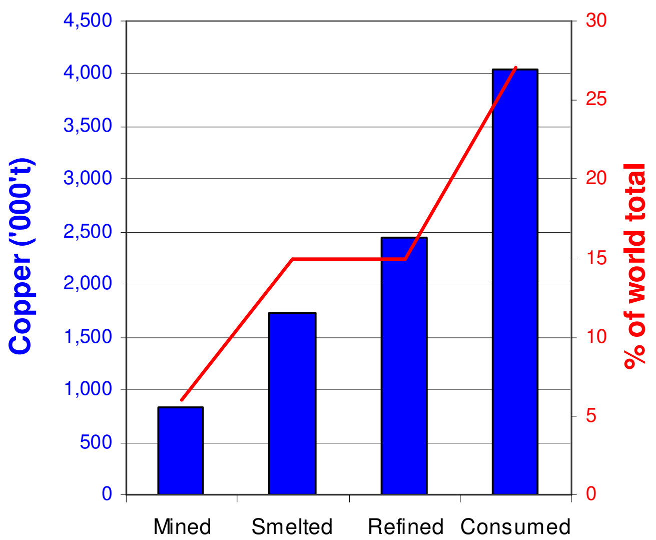


Figure 27: EU copper production imbalance

The most important drivers in the European context are minimising/reducing process costs and alleviating environmental impact. This poses the following technical challenges:

Europe is a high energy-cost region, so processes must be very energy efficient.

The EU is subject to progressive and strict environmental legislation. Any new technology is viewed very critically in this context

The resource assessment performed under WP1 shows that deposits of polymetallic ores are relatively common in Europe. Metallurgical processing of these ores is more complex than for mono-metallic ores, and is often further complicated by the need to produce concentrates that are acceptable as a feed for smelters. In consequence, there may be constraints on the production of high-grade concentrates, often coupled to production of waste flotation tailings that still contain significant metal content. For polymetallic resources the primary challenge is to develop a bioleaching process capable of treating a bulk sulphide concentrate to ensure maximum flotation recovery of metal values.

With a few exceptions, primary metals resources in Europe are small by international standards and this will impose additional technical challenges with respect to costs.

Ore deposits in the European region are generally low in grade compared to other parts of the world. There are many low-grade copper and zinc deposits that are not currently being fully exploited and for which alternative hydrometallurgical process routes are being assessed.

The presence of contaminants such as arsenic in European ores, or significant levels of precious metals, is a further complication.

Wastes from mining, mineral processing and metal refining, have been accumulating in Europe since the early 20th century and continue to this day from present mining operations. The key challenge relates to developing low-cost technology suitable for treating these materials cost-effectively. Although the removal and recycling of these wastes has substantial environmental benefit, the treatment nevertheless needs to be profitable based on the metal recovery and the value of the reclaimed land.

Commercialisation

It is well known that it takes a long time, and significant resources, to establish a new technology in the mining industry. This is due to long development time of new projects, the capital-intensive nature of the industry and the associated high risk of prematurely adopting unproven technology.

For these reasons most of the commercialisation will occur after the end of the BioMinE Project. The commercially-orientated discussions held to date with the short-listed potential users of the technologies have been reasonably positive.

Strong relationships between the participants have been forged during the project, and many of these participants intend cooperating after the conclusion of the project in the commercialisation of their technologies.

Knowledge dissemination

This aspect is as important as the commercial activities mentioned previously. The project has also focused on disseminating the research findings amongst the research community and general public so as to (a) improve public awareness and perception, and (b) improve EU capability for advancing research in the field.

This dissemination has been done through the medium of papers, conference proceedings, posters, radio, television and the internet – promoting the bioleaching concept as a green mining technology of the future.

Conclusion

BioMinE has been a very productive project in many aspects of a field that is still unsifficiently recognized at industrial scale and not so well known from the largest audience.

It has opened the road to a new perception of the exploitation of the mineral resources in Europe. It has particularly demonstrated that the analysis of the issue of searching for a reduction of the import of base metals could be approached in two converging directions. One was from the geological resources point of view and the other from the processing technologies one. At the crossing point of the two rationales, new concepts could come up. BioMinE did show which biohydrometallurgical technologies would be relevant to European mineral resources for extending the potential of production of metals in this region.

Fundamental and applied research has given more substance to the credibility of biohydrometallurgy in general because participants have been able to significantly improve knowledge and know-how in this area.

Finally, the results of the project support the idea that mining operators should seriously consider biohydrometallurgy for the processing of metal-bearing minerals as a real opportunity for a more profitable exploitation of European resources in a more sustainable way than ever. A network of higly qualified organisations across Europe is ready to provide a pertinent expertise for fostering their needs in this matter.

BioMinE FP6 Integrated Project - Website: http://biomine.brgm.fr

Dominique H.R. MORIN - General Coordinator BRGM - EPI/ECO

3, avenue C. Guillemin - BP 6009

45060 Orléans Cedex 2, France

Ph: +33.2.38.64.32.00

Fx: +33.2.38.64.36.80

biomine@brgm.fr