Institute of Geology
and Mineral Exploration

Sustainability in Mineral Industry through the application of Biotechnology

By

Vassiliki Angelatou
Chemical Engineer

SDIMI 2007, Milos

INTRODUCTION

Human activities - industrialization, urbanization, agriculture, mineral extraction etc - profoundly affect the environment.

To achieve industrial sustainability, resources need to be better managed, and wastes and pollution need to be reduced.

Industrial sustainability is not possible without creative innovations based on advanced science and technology.
In this regard biotechnology plays an increasing role also in the minerals and mining industries. It is clear that any move towards industrial sustainability (i.e. lower consumption of energy and raw materials, and reduction or elimination of waste) affects all stages of process technology.

Therefore global environmental concerns, help drive the use of biotechnology in industry not simply to remove pollutants but to prevent pollution at the source.
Efforts to achieve clean industrial products and processes will bring great benefits to industry over the next ten to twenty years.

Modern biotechnology refers to the application of biological organisms, systems and processes to the provision of good and services
(OECD definition, 1998)

or

Biotechnology is the application of science and technology to living organisms as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.
(OECD definition, 2001.)

BIOTECHNOLOGIES
COVERED UNDER THE OECD DEFINITION

DNA (the coding): *genomics, pharmacogenetics, gene probes,* DNA sequencing/synthesis/amplification, *genetic engineering.*

Proteins and molecules (the functional blocks): protein/peptide sequencing/synthesis, lipid/protein *glyco-engineering,* proteomics, hormones, and *growth* factors, cell receptors/signaling/pheromones.

Cell and tissue culture and engineering: cell/tissue culture, tissue engineering, hybridisation, cellular fusion, vaccine/immune stimulants, embryo manipulation.

Process biotechnologies: Bioreactors, fermentation, bioprocessing, bioleaching, bio-pulping, bio-bleaching, biodesulphurization, bioremediation, and biofiltration.

Sub-cellular organisms: *gene therapy,* viral vectors.

Source: OECD, Paris 2001

There are two major areas in which biological systems are currently utilised in full-scale operations by the mining industries:

- metal extraction (“biomining”)
- treatment of acid mine drainage (bioremediation).
- A third, much-researched area, biosorption of metals, has yet to become established as a proven biotechnology.

Mineral processing using microorganisms has been exploited for extracting gold, copper, uranium and cobalt, and current developments are targeting other base metals.

Engineering systems ranging from crude heap leaching systems to temperature-controlled bioreactors have been used, depending on the nature of the ore and the value of the metal product.

BIOMINING

Microorganisms have had significant impact on the extraction and recovery of metals from wastes and ores long before their existence and activity were recognised.

Mining companies have become increasingly aware of the potential of microbiological approaches for recovering base and precious metals from low-grade ores, and for remediating acidic, metal-rich wastewaters that drain from both operating and abandoned mine sites.

Biological systems offer a number of environmental and (sometimes) economical advantages over conventional approaches, such as pyrometallurgy, though their application is not appropriate in every situation.

What is Bioleaching?

Bioleaching is the extraction of metals from sulphide ores or concentrates, using components found readily within the environment. These components are principally

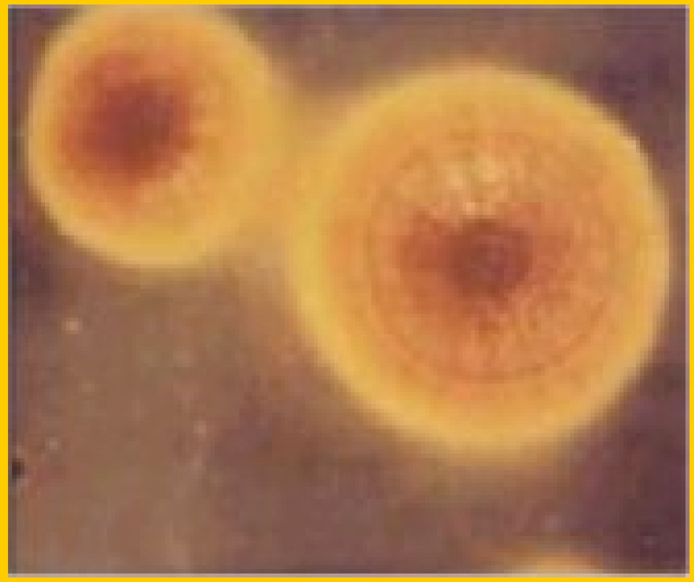
1. Water
2. Air
3. Microorganisms

In chemical terms the process can best be described as a ferric leach, with the re-oxidation of ferrous back to ferric, being catalysed by microorganisms.

Elemental sulphur is frequently a by-product of bioleaching and microorganisms are responsible for it's oxidation to sulphuric acid.

The major areas of metabolism of the microorganisms are the oxidation of ferrous iron, the oxidation of sulphur and the fixation of carbon dioxide.

World's smallest miners - sulfur oxidizing microbes



Mineral bioprocessing microorganisms.

The conditions for sulfide ores and concentrates to be subjected to accelerated oxidation include low pH, high concentrations of dissolved metals and, in some cases, elevated temperatures.

These conditions limit the diversity of life forms that occurs in commercial bioleaching operations.

They are invariably simple, often single-celled organisms, and predominantly prokaryotic (bacteria and archaea). Most live only in extremely acidic liquors (pH <1-4) and are obligate acidophiles, some are thermophilic (to varying degrees) and some fix carbon dioxide (as green plants). (Johnson, 2001).

The known diversity of bacteria that have been implicated in accelerating sulfide mineral oxidation has expanded beyond *Acidithiobacillus ferrooxidans* (formerly *Thiobacillus ferrooxidans*) which was once considered (and still is by some scientists) to be the most significant pyrite-oxidiser.

Some of the recent discoveries have extended the range of conditions within which ore bioprocessing may occur.

MINERAL-DEGRADING ACIDOPHILES	THERMAL CLASSIFICATION*
IRON-OXIDIZERS	
LEPTOSPIRILLUM FERROOXIDANS	MESOPHILE
L. THERMOFERROOXIDANS	MODERATE THERMOPHILE
SULFUR-OXIDIZERS	
ACIDITHIOBACILLUS THIOOXIDANS	MESOPHILE
AT. CALDUS	MODERATE THERMOPHILE
METALLOSPHAERA SPP.	EXTREME THERMOPHILE
SULFOLOBUS SPP.	EXTREME THERMOPHILE
IRON- AND SULFUR-OXIDIZERS	
ACIDITHIOBACILLUS FERROOXIDANS	MESOPHILE
ACIDIANUS SPP.	EXTREME THERMOPHILE
SULFOLOBUS METALLICUS	EXTREME THERMOPHILE
IRON-REDUCERS	
ACIDIPHILIUM SPP.	MESOPHILE
IRON-OXIDIZERS/REDUCERS	
ACIDIMICROBIUM FERROOXIDANS	MODERATE THERMOPHILE
IRON-OXIDIZERS/REDUCER AND SULFUR-OXIDIZER	
SULFOBACILLUS SPP.	MESOPHILES AND MODERATE THERMOPHILES

* MESOPHILES (OPTIMUM <40°C); MODERATE THERMOPHILES (OPTIMUM 40-60°C). EXTREME THERMOPHILES (OPTIMUM >60°C).

Why Bioleaching?

There are many advantages to using bioleaching for the extraction of base metals:

- Low cost, and energy-efficient production
- Simple and safe operation, as processing is at ambient temperature and pressure
- No noxious gases production
- No toxic effluents production
- Exploitation of low-grade ores
- Increased value of run-of-mine products

**DP, Monterrey,
Penoles + Mintek**

Tank bioleaching, Monterrey

Girilambone Copper Heap Leach

Youanmi BIOX Plant

Agnes GEOCOAT Plant

Bioremediation of metalliferous mine waters

Acidic, sulfur-rich wastewaters are the by-products of a variety of industrial operations such as galvanic processing and the scrubbing of flue gases at power plants (Johnson, 2000).

The major producer of such effluents is, however, the ***mining industry.***

Waters draining active and (in particular) abandoned mines and mine wastes are often net acidic (sometimes extremely so) and typically pose an additional risk to the environment by the fact that they often contain elevated concentrations of metals (iron, aluminium and manganese, and possibly other heavy metals) and metalloids (of which arsenic is generally of greatest concern).

The global scale of the environmental pollution caused by mine water discharges is difficult to assess accurately, though in 1989 it was estimated that ca. 19,300 km of streams and rivers, and ca. 72,000 ha of lakes and reservoirs had been seriously damaged by mine effluents.

BIOLOGICAL REMEDIATION

"Active" systems

- Off-line sulfidogenic bioreactors
- Accelerated iron oxidation (immobilized biomass)

"Passive" systems

- Aerobic wetlands
- Compost reactors/wetlands

BioMinE

Biotechnology for Metal bearing materials in Europe

Sixth Framework Programme


brgm
TAMPERE UNIVERSITY OF TECHNOLOGY
INETI
bioclear
PAQUES
DE BEERS
A DIAMOND IS FOREVER
MINTEK
WAGENINGEN UNIVERSITY
UNIVERSITY OF CAPE TOWN
UAM
LULEA UNIVERSITY OF TECHNOLOGY
MEAB
Imperial College London
RIO TINTO
WARWICK
OUTO KUMPU
umicore
SKERIA
IKP
Universität Stuttgart
GaBi
PE EUROPE GMBH
Life Cycle Engineering
IMNR
MILTON ROY
Mixing
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

BioMinE is a large Integrated Project under the Sixth Framework Programme.

The Consortium of BioMinE comprises 35 partners

- from industry (12 including 5 SMEs)
- research organisations (7)
- universities (14) and
- government (2)

The participants are from 12 EU countries, 1 candidate country and from South Africa (INCO country)

BioMinE is aimed at "the production of tomorrow" and involves biotechnological research to provide "radical changes in the Basic Materials industry for cleaner, safer and more eco-efficient production". The objective of BioMinE is to develop sustainable solutions covering the whole life cycle of products and equipment.

Industrial Sustainability

According to the project statements , are at least four main drivers for clean technology based on the use of biotechnology:

- economic competitiveness, with companies considering the benefits of clean processes in terms of cost advantages or expansion to using new resource materials;

- depletion of conventional resources provides additional incentive to the industry to seek innovative bioprocesses;

- government regulatory policies, which enforce or encourage changes in practice; and

- public pressure, which takes on strategic importance as companies seek to establish environmental legitimacy.

Resources and Sustainability Assessment

BioMinE works on primary and secondary metal bearing resources from different parts of the world to advance the understanding of the fundamentals of metal recovery associated with microbial activity. A further integrated and enhanced fundamental knowledge it is applied to primary and secondary resources in Europe for metal extraction highlighted by economic, environmental and societal needs.
Based on the needs of the economy and the obligation to minimise negative environmental and social impacts, an initial series of European metal bearing target resources is prepared in dialogue with the mining company partners and the BioMinE partners.
Following the RTD in all the work packages, potential impacts of the identified biotechnological processes on human welfare and on the environment will be compared to "conventional" metal recovery processes. The interaction of the technologies will be monitored and directed by integrated process-chain and life cycle environmental information, costs, and work environment (i.e. accidents, labour, health etc.) within one consistent model.

Methods of Sustainability evaluation

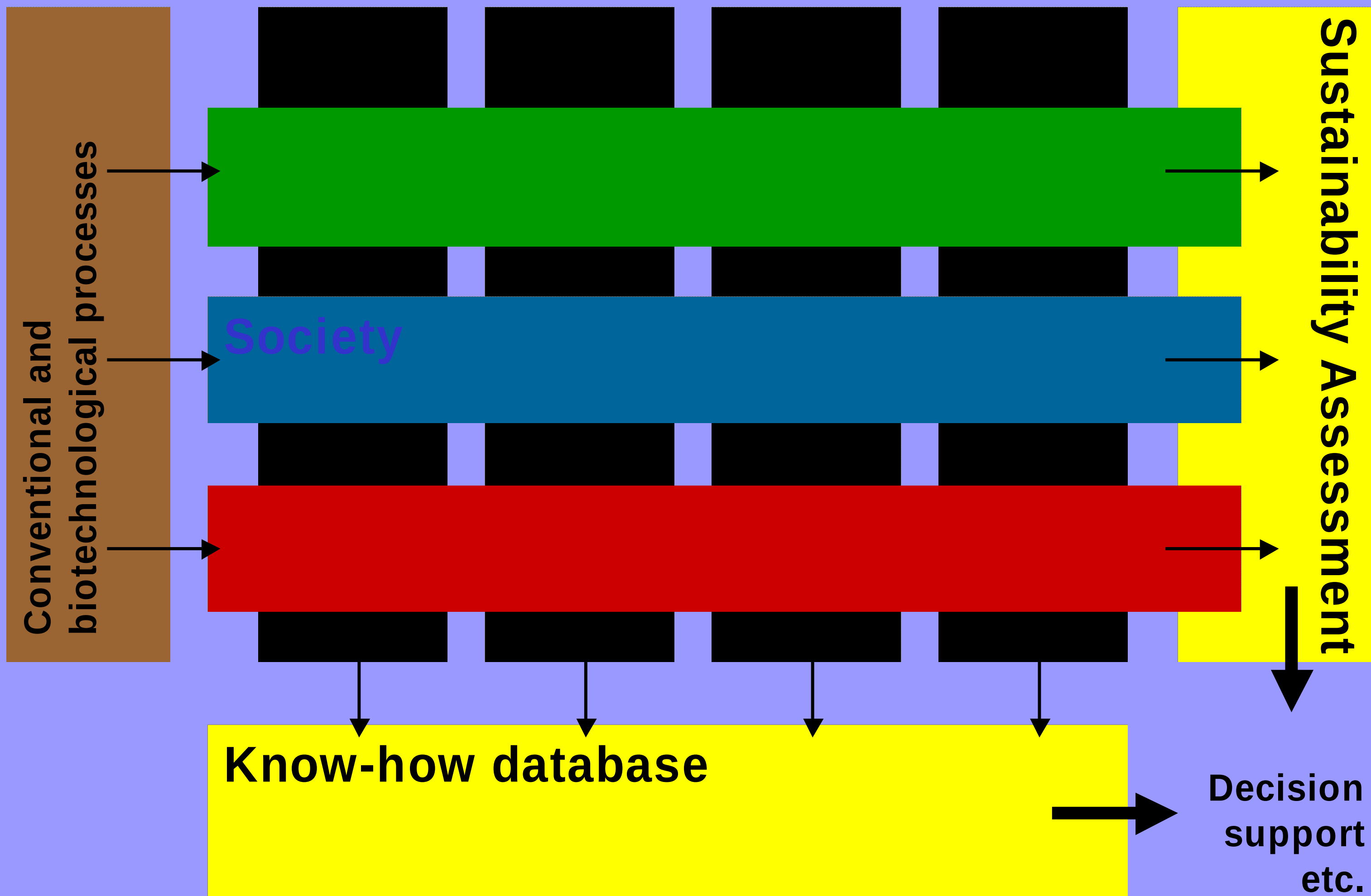
The idea of the Task "Sustainability Assessment is to assess and accompany the RTD development work on biotechnologies, carried out in other work packages.

The selection of meaningful parameters and indicators to describe the sustainability performance of the considered biotechnologies is of high relevance in order to produce reliable results.

- Emmisions to air, emmissions to water, emmissions to soil, resource consumption > climate change, acidification, human health… > ***environmental criteria***
- Personnel cost, machine cost, overhead cost,energy cost,material cost, transport cost > Life cycle costs, qualitative internal criteria,qualitative exter~~nal~~ criteria > ***economic criteria***
- Accidents, Qualification/education, Non-discrimination, Labour conditions >Qualified working time, Health and Safety, Humanity of working conditions > ***Social criteria***

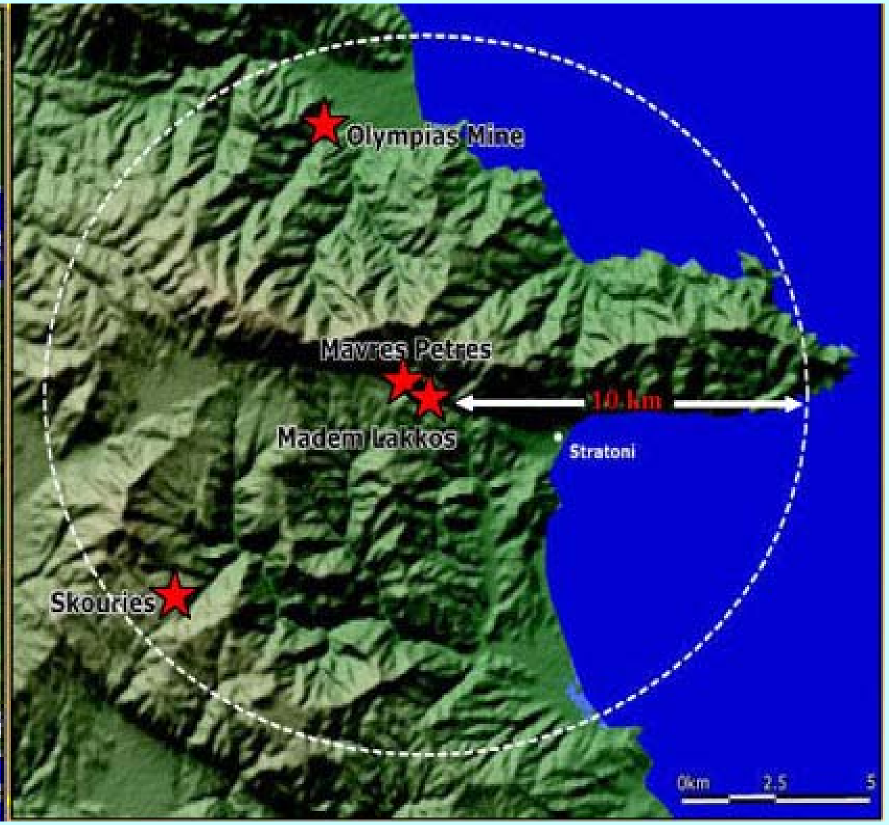
All contributing to Sustainability Evaluation

Interim report on the continuous decision support recommendations on integrated sustainability of processes and process chains under development."



KASSANDRA MINES LOCATION

Stratoni base metal sulphide ores



The proposed project for the development of the investment by Hellas Gold S.A , concerns the overall of Kassandra Mines, which occupy a total area 314.000.000 sq. meters of mine concessions. The owner of the concession has the responsibility of the project according to the contract signed by the Greek State (Co.nr. 22138/12-12-2003) validated by the Law 3220/18.01.2004 (JGG 15A/2004).
More precisely the project comprises the following sup-projects , as proposed to be materialized in the frame of the Hellenic Gold S.A Business Plan.

Sub-project	Activity	Size	Relative works
Skouries	Development of new Mine for the exploitation of gold-porphyry-copper mineral deposit	Mining 153,6 Mt	Gold Mineral Processing and gravity separation plant
Olympias	Development of the existing mine for the exploitation of gold bearing mixed sulfide ore deposit	Mining 11,52 Mt	Mineral Processing plant
Mavres Petres	Development of the existing mine for the exploitation of mixed sulfide ore deposit	1,92 Mt	
Metallurgy	Processing of gold bearing pyrite concentrate of Olympias ore deposit	1000 t/day	
Harbour works	Transportation of the final products from Min.Proc. plant and metallurgy		

KASSANDRA MINES

Resources and grades

(total resources 11.6 Moz Au,85.5 Moz Ag,1900 Kt Pb&Zn,1000Kt Cu)

Stratoni

- **Resources : 14,4 Moz Ag; 0,2 Mt Pb; 0,3 Mt Zn**
- **Grades: 1,9 Mt of 190 g/t Ag; 8,1% Pb and 10,8% Zn**

Skouries

- **Resources : 5,0 Moz Au; 1,0 Mt Cu**
- **Grades : 130 Mt of 0,9 g/t Au and 0,6% Cu**

Olympias

- **Resources : 4,3 Moz Au; 60,1 Moz Ag; 0,6 Mt Pb; 0,8 Mt Zn**
- **Grades : 14,1 Mt of 8,6 g/t Au; 120 g/t Ag; 3,9 Pb and 5,2% Zn**

KASSANDRA MINES

Production plans and perspectives

Stratoni : Six year mine – life; 170 – 400.000 tpa
Olympias : Twenty year mine – life; 250 – 900.000 tpa
Skouries : Twenty year mine – life; 40000 tpa Cu;
200000 ozpa Au

- Two potential treatment routes under investigation for Olympias refractory gold
  - Pyrometallurgical process of flash smelting; 92% gold recovery
  - Roasting pressure oxidation and leaching; 95% Au recovery
- Strong exploration potential for new Au-bearing porphyry copper and massive sulphide deposits

Production of mixed sulfide ores in the Mineral Processing Installations of Stratoni Period 1953-1995

Year	*ROM (t)*	*Pb%*	*Zn%*
Up to 1976	6.971.821	N/A	N/A
1979	436.326	4,05	4,12
1980	487.808	3,65	3,79
1981	532.312	3,59	3,43
1982	446.361	3,38	3,20
1983	455.920	3,37	3,39
1984	487.882	3,19	3,43
1985	456.085	3,53	3,56
1986	380.780	3,97	4,00
1987	450.092	3,77	3,90
1988	412.045	5,84	4,45
1989	401.323	5,46	4,91
1990	360.454	6,00	5,57
1991	370.201	7,57	6,05
1992	318.786	7,61	6,23
1993	225.722	7,69	6,44
1994	211.897	8,06	6,47
1995	163.472	6,89	6,42
TOTAL (1975 –1995)	8.209.287	5,04	4,67
TOTAL (1953 –1995)	13.569.287		

Production of mixed sulfide ores in the Mineral Processing Installations of Stratoni Period 1996-2003 (TVX)

Year	Ore Production ROM (wet tonnes)			Feed material for the mineral processing plant (dry tones)	Quality of feed material			Products		
	Mavres Petres	Madem Lakkos	Total		Pb %	Zn %	Ag g/t	Pb in the concentrate (dmt)	Zn in the concentrate (dmt)	Ag in the Pb concentrat (dmt)
1996	2.145	115.781	117.926	113.609	7,79	7,01	168	8.383	7.218	16,67
1997	0	243.730	243.730	233.470	8,73	8,28	170	19.335	17.627	37,37
1998	10.908	242.121	253.029	246.169	9,81	8,80	200	22.646	19.864	43,80
1999	121	227.269	227.390	224.287	9,87	9,16	200	20.165	18.059	39,93
2000	63.613	128.809	192.422	183.435	9,73	10,57	199	15.563	16.889	30,64
2001	199.961	129.367	329.328	336.849	8,65	10,46	214	26.449	31.713	62,33
2002	319.633	98.378	418.011	391.693	7,76	9,51	205	27.976	33.979	70,28
2003	6.537	0	6.537	7.109	7,12	9,17	179	462	586	1,13
TOTAL	**602,918**	**1,185,455**	**1,788,373**	**1.736.621**	**8,83**	**9,33**	**198**	**140.979**	**145.935**	**302,15**

STRATONI BASE METAL SULPHIDE ORE

Two ore deposits and mines

■Madem Lakkos mine (mined out)

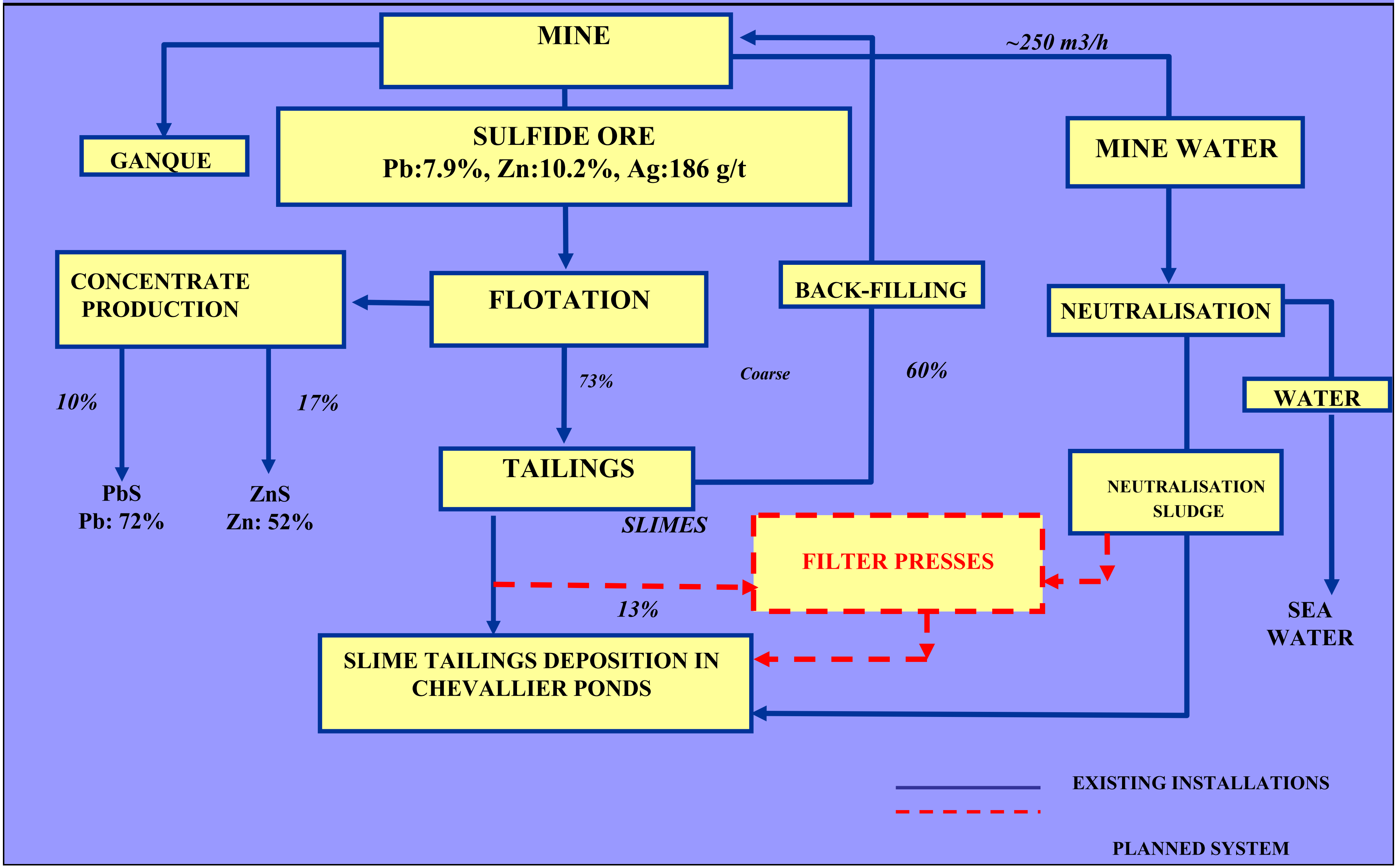
■Mavres Petres mine (operating)

→amounts to 2.2 m.t. of 9.7 wt% Zn,6.9 wt% Pb,172 g/t Ag.

→total 2006 production of 32351 Zn and 15780 Pb tonnes concentrates, and 818139 oz Ag. Au concentrate of 17649t.

→hosts extensions of potential ore bodies in deeper levels (<150 m.) and along unexplored parts of fault-marble intersections. A 12800 m. drilling exploration program is underway. The expected target comprises about 0.4 m.t. grading 7.5% Pb, 9.5% Zn and 160 g/t Ag.

Flow-sheet of Stratoni Mineral Processing Plant



FLOTATION PRODUCTS AND TAILINGS

Grade	Ore	Pb concentrate	Zn concentrate	Flotation tailing
Pb (wt%)	7,015	70,970	1,080	1,100
Zn (wt%)	10,260	1,840	52,690	1,805
Fe (wt%)	20,840	4,305	9,560	25,260
Cd (wt%)	0,060	0,015	0,283	0,018
As (wt%)	2,270	1,335	0,425	2,560
Au (g/T)	3,610	1,350	0,750	4,125
Ag (g/T)	171	1837	80	27

CONTROL OF ENVIRONMENTAL QUALITY

During the whole period of the operation of the project as well as during the stop of the works and the subsequent restoration works , is foreseen the application of the a programme for the monitoring of the quality of the environment

The Environmental Programme comprises monitoring and inventory of :

- The quality of environmental parameters such as (acoustic and atmospheric environment, surface and groundwater quality, sea water quality, soils, meteorological data, biodiversity, ecosystems) in the adjacent and broader area of the project
- The quality of gaseous, liquid and solid wastes periodically
- The quality of the leachates from solid waste disposal sites and the surface leakages

NATURAL RECIPIENTS

- Stream waters
  - Ground water monitoring adjacent to tailing ponds
    - Sea water
      - Sediments

Leaching tests on :

- cement stabilized tailings used for backfilling of mine drifts (according to NEN 7345).
- mine wastes and tailings (EN protocols)
- stream sediments (Sequential extraction tests) and also
- Net Acid Generation capacity (NAG) determined for the tailings samples.

These tests give very important and necessary information when investigating the appropriate remedial actions to undertake regarding a particular waste stream.

SUSTAINABLE DEVELOPMENT INDICATORS (SDI)
- COMPANY LEVEL

EMPLOYMENT	-Total direct employment -Total indirect employment
EXPLORATION COSTS	-Costs for exploration/turnover
R&D INVESTMENT	-Total R&D expenditure/turnover
TRANSPORT CONSTRAINS	-Average transport distance from source to customers and % of transport by road,water
HEALTH AND SAFETY OF EMPLOYEES	-Number of fatalities per year -Number of working hours lost per year as accident results/total hours worked -Number of hours in health and safety/total number of hours worked
COMMUNICATION TO COMMUNITY	-Does the company have a system for registration and follow-up complaints (YES/NO) -Number of public meeting , including “open days”, school visits, etc

DEVELOPMENT OF SKILLS	Number of hours of training/total number of hours worked
ENERGY EFFICIENCY	Energy carriers in MJ per functional unit (1 tonne product)
WATER DEMAND	Of net raw water consumption per unit (e.g tonne product)
LAND DEMAND	Total land area for mineral extraction for the survey year
LAND MANAGEMENT	Total surface land area put into use for mineral extraction during the survey year
USE OF DANGEROUS SUBSTANCES	Rate of classified dangerous substances having potential risk (environment-human health used in the mineral processing per functional unit
ENVIRONMENTAL INCIDENTS	Number and type of reportable environmental incidents

MINE WASTES

COARSE TAILS

FINE TAILS

Discharge of Mine Water to the sea after the neutralisation

SOCIOECONOMIC IMPACTS

- Main concerns of local communities

-subsidence problems adjacent to the village of Stratoniki
-use of underground blasting right below Stratoniki
-potential risks for toxic leaching of the cement stabilized tailings used for backfilling of mine drifts

- Main benefits for local communities

-employment of about 350 local workers; within 9-years time number of employees will increase to 1300.During this period work will be provided for another 600 in the construction phase
-a committee comprising ministry personell and members of the local community was appointed to monitor environmental Issues
-financial and technical support to infrastructure and social projects. Plans for geo-mineral park and mining museum

Unemployment records in the region according to 2004 data

	Economically active	Employed	Unemployed	Percentage of unemployment
Municipality of Stagira – Akanthos	3.242	2.823	419	12,9
Municipality of Panagia	1.257	1.140	117	9,3
Municipality of Arnea	2.168	1.867	301	13,9
Total of the broad area of Mine Activity	6.667	5.830	837	12,6
Chalikidiki Prefecture	**42.377**	**37.777**	**4.600**	**10,9**
Greece in total	**4.622.822**	**4.108.085**	**514.737**	**11,1**

Acknowledgement

This work was carried out in the frame of BioMinE (European project contract NMP1-CT-500329-1).The author acknowledge the financial support given to this project by the European Commission under the Sixth Framework Programme for Research and Development. We also wish to thank our various partners on the project for their contributions to the work reported in this paper