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IMAAC COPPER FORUM & JORNADAS CYTED

TECHNICAL REPORT

Sponsored and Organized by

- International Materials Assessment and Application Centre of UNIDO
- Subprograma XIII - Tecnologia Mineral of CYTED
- Ministério da Ciência e Tecnologia da República Portuguesa, Coordenação Nacional CYTED

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IMAAC COPPER FORUM & JORNADAS CYTED

Volume III

EXPERT CONTRIBUTIONS

Sponsored and Organized by

- International Materials Assessment and Application Centre of UNIDO
- Subprograma XIII - Tecnologia Mineral of CYTED
- Ministério da Ciência e Tecnologia da República Portuguesa, Coordenação Nacional CYTED

ANNEX ONE

THE EXPERTS CONTRIBUTIONS

Sustainable development in the extractive industry: concept and practice of the Geological and Mining Institute (IGM) of Portugal

Luís Rodrigues da Costa[✉]

Introduction

The concept of development has an essentially ethical content, meaning an evolution in the direction of the " values " that the society, the institutions or the individuals, consider desirable. Thus, it is understood that the options of development can differ in the space, in accordance with the geographic area of its exercise, and in the time, in accordance with the degree of technological, scientific or cultural advance considering this last one in the multiple dimensions of Man. In this meaning development has one material component of well-being and one moral or spiritual component, associated to the deepest meaning of the existence.

The material component of the development is consumer of natural resources, which, being finite, raises issues related to its availability and distribution, which are going to reflect, in its last analysis, on the sustainability of the development models adopted. Confronted with the studies of the Club of Rome, in the Seventies, the Brundtland commission (Worl Commission on Environment and Development, 1987) adopted the following concept: " **a development model that allows to the present generations to satisfy its needs without putting in risk the possibility of the future generations to satisfy its own necessities** " as a way to face the perspective of depletion of natural resources in a 1-2 generations time, according to the forecast models of the mentioned group.

Being, basically, the expression of an ethical beginning and an interengenderly engagement, the practical application of the concept has shown to be complex

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and difficult. Its application placed in the agenda the necessity to evaluate the impact on the natural resources of the execution of industrial projects and of the implementation of public policies, among others. As essential elements of this evaluation one should consider the characterisation of the impacts of industrial activities and of the economical decisions, as well as the definition of the measures for its mitigation and control. In this way the capacity of the natural resources is evaluated in order to satisfy the necessities of the project, preventing irreversible losses to occur or, somehow, to become unacceptable.

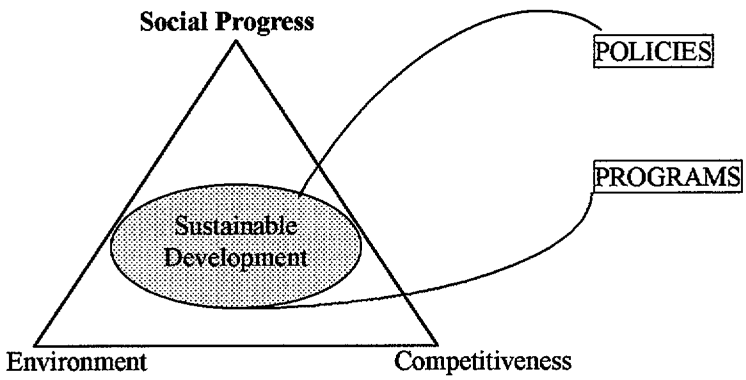
In the last years the idea that also the policies and environment's regulations can have a negative impact in the competitiveness of the companies with the corresponding economical and social implications. Thus, the most dynamic enterprise sectors had been organized in the preparation of normatives describing what must be the relations between the environmental factors and the activity of the industrial companies. The concept of eco-efficiency appears thus considered by the World Business Council for Sustainable Development: " **the eco-efficiency corresponds to the production of goods and services at competitive prices that do satisfy the human being needs, improve quality of life and, gradually, reduce the ecological impacts and the intensity of the use of resources at the different stages of its life cycle, until a compatible level with the load capacity estimated for the planet** "

In this statement the formulation of the concept of sustainability "... **until a compatible level with the estimated load capacity for the planet** " takes place, while it introduces the idea of competitiveness as an essential element to the continuation of the activity. Also the perception of the social importance of the economical activity would make evident the need to add a new dimension or approach to the concept of sustainable development.

Therefore it comes out the concept of the three pillars of the sustainable **development : economic growth, ecological equilibrium and social**

progress or, in an alternative formularition, competitiveness, environment and social development. This trilogy corresponds after all to the interaction of the great groups of performers in presence: the companies, the public administration and the civil society .

Model of the three pillars of sustainable development



Sustainable development* and extractive *industry

A department or a geologic institute finds in the action programs a chance for the exercise of its abilities, the conduct live guided for best exploitation of the economic-social benefits of extractive activity. However, the formulation of these programs requires an analysis and diagnosis of the country situation.

The Recent Past in Portugal

On describing the environmental situation in Portugal, concerning to the diverse industrial sectors, it becomes evident that the extractive industry does not integrate the most critical sectors. However, the fact that the operations do assume, often, easy and immediately perceivable aspects for the public opinion, particularly in the areas of concentration of great exploitation at open pit, has contributed for its association with less correct environmental practices. More recently, the spreading by the press of the situation of some abandoned mines, with the frequent adoption of sensationalist aspects, has increased the public sensitivity for the industry practices.

The last decade has fully confirmed the relevance of the environment questions in the industrial activity, placing the mining industry before new problems and challenges. This new conjuncture has deeply modified the characteristcs of mining projects, first of all introducing a new factor of risk, which came to add to the classic geologic and technologic risks of the market, by depending the decision on administrative authorisation for the exploitation, on the approval of a study of an environmental impact. Although the goodness of this requisite is unquestioned, we evidence that one has not reached yet the phase of enough maturity and in which its objectives are clear and consensualy recognised for all the intervening parts in the process of environmental evaluation. This source of uncertainty of the viability of the project does often appear, associated to the opinions of the local communities, particularly when they are stimulated and amplified by environmental lobbies and when the perception of positive and negative impacts of the project is not dealt with the due caution, being able to generate strong negative reactions that hardly are solved or do even lead to the unviability of the project. One can say that we are dealing with a circumstance identical to any other economical activity, though, in the case of the mining industry, the project will carry through in that place or it will not carry through at all!

But also the need for the closing and abandonment of the exploitation site having to be made in such a way that assures its requalification and devolution to the community for alternative uses, has introduced a particular profile in the financial streams of the project, with the accomplishment of expenditures, of a generally raised sum profile, at the end of its useful life, when the volume of incomes already have fully diminished or ceased, thus it implying that the necessary financial resources have to be accumulated along the useful life of

Today it exists the general perception by the industrial operators that the environmental adaptation of the mining industry is a basic factor its sustainability and therefore, in a modern and current perspective, the mining activity has to integrate the environmental protection, through methods and processes leading to a standard of compatible performance with the principles of the sustainable development. Methodologies of planning and control must, therefore, be chosen in order to assure the adoption of the best technical and economical alternatives and respecting the applicable legal frame. The Mining Plan, the Evaluation of the Environmental Impact, the System of Environmental Management and the Closing Plan do appear, therefore, as the indispensable tools to the exploitation of the mineral resources, in a commitment between the economic and social benefits as a result of its use and the preservation of the quality of the environmental systems the present and future generations depend on. In our opinion this change represents the move from a paradigm of the supply, in use in the past, for the new one of the sustainability, that will assume a stronger importance in the future, and in which the clarification and stabilisation of the environmental requirements is a decisive factor of the activity.

The implementation of the protocol between the Ministries of the Economy and of the Environment, about the requalification and improvement of the environmental performance of the extractive industry, recently signed (October/99), does create the expectation of an actuation and the application of policies with greater degree of agreement.

What concerns to a public vision of the industry information and sensibility action will have particularly to be undertaken promoting its public acceptance and in particular spreading out the good practices. This will be, by the way, one of the aspects of the importance of the psycho-social factors in the development of the activity, very particularly in the establishment of new operations. The forms of increasing public participation in the process of decision of licensing operations (case of the public hearing in the AIA) will tend grow deeper and to obtain an increasing importance, not reducing to the cases of extreme manifestation (very frequent of arguable civism) we can observe today.

We think that the execution of rehabilitation programs of abandoned mines can have a very positive impact driving to the rectification of this image, when returning to the community, duly requalified, places that were example of environmental scenic, and human degradation.

Also the circle of the analysis and debate of the industrial environmental questions must be widened, preventing its reduction to the traditional scope of the geosciences, making possible a better understanding of the processes and of the positions in presence. In reality, in order to make this type of actions fully effective we must correctly know the perception of other intervening people regarding to the mining activity.

The importance of the questions related with the management of the residues of the mining industry, particularly the non inert ones, places in a first priority level the needs for the approval of a specific regulation. The Government recently approved a diploma that one does expect to have a positive impact in the discipline of the extractive activity (including the quarries), since it contemplates the specificity of the industry, exempting it from the subjection to the general regimen inadequate to the sector.

But it will be, probably, in the European level, through the mechanism of transposal of environmental directives, that the industry will have to suffer the main impact of the activity regulation. The areas of special protection will limit the access to the resources by imposing restrictions whose severity will be expressed, in practice, for an effective impossibility of the development of any industrial activity in those areas (case of the Natura Network). Also the landfill directive can have in the future the most serious implications for the industry, particularly if it doesn't happen to become recognised the specificity of the industry, though that does not correspond to the claim of a statute that excuses it from the fulfilment of the environmental standards in force for the generality of the industrial activity . In the current point of preparation of the directive the non polluted ground and the non dangerous inert materials resultants of the exploration, exploitation, handling and storage of mining products are excluded, however the non inert and non dangerous residues have an excessively rigorous approach.

Still in the European level the legislative and regulamentar harmonisation is today faced as a basic element of the reconciliation of the principle of the freedom of goods circulation and of the environmental concerns in the framework of creation of the internal market. In this frame the use of voluntary agreements and environmental systems of management and audits, as well as the use of the procedures corresponding to the best practices are important, particularly while increasing the industrial competitiveness in the global economy without the needs of new regulations .

The Geoindustry & Environment Program

The Geologic and Mining Institute has looked for to pay attention to the evolution of this reality, therefore drawing an intervention program named as **"Geoindustry & Environment program"**.

The program has the following intervention axles and fundamental ideas:

Intervention axles	Key principles
New exploitations	Innovation
Actual Exploitations	Adaptation to the Environment
Abandoned Exploitations	Environmental Requalification

Let us see some examples of running programs that correspond to the concrete application of the concepts we have been developing.

i) the Requalification of Abandoned Areas of Exploitation Program

In the past, the process of development of the extractive activity accumulated important environmental impacts, in such it became urgent to start to recover, due to the potential risks for the populations and ecosystems, becoming evident it does necessarily imply an expensive and long time program. The solution for these situations goes throw the accomplishment of safety and environmental rehabilitation works , being however necessary to identify the cases most urgent, in order to establish intervention priorities.

Many of these exploitation are abandoned, having been extinct the society concessionaire of the exploitation, while others had been previously decommissioned before coming into effect of the current environment legislation, making impracticable the application of the principle of the polluting agent-payer. For this reason the Portuguese State has assumed the material and financial responsibility of its environmental rehabilitation.

Thus, in 1995, the IGM and the Direcção-Geral do Ambiente have launched a program of characterisation of the situation of the abandoned mining areas, which has been financed by the Strategic Program of Modernisation of Portuguese Industry (PEDIP II) and by the budgets of the two institutions. In the particular case of the IGM this area was identified as strategical for the development of new capacities, application of abilities and exploitation of information collected along the years of activity related with the exploitation of mineral resources. The attached table presents the listing of the developed and running actions.

Recognising the importance and the quality of the achieved results and having present the great objectives of environmental industrial and territorial policies, decided the Government has decided to execute a **program of environmental requalification of abandoned mining areas**, carried in the framework of the celebrated protocol between the Ministries of the Economy and the Environment aiming to promote the security and welfare of the populations and, whenever that the local conditions provide it, identify the endogenous potentials of job creation and development of economical activity, namely in the tourists and cultural aspects.

Areas of Intervention – Current Actions under the scope of the Program - Abandoned Mining Areas

PROJECT		Accompaniment and execution		
Designation	**Type of Share**	**Situation**	**Promotional Entity**	**Entity Executor**
Jales Mine	Development of methodologies and Definitive Diagnosis	Finished	DGA	IGM
	Geotechnic stabilisation of tailings dam - Project of engineering	Aperture of tender Concluded November 99	IGM	Public tender
	Geotechnic stabilisation of tailings dam – Execution of Workmanship	Launching of tender in April 2000	IGM	Public tender
Cunha Baixa Mine	Development of methodologies and Definitive Diagnosis	Finished	DGA	IGM
	Containment of the dispersion of the underground aquiferous	In course	IGM	ENU(execution)-IGM, DGA, DRAC, DRE (accompanying)
Pejão Mine	Development of methodologies and Definitive Diagnosis	Finished	DGA	IGM
S. Domingos Mine	Definitive Development	Contract signature in October 99	IGM	Public tender
Lousal and Caveira Mine	Definitive Development	Contract signature in November 99	IGM	Public tender
70 Mines Inventoried - Diagnosis extensive preliminary (all the territory)	Zone North of the Aveiro-Pinhel parallel (work of analytical field and in about 40 mines)	In course	IGM	IGM
	Zones Center and South (work of analytical field and in about 30 mines)	In course	IGM	IGM

Objectives:

The Program has as mainly objective to proceed to the environmental requalification of abandoned mining areas and as specific objectives the following ones:

- ✓ To eliminate, in stable conditions at a long term, the risk factors that constitute threat for the public health and safety, resultant from the water pollution, the ground contamination and the eventual existence of unstable water or forsaken cavities;
- ✓ To rehabilitate the surrounding landscape and the natural conditions of development of the local flora and fauna, having as reference the respective previous habitats to the exploitation;
- ✓ To assure the preservation of the abandoned haitage by the old exploitation, whenever this one presents a significant economical relevance or as a testimony of industrial archaeology;
- ✓ To promote the economical valuation of the recovered areas, in function of its specific ability in each concrete case, assignedly for agricultural or forest use, tourist and cultural promotion, beyond other types of exploitation that do present as adequate and convenient;
- ✓ To assure an excellent application of the financial resources to affect to the Program, through the maximisation of the binomial profits/ social costs, namely in what it concerns to the economy and effectiveness of the corrective solutions adopted.

On selecting of the intervention areas the risk of people and goods will serve as priority criteria as well the incentive of the economical activity and the creation of jobs.

Action Development

The interventions will involve different phases, having as a final result a safe area, duly requalified and susceptible of an alternative use. The main phases of the environmental actions development, independently of the final use of the recouverde site, are: **the definitive diagnosis, the requalification project and the execution of the requalification works.**

In this direction, the proposed Program integrates the following set of actions, some of which had already been partially or total carried out:

- ✓ Inventorying the situations clearly fitted with the characterisation of the abandoned mining areas ;
- ✓ Selection of a set of those that demand an urgent intervention and a present better relation social benefits/costs ;
- ✓ Detailed analysis of further elements of diagnosis in what concerns to the nature and extension of the existing problems, when ever it is indispensable, involving field works for sampling and corresponding analyses, measurements flow and volumes, and general characterisation as much of the ecological systems in cause, as of the socio-economical and cultural envelopment, including the eventual relevance of recoverable constructions and/or of the testimony of industrial archaeology;
- ✓ Elaboration of rehabilitation projects that guarantee the fulfilment of the considered objectives, appointedly in what it concerns to the maximum technical and economical efficiency of the solutions adopted, without sacrificing the necessary rapidity, of the improvement and implementation phases.
- ✓ Accomplishment of the requalification works and its fiscalization until the definitive reception;
- ✓ Whenever it is required, the definition of the permanent monitoring systems to implement after the base requalification program, and presentation of suggestions or studies for the best later economical valuation of the rehabilitated areas.

Schedule list

According to the methodology of the environmental impact adopted on a preliminary characterization of the abandoned mining areas four levels of impact has been considered:

- ✓ Level 1 – very significant Impact
- ✓ Level 2 – Significant Impact
- ✓ Level 3 – Medium Impact;
- ✓ Level 4 - Small impact.

So, for the situations registered until the present and to requalify between the 1st of January of 2000 and 31th of December of 2006, one foresees the handling of 10 level 1 cases, 12 level 2 cases, 20 level 3 cases and 40 level 4 cases.

This plan could be reviewed on the basis of information gotten by the time of program execution. On planning the execution, priority will have to be given to the accomplishment of safety works, independently of future interventions of another level, as well as the launching of level 1 and 2 interventions during the first years, foreseeing its prolongation in the time. The initial global budget for this program is of 8 billion escudos (≅40 US$).

ii) The Industrial Planning and the Improvement of the Environmental Performance of the Extractive Industry Program

The dynamization of the supported growth of the companies competitiveness, strengthening and promoting the modernisation of the industry, is in the center of the industrial and environmental policies and in the seek of articulation and compatibility ways of implementation. The extractive industry, though having already initiated the process of environment adaptation, needs to continue with the introduction of methods and production processes assuring the environment qualification of its activity areas, through the constant improvement of its environmental performance.

The improvement of this performance demands the knowledge and spreading of the correct technologies, the availability of qualified technicians and the monitoring of the activity, very particularly in the areas of exploitations concentration, through the increasing dissemination of environmental management systems.

The full benefit of these orientations demands the definition of the national territory areas that, due to the nature of the mineral resources occurring on them and the proximity to the great centres of demand, must be preserved and submitted to land use plannings guiding the intervention of the Central Administration and assure to the economic agents a reasonably defined frame of supply and demand of raw materials. This process does equally create, the conditions of proceeding for the licensing of the extractive industrial activity, either at its access phase, either in its adaptation to the evolution of the external conditions of its exercise, improving, in this way, the entrepreneurial involvement;

Designation	Situation	Administrative Region	Area (ha)	Date of Conclusion
Alenquer-North	Finished	Lisbon and Tagus Valey	600	1996
Atouguia	In course	Lisbon and Tagus Valey	200	Oct-99
Chainça	In course	Lisbon and Tagus Valey	78	Nov-99
Rio Maior	In course	Lisbon and Tagus Valey	65	Dec-99
Redinha	In course	Center	100	Dec-99
Monção	In course	North	30	Oct-99
Pedras Salgadas	In course	North	450	Nov-99
Silves	In course	Algarve	72	Oct-99
Foz Côa	In adjudication phase	North	130	Junhe/2000
Alpendurada	In adjudication phase	North	250	June/2000
Mouro-Barro Branco	In adjudication phase	Alentejo	220	June/2000
Relvinha	In Programming phase	Lisbon and Tagus Valey		
Pero Pinheiro	In Programming phase	Lisbon and Tagus Valey	————	
Barracão	In Programming phase	Center		

Thus, having present the obtained experience under the scope of the Contract for the Environmental Adaptation and the projects " Integrated Studies of Planning Actions, Environmental Impact and Scenic Rehabilitation " (see the table of action in course financed by PEDIP II), it was understood as fully justified the development of the **"Industrial Planning and Improvement of the Environmental Performance of the Extractive Industry " Program.**

Objectives:

The main objective of the program is the **Industrial Planning and Improvement of the Extractive Industry Environment Performance** and it is developed under the following specific objectives:

- ✓ land use planning, through the definition of the spaces with extractive vocation and the consequent easiness of the industrial licensing process;
- ✓ elaboration and application of integrated plans of exploitation and environment rehabilitation;
- ✓ promotion of the continuous improvement of the companies environmental performance;

Actions Development

The program embodies various types of action:

- ✓ preparation of a sectorial mineral plan of the extractive activity, supported by the convenient computer functionalities making possible its permanent update, as well as the access by all the Central Administration entities who need this information.
- ✓ elaboration of directive plannings for supplying the most demanded mineral substances (sands and broken stones), for the areas of the most intensive use;
- ✓ concluding of the covering of the main areas of extraction with the elaboration of the correspondent integrated exploitation plannings and environment rehabilitation;
- ✓ promotion of the accomplishment of the demo projects of rational exploitation of mineral deposits, aiming the maximum resources recover and minimizing the exploitation wastes;

- ✓ improvement of the professional qualification of the technicians and its formation through the publication of tutorials, information and sensitization meetings, spreading of technological knowledges and codes of good practice;
- ✓ promotion of the improvement of the industry image through the environmental certification and spreading of success cases;

Schedule list

An average a number of 6 interventions per year is considered, as well as a global expenditure of 60 000 million escudos per year (300 thousand US$).

iii) The Marbles Zone Planning Program

The economical and social importance of the marble extraction and transforming activities in the region of Estremoz-Borba-Vila Viçosa (180 km to the east of Lisbon, and in Lisbon-Madrid axle) confers a regional strategical nature to it. The traditional exploitation, that started an expansive phase in the sixties, was developed, on a non planned way, accelerated in the last two decades (the exploitation passed from 217,000 tons, in 1977, to 635,000 tons, in 1996).

This model of growth has originated the accumulation, along the time, of raised environment impacts and bottlenecks to its normal pursuit, becoming imperious the inversion of this trend with the adoption of an integrated plan that safeguards the access and the availability of the resource, the possibility of its exploitation in sustainable way and leads to the gradual rehabilitation and environment requalification of all the area affected by the extractive and transforming activity.

Main parameters of the Zone of Marbles

Regional parameters		**Parameters of Exploitation**	
Area of influence:	$40 km^2$	Average area of exploitation:	2,8 ha
Area affected to the exploitation:	$9 km^2$	Average area of the pit:	1,0 ha
Area of exploitation:	$6 km^2$	Average area of waste dump:	1,6 ha
Waste dumps:	42%	Average height of the wastes dump:	15 m
nº of quarries:	220	Average recovery:	20%
nº of companies:	108	Average depth of the pit:	32m
Volume of wastes:	22 Mt		
Nº of workers:	2.500		
Annual volume of production:	630 kt		
Value of the production:	110 MUS$		

Source: Victor Duque, Direcção Regional de Economia do Alentejo (DRALE)

Very recently concluded (February 1999), a planning document is available - Regional Plan for the Territorial Ordinance of Marbles Zone (PROZOM) - integrating a global proposal for the area ordinance. Its elaboration had a Follow-up Commission, co-ordinated by the Commission for the Co-ordination of the Alentejo Region (CCRA), promoter of the study, and has integrated a diversified range of entities, among which the IGM and the DRALE (Regional Directorate for Economy of Alentejo).

The axles of action of its proposals are:

- dynamization of the marbles sector as a structuring activity of the local economy;
- adoption of a standard performance compatible with the protection and environmental valuation and the gradual rehabilitation of the affected zone;
- promotion of traditional alternative activities of the region, that do attenuate the economical dependence of marble extraction.

These axles contain the PROZOM objectives:

i) to guarantee the rational exploitation of the marble;
ii) to protect and to value other natural resources, in particular, the water resources, the agricultural ground and the ecological structures;
iii) to improve the internal infrastructure networks and accessibility and its articulation;
iv) to guarantee the adequate exploitation of waste and by-products of the exploitation;
v) to encourage the gradual recovy of the zone affected by the exploitation;
vi) to define the zoning and rules for the space use articulated with the PDM's (Municipal Land Use Plans) that can safeguard the above mentioned values.

About the structural impact of the geologic cartography in the ordinance of the territory in the area of influence of Marbles Zone

The historical activity of extraction of marbles bequeathed us a deeply deprived of characteristics area of the environmental point of view and that during long years developed out of enough technician-legal justification (seldom in licensing absence, disrespect of hygiene regulations and safety regulations). The committed action of the official authorities, very particularly the Regional Direction of Economy and the Work Inspection, led to the radical alteration of this situation (today there are not any exploitation not licensed in the area). Also the installation of the Technological Center - CEVALOR -, in Borba, made available until then inexistent or not very accessible technical services (a paradigmatical case is the work medicine services the covers already 2.500 workers, or the regular resource to drilling works for delineation of the future exploitation areas, a practice previously totally ignored). Also the generality of the universities began to face this activity as a potential job market for its graduated people and development of formation actions, graduation and master themes and, still for the accomplishment of research projects. To other formation levels the CEVALOR, started to develop an excellent formation action for active people, promoting specialised courses (level II) and, since the last year, in association with the University of Évora, started a technological area course in the domain of the ornamental rocks.

In this period it was also concluded the geologic survey of the whole Marble Zone, at scale 1/10.000, made by IGM, basic work of infrastructure for the land use planning of the area and interventions planning.

The next consolidation phase of activity in this zone passes through the deep alteration of the patterns this one has been developing, conferring to it a sustainable perfomance, by the adoption of new standards of environment compatibility. In the base of this new phase it is the adoption of integrated exploitation plans that recognise and contemplate the underlying geologic unit (the geologic deposit) and brake with strict cadastral criteria, resulting from the division of the property. The experience obtained in other areas of the Country, eventually in not so complex contexts, leaves us to admit the existence of potentialities in this approach .

The work carried through until the present has allowed to map the exploitation areas (AE), of potential exploitation (APA), in which one does admit can come to occur exploitation even though the occurrence of economically exploitable resources to be exploited do require exploration works, and the areas of common deposition of wastes (ADC). Based on these one it was possible to define 5 units of ordinance (UNOR), constituting diversified and complementary zones concerning the use the functions and the activities, which will have to be object of a specific plan. The UNOR can also include Industrial Concentration Areas (industrial zones), for the location and concentration of sawing and polishing plants for ornamental stones.

The plan of detail of each UNOR will define the respective physical planning.

Thus, from the characterisation of the existing situation it must define the general conception of the AE and the ADC, the free spaces, the scenic arrangements and the schematically tracing of the road network and main infrastructures, the analysis of the environmental impact of the existing exploitation and the mitigation measures of the negative impacts on the environment. These plans will constitute the basic reference frame for the expansion proposals, adaptation or updating of mining works plans, as well as those of the correspondent scenic recover plans submitted by the explorers to the competent licensing services of the industrial activity, either in the exploitation phase, or in exploration as well as transformation phases.

We think, that the consideration of areas of common deposition of waste (whatever they are broken rock or sawing mud), already treated by proper legislation, as well as the water exhaure from the pits will be able to improve the forms of cooperation or association among the explorers.

Under the Ministry of the Economy point of view the regulating tools can be elaborated in the frame of the regulation for the consisted captive area at the marbles zone (directive nº 441/90, of June 15th), while the elaboration of the detail plans must be achieved in the next Supporting Communitarian Frame, in the context of a regional program very widened for all this area. Once updated, this tool will guide the action of the regional licensing services for (economy and environment), speeding up the industrial licensing, disciplining the activity and conferring to it the characteristic of sustainability.

IV) the Underground Marble Exploitation Project

The geologic investigation of the deposit, lead in the frame of the geological mapping of Estremoz-Borba-Vila Viçosa marble deposit, has evidenced the occurrence marble with chromatic and fracture features of good quality up to 400 m depth. It is known that, on account of geotechnical stability reasons of the rock massif, the depth of the digging at open pit should not exceed 100m. Arising therefore the question of equating the exploitation mode of the resources laying between those two elevations was prepared the project **Underground Marble Exploitation** whose main objective is to define an underground exploitation with dimension and resources of good quality and to test the technical and economical feasibility of the underground exploitation through the accomplishment of a pilot project. The demonstration of the feasibility for the exploitation will have the following consequences:

- ✓ Possibility of recovering resources inaccessible by any other exploitation method;
- ✓ Prolongation of the useful life of the deposit per decades;
- ✓ Substantial reduction of environmental impact of the exploitation.

The project was planned in two phases:

Phase 1: valuation of the alternatives concerning the economical and technical aspects and to select the best alternative for the conceptual project of an experimental mine;

Phase 2: to support technically a company or a group of companies, in the underground marble exploitation at an experimental scale.

The first phase of the project is near its conclusion, after what one will evaluate the achieved results and the conditions for passing to the second phase, which will be able to be financed by the next Operational Economy Program.

Conclusion:

We looked for, through some concrete actions examples carried out by IGM, to show some of the intervention domains of an institute or geologic work service in the mineral resources, formulated under the perspective of making operational the concept of sustainable development.

We think that **sustainable development gives the opportunity for application of geoscientific knowledge and use of geologic and mining information, once the needs of the users are correctly identified and given a useful, practical and direct reply to their problems.**

Oporto, October 25th of 1999

MATERIALS PRODUCTION AND THE ENVIRONMENT

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Abstract
Materials play a fundamental role in developing a nation and in maintaining or increasing its share in the world economy.
However, any material to be produced has in its transformation cycle, at least one extracting, processing, fabrication and manufacturing step in which releases of substances, gases, liquids, or solids, occur to the environment.
This paper addresses some environmental problems associated to the extracting and processing of some non-fuel-non-ferrous commodities that are of major interest to the hydrometallurgist in an attempt to design environmentally sound products.

1 Introduction

The production and utilization of material in general, and as consequence those of ores and metals, obey, within a given framework of industrial development, the economic cycles that are in effect in a certain time period. These cycles have been well-discussed in the literature[1][2][3][4] and might reflect a world, a local or a geopolitical trend.

As the selection of a given set of materials depends upon the predominant cycle in the industrialized countries, these determine, to a greater or lesser extend, the consumption pattern of a given commodity, inducing the market to adapt itself to such a new reality.

In materials based industries two general strategies arise: there is a search for materials that suit an available technology, and the development of technology for an available material.

The recycled materials, which magnitude of use of the industries varies from economy to economy, need, as a general rule, lower capital and energy expenditures and more manpower than that of the primary processing. Also, they require lower pollution control costs than the primary ores. Such a recycling is more intense as the sophistication of the economy increases, since viable quantities of recycled materials must be available in order to reutilize them.

However, as important as they are in the world's economy, materials to be produced promote changes in the environment: they require energy to be processed, land to be installed, disposal sites to receive tailings or disposals, give off gases and dusts, and require water and earth movings. In fact, since early times such environmental impacts have been recognized and some actions and concerns arouse, here and there, to minimize them or at least leaving them within a tolerable acceptable limit.

Such acceptability, of course, changes from time to time, as social pressures increases, forcing legislative decisions that promote technological alternatives which, in turn, reflect on the economy.

As regarding to the environment, two major questions are receiving worldwide attention: what are the effects linked to the production, disposal and use of materials, and what are their availability in a foreseen future?[5].

This paper tries to focus on the first of these issues, reviewing some of the facts and figures of the environmental impacts caused by a limited range of commodities, withing the non-fuel-non-ferrous industries.

2 The average metal recoveries and the production steps

For any material to be produced there are corresponding **steps** in which **discards** are also produced. These **discards** might be of two broad cathegories: **losses** and **effluents**. **Losses** are those discards readly identified to the main material produced, i.e., parts of that material that are left behind throughout the production steps. **Effluents** are the discards coming from these same steps and that are inherent to the applied technology within each production step, but not necessarily identified to the main material.

2.1 The average metal recoveries

In order to systemize the analysis of the environmental impacts of the discards an attempt is going to be made in quantifying such average metal losses.

No universal claims are made on the exposed reasonings, but they migh help to point-out the emergency of the facts and impacts.

It is well recognized that ore recoveries, from mining to final metal product varies from country to country, from economy to economy, as a function of technology, skill, regulatory laws, finantial capability, etc...; so are the environmenal impacts caused by primary and secondary metals production.

Therefore, **recoveries** and **losses** figures from metal to metal and even for the same metal from country to country, even when apparently similar technologies are used, do vary substantially due to the so called "particularities" of the mining world: the cut-off-grade and the compromise between grade versus recovery optimal combination, making each orebody unique in its physical and economic characteristics.

Other things being equal, the lower the grade or the poorer the quality of the ore, the higher will be the cost of recovery of the valuable products. To the extent that there is a choice of the grade of the ore to be mined, there is also a choice of the total tonnage and of the total product recovered; the lower the permissible grade, the higher the tonnage. Therefore, the fixing of the cuttoff grade in deposits of irregular grade-distribution may require several computations of alternative tonnages and grades on the basis of different assumptions as to mineable limits.

Equally important with grade is the workability of the ore which is measured by the cost of physical removal of the rock. Other factors, such as accessibility from mine openings, thickness and regularity of the ore zone, hardness and toughness of the ore, presence of interfering structures, such as faults, weak ground, et allia, all must be evaluated when the decision on which ore must be taken should be made.

Variations in the grade in the workability of an ore body, may go side by side, or they may partly compensate each other. Ores of many different grades and many different costs, but sufficiently similar in other qualities to be amenable to the same treatment process may be mine or blended to profitable recovery of otherwise para marginal ore.

Complete removal of all available ore from mine, or complete extraction of all available ore is never achieved. Cost per unit recovered rise almost continuosly and usually with increasing steeps as attempts are made to increase the percent extracted. In the short run, with the recovery plant given, the percent extraction of metal will depend, to some extent, on the grade of the ore itself; the mining method usually limits the recovery of the ore in the mine[6] [7].

As well as the utilized processing technology. For **gold leaching**, for example, the recovery figures are those shown in Table 1.

Table 1. Gold leaching recoveries[8].

OPERATION	PARTICLE SIZE	METTALURGICAL RECOVERY	COSTS
Agitation	< 0,1mm	90 - 95% > 20h	###IN ###OP
Vat	< 10mm	70 - 80% 3 to 4h	###IN
Heap	> 10mm	40 - 60% 3 to 4w	###IN ###OP

IN = investment costs
OP = operational costs

h = hour
w = week

Lets have a look on some select mineral commodities, as regarding recoveries and grades, as shown in Table 2.

It can be readly seen that the problem associated to earth moving and tailing disposal is quite a severe one, since from the grade of the ore up to the production of a salable concentrate, the mass of the produced concentrate, as related to that of the ore total (MC) and the mass recovery itself (MR) are, of course, far from the sustainable target of total utilization, for the aforementioned reasons.

Table 2. Selected mineral commodities recovery/grade

ORE	RECOVERY	GRADE	COMPANY
Nb_2O_5 (3,0%) piroclore	MC = 3,3% Ore MR = 66%	60% Nb_2O_5 Conc.	CBMM (9)
TiO_2 (1,5%) ilmenite	MC = 2,2% Ore MR = 81%	55% TiO_2 Conc.	RIB (9)
Cr_2O_3 (17%) chromite	MC = 28% Ore MR = 65%	37% - 46% Cr_2O_3 Conc.	FERBASA (9)
WO_3 (0,5%) scheelite	MC = 0,49% Ore MR = 74%	75% WO_3 Conc.	TUNGSTÊNIO (9)
Sn (1,3%) cassiterite	MC = 1,9% Ore MR = 69,1%	48% Sn Conc.	RENISON (10)
Ta_2O_2 (0,16%) tantalite	MC = 0,22 Ore MR = 70%	49% Ta_2O_5 Conc.	BERNIC (10)

As already pointed out MC stands for the mass of produced concentrate, as related to that of the ore total, in percent, and MR is the mass recovery, i.e., the recovered amount of the valuable commodity as related to the original amount in the ore.

A very illustrating example of recovery, grade, mass recovery, earth moving, generated by-products is the production of phosphate fertilizers, from volcanic rock, that besides the usual earth-moving and disposal problems associated to the production of the concentrate, it generates five times the mass of gypsum as that of the concentrate, P_2O_5 based, when such a concentrate reacts with sulphuric acid to produce the fertilizer.

2.2 The Production Steps

Lets describe such **production steps** and their **discards**, for the purposes of this presentation, identifying **four** steps, namely **extracting**, **processing**, **fabricating** and **manufacturing**, as follows:

- **extracting step**, i.e., the mining and beneficiation of the ore to a commercial concentrate. The **losses** are dependent upon the mining method (open pit, cut-and-fill, room-and-pillar, etc...) and beneficiation techniques (gravity separation, flotation, etc...); the **effluents** generated are CO_x NO_x from machinery and equipment, process waters and contaminated freatic waters, particulate material, and earth moving disposals/rearrangements;
- **processing step**, i.e., the extractive metallurgy or chemical operations to convert a concentrate into a metal; **losses** are depend upon the chosen technologies and skills involved (pyro, hydro and/or electro), and the **effluents** generated are gases (CO_X, NO_X, SO_X), liquids (heavy metals contamined waters) and solids (sediments, and heavy metals dusts);
- **fabrication step**, i.e., those operations devoted to produce rods, bars, sheets, etc...; the losses are scrap materials resulting from those operations, denominated "home

scrap"[11] endlessly recirculated, without any net loss of metal; the **effluents** are waste waters and industrial gases;

- **manufacturing step**, i.e., the application of mechanical operations for the shaping of metals by machining, stamping and forging, other than those of the fabrication step; the **losses** are parts of metal resulting from such mechanical treatments that does not produce the aimed product, being denominated "new scrap" or "prompt scrap" [11][13][14][12], which recycling is well organized and efficient[12][13]; the **effluents** are water vapors and industrial gases.

The utilized average metal recoveries figures from ore to metal, involving the **extracting** and **processing** steps are those of HASIALIS[15] and for the **manufacturing** step that of MAR[14]. It is acknowledged that this last figure is well obsolete for the U.S. where it was obtained in 1954(!); however in other parts of the world such figure might be still reasonably valid. As for those of HASIALIS they are average figures, and large departures from these figures, for a given particular case, do exist.

The **production steps**, as indicated, are all illustrated in Figure 1. Such a flowchart, or Sankey diagram, helps to seek solutions related to the **discards** involved in each production step. A similar chart might be attempted in terms of overall mass flows (MC's), if defined for each production step, resulting in more impacting figures, since earthmovings, then, would be included.

Tunneling into **each** of the aforementioned **four** production steps, a clear picture, hopefully, will then be achieved. Lets try that!

For this, some explanations are needed to follow Figures 1 the remaining Figures of the text:

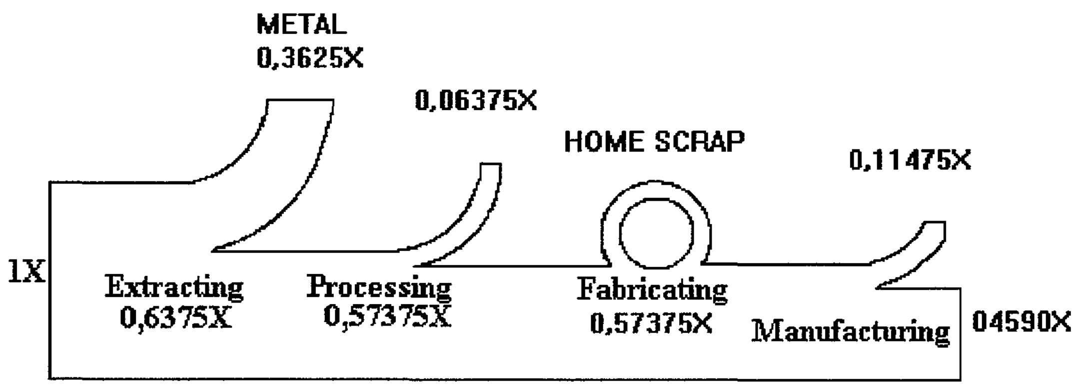

Figure 1. The production steps

X = the metal content of the *"in situ"* ore

L_E = is the **loss** in metal resulting in the extracting step, and is equivalent to 0,3625 X.

P_E = is the **product** in metal originated from the extracting step, and is equivalent to 0,6375 X.

L_P = is the **loss** in metal resulting from processing, and is equivalent to $0,0637^{\underline{5}}$ X.
P_P = is the **product** in metal resulting from processing and is equivalent to $0,5737^{\underline{5}}$ X.
L_F = is the **loss** metal resulting from fabrication and is equivalent to O X (endless recirculated).
P_F = is the **product** in metal resulting from fabrication, and is equivalent to P_P.
L_M = is the **loss** in metal resulting from manufacturing, and is equivalent to $0,1147^{\underline{5}}$ X.
P_M = is the product in metal resulting from manufacturing.
E_i = is the **effluent**, generated in each stage.

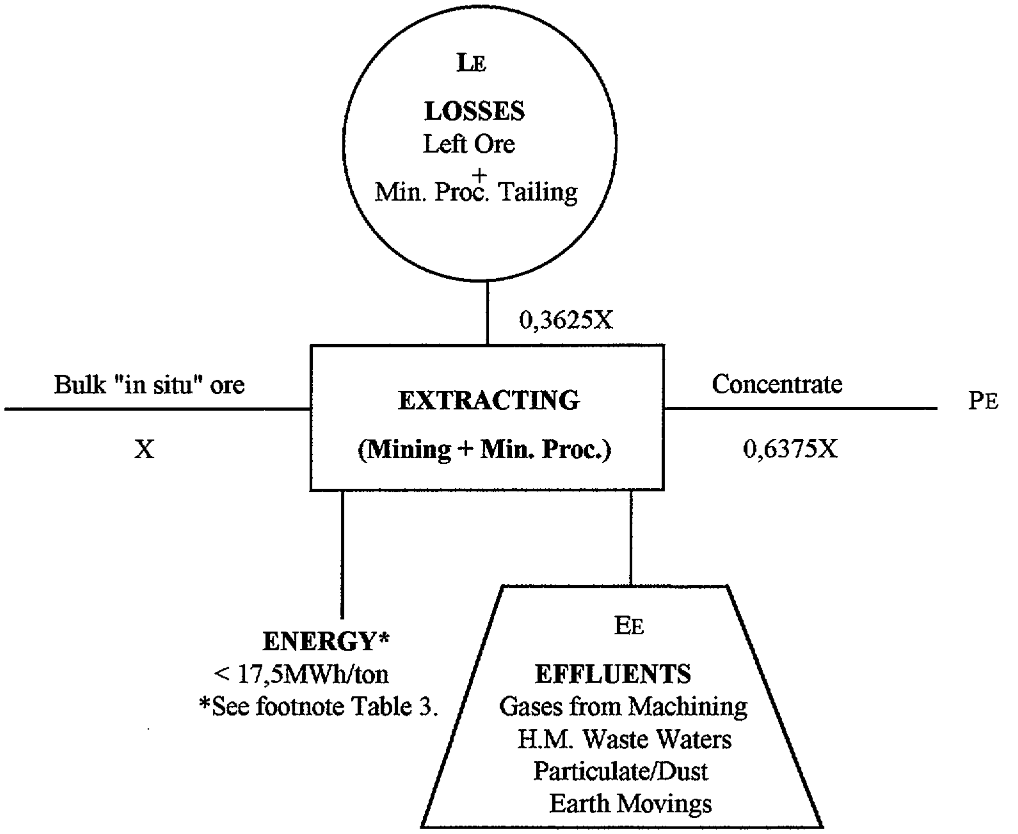

Figure 2. Income/outcome of the **extracting** step.

2.3 Identifyable environmental impact and prospects in the extracting step

From Figure 2:

A. **Energy:**

Taking up of energy. There are technical rooms for improvements. Figures in kWh (thermal), per tonne of primary metal, as reported in ref. 16; Al (10,175); Cu (17,420); Zn (1,240).

B. **Losses:**

B.1 Left ore, function of cut-off and mining method, there are technical rooms for improvement.

B.2 Mineral Processing tailings, rooms for gains pending on improvements in the next step (processing), since commercial grade concentrates are inputs to a given processing technology.

C. **Effluents:**

C.1 Mining, earth moving impacts associated to land reclamation; rooms for improvement based upon compromises between legislation (function of social pressures) and costs of reclayming. Physical disturbances are permanent; dust

C.2 Mining: gases from machinery and equipment (as well as noises and vibrations), there are technical rooms for improvement.

C.3 Mining: disruption of water regimes. Little room for improvements in present day mining methods.

C.4 Mineral processing: process waters and dust, still technical rooms for improvement.

C.5 Mineral processing: tailing disposals, solids, and control of acid generation.

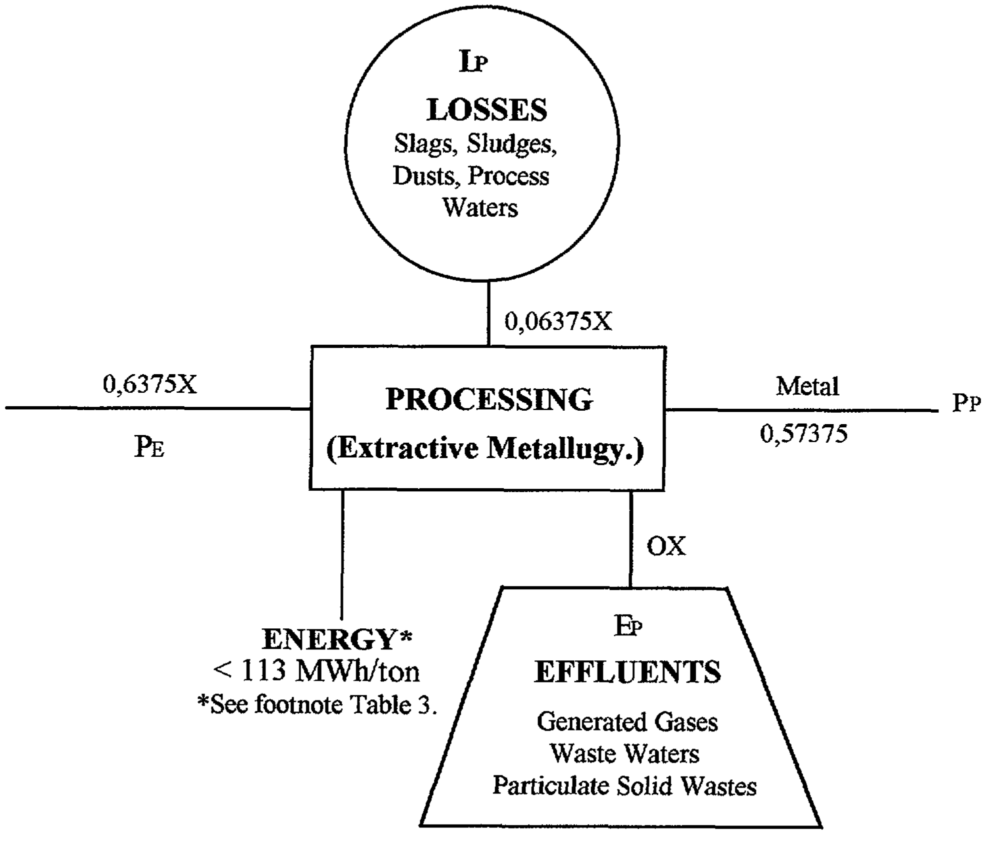

Figure 3. Income/outcome of the **processing** step.

2.4 Identifiable environmental impacts and prospects in the processing step

From Figure 3:

A. Energy:

Taking up of energy. There are rooms for improvements. Figures in kWh per tonne (thermal) as reportes in ref. 16; Al (35,384); Cu (26,520); Zn (17,560); Mg (103,000). Other figures are reported for Al and Mg if hydro-based power is available (much lower figures).

B. Losses:

Left metal as function of the process technology utilized, skills and legislation. There are rooms for improvements, specially those devoted to recover metal from slags, sludges and dusts of existing technologies or new technologies based on decreasing the number of operations/equipment stages (i.e., continuous converting for Cu and the still pending solution to the red mud problem in Al.).

C. Effluents:

Generated process gases (CO_x, NO_x, SO_x); waste waters after eventual removal of metal(s) from process waters; particulates throughout the processing stages and solid wastes other than slags, sludges, etc... (for the Al industry, for instance, spent potlinings, drosses, electrodes, etc...),still rooms for technical improvements.

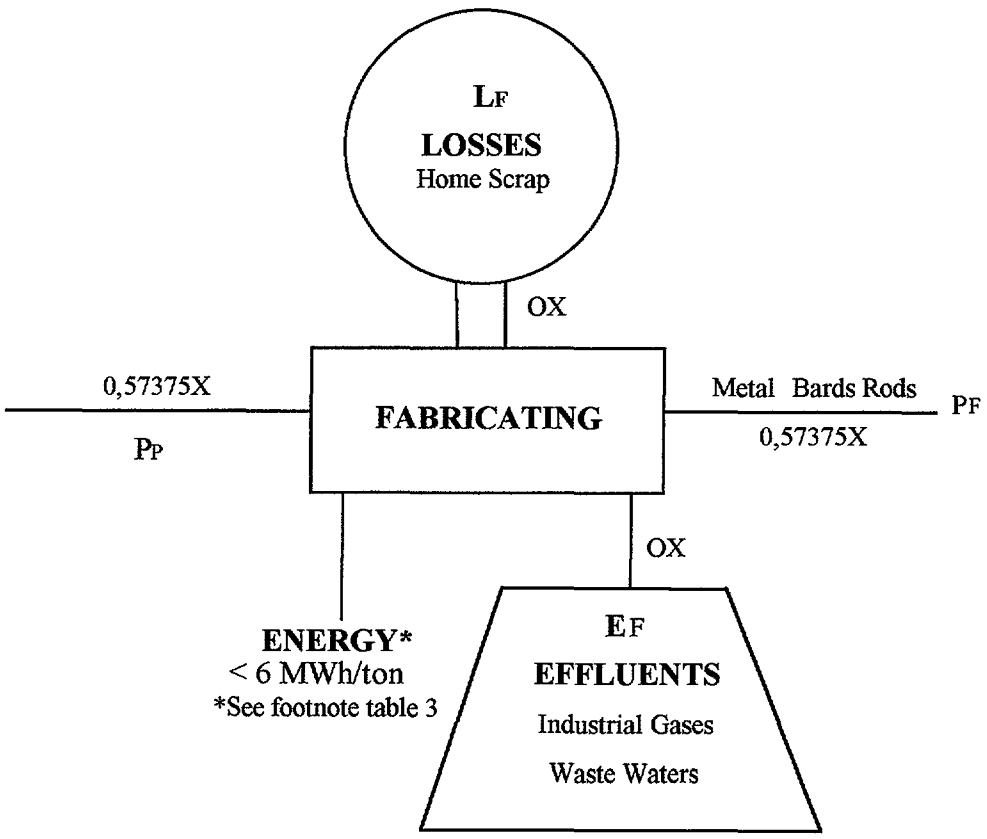

Figure 4. Income/outcome of the fabrication step.

2.5 Identifiable environmental impacts and prospects in the fabricating step
From Figure 4:

A. Energy:

Taking up of energy. There are rooms for some improvements. Figures in kWh/tonne (thermal), as reported in ref. 16; Al (4,937); Cu (5,970); Zn (1,492).

B. Losses:

Generation of home scrap, no net losses. However, rooms to reduce such generations as fabrication operations/equipments become more efficient.

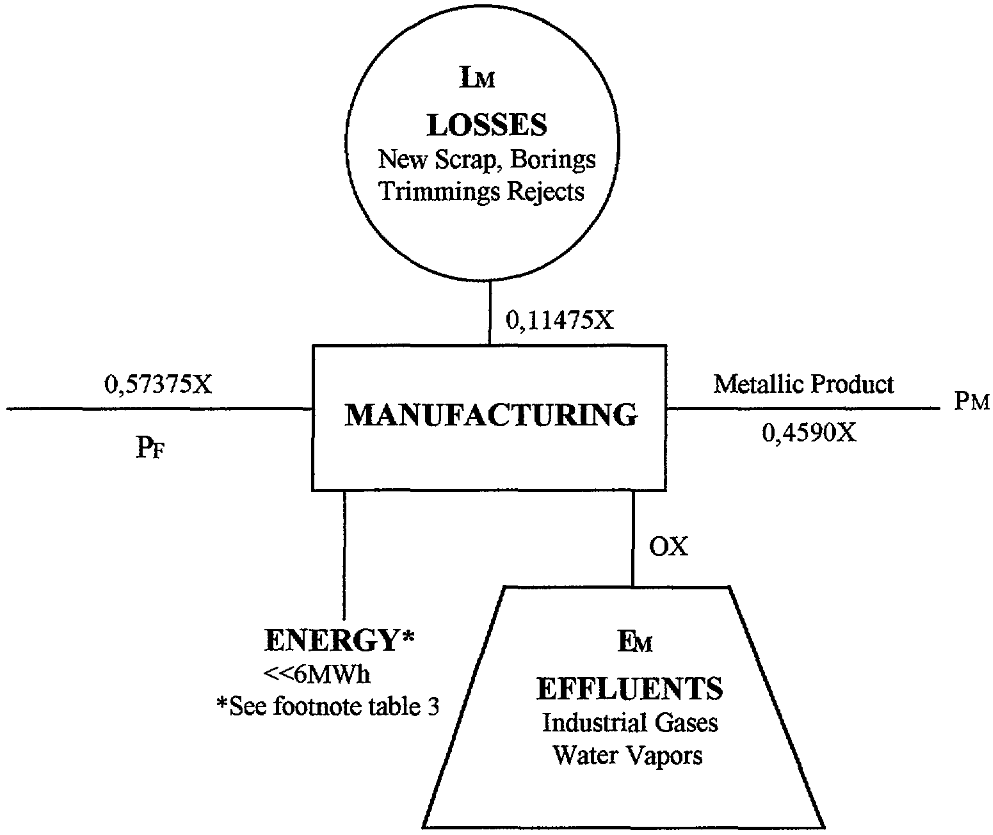

Figure 5. Income/outcome of the manufacturing step.

2.6 Identifiable environmental impacts and prospects in the manufacturing step
From Figure 5:

A. Energy:

Quite variable depending on the particular metallic product through forging, stamping and machining. Much less than any other of the previous production stages.

B. Losses:

They are the so called new scrap that usually goes to secondary production.

C. Effluents:

Industrial gases and water vapors.

3 Role of the hydrometallurgist

For an account of the role of hydrometallurgy in achieving sustainable development the interested reader refers to CONARD[17], where acidic mine drainage, metals removal from waste streams, arsenic management, reduction of gaseous pollutants and energy conservation, cyanide destruction, waste processing and product recycling are matters discussed through selected examples of hydrometallurgical technologies as applied to a better environment.

For those interested in research and novel techniques in hydrometallurgy and the aqueous processing of materials and industrial minerals, the recent review of DOYLE and DUYVESTEYN[18] is indicated, as well as that of NICOL[19] on electrometallugy.

If the interest is in energy requirements for manufacture of some non-ferrous metals and to process ingots, semifinished, and finished products, besides the already mentioned references, the reader may address to HANCOCK[20] and WHITTER & HOSKINS[21], as well.

The points to be raised, in this section however, are those of a general nature that may guide the hydrometallurgist towards a better understanding of the overall effect a given process has upon the environment, thus hopefully enhancing his/her chances of designing environmentally sound processes which in turn produce products.

Let's raise some major points in each of the **income/outcome** of the production steps, namely **energy**, **losses** and **effluents**.

3.1 Energy

Table 2 lists the energy taken up in each production step.

Table 2. Energy utilized in each production step

PRODUCTION STEPS	ENERGY (MWh [thermal]/ton*
Extracting	< 17.5
Processing	< 113.0
Fabrication	< 6.0
Manufacturing	<< 6.0

* Figures as mentioned, not averages but maximum, for a selected class of metals (Al, Cu, Zn, Mg, Ti)

The role of the hydrometallurgist is to seek for processes that minimizes energy consumption; his/her tasks are, thus, primarely devoted to the **processing step**, following the **extracting step** and, then, **fabrication** and **manufacturing**.

Indeed, the efficiences of processing operations have been compared by CHAPMAN & ROBERTS[13], appearing in other papers dealing with the subject of environment, metals production and energy such as YOSHIKI-GRAVELSINS, et al.[16], and FORREST & SZEKELY[22].

For the purposes of this article, the overall energy efficiences in the processing step, i.e. the energy take up by the whole step and not just the direct one, as compared to the thermodinamical Gibbs Free Energy, ###G, for that same processing step, are of interest, since they give a strong indication to where to search for process improvements, energywise. Table 3 lists some selected metals and their overall efficiencies[13][16].

Table 3. The **processing step** overall energy efficiences for selected metals.

PRIMARY METALS	OVERALL ENERGY EFFICIENCIES* (%)
Al	13
Cu	1.4
Zn	5.5
Mg	6.1
Ti	4.1

* Energy take up by the whole step, as related to the Gibbs Free Energy.

Of great concern to the hydrometallurgist is the **power source** of energy, i.e., hydro or coal based, due to the greenhouse effect. Such a concern was extensively dwelled by FORREST & SZEKELY[22].

3.2 Losses

Table 4 list the average metal losses to the environment, per production step.

Table 4. Metal losses to the environment per production step.

PRODUCTION STEP	AVERAGE METAL LOSSES*
Extracting	0,3625 X
Processing	0,06375 X
Fabrication	0
Manufacturing	0,11475 X

* Average metal loses as referred in the text.

Here, the hydrometallurgist has to focus his/her attention to the **extracting step**, first, and to a lesser degree to the **manufacturing step**.

It is worthy point out, however, that those average figures may be misleading. For each particular metal/substance that the hydrometallurgist is studing he/she has to refer to the actual values that are particular to the mining method, metal, process, skill, country, etc..., as previously discussed.

Nevertheless, mining and minerals processing techniques are, in general, responsible for the greatest losses. In-situ mining techniques, that usually refer to the injection of a leach solution through boreholes into the ore are to be taken into account whereas possible[17].

The losses of the **manufacturing step** usually goes to secondary recovery and besides the strategic/economic aspect to the enterprise itself, as discussed by CHAPMANN and ROBERTS[13] through the GER (gross energy requirement) concept, no major role of the hydrometallurgist is to be foreseen, since such efficiencies are rather linked to the mechanical/electronics/physical metallurgical aspects of the issue.

In the **processing step**, several improvements have been and are still made through process optimization and process improvements[16][17][18].

3.3 Effluents

Regarding the effluents, the discards to the environment are several assuming the liquid, the gaseous and the solid states, giving to the hydrometallugist an extraordinary opportunity and offering several challenges.

Table 5 gives a list of problems that seek solutions at each of the production steps, compairing in relative terms the land, water and air impacts; the relationship is made referring to acceptable environmental standards in OECD's countries and they may vary considerable from country to country and from metal to metal.

Table 5. Comparison between the impacts of the effluents in each production step.

PRODUCTION STEP	LAND	IMPACT WATER	AIR
Extracting	S	S	M
Processing	M###S	M###S	S
Fabrication	L	L	S
Manufacturing	L	L	L

L ### low impact
M ### moderate impact
S ### severe impact

For the identification of the specific problems that face the particular metal industry, the reader is referred, for instance, to references[23] and [24].

Thus the role of the hydrometallurgist in developing environmentally sound processes has to be focused on the **extracting step** (i.e., land disturbance, soil erosion, mine run-off water, water regimes, dust tailing disposal, revegetation, etc...) and the **processing**

step (i.e., acid generation, heavy metals effluents, disposal of solids, gas generation), primarely. For the specific techniques (biosorption, liquid-liquid exchange, electrowinning of dilute solutions, membranes, etc... see references[17][18] and [19]). Table 6, lists some environmental impacts associated to selected mineral industries.

Table 6. Major environmental impacts for selected mineral industries.

METAL	IMPACT
Al	Red mud slurry; HF; CO_2; tar pitch volatiles; spent pot linings; cyanide
Cu	SO_2; metal fumes; heavy metal effluents
Zn	Iron oxide; SO_2; Cd; heavy metal effluents
Mg	CHCs; dioxin
Ti	$FeCl_3$; volatile chlorides; CO_2
Ni	Metal carbonyl; heavy metal leachate;severe dusts and particulate emissions
P_2O_5	Gipsum, water consumption and disposal; radiation (whenever present)

4 Minerals as Environmental Helpers

Up to here, the discussions were focused on the effects on the environment due to the utilization of minerals.

It is worthy remember, at least, that minerals may be viewed not just as vilains, but as well as helpers to the environment. Tightening environmental legislation are forcing that the rules governing waste water treatment and disposals be stricter; bentonite, lime, soda ash, magnesium hydroxide and zeolites are reported as environmental helpers in the literature[25] and open, as well, a vast field of investigation to the hydrometallugist, or mineral technologist as a whole.

5 Conclusion

It is hoped that the presentation of the **production steps** always present in the production of materials, namely, **extracting**, **processing**, **fabrication**, and **manufacturing** that incorporates the incomes/outcomes for each of these steps, namely, the **input/output** of **materials**, **energy**, **losses** and **effluents**, and their discussions, have helped the hydrometallurgist to choose the relevant areas of his/her research interests from the sake of designing environmentally sound processes to promote sustainability.

No universal claims, regarding the average or maximum figures presented throughout the text, are made; rather the figures are for illustrative purposes in an attempt to point out some guidelines that the hydrometallurgist may take in his/her suggestions of scientific and societal conditions to achieve sustainability.

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SUSTAINABLE DEVELOPMENT: CONCEPTS, SCENARIOS AND STRATEGIES FOR R&D

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INTRODUCTION

This paper presents the contemporary debate about the concept of sustainable development, also presenting two possibles scenarios and their effects on technological research. This consideration is appropriate because the term sustainable development has been taken by different groups of the society: environmentalists, politicians, scientists and others that refer to it as an aprioristic concept. On the one hand, the frequent use of the term is important as it shows acceptance but, on the other hand, the absence of a clear definition results in a lack of content. Therefore, it is often misunderstood as a mere environmental concern. This brings serious consequences when we need to define action policies because the conceptual unclearness leads to a an irresolution of the ways to take. The concern over the concept of sustainable development is not only academical but it is also related to the practice without which the term sustainable development lies empty and useless, reduced to a modernizing rhetorical resource.

The need of the proposition contained in this paper is that this debate are gaining the media and forcing a public opinion commitment that eventually leads to social pressures against changes in legislation that, in turn, are translated into more restrictive codes of behaviour of certain economic activities.

This paper is divided in four parts: first, the concept according to the International Organizations; second, the theoretical concept; third, the scenarios and finally, the fourth part the rebatment of the scenarios on R&D.

THE CONCEPTS ACCORDING TO THE INTERNATIONAL ORGANIZATIONS

Discussions about the concept of sustainable development go back to the 70s when, during the Founex meeting (Founex UN/EPHE, 1972) a new development option was outlined, incorporating "environmentally suitable strategies for fostering more equitable socioeconomic development"[1], called ECO-DEVELOPMENT.

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[1] SACHS, IGNACY. Strategies for the 21st Century. In DESENVOLVIMENTO SUSTENTÁVEL. BURSZTYN, MARCEL. Editora Brasiliense, 1993.

SUSTAINABLE DEVELOPMENT: CONCEPTS, SCENARIOS AND STRATEGIES FOR R&D

The 1972 Stockholm Declaration and the 1974 Cocoyoc Declaration reasserted the concept and the proposals of eco-development. However, it was in 1980 in a document entitled "WORLD CONSERVATION STRATEGY", prepared by the International Union for the Conservation of Nature, that the words Sustainable Development were acclaimed.

The concept arose closely followed by strategies of action for its implementation in this sense it is not a theoretical concept strictly speaking, but is instrumental.

It is in this guise that it is criticized, according to Baroni, by Khosla and Sunkel. Khosla criticizes the Stockholm Declaration because it establishes a *"strategy confined to live resources, focused on the need to maintain genetic diversity, the habitats and the ecological processes and incapable of dealing with controversial matters related to international political and economic order, wars, as well as armament, population and urbanization problems."* [2]

Sunkel makes a second criticism of the document to the effect that the strategy presented *"was essentially concentrated on the supply side, assuming that the structure and the level of demand were autonomous and independent variables, and ignoring the fact that 'if a style of sustainable development must be pursued, hen both levels and particularly the demand structure, must be fundamentally changed".* [3]

A series of Workshops were held and Reports were produced by international organizations, as a way of giving substance to the term and to establish principles. Among the most important is the United Nations Programme for Environment (PNUMA) which supports the document "World Conservation Strategies".

And, finally, The World Commission on Environment and Development (WCED) took up the concept of sustainable development as being development that satisfies the needs of the present without jeopardizing the *abilities of future generations to satisfy their needs.*

It is the same Commission (WCED) that elaborates the first document which tries to express the concept concretely: the Brundtland Report, presented at the UN General Assembly in 1987.[4] The Report exhaustively defines the so-called *"imperative strategies".*

The great merit of this report seems to be the effort to make the concept of sustainable development operative, expressed in synthesis in the imperative strategies, as well as to seek to establish itself as a platform for international

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[2] Baroni, Margaret. Ambiguities and shortcomings of the concept of sustainable development. In Revista de Administração de Empresa. São Paulo, 32 (2). April/June, 1992.

[3] Baroni, Margaret. Op. cit.

[4] THE REPORT OF THE WORLD COMISSION ON ENVIRONMENT AND DEVELOPMENT. Sustainable Development. A guide to our common future. Geneve 1990.

negotiations. For Baroni, the greatest criticism is that referring to the withdrawal of the *"requirement established originally in 1986 at the Ottawa Conference, regarding the need for equity and social justice for sustainable development".* [5].

THEORETICAL CONCEPT

In literature that bothers to make a more theoretical analysis, basically two concepts of sustainable development are found, according to the interpretation of development and sustainability or of the binomial development/environment.

For Baroni, for example, when seeking to define development and sustainability, the different and even contradictory concepts are quite clear. Whereas for Acselrad, the differentiation of the concept of sustainable development emerges when the environmental crisis is interpreted. He says: *"The first (meaning of the term) recognizes the market's inability to respect the environment's limits and proposes the creation of signaling elements that would make it possible to assure the continuity of the capitalist development model. The second line of interpretation sees the environmental crisis as a manifestation of a crisis in the capitalist development model and finds ways for overcoming it in the introduction of changes in the structure of power over natural resources."*[6]

In fact, both authors share the opinion about the existence of two ways of interpreting the term sustainable development and come to the same conclusions along complementary routes. As a matter of methodological option, we are using the differentiation of the term proposed by Baroni, because it will allow the two viewpoints to be distinguished more precisely.

In the first meaning of the term sustainable development means economic growth. For this viewpoint there is no contradiction between growth and sustainability because *"governments concerned with long-term sustainability do not need to limit the growth of the economic product as soon as they stabilize the consumption of aggregate natural resources".* Still adhering to this viewpoint, a more positive argument in favor of economic growth starts from the presupposition that poverty is largely responsible for environmental degradation. The elimination of poverty would be a condition for ecological sustainability and the role of economic growth in that process would be fundamental, with the need to change the quality of such growth. Baroni says *"It is argued ... that economic growth is absolutely necessary for sustainable development."* [7]

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[5] Baroni, Margaret. Op. cit.

[6] Acselrad, Henri. DESENVOLVIMENTO SUSTENTÁVEL: A LUTA POR UM CONCEITO. REVISTA PROPOSTA N° 56 MARÇO 1993.

[7] Baroni, Margaret. Op. cit.

For this viewpoint, social objectives such as improving the quality of life and the end of poverty are objectives of sustainable development, although based on an operational strategy of economic growth.

The term sustainability, for this meaning of sustainable development, contemplates basically the ecological dimension, and not the social policy. Hence, it would be *"the existence of ecological conditions necessary for providing support for human life at a specific level of well-being through future generations."* [8] Acselrad, on this point, says: *"Concerned with sustaining the basis of natural resources for future production, this concept proposes the introduction of a new environmental restriction (...). Ignoring the conflict for control over natural resources, it seeks to create conditions for saving natural resources, without, however, considering the sociopolitical conditions that govern the control and the use of such resources.* [9]

The same author considers that the concept of sustainability for this viewpoint has evolved from the simple intention to preserve natural resources to identificate the environment as a capital in terms of accounting system.

David Pearce elucidates this thinking: *"sustainable is the development which considers the expansion of environmental capital in proportion to the population growth" and "Sustainable is the development that reinvests in the environment to assure its conservation and its recovery"*. [10]

Nature, which until then had provided the working capital (raw materials and input) and free services (water, soil and air for disposing of waste), then begins to provide fixed capital elements, that is, those that need to be conserved throughout the productive cycle. This new viewpoint opted to appropriate economic concepts through analogy because. In this case to distinguish the environment like the other production factors the elements of nature need to have an owner.

For Acselrad, the *"diagnosis of this line of thought says that the roots of the environmental crisis are in the fact that capital considers the environment to be a free asset, and environmental damages as externalities (...) this system sanctions only what is the subject of private appropriation (...) all damage caused to the public interest is not expressed in prices. In this sense, the environmental crisis results from the inability of capitals to calculate the environmental damages that their activities generate (...). The solution would be to correct the shortsightedness of entrepreneurs and start seeing the*

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[8] Lelé, S.M. Quoted by BARONI, MARGARET. Op. cit.

[9] Acselrad, Henri. Op. cit.

[10] Op. cit.

environment as an economic asset, with a price. (...) what is put forward as a solution ... the 'internalization of environmental costs."[11]

The second meaning of the term sustainable development sets development against economic growth, considering sustainable growth to be a contradiction. For this meaning, development would therefore involve a socially desired phenomenon assuming two basic objectives: the end of poverty and better distribution of income, which are not very unlike the traditional development declared goals. The so-called limitation of the ecosystem's ability to support, which appears in the two senses of development, has a special meaning for the latter, involving the redefinition and even limitation of humanity's consumption habits, which would be determined socially.

The term sustainability, for this meaning of sustainable development, assumes the concept of ecological, political and social sustainability, and in this sense, for both concepts, there is the matter of environmental rationality, strange because it is new, and which opposes or aggregates to the traditional economic rationality. The difference lies in the how strategies should be established for attaining sustainability. In this meaning, what can be sustained, how and for how long, are answers determined socially in a process of participation of society and even of social consensus. Hence, while for the first meaning of the concept of sustainable development the internalization of environmental costs depends upon the existence of basic instruments which make it possible to define parameters of the limits on the ecosystem's ability to support, and also the "measurement" and defining the problems of environmental damage, for the second meaning the nonexistence of such instruments does not represent such an important technical-scientific barrier, to the point of significantly interfering either in the debate or in the definition of strategies for action.

For this latter viewpoint, the origin of the environmental crisis is exactly in the model of development and in the way of using nature that it implies. In capitalist logic, the utilization of natural resources is the result of the private economic reckoning of companies, which only consider those mercantile elements that are expressed through the prices system - such as raw materials and land. The conditions and the global equilibrium of the environment are not considered. In this way, sustainable development would only be possible if the limits on the control of capital are put on the use of the environment, through a predominantly political action.

It can, therefore, be seen that sustainable development would involve a change, or even societal rupture.

For Lélé, quoted by Baroni, the prevailing interpretation of sustainable development is "*a form of societal change which, in addition to the traditional development objectives, has the objective or the restriction of ecological*

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[11] Op. cit.

sustainability. Obviously, this is not independent of other objectives (traditional) of development. Trade off normally have to be made between the extent and the rate at which ecological sustainability is attained vis-à-vis other objectives. In other cases, however, ecological sustainability and traditional development objectives (like satisfying basic needs) can mutually strengthen each other.[12]

SCENARIOS[13]

The scenarios constitute methods of anticipation which indicate ways to future development. In this text, two large alternative scenarios were adopted: Scenario I, inertial or tendential, which is characterized by the continuity of present day dominant tendencies and another of change or rupture, Scenario II, based on the discontinuity of present courses and wider ranging transformations. The time horizon considered is the year 2015.

SCENARIO I

This scenario describes and explains the results of continuity and the expected evolution of the main tendencies noted at present with regard to factors that are critical in the future of the materials.

The standards of consumption and production in the industrialized countries undergo continual pressure from the environmental groups. As a consequence, there is a growing incorporation of new technologies that increase energy efficiency, intensive recycling of materials and the substitution of scarce materials, specially rare metals, with abundant materials.

The tendential scenario adheres to the modernizing line of globalization of the economy, imposing a model of competitive insertion under the terms dictated by the *"world class standard"*[14], in which the more dynamic sectors are those that are more intensive in technology[15]. Control over the new technical production paradigm (new ways of organizing production, greater flexibility in

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[12] Baroni, Margaret. Op. cit.

[13] This item is an adapted extract from the paper: Sustainable Development and Microelectronics in Brazil, by Heloisa Medina, Maria Laura Barreto and Ivan da Costa Marques, 1994.

[14] John Sequeira, in "World Class Manufacturing in Brazil: A Study of the Competitive Position", presented by the American Chamber of Commerce and FIESP (Federation of Industries of the State of São Paulo), defines: World Class standard is that which today's best business is able to achieve ... In the current environment of "continual improvement" the better businesses are constantly redefining what is understood by "world class". That is, the parameters are always changing.

[15] Such as for example, at present, the electroelectronic, aerospace, information technology and communications sectors.

productive processes and intensive use of new technologies) is exercised by the developed countries, to by-pass environmental restrictions and to exploit their availability of natural resources. Technological innovation is seen only as a competition factor, that is, technology is conceived as a strategic element to be incorporated into products so as to increase their penetration in world markets.

The market is the conductor of the logic of the economic growth process, where external competitiveness is the basic indicator, with little emphasis on social problems. Political and socioeconomic inequalities are heightened between the developed and developing nations, as well as in the interior of the less developed countries, where levels of absolutely poverty get worse.

In international trade, there is a prevailing tendency to greater liberalization with regard to industrialized products. With the new technical production paradigm, there is an accentuated reduction of trading in primary products and particularly nonrenewable products.

The internationalization of markets, however, heightens the concentration of trade among industrialized countries, strengthening integration in the regional economic blocs, and increasing the North-South lag. Technological development, pressured by environmentalist interests, has a strong reducing impact on the exports of the developing countries which are mainly concentrated on primary products. Without foreign exchange revenues, these countries are not participating in the growth of world trade. The access of the countries of the South to the new technologies is restricted on account of their strategic value in global competition.

Another significant aspect in this scenario is its environmental protection model. It differs, firstly, because it fosters a process of imposition, where the emphasis is put on the exercise of authority, particularly through regulatory mechanisms that inhibit and penalize. Secondly, in this scenario, the technological capability necessary for dealing with environmental problems remains virtually concentrated all in the developed countries, which make a point of exercising a monopoly over such technologies.

In this context, however, there are less possibilities of environmental protection measures really being effective at long term, since they are carried out "from the top downward", without being essentially rooted in social participation and specific ecological awareness for each local context.

In connection with this model of environmental protection, it is noted that there is a predominance of a "cultural mimicry" distinguished by a dual reality: On one side, a First World where the consumption standards derive from a particular culture and are compatible with the rates of growth and of spatial distribution of their populations; and, on the other, a Third World that yearns after the First World's consumption standards. In this way, the First World's style of society and values are hegemonic and conduct all the appraisals of level of development and quality of life, specially with regard to the ecological issue.

In the meantime, while the First World seeks to keep up its standard of living, with some incremental alterations already under way in its consumption standards[16], it tries to prevent the less developed countries from attaining this standard of living, and to stop their economic exploitation of their natural resources, alleging that the environment must be preserved.

In this scenario, the State's role is marked by the fact that it is in the hands of two large interest groups: that of the big companies and, on a smaller scale, that of the international environmentalist movements. The financing criteria for sustainable development are dictated by international organizations.

The feasibility of the tendential scenario has its bases in the political-economic hegemony of the developed countries, which make their proposals prevail, dictating the rules and institutional models that govern international affairs. They preponderantly establish and benefit from pacts, blocs and political and economic alliances among nations. This scenario represents the strengthening of the "hypercolonialist" positions in the world context, the reduction of the sovereignty of States of the developing countries and the strengthening of the role of transnational capital.

The political support of this model of international inequality is based on the performance of the industrialized countries. The new technical production paradigm applies, essentially, to the industrial sector which - because it saves labor - causes technological unemployment. To avoid the political and social consequences of unemployment, governments are obliged to direct their economies toward greater verticalization, fostering technologies that take advantage of their natural resources to use up the excess workers in primary production.

The peripheral countries are going through serious economic difficulties. Their exports are faced with the barriers of the regional blocs, their products are in sectors where there is declining demand and they have no access to technology. In view of the strong social tension deriving from the growing socioeconomic disparities and from the strengthening of ethnic movements, there is a proliferation of regional military conflicts, mainly involving peripheral countries. This political instability involves the industrialized nations which, through international organizations, are called upon to mediate in the conflicts and receive their refugees.

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[16] With regard to the environmental issue, the developed countries still are, with their development model, the greatest polluters. All the same, some attenuation of this process has already been felt since the 70s, when the crisis of the model began at world level, such as: less intensive use of natural materials, greater efficiency in the productive process with regard to raw materials and energy input in general, greater emphasis on recycling, of products and materials, among the principal changes. That is, the change began on the production side, exactly to avoid the level of material consumption of the developed societies being affected.

SUSTAINABLE DEVELOPMENT: CONCEPTS, SCENARIOS AND STRATEGIES FOR R&D

In view of this situation of economic and social inequality and growing conflicts, migrations from the less developed countries to the more developed countries grow in volume, increasing their unemployment problems.

In spite of the pressure from the international organizations and environmentalist groups, the developing countries do little or nothing to alter their standards of natural resources exploitation, nor to restrain the degradation of the environment. The environmental consequences, of the rain forests disorderly occupation, of the atmospheric pollution caused by heavy industry and the military conflicts, are worldwide. The environmental gains achieved in the industrialized countries are outweighed by the environmental degradation in the peripheral countries.

SCENARIO II

This scenario represents both a deep discontinuation of the historic tendency of competition and a global political economic and technological restructuring. These changes favor a more equitable and balanced international development.

In this scenario, the logic of the market coexists with the logic of its control and social satisfaction, where the principles of reciprocity and redistribution in the conducting of economic and social activities are strengthened. Economic sustainability is provided by the pursuit of efficiency in macrosocial terms, and not only according to microeconomic profitability criteria. The growth rates are not so important as absolute indexes, but rather seen as being related to the social and spatial distribution, of the population's quality of life. Economic and social development is fundamentally the result of production focused on raising the majority of the population living standards and not to satisfy the sophisticated standards of those who are already part of the select consumer market. In this way, the market grows by absorbing those at present excluded.

In this scenario there is in fact a depolarization in the present pattern of North-South relations, as much in terms of trade as in financial and scientific-technological affairs. The more developed societies are able to provide the less developed societies with funds to facilitate the acquisition of the linguistic, educational and professional attributes necessary for keeping up with them and also to influence in the redirecting of the *"global development model"*.

Access to science and technology, as well as the development and redirecting of such knowledge, are the highlights of a new standard of international cooperation, particularly because of the need for new ways of using natural resources and of adapting to different ecosystems, in order to achieve environmentally healthy development.

In this scenario, there is a greater balance of forces between the different players, while the dominant political force comes from the civil society, which begins to have more availability and access to information.

The environmental protection model is marked by encouragement and by making use of opportunities offered by a new paradigm that is global rather than ecologically healthy, motivated primarily by endogenous ecological awareness adapted to each regional and local context in accordance with each other. It is this new awareness that alters the market conditions which, in their turn, point to environmentally suitable productive practices. At the same time, technical-scientific capability in the environmental area of developing regions is strengthened by the cooperation and by the financial support of the more developed regions.

In the context of scenario II, competition is replaced by an interpretation of the concept of "competitiveness", which gains force in the relations it establishes with other concepts (equity and sustainability) and social values (democracy, human rights and social participation. In this interpretation, competitiveness is not interchangeable with competition, but also it has not yet been able to manifest its own status as a concept.[17]

The new productive paradigms may be described as a "partnership" between the developed regions and those that are developing technologically. The consumption and production standards will be profoundly altered in favor of energy efficiency, diversification of sources of energy (specially renewable sources), greater durability of products, recycling of materials, the substitution of scarce materials by abundant materials, and by the miniaturization of components and products. In fact, scarce natural resources are being progressively replaced by intellectual resources, with much benefit for the protection of the environment.

Finally, attention should be drawn to one aspect which could be called "unfinished" in Scenario II, whose main difficulty results from the generalization of promises of social participation, equity and control of the environment. In the case of Scenario I, if the social security and unemployment aspects are not embodied, in rebuttal the actual continuity of the current economic rationality points to what should be done at a micro and even sector level. Whereas in Scenario II, as the paradigmatic behavior of the competition inclines toward a more complex competitiveness, the routes of this "world model-to-be" are less clear even at the micro and sectorial level.

SCENARIOS AND IDEOLOGY

In the different approaches presented we can visualize that, at the present, there is an ideological struggle to appropriate the term sustainable development. Actually, this struggle is not explicit but it can be well observed in the various

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[17] Müller, Geraldo, *A Competitividade como um Caleidoscópio,* São Paulo Perspectiva, V.8, N.1, pp. 23-32, 1994.

documents issued by the international organizations and in the literature concerned with a conceptual definition. A deeper discussion about the aspects of the different definitions presented is usually avoided - especially at the level of international organizations - because an agglutinating concept of sustainable development is intended. The concept should bring together the various interests of the UN countries and not separate them, as the old and well-known Third World discourse or even the North/South dialogue. This aspect could explain the lack of debate upon the term sustainable development.

It is to notice that the implementation of the sustainable development could only be possible if it were global - at least according to one conception. It would not be possible the existence of the sustainable development in one single country or in a single group of countries. Moreover, for those who adopt this conception, the wealthiest countries should contribute to the development of the poorest ones by providing them with financial, technological and human resources, lowering, in this way, their own consume standards. All these objectives would only be achieved by means of a global political commitment. To reach this political commitment the concept of sustainable development should agglutinate the interests rather than separate. Actually, if something can be considered agglutinating, it is not the concept of sustainable development, but its cause: the environmental crisis. Thus, the sustainable development would be seen as a necessity, for the lack of an option before the imminent environmental crisis. The sustainable development would be the only alternative for rich and poor countries to avoid a crisis that would equally affect them. While the ways to reach the sustainable development or even the variables of sustainability are discussed, the disagreements on the concept or on the understandings of the term seem clear and even polarized, as we can observe in topics 2 and 3 of the present paper.

The two scenarios may be viewed as shown in Table 1.

SCENARIO 1	*SCENARIO 2*
Social dimension: Social aspects are not stressed; growing inequalities of income among individuals and nations.	**Social dimension:** Involving more equality in the distribution of income property and access to goods.
Economic dimension: Emphasis in international competitiveness imposed by the technical standards of production in the developed world.	**Economic dimension:** Macro-social factors overcome micro-economic profitability, as decision criteria, mainly for improving well-being and valorizing work.
Ecological dimension: Emphasis on preservation and recuperation of the physical	**Ecological dimension:** Creative use of each ecosystem's potential; rational use/conservation of

environment through technology. Environmental cost penetrate the decision criteria.	energy and natural resources; reduction of the volume of discards and pollution.
Political-institutional dimension: "Global commitment" is imposed by the proposals, rules, and institutional models of the developed world.	**Political-institutional dimension:** "The global commitment" is achieved by a new agreement, among policy-makers and domestic and international agents.
Cultural dimension: The consumption standards in the developed world are maintained and used as reference for the rest of the world, in spite of the modifications in way of life caused by environmental factors.	**Cultural dimension:** The search for sustainable solutions is mainly oriented by the increasing importance of local conditions, looking for better standards of life all over the world.

THE REBATE INTO R&D

The rebate to the strategies of the respective R&D needs are shown in Table 2.

SCENARIO 1	*SCENARIO 2*
Social dimension: Emphasis on materials intended for increasingly selective and sophisticated markets, and highly specialized jobs.	**Social dimension:** Emphasis on materials intended for meeting social needs and generating accompanied by training local labor.
Economic dimension: Emphasis on materials intended for increasing competitiveness in the external market.	**Economic dimension:** Emphasis on strategies for materials that produce a positive effect one earnings and employment.
Ecological dimension: Emphasis on substituting materials that are scarce in the developed countries.	**Ecological dimension:** Emphasis on materials based on renewable or abundant natural resources, according to the local availability.
Political-institutional dimension: Technological control by the developed countries.	**Political-institutional dimension:** International technological cooperation in materials field.
Cultural dimension: Materials based on consumer	**Cultural dimension:** - Materials based on endogenous

standards imposed by the globalization process.	natural/mineral reality; - Materials based on endogenous S&T, business experience/capability; - Materials intended for the local consumption standards.
Spatial dimension: Spatial concentration of activities on materials.	**Spatial dimension:** - Materials that can be processed locally; - Regional coordination in the materials; - Balance in the territorial distribution of activities.

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The Mercury Problem in Amazon due to Mineral Extraction

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Abstract

Materials play a fundamental role in developing a nation. How deep such a role will depend upon the overall economy, as expressed through its own domestic industrial production and innovation capacity, its consumer demands, and, last but not least, its worldwide exchanging power.

In Brazil, particularly in the environmentally sensitive areas of the country, e.g. Amazon, Wetlands, etc., that accounts for the larger part of the national territory, the natural resources are an asset in providing the material bases for development. However, what are the environmental problems posed in developing mineral resources, and what is known of these ?

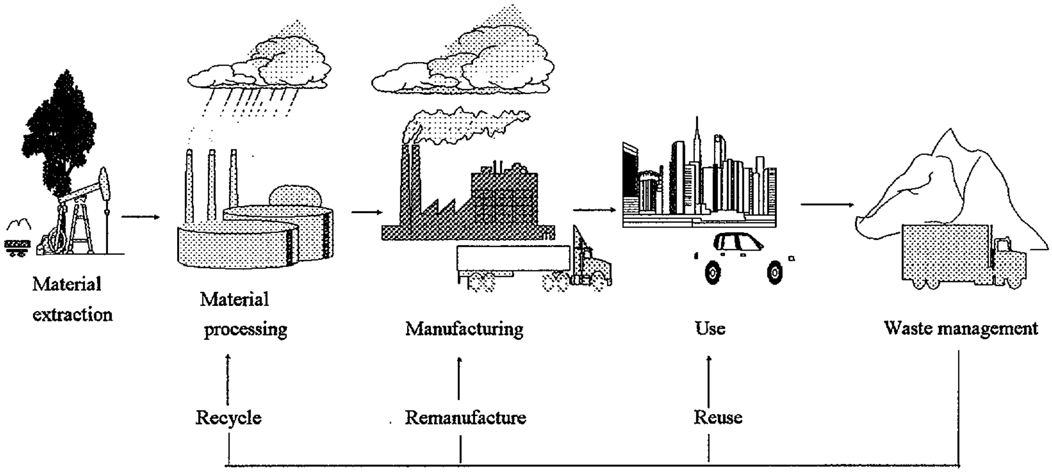
This paper tries to summarize some of these problems, with emphasis on gold and aluminium.

Introduction

Several are the stages of the product life cycle and the way they interact with the environment. Figure 1, illustrates, in a simple fashion, such a life cycle.

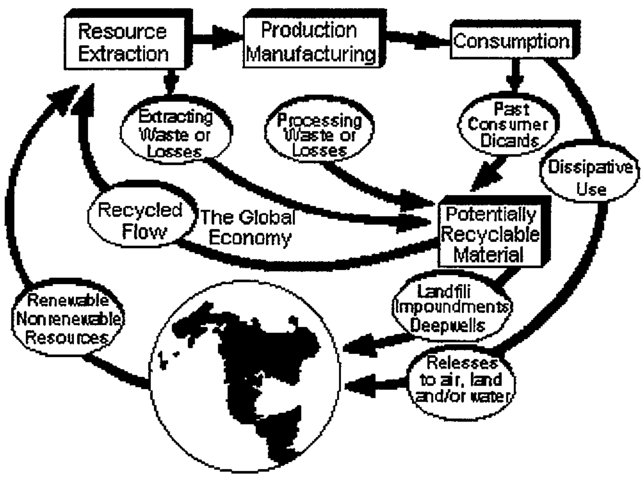
(*) Paper to be presented at "Mining and Metallurgy in a Changing Environment, University of Zimbabwe, Harare, Zimbabwe 3, 5 June, 1996.

Figure 1. Stages of Product life Cycle (1)



Such an interaction with the environment is inherent to the production processes due to the very fact that they require inputs from the surrounding (energy, ores, fuel, etc.) as well as, like the thermodynamic demon, their very presence interfere with the surroundings! Figure 2 shows such an interaction.

Figure 2. The Material Cycle (1)



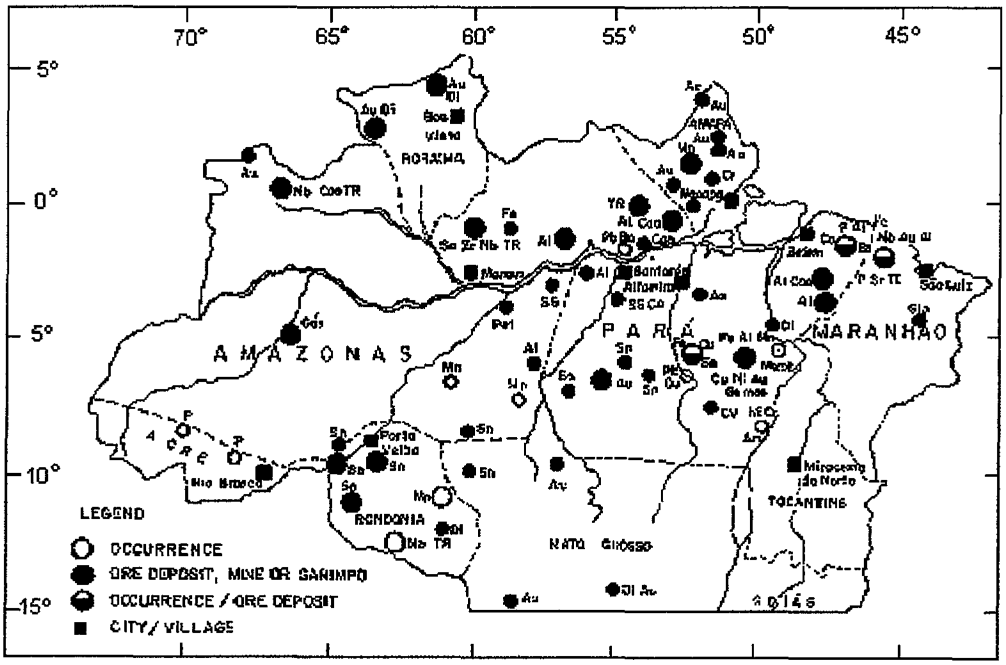
The stage that attention is given in this presentation is the mining and beneficiation one, identified as "material extraction", in Figure 1, as it relates to the sensitive areas, e.g. the amazonian region.

The main ore products extracted and commercialized in the brazilian amazon are iron ore, bauxite, alluvial gold, tin, caolim and to a lesser degree manganese. Large caolim project expansions are underway in the Rio Capim area (2).

The amazonic potential, however, seems to be much larger and has been reported in the literature (3-5). Figure 3 shows the mineral resources of the brazilian amazon.

In the wetlands, the world famous Pantanal, diamond, iron and manganese ores, as well as gold, predominates.

Figure 3. Mineral Resources of the Brazilian Amazon (4)



Environmental Impacts

A comprehensive study, under the Mining and Environmental Research Network, coordinated by the SPRU group at the University of Sussex, in England, and involving several organizations in Europe, United States, Africa, Asia and South America, was recently issued to the interested public, dealing with the brazilian aspects of mining/metallurgy and the environment (6).

Of the interest to the amazonic aspects of the discussion are the remarks made on the ALBRAS/ALUNORTE projects, belonging to an association of CVRD with the japanese, and the ALUMAR project of ALCOA in association to Shell/Billiton, dealing with the environmental concerns that were incorporated into the process design of the production stages. In this same study, coordinated in Brazil by the NAMA/USP group, a review of the environmental aspects of tin extraction, largely represented by the PARANAPANEMA group is given, as well as that of gold extraction in garimpos and mining companies.

The iron ore project of CVRD, located in CARAJÁS has been, as well, subjected to an overall analysis of its environmental sustainability, with very interesting experiences being registered (7).

If one tries to summarize some of the aspects linked to the production of the aforementioned commodities and the effects on the environment, Table I may be built.

Major Environmental Impacts

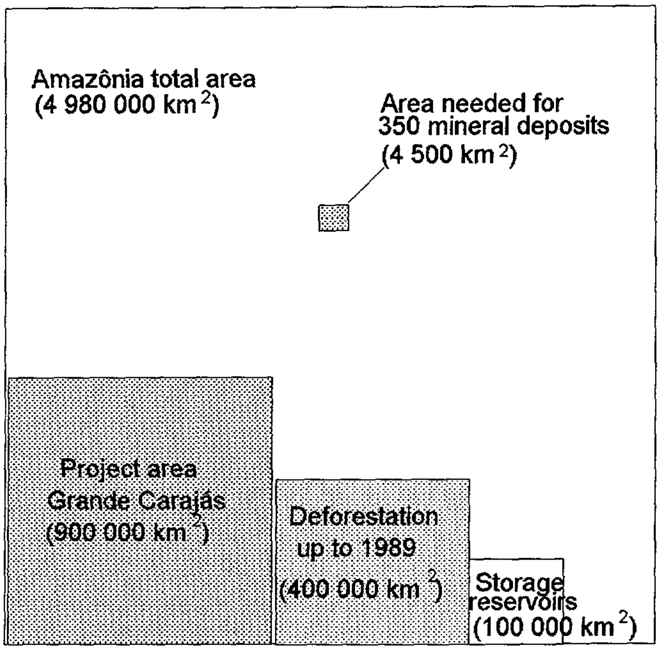
Table I. Major environmental impacts of selected commodities of interest to the brazilian Amazon.

Al	Fe	Sn	Au
red mud, HF, CO_2; Tar pitch; volatites; spent pot linings; cyanide; earth movements; reclamation; dusts.	Waste water; solid wastes; heavy metals; CO_2; earth moving; reclamation; dusts.	Waste waters; heavy metals; CO_2; rivers and earth moving; reclamation; particulate matter.	Waste water; solid wastes; cyanide; mercury; particulate; rivers & earth moving; reclamation.

Sustainable exploitation methods are being sought, trying to introduce agribusiness into the play at the rain forest amazonian area. However, timber productivity is low 2-3m^3 (8) per year. The reasons for such a low productivity are the heavy leaching of nutrients from the soil and the fast decay of organic matter that follows; if agriculture is sought, the soils of the Amazon are very poor in nutrients and lime is absent, showing a very low cation exchange capacity and high aluminum toxicity.

Mining is a prospect for the sustainable development of the Amazon, as in the words of HOPPE (9): "Mining in the Amazon offers the best chance to participate in the wealth of the Amazon without destroying for short-term profits either the Indian tribes or the unique diversity of plants and animals found there, or the source of livelihood for future generations".

Figure 4. Brazil's portion of tropical rainforest of the Amazon with the amount of forest destruction and comparison of possible uses. After HOPPE (9).



Recently, STIGLIANI (10) advanced the concept of "chemical time bomb", i.e., a "waste deposit or contaminated hotspot which initially appears to be relatively benign, but which can eventually have disastrous environmental effects as geochemical conditions change and toxic contaminants are released. The effects of these time bombs are non-linear and delayed (e.g., toxic metals can "break through" once the specific buffering capacity of a sediment or soil system has been surpassed [1]. Consequently, these sites require proactive assessment and management", as in the words of FÖRSTNER (11) In the Amazon, SALOMONS and LACERDA (12) dwelled with such a concept.

In assessing the effects on the environment the "Index of the Relative Pollution Potential", as defined by FÖRSTNER and MÜLLER (13), or "Technophility Index", as proposed by NIKIFOROVA and SMIRNOVA (14), "the ratio of the annual mining activity to the mean concentration in the earth's crust, suggests that the highest degree of changes of the geochemical budget by man's activities, has occurred for metals such as Cd, Pb, and Hg (values in 5×10^7)

Mn =	Fe <	Ni <	Cr <	Zn <	Cu =	Ag <	Hg =	Pb <	Au <	Cd
1	1	2	4	10	20	20	30	30	60	140

The technophility index is unstable in time, and in accordance to the demands of the society, each metal is characterized by its own TPt growth. By the year 2000, the TP value of mercury will increase by 3 times and that of lead by 4.5 times as compared with the beginning of the century [7]".

What about Mercury ?

In gold processing of alluvial ores in rainforest areas (15-19) mercury is widespread utilized as a gold amalgam.

Its utilization is not just a question of legislation, law enforcement and social pressures exerted upon the utilizers (20); it is a question of survival for the garimpeiros!

On the other hand, the environmental problems that may be originated by the presence of mercury in the environment, being it through liquid, ionic form or vapor, are all well documented in the literature (21-23). However no alternative route to Hg amalgamation is in effect, and processes like cyanidization (a problem in itself), oil or wax agglomeration, halide extraction, etc. neither compete economically nor are suitable for the kind of operation usually employed in such tropical areas (24).

According to FERGUSSON (25) , some of the alkyl derivatives of the heavy metals relevant to the environmental chemistry are as presented in Table II (25), being the environmental interest in the compounds, their toxicity and the fact that methylation occurs for many of the H.M. elements.

Table II. Some organometallic compounds of the heavy elements

Periodic Group	IIb 12	IIIb 13	IVb 14	Vb 15	VIb 16
	Cd Hg	In T1	Pb	AS Sb Bi	Se Te
Alkyl Organo-Metallic Compounds	R_2M RMX	R_3M R_2MX RMX_2	R_4M R_3MX R_2MX_2	R_3M R_2MX RMX_2	R_2M R_2MX_2
Oxidation	2	3	4	5	2,4

Methylation stands for the transfer of a methyl group from one compound to another, the process may occurring Biologically or Abiotically.

Bacteria and Fungi so far reported to methylate Hg, As, Se, Te, Pb, Cd, Tl and In, are usually Aerobic (except clostridium sp and methanobacteriumm ### anaerobic). There is good evidence for the biomethylation of mercury, arsenic, selenium and tellurium; however doubts exist over that of the other heavy metals.

The evidences of human poisoning lead to the disclosure of environmental methylation: arsenic (nineteen century); mercury (in the fifties ### Minamata). In the 60's it was revealed that the main form of Hg in the Minamata Bay fishes was CH_3Hg^+.

In 1964 the cobalt complex ion $[CH_3Co(CN)_5]^{3-}$ (model for vitamin B_{12}) was shown to methylate mercury. In 1968 WOOD suggested that the methylating agent associated with methane producing bacteria was methylcobalamin, i.e. the methyl derivative of vitamin B_{12} where the CN^- group is replaced by CH_3

Methylation by non-enzymatic $MeCoB_{12}$ may be treated as abiotic, except that the reagent itself is produced biotically and may be re-methylated biotically. The two main abiotic methylation processes are transmethylation, and to a lesser extend photochemical redox potentials and possible methyl transfer processes for the H.M.

Several features of the chemistry of mercury facilitates its existence in organo-species. Both Hg^{2+} and CH_3Hg^+ are soft acids and bond well to soft bases S^{2-} and SH^-. The action is large and polarizable, and because of the dipositive charge, itself a good polarizing action and tends to form covalent bonds.

The Hg-C bond (around 60 - 120 kJ/mole) though not that thermodynamically strong, is stronger than Hg-O bonds, therefore persisting in the environment! It is, also, non-polar.

Turning to the bacteria associated with methylation of mercury, they are located in the bottom sediments of rivers, estuaries and the oceans, in intestines and faces, in soils and yeast.

Several are the factors influencing the formation of CH_3Hg^+, including temperature, mercury and bacteria concentrations, pH, type of soil, type of sediment, the sulphide concentration, and of course redox conditions. Seasonal variations in methylation, in estuarine sediments, relate to bacterial activity, which may also apply to organic sediments, compared to sandy sediments.

Methylation of Hg occurs in both aerobic and anaerobic conditions, though the latter are the best; maximum methylation occurring in the Eh range +0,1 To - 0,2V; the pH has a very significant effect as CH_3Hg^+ is more stable in neutral to acid conditions and $(CH_3)_2Hg$ in basic. The binuclear species $(CH_3Hg)_2$ OH seems to be of minor importance.

The influence of sulphide ion depends on the redox conditions: if anaerobic HgS (low soluble) will remove much of the Hg from being methylated if aerobic, the S^{2-} ion may be oxidized to SO_4^{2-} freeing thus Hg ion for methylation.

The rate of production of CH_3Hg^+ depends on the exposed conditions and the reaction matrix, being generally greater in saline than fresh water.

Methylmercury accounts for circa 0,1 to 1,5% of the total mercury in sediments, and around 2% of the total in sea water, but in fish it is > 80% of total mercury.

It is not clear, however, it the CH_3Hg^+ is taken in by the fish from sea water or formed within the fish. The evidence tends to suggest the former, though in rotting fish $(CH_3)_2Hg$ is formed.

The changing chemistry of mercury, as pointed out by RENUKA (26) is always a point of concern amony those that study mercury.

Recently, the electroxidation method for removal of mercury was utilized to remove it from "garimpo" tailings, the chemistry of the process being:

$$2NaOCl + Hg^0 + 4HCl \rightarrow 2Na^+ + HgCl_4^{-2} + 2H_2O + Cl_2$$

the mercury being precipitated then as stable tetrachloride (27).

And the Particulate ?

Besides mercury, the release of particulate material coming from the earth moving operations also contributes to the deleterious effects on the biota.

The physical impacts on the environment coming from the mining activity are concerned to the release of particulates to rivers, lakes, oceans and the air.

For the purpose of this article, particulate emissions in the region of the brazilian amazon are referred to the production of dusts coming from the mining of bauxite, iron ore, manganese, and sediments coming from gold and tin extraction; these interact with the environment and may alter the biota.

In this regard, little is known for the brazilian amazon, and few publicated results are available, particularly for mercury (28).

Of the known, mercury seems to be associated to the fines of the sediments, the "sands" being poorer in mercury than the "fines", due to the presence of iron-aluminate-hydroxides.

As in the words of DUURSMA (29) "Contaminants may be partitioned between water, sediment, particulate matter and organisms compartments, for which partition coefficients (Kd's) can be determined. The se Kd's are useful empirical factors to calculate the percentage distribution between dissolved and particulate matter, the diffusion of contaminants into the bottom and the accumulation in organisms. Thus analyzing both sedimentary material, and organisms may render useful indications of the concentrations of the contaminates in the water compartment. If tropical estuaries are sources or sinks, this has to be answered in a time context. A tropical estuary, newly contamined will be a sink for a very long period, although equilibrium between input and output may be sooner obtained than in temperate climates, it may afterwards become a source, buffer with very long turnover times, up to 1000 years".

A very extensive programme in monitoring the garimpo activities at the Rio Tapajós area is being conducted by the Government of the State of Pará; such a programme is denominated CAMGA-TAPAJÓS and SEICOM is the executive body of it (30).

Table III, resulting from the aforementioned report gives the relationship between the extraction and concentration techniques employed in the area and the impacts caused on the environment.

Table III. Environmental impacts derived from extraction and concentration techniques for gold recovery in Rio Tapajós, as related to the particulate

<table>
<tr><th>CAUSES</th><th>Physical and/or Chemical</th><th>Biological</th><th>Anthropic</th></tr>
<tr><td rowspan="5">EXTRACTION & CONCENTRATION</td><td>erosion/increasing of suspended load</td><td rowspan="2">changes in ecological habitats</td><td>compromising fishing activities</td></tr>
<tr><td>changes in color, turbidity and other organoleptic water properties</td><td>increase in water treatment costs</td></tr>
<tr><td>silting-out and changes in river courses</td><td rowspan="3">changes in ecological habitats</td><td>losses of natural resources</td></tr>
<tr><td rowspan="2">water pollution (soaps and oils)</td><td>endemic diseases</td></tr>
<tr><td>losses of natural resources</td></tr>
</table>

What about Aluminium ?

Table IV shows the structure of the Al Industry in Brazil (31).

Table IV. Profile and Structure of the Al Industry in Brazil.

Mines	Alumina	Refineries	TRANSFORMING	
			Large/Medium	Small/Micro
11	4	7	300	35,000

There exists a coordinated effort, within this diverse framework of operating companies in Brazil, towards an up-to-date worldwide environmental approach. Thus, technical expertise on mine rehabilitation, dry stacking of red mud, fluoride emission control, safe disposal of pot liming are available within the country.

Such a fact is not surprising, indeed, since the vast majority of the Al operations are located in environmentally sensitive areas, e.g. the Amazon and Vale dos Sinos.

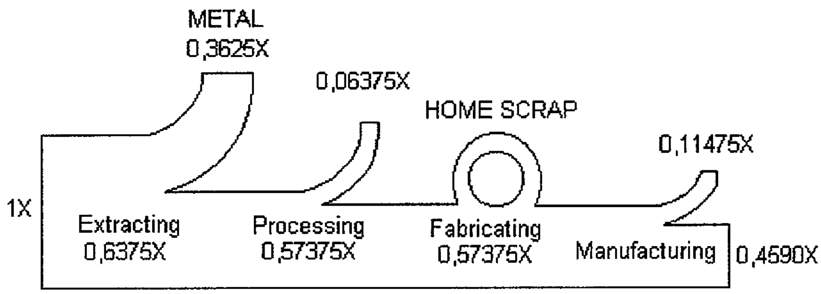
A recent visit of UNIDO experts to industries of Brazil, Guyana, Jamaica, Suriname and Venezuela stated quite strongly: "Observations made by the UNIDO team of the environmental impacts of plant operations and of environmental management at the plant were very favorable and indicated a serious commitment on the part of plant authorities to comply with if not to exceed the license provisions. As such, the development of regulatory programmes in Brazil cannot be viewed as a barrier to sustainable development" (31).

Materials and the Environment

In a previous paper, presented at HYDROMET'94, this author (32) analyzed in the form of SANKEY diagrams the average metal recoveries within the several production steps to produce a given commodity, e.g. metal.

Figure 5 shows the basic diagram from which every single step was, then, analyzed.

Figure 5. The Production Steps



From these average figures, one may see that there are a lot to do regarding better extraction efficiencies (recoveries, energy utilization, generation of effluents, etc.).

Conclusions

- environmentally sensitive areas in Brazil are rich mineral compartments.
- the exploitation of such mineral richness may be conducted under sustainable development concepts, minimizing environmental impacts energy utilization and generation of effluents, if care is taken at the engineering design phase.
- as well, if such green design concepts are not taken into account, a chemical time bomb effect may, eventually, arise.
- however, even when well established and advanced techniques are applied, the present knowledge status in mining and metallurgy technologies may be still far away from the maximum theoretical efficiencies that may be attainable.

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Figure 1. Stages of Product life Cycle (1)

Figure 2. The Material Cycle (1)

Figure 3. Mineral resources of the brazilian amazon (4)

Figure 4. Brazil's portion of tropical rainforest of the Amazon with the amount of forest destruction and comparison of possible uses. After HOPPE (9).t

MINING & SUSTAINABLE DEVELOPMENT

Professor Alyson Warhurst

This briefing note was prepared for IIED (The International Institute for Environment and Development) as part of the scoping study they are undertaking for the WBCSD (the World Business Council for Sustainable Development). Professor Warhurst is Senior Project Advisor to that study. The paper builds on the research she has been undertaking on mining and sustainable development over the last decade and her inaugural lecture as Professor of Environmental Strategy at the School of Management, University of Bath

The author acknowledges the many contributions of her international and University colleagues of MERN* to the development of the argument presented in this paper. Nonetheless, the paper is a personal view and not a formal MERN view of the roles and responsibilities of business in the quest towards sustainable development.

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1. Introduction & Defining a Point of Entry

Addressing the theme of mining and sustainable development and defining practicable strategies for mining companies to follow will require exciting new international collaborative research and training that is a product of different disciplines, cultural perspectives, skills, innovative thinking and frontier pushing. New research is needed urgently to inform and frame the changes that mining companies will need to make to contribute positively and demonstrably towards sustainable development processes.

These changes will need to demonstrate progress; progress towards a more equitable society where industrial and agricultural production activities can be guaranteed to contribute to, and not undermine, human health and quality of life and healthy ecosystems, on a path towards sustainable development.

The concept of Corporate Social Responsibility is considered crucial to the quest of operationalising the new corporate strategy that will be required of companies. This concept is about companies pro-actively seizing opportunities and targeting capabilities, that they have built up for competitive advantage, to contribute to sustainable development in ways that go beyond traditional responsibilities to shareholders, employees and the law.

The urgency with which these new corporate strategies must be developed is underlined by the continued pollution from mining that is unacceptable, the land dereliction that is irrecoverable and still continuing and the community deprivation that is too often associated with the inequitable distribution of the benefits of mining – resource rents.

This is not to ignore the mining projects that have introduced new clean technologies, participative community development programmes and pro-active social and environmental impact assessments but to be cognisant of the fact that the sector as a whole is judged by the worst performing companies at present, not the best.

The challenge for marrying mining and sustainable development, therefore is:

> Can minerals development, demonstrably essential to modern industrial society, be undertaken without damaging the environment or undermining the development opportunities of local communities and can the benefits be distributed amongst stakeholders equitably?

This is in fact the never-ending research quest of the Mining and Environment Research Network – and some of our initial exploratory research undertaken in the early 1990s sought to understand in the first instance what was the nature of those environmental and social effects and what were the patterns associated with its world-wide distribution. (See Box 1). This led us to argue that minerals development can be planned and undertaken in ways that are environmentally and socially responsible. Today's technology and managerial expertise, combined with informed investments in innovation and the capabilities to effect "change", mean that there is no excuse for pollution whatsoever and that overall only social benefits, not costs, should result from mining.

My argument is also that pollution penalties, regulatory "Big Sticks" and resource rent distribution agreements are not the answer to environmental protection and social equity - such public policies provide the framework - it is corporate strategy that today can, so therefore should, make the difference.

BOX 1: THE MINING & ENVIRONMENT RESEARCH NETWORK?

A collaborative research network - 130 research institutions across 44 countries

Clear Goal: generation of analysis to inform the environmental management and social strategies of mining firms and their suppliers and the public policy framework within which they work and an understanding, from local communities' and other stakeholder perspectives, of the extent to which mineral development projects are contributing to or detracting from sustainable development

Special Research Focus: environmental and social responsibility, technological and organisational change, competitiveness and sustainability indicators

Tools & Dissemination Mechanisms: Research Bulletin, workshops, working papers (160 to date), industry sponsored PhDs and training

Build up international inter-disciplinary pool of research competence

BOX 2: MERN SPONSORS/USERS

Institutional Club	Industry Club
BGS	Aggregate Industries (UK)
DFID (UK)	Anglo American
ESRC/EPSRC/NERC	B&Q
IDRC (Canada)	BHP
IFC	Billiton
MacArthur Foundation	English China Clays International
MIGA	North
Natural Resources Canada	Placer Dome
OECD	Riomin
UNEP,. UNCTAD	Rio Tinto
World Bank	WMC
WBCSD	Metal Mining Agency of Japan

Corporate Strategy, as a field of study, particularly where it pertains to corporate social responsibility, has evolved fast over the past few decades from the view of Friedman that "the social responsibility of business is to increase profits" – to the 'business is the business of business view' – towards working definitions of corporate strategy, such as the definition I quote here by Andrews, (in Box 3), that comfortably encompasses environmental and social goals including broader non-economic contributions to local community and longer term proactive decision making.

BOX 3: DEFINING CORPORATE STRATEGY

> **"...the social responsibility of business is to increase profits..."**
> ***Friedman (1970) New York Times***
>
> **"...corporate strategy...is the pattern of decisions in a company that determines and reveals its objectives, purposes, or goals, produces the principal policies and plans for achieving those goals, and defines the range of business the company is to pursue, the kind of economic and human organisation it is or intends to be, and the nature of the economic and non-economic contribution it intends to make to its shareholders, employees, customers and communities..."**
> ***Andrews (1987) The Concept of Strategy***

I have therefore defined my point of entry into the mining and sustainable development debate as one that:

a) defines sustainable development as a process and as having constituents that incorporate: sustained equity and sustained improvements in human health and quality of life and ecosystem health

b) puts the emphasis on corporate strategy as opposed to public policy, as being the prime-mover in ensuring mining contributes to, and does not detract from, these constituents of sustainable development

c) suggests pro-active corporate social responsibility is key to operationalising the changed strategic role that mining companies need to play a pro-active part in the sustainable development process.

This briefing note therefore addresses:

- Why is **mining so important to society** and the world economy. The rationale for this is that the mining industry, in my view, has not addressed the **education** of children, or society at large, in the area of understanding how important minerals and metals are to our well-being and quality of life and indeed any definition of what might constitute sustainable development.
- What are the **social, economic and biogeophysical effects** of mining and how are they distributed across a spectrum of different stakeholders. The rationale for this is that **different stakeholder groups** will experience these effects in quite different ways and mining companies have traditionally been concerned principally with employees, shareholders, host governments and financiers. Furthermore this discussion can be linked with the concepts of **development rights and human rights**, which are fundamental to civil society and sustainable development.
- How might the concept of **corporate social responsibility** be **operationalised?** What defines **best-practice** for different stakeholders, what are the strategic changes corporate management may need to make and how might mining companies **communicate** their improved performance and achievement to both internal and external stakeholders, and as a sector, more broadly to **civil society** at large.

2. Minerals and Metals in a Sustainable Economy

The role of minerals and metals in a sustainable economy can be addressed in three ways:

i) They are essential to modern living and ingredients of most products, industry inputs and services

ii) They are of considerable economical importance to many developing countries and international commerce

iii) Mineral resources comprise an estimated 50% of natural capital and exploiting them affects all other components of natural capital – land, water, air and biodiversity

i) Box 4 below shows the range of uses of mineral sand metals in modern society.

Box 4 COMMON USES OF MINERALS AND METALS

ALUMINIUM	Aircraft parts, window frames, engines, drinks cans etc.
ANTIMONY	Metal hardening
ARSENIC	Glass production, semi-conductors and wood preservative.
CADMIUM	Paints and batteries.
CHROMIUM	Metal plating, corrosion resistance, alloys and ceramics.
CLAYS	Ceramics, nutritional additives, concrete, mortar
COPPER	Electrical wire, coins, bronze production and cookware.
DOLOMITE	Nutritional additives, building stone
GOLD	Ornamental, electronics, jewellery and glass colouring.
GYPSUM	Prefabricated wall board, plaster, cement and agriculture
IRON	Steel production
LEAD	Car batteries, cable sheathing, lead crystal, solder and radiation protection.
LIMESTONE	Aggregate, cement, fertiliser, soil conditioner, iron flux, paints, plastics, livestock feed
LITHIUM	Grease, batteries, glass and treatment of manic depression.
MANGANESE	Hardened steel, soil and food supplements.
MERCURY	Chlorine and sodium hydroxide manufacture, plant treatments, lighting, and electronics.
MOLYBDENUM	Alloys, catalysts, electrodes and lubricants.
NICKEL	Gas turbines, rocket engines, stainless steel, plating and coins.
PLATINUM	Anti-cancer drugs, chemical catalyst, catalytic converters, and corrosion resistance.
PLUTONIUM	Nuclear fuel and weapons
SAND & GRAVEL	Concrete, bricks, roads, building materials
SILICA	Glass (bottles and jars)
SILVER	Widespread industrial uses, photographic, jewellery and tableware.
SULPHUR	Sulphuric acid production
TITANIUM	Production of light weight alloys, aircraft components, replacement joints and paints
TUNGSTEN	Light bulbs and high strength alloys.
URANIUM	Nuclear Weapons
ZINC	Galvanising, alloys, batteries, rubber and plastics.

They range from aluminium to zinc and cover household products through industrial machines and transportation to jewellery, nutritional supplements and anti-cancer drugs. Many concerns about mining are rooted in considerations of our society being too material intensive and wasteful. Some researchers argue that the scope and hazards of metals toxicity are not fully understood and that recycling can be increased, from it's already high levels, as can resourcefulness. Although the industry has to demonstrate a commitment to better product stewardship, reducing material intensity and renewed recycling, and, better communication about the use of metals and protection from any eco-toxicological effects, minerals and metals will always have a role to play - especially as consumerism grows in developing countries.

ii) Secondly, mining is particularly important to developing countries and international commerce. Indeed, many developing countries entered the world economy, as did the UK, as exporters of minerals. The current importance of mining to selected developing countries is illustrated by Box 5 which shows minerals contributions to GNP and foreign exchange earnings across Asia, South America and Africa and Box 6 which shows 1997 Foreign Direct Investment flows to the top eight developing country mineral economies.

Box 5: DEVELOPING COUNTRIES WITH SIGNIFICANT MINERAL WEALTH

COUNTRY/REGION	KEY MINERALS/METALS PRODUCED	% OF GDP	CONTRIBUTION TO FOREIGN EXCHANGE
SE ASIA			
Indonesia	Coal, Gold, Copper, Silver, Tin	11.9	>40%
Papua New Guinea	Gold, Copper, Silver	25.0*	>40%
Philippines	Copper, Gold, Silver, Lead, Chromium, Manganese	1.5	> 5%
S.AMERICA			
Bolivia	Tin, Gold, Copper, Silver, Lead, Zinc	8.1	>43%
Chile	Copper, Gold, Silver	45.0	>50%
Guyana	Gold, Bauxite, Diamonds	35.0	>35%
Peru	Zinc, Copper, Gold, Lead, Manganese, Silver, Arsenic	n/a	>50%
Venezuela	Gold, Diamonds, Coal, Emeralds	1.0	> 5%
AFRICA			
Ghana	Gold, Diamonds, Bauxite, Manganese	10.0	>40%
Namibia	Diamonds, Gold, Silver, Uranium	13.0	>50%
South Africa	Gold, Coal, Diamonds, Chromium, Manganese, Lead, Zinc, Platinum, Titanium	8.1	>37%
Zambia	Copper, Cobalt	20.0	>90%

Box 6: FOREIGN DIRECT INVESTMENT (FDI) IN US$BILLION

to Selected Top 8 Developing Countries 1997

Country	*1997*	*Rank*
China	37.0	1
Brazil	15.8	2
Mexico	8.1	3
Indonesia	5.8	4
Malaysia	4.1	5
Argentina	3.8	6
Chile	3.5	7
Venezuela	2.9	8
Total	***66.5***	

Source: World Bank staff calculations, Global Development Finance, 1998

Mineral economies are defined as those generating at least 10% of GNP from mining and at least 40% of their foreign exchange earnings from mineral exports. They account for over one quarter of all developing and transition economies.

Given, mines can last for an average of 20 – 100 years, it is therefore obvious that establishing mechanisms for the effective capture and allocation of mineral revenue streams will remain central to those countries' development objectives for some time to come.

However, in a recent review undertaken by Professor Markandya and myself for the OECD[1] – we discovered that there are no research studies, bar an exemplary one by our MERN collaborator in Chile –Gustavo Lagos on Escondida - of the costs and benefits at the micro-level of mining nor systematic studies of resource rent distribution at the macro level. Underlining the need for such research and the fact that the mining industry has yet to address the critical challenge of demonstrating that mining brings value added to local communities and host-economies.

iii) Thirdly, according to the paper 'Expanding our Measurement of Wealth' by the World Bank, produced in 1997, mineral resources comprise up to 50% of the natural capital assets of developing countries and their exploitation affects all other components of natural capital – land, water, air and the ecosystem. The importance of minerals and metals further underlines the imperative of ensuring their environmentally and socially responsible extraction and transformation.

Box 7 illustrates some of the possible hazards associated with the mining life cycle and the environmental and social, particularly health effects, that may ensue.

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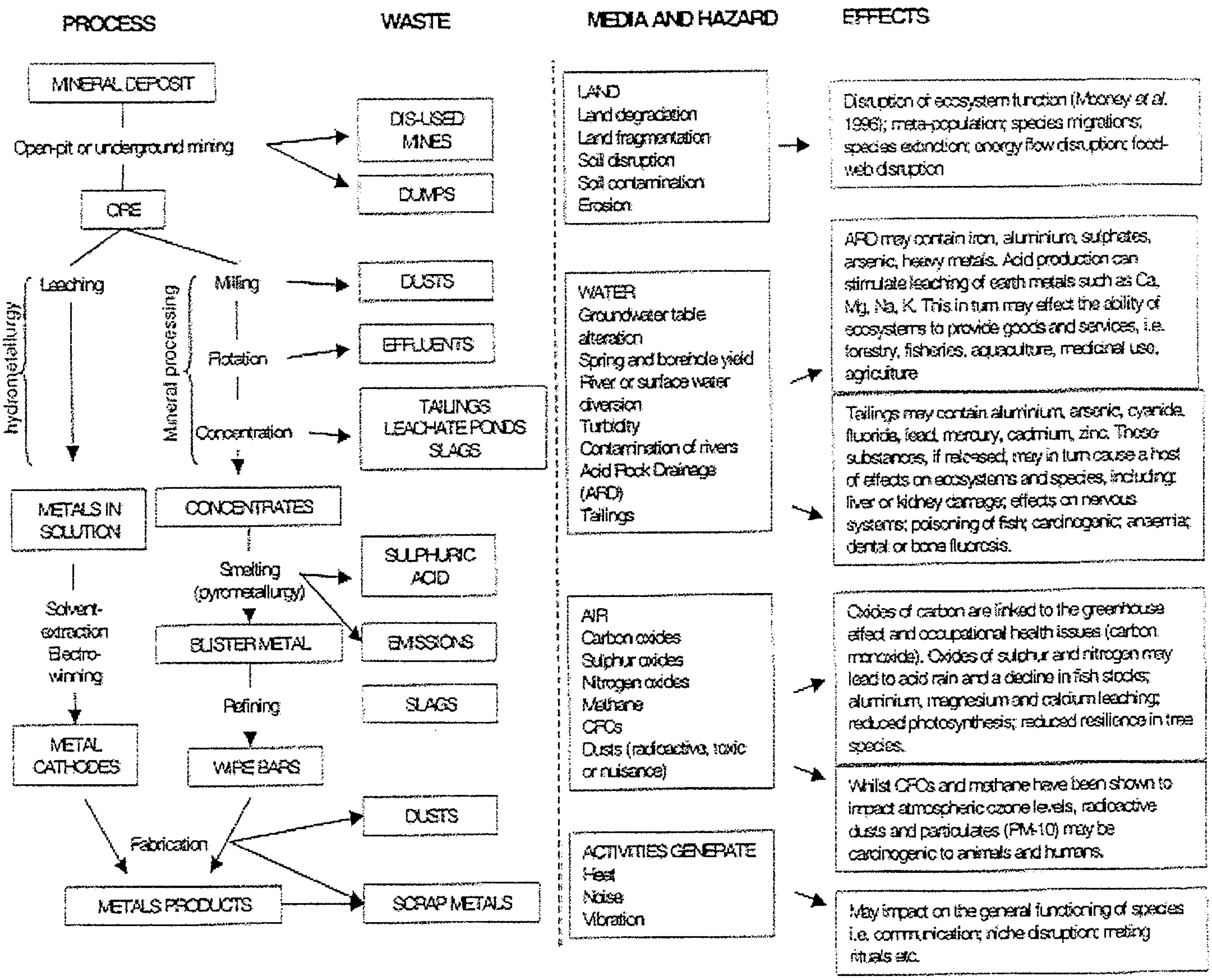
[1] Meeting of Management experts on *'Mining investment and its effects on developments'*, discussion paper presented to the Labour/Management Programme, OECD, Paris, November 1998

BOX 7: MINING LIFE CYCLE



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Metals are won from ore in stages. They begin their life as anything from the size of specks to a nugget embedded in hard rock or earth. They are gradually separated out in a process of purification, that sometimes stretches world-wide since the richest most accessible ore deposits are not always found where the cheapest sources of electricity can be harnessed for their energy intensive refining - nor where the principle markets exist for final metal products. It is this geographical spread of the production process that particularly sets up challenges for the distribution of mineral resource rents between economies – the principal country of mineral exploitation and the country where profits are accumulated.

Another way of capturing the multifarious effects of mining is to look at them from the perspective of decommissioning –also the topic of a recent book I have written with Ligia Noronha entitled: "Environmental Policy and Mining: Corporate Strategy and Planning for Closure" which contains 30 case studies from around the world. Box 8 for example shows some of the socio-economic effects of mine closure extracted from my Chapter 6 in this book.

BOX 8: SCHEME OF SOME OF THE SOCIO-ECONOMIC EFFECTS OF MINE CLOSURE

SOCIAL EFFECTS

- Loss of social welfare benefits provided by firm.
- Loss of political rights to organise and improve conditions of work.
- Reduction of education opportunities
- Feeling of disempowerment
- Alcoholism, drug dependencies, domestic violence and depression
- Health and well-being (eg. respiratory diseases, disability through accidents) impaired reducing possibilities to obtain alternative employment.
- Relocated populations
- Hazards associated with unsecured dumps, unsafe plant equipment

Closure of service and supply industries

Closure of Mining Project

ECONOMIC EFFECTS

- Loss of value of home and land and reduced mobility to find new work
- Loss of income
- Loss of demand for skills and inability to return to previous work
- Loss of demand for local goods and services
- Resource rent reductions limits potential to re-invest economic benefits in productive activities at each level - locally, regionally, nationally and internationally
- Reduced maintenance of transport systems and civil infrastructure

BIO-PHYSICAL EFFECTS

Local effects on bio-geophysical bases of livelihood

- land (eg. degradation of soils, landscape blighted)
- water (eg. contamination)
- air eg. (dust from tailings)
- biodiversity (effect on ecosystem leading to loss of pastures or food crops)

Source: *Issues in the Management of the Socio-Economic Impacts of Mine Closure: A Review of Challenges and Constraints*, Warhurst, A. MacFarlane, M. & Wood, G. (1999) in Environmental Policy in Mining: Corporate Strategy & Planning for Closure (CRC Press)

My chapter summarises some of the key socio-economic issues to be addressed regarding the closure of mines. These include[2]:

- Social Impact Assessment (SIA) needs to be ongoing throughout the life phases of the mine and planning for decommissioning, downsizing and closure needs to begin at the outset based on criteria developed through the SIA
- Closure planning should address effects and solutions for the remote community involved in supplying the industry, as well as the formal and informal work-force of the mine
- Profiles of recruits, recruitment strategies and human resource development through the mine life needs to be included in closure planning to facilitate transition for redundant workers and their families and broaden the possibilities of future work.

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[2] Extract from Warhurst *et al*, *'Issues in the Management of the Socio-economic Impacts of Mine Closure: A Review of Challenges & Constraints'* (Chapter 5) in Environmental Policy in Mining: Corporate Strategy & Planning for Closure (CRC Press, 1999).

- An environmental management plan, post closure – needs to be in place where there is a threat of ongoing contamination/environmental damage such as acid rock drainage or tailings leaks/slippages, so as to improve possibilities of alternative land uses, particularly farming.
- Closure planning could include altemate uses for housing, facilities and equipment, and, policies to protect the continuation of social networks and community activities.
- Consultation throughout is paramount assisted by participative approaches to forward planning so as to involve the community from the outset in addressing eventual closure and future options.
- Financial mechanisms need to be in place to ensure sufficient resources exist at the end of the mine's life to implement closure plans and fund appropriate compensation and redundancy schemes. Bonding regulatory systems could cover social as well as environmental issues.
- More research is required on the socio-economic effects of mine closure and their mitigation; and case study analysis needs to inform the drawing of lessons to design best practice corporate strategy and improved public policy.
- What capabilities do companies need to develop, and how might different areas of expertise be integrated to ensure improved planning for closure form the outset and its subsequent implementation.
- How might research contribute to the development of indicators that might define the quality of closure plans with regard to the predictions made and the effectiveness of mitigation efforts and responses.

Indeed, some of the unemployment effects of mine closure have been massive, which is a major issue that has fuelled public concerns about the role of mining in social development. As the large public mine sectors of many countries, including the UK, have closed down we have seen workforces reduced by tens of thousands from one year to the next. For example, Peru saw employment fall from 100,000 in 1996 to just under 50,000 in 1997. Similarly, in the UK, 180,000 people were employed in this sector in 1989 and only 70,000 by 1999. In Bolivia, employment in the mining sector has seen dramatic fluctuations: from 100,000 in the early 1980's down to 15,000 in 1994 and currently back up to 20,000 today.

This discussion of the effects of mining can be developed in two other directions, which have special relevance for the consideration of mining and sustainable development. First is the issue that 'effects' are two-way. The fragility of the ecosystem, poverty, the vulnerability of a local community etc. will all in turn have effects on the mining project, and will in turn define what a given project can at a point in time contribute to sustainable development. Secondly, we have raised the fundamental issue of improved quality of life as a constituent of sustainable development, but have not answered the questions 'quality of life for whom?', 'as defined by whom?'. This is because the distribution of the effects I have been discussing will vary for different stakeholder, depending on whether they are members of the working community, local community, regional community, national or international community. This concept of stakeholder differences in the sustainable development process can be further explored by reference to the World Bank definition of sustainable development in terms of overall net increases.The World Bank approach discussed suggests Four 'Capital' components determine a nation's wealth: natural capital, produced assets, human capital and social capital (World Bank, 1997). Sustainable Development is about sustaining increases in the combined stocks of environmental resources, produced assets and human/social resources that underpin an equitable distribution of opportunities to enhance quality of life and ecosystem health over time.

This provides a more operational definition of the role of corporate strategy in contributing to sustainable development objectives, than did the famous Brundtland Report – with its memorable emphasis on not jeopardising our children's, children's futures.

Moreover, by further introducing the concepts of quality of life and ecosystem health into our research enquiry, we have also injected a dynamic element into our consideration of mining and sustainable development.

The idea being that people are not so much concerned with the details of which particulates are in the air they breath or the pH of the water they drink – rather they are interested in the health and well-being effects on their families – will their children die from dehydration or will the family breadwinners have their lives cut short through respiratory disease.

This approach also dovetails with some of the theoretical advances being made within development studies, the UN Commission for Human Rights and Oxfam regarding development rights – the idea that everyone has a right to health, education, a safe environment and a quality of life beyond the immutable concepts of the Universal Declaration of Human Rights which protects individual liberties and ethical integrity. This also gives shape to two major thrusts of research enquiry relevant to mining and sustainable development by MERN:

- How might the gains emanating from the transformation of natural capital - specifically minerals - contribute more positively to sustainable development in the host country rather than economic growth at the global level

- How might research inform a pro-active interpretation of environmental and social responsibility by mining companies in the role they play transforming natural capital - minerals - into wealth

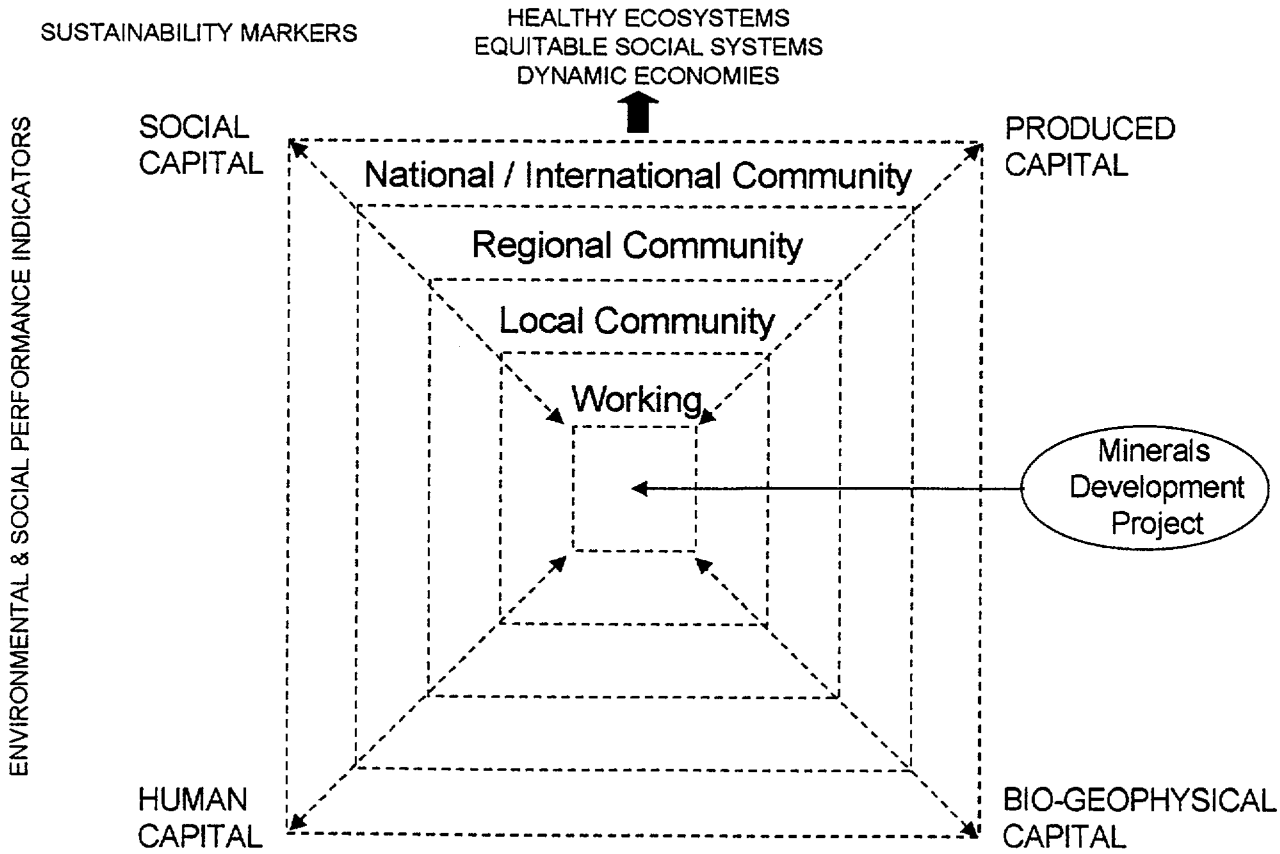
There are two models that I suggest we might work with that I think are all-inclusive in understanding the relationship between mining and sustainable development at any one point in time. The first is the Sustainability Square (See Box 9, below); the second is Environmental Trajectories (See Box 10, below).

2. Sustainability Squares and Environmental Trajectories

These zones describe direct and indirect effects from the stakeholder perspective of mining on development opportunities and the bio-geophysical environment that underpins them

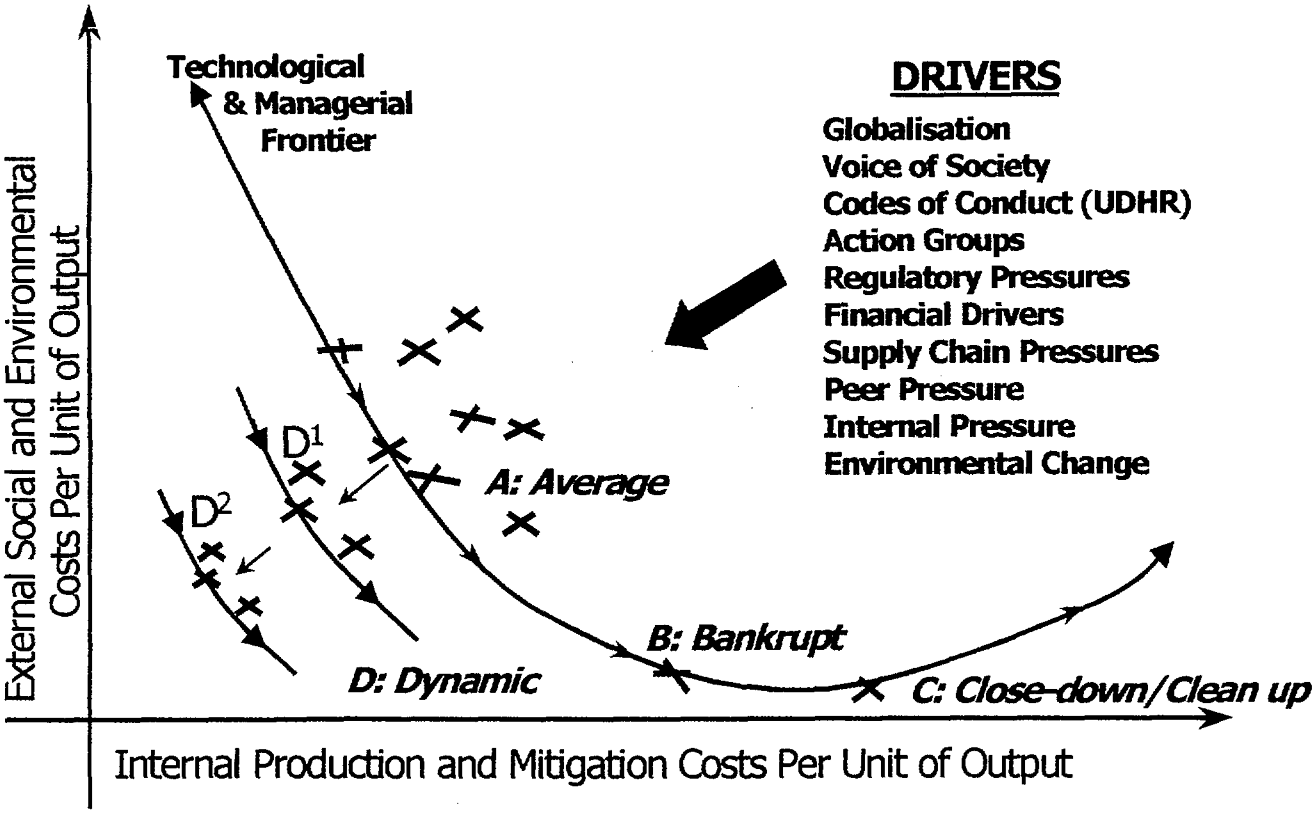
- Bio-geophysical effects: Dynamics of ecosystem health, biodiversity conservation and the physical bases of livelihoods
- Economic/business effects: Effects on wages/salary rates, the distribution of resource rents - that is taxes, royalties, compensation/liabilities etc between central, regional and local state agencies,
- Social/human dimension:
  - Socio-political effects over time on individuals and groups, and their capacity to organise, including effects on human health and working conditions
  - Socio-cultural effects over time on the cultural heritage of individuals and groups, on their spiritual and cultural well-being and with respect to their education

BOX 9: SUSTAINABILITY SQUARE



Adapted from Mergler 1997

BOX 10: TRAJECTORIES OF CORPORATE ENVIRONMENTAL & SOCIAL RESPONSIBILITY



Trajectories of Corporate Environmental & Social Responsibility

Firms have **two types** of costs associated with their production **activities – internal and external costs**. Their production activities, or in our case a minerals development project, can be mapped onto an imaginary technological/managerial **frontier**. The average company is located here – **'A' for average** – clustered on or behind the frontier. With time, a growing number of **drivers** act upon these firms shaping the trajectories that they might follow in response to the drivers' requirements that they increasingly internalise those **externalities**. Before investigating the different paths those firms might follow as they respond to those drivers, or pro-actively anticipate them, below we examine the drivers themselves in more detail.

<u>Globalisation:</u> Over the last decade, MNC activity has expanded. In 1970 there were only 7,000 MNC's and now there are around 40,000 with over 200,000 globally spread affiliates. In the minerals sector they are particularly active in developing countries and potentially major conduits for technology transfer and economic benefit.

Since 1989, over 75 countries have liberalised their investment regimes for mining to promote further investment and have privatised the large old state dinosaur mining companies such as COMIBOL in Bolivia and CENTROMIN in Peru, leading to downsizing and drastic direct and indirect employment effects, as mentioned earlier.

In turn this has led to a reduction of the welfare-providing role of the state – which previously supplied to those large work forces and their families a 'social wage' through the provision of subsidised food stuffs, health services and schools. A traditional form of corporate social responsibility, if you like, as distinct form the pro-active corporate social responsibility we are discussing - **since these benefits were not sustained and were often taken away from one day to the next** - leading to increased poverty and inequity, particularly around old mining regions.

As a result a growing **voice of society** is demanding that, irrespective of formal requirements, MNCs, particularly those that have benefited from privatisation, adopt a longer term, forward looking approach. **One** that pro-actively anticipates these drivers and implications and takes responsibility for addressing some of the past inefficiencies that have now provided them with their opportunities.

Looked at in this context, it should not be a surprise to the industry, that this **voice of society** is controversially demanding that MNC's apply their capabilities more broadly to address some of the more far-reaching and indirect effects of their activities on the quality of life of local communities affected by minerals development in general, including the 'sins of the past' – that is environmental damage and potential health liabilities resulting from past pollution, generated in the absence of regulation.

'Voice of society' concerns are increasingly being expressed as demands for information, accountability and particularly community participation – an area of research of Assheton Stewart Carter and Kevin Franklin, RO's within MERN, who are working from a social and biodiversity perspective respectively. These concerns are also reflected in Agenda 21, the action plan resulting from the Rio Earth Summit in 1992, which amongst other imperatives obliges industry – morally not legally - to contribute to local capacity building in developing countries and to transfer clean technology.

Some of these concerns have given rise to voluntary **codes of conduct**, which are becoming important levellers of MNC activity and useful guidelines for environmental and social reporting – examples include the Amnesty International principles for international business, the SA8000 accreditation scheme, the World Bank's environmental guidelines and the International Chamber of Commerce's Business Charter for Sustainability.

At a sector level there are industry codes of conduct. For example in mining – we have the International Council of Metals and Environment code of practice and within the quarry industry in the UK there is the Quarry Products Association, Environmental Code of Practice.

Action groups, specifically **Non-Governmental Organisations (NGO's)** are increasingly important drivers of change. Friends of the Earth and Greenpeace have launched high profile 'exposé' campaigns and more recently have sought to develop a **'solutions agenda'** with the business community as **NGO's** themselves have recognised the creative and shaping role that business can play in the global economy. The role of special interest NGO's has recently grown in importance, parallel with the **'retreat of government'** and the **diminution of scientific authority** – as seen with the scares surrounding **BSE**, **salmonella** and more recently, **genetically modified foods**. Those special interest groups that are especially active with respect to mining include: Minewatch, Third World Network and Survival International.

Regulation has always been considered a key driver of environmental and social performance. And I would not want to under-emphasise the role that public policy has to play in framing the route towards the sustainable development goal. However, as I mentioned in a developing country context, it is often weakly developed and poorly enforced and plays its principal role in defining the conditions attached to the permitting of industrial activity – **the licence to operate** – rather than the performance of an ongoing operation or its closure.

Notwithstanding, it is important to note that there has been a fundamental shift from the regulation **paradigm** of **'command and control'**, single medium, pollution clean-up incrementally enforced through inspectorates, the courts and penalties – to a **paradigm of integrated pollution control** and pollution prevention, promoted through market incentives and innovative rehabilitation bonds

Financial Drivers: However, in our research we have found that the environmental and social conditions attached to the provision of mine project finance proved to be an even more significant driver of improved environmental and social performance on the part of business.

–this was a finding of a recent DFID supported project undertaken by myself and Nia Hughes of MERN. We found that more than 90 international banks undertake environmental financial risk assessment of borrowers and 50 of these incorporate environmental liability into loan terms. Equipment if bought on credit increasingly has environmental conditions attached to its purchase.

In mining, the investment costs are so high - most projects are financed, as a rule of thumb, one third equity, two thirds debt, and that equity investment or credit has **environmental** or, increasingly now, **social** conditions attached to it in order to promote environmental and social performance that reduces potential future liabilities.

The **case of Grasberg, a mine of Freeport McMoran Ross and Rio Tinto in Irian Jaya** in Indonesia, illustrates this point well when in 1995, **environmental history** was made when the political risk insurance of $100 million was pulled by OPIC, the US based 'Overseas Private Investment Corporation', on environmental and social grounds. This was due to the predicted environmental damage and related threats to the livelihood of local communities considered likely to result from planned mine and tailings expansion. This prompted the company to respond rapidly and a radical remediation plan and social welfare spending programme was set up, leading to the re-instatement of the political risk insurance and greatly enhanced social and environmental performance and reputation.

Other drivers include: **Supply Chain Pressures.** An important marketing drive of B&Q, for example, is to become Britain's foremost green retailer. So it commissioned MERN to review the environmental and social issues pertaining to all its products containing metals and minerals. Increasingly, we are noting a trend for firms to purchase products only from environmentally proficient or ethically-sound sources – driving environmental performance up the supply-chain.

There also exist **Peer Pressures** from other companies in the sector – certainly in the mining sector there exists the challenge that the best environmental performer is still judged by the poorest performer in the sector. At present throughout the minerals sector, the majors are seeking 'Environmental Management System', ISO 14000 accreditation, and, in the quarrying sector, the UK company 'Aggregate Industries', is taking the lead. **Miles Watkins** is currently completing his PhD with MERN on a 3 year secondment from **Aggregate Industries**, and is developing a methodology for stakeholder analysis and environmental performance indicators focused on improving organisational competence and business.

There are also growing **internal pressures** from shareholders and employees for mining companies to be more environmentally and socially responsible – some NGO groups are even buying shares so as to be able to ask questions at AGM's. In MERN we are responding to this driver with regard to the training of mining company employees and have recently begun a link training programme with Rio Tinto.

Finally, a key driver of environmental performance is the natural dynamic of **environmental change** itself. There are many naturally occurring pollution hazards – such as volcanic dust and acid rock drainage – as well as rising sea levels, changing levels of precipitation and natural variations in biodiversity, that are also prompting companies to respond pro-actively to reduce risks of potential environmental disasters.

Our trajectories diagram represents the findings of several multidisciplinary and collaborative MERN projects. A □ B describes the traditional trajectory of corporate performance which is supported by the perspective that there exists a trade-off between competitive production costs and investing in environmental and social performance.

Average firms, as highlighted before, are clustered at 'A' – on or behind the technological/managerial frontier (a proxy for generally competitive and compliant industrial production).

Firms with existing operations, high sunken costs in existing facilities and practices, and that are more reactive than dynamic in their technological / managerial behaviour, would tend to experience 'imperatives of environmental and social responsibility' as a cost burden.

This would consequently drive them along a trajectory south and east from A towards B (bankruptcy) and ultimately to C (close down).

Costly add-on environmental clean-up and social development projects or mitigation efforts: a water treatment plant, a smelter-scrubber, a school, a hospital, food subsidy, a reclamation and after-use plan, or a health compensation scheme etc.

Our research suggests that other firms, **however**, might respond to the imperatives of corporate responsibility quite differently. They **innovate** and build into their business strategies and production practices, new organisational models and technological processes that over time result in a lowering of both the relative production costs associated with their business activities and the external environmental and social costs. They also prevent pollution and minimise waste from the outset.

It should be remembered that those very same drivers may act to increase costs across the board changing the competitive framework within which all companies are working – hence my reference to 'relative costs'.

In doing so, our research suggests, they push the imaginary technological and managerial frontier forward from A – D (dynamic) and then over time to D1 and D2 to achieve new performance levels of economic efficiency and environmental and social proficiency.

We described these trajectories in the mid-1990's. Since then our research has aimed to understand: **what are the elements of corporate strategy and public policy** that promote trajectories towards **'D'.**

Our findings provide empirical evidence to support an important new part of the business and environment literature: that corporations and societies need not always envisage a trade-off between production costs and environmental and social responsibility. Indeed, the elements of corporate strategy, public policy and community wellbeing that describe a **sustained 'win-win' scenario** may be a key aspect of the '**operationalisation**' part of our working definition of '**sustainable development'.**

Porter and Van der Linde have described this 'win-win' scenario more broadly in a seminal work in 1995 published in **the Harvard Business Review** albeit with reference to environmental not social win-wins.

We would contend that due to it's frontier nature, the **mining** industry provides some of the very best examples.

Currently MERN is working on an ambitious multidisciplinary 3 year programme principally aimed at developing environmental and social performance indicators and sustainability markers for mining.

It is core-sponsored by DFID and includes collaborative support from our principal Industry Club members and research users – particularly for the fieldwork and research workshops phase. We are now starting Phase 2.

We have battled to scope the issues that are of concern to different stakeholders across our different sustainability squares; having first battled – theoretically, not physically, to identify the pertinent stakeholders and verify with them the **issues** selected. We have worked out some methodological approaches to indicator development and have some working frameworks to take with us into the field.

Fieldwork is being undertaken in conjunction with our users and collaborating communities we have formed multidisciplinary teams and will be spending this year undertaking **holistic case study research** at selected project sites of our industry sponsors.

Each case study includes a team of 4-6 researchers working together. Some are holistic, like the proposed research at the **Placer Dome site – Western Areas - in South Africa,** others have a particular focus – although they will also be approached with a multidisciplinary methodology - such as the special emphasis on social impact/health impact assessment and community participation, in **Madagascar**, the emphasis on biodiversity and resource rent distribution issues surrounding **Richards Bay** in South Africa; and, the indigenous peoples issues surrounding the **Cerrajon** project in Colombia.

4. In Conclusion

Corporate social responsibility in minerals development on a path towards sustainable development is possible.

Mining can be undertaken without compromising the environment, social benefits can be distributed more equitably and communities are becoming empowered to participate more productively. The technologies, management approaches and capacities exist, or can be feasibly generated.

But it's not happening on a broad scale yet and rarely within one mining project, across the board.

In the current context of globalisation, privatisation and foreign direct investment, regulation is not the major determinant of corporate environmental and social responsibility, and, therefore it cannot be relied upon to be the prime-mover of change.

Other drivers include: a growing 'Voice of Society', pressure groups, codes of conduct, environmental and social conditions attached to credit and insurance – our financial drivers, supply chain pushes, peer pressures, internal awareness and environmental change.

These drivers are also shaping corporate strategy directly in terms of promoting:

- clean technology transfer and diffusion,
- proactive and holistic baseline EIAs, SIAs and HIAs,
- planning for closure from the outset,
- stakeholder analysis → prior consultation → towards Sustainability Permits,
- community participation and capability development.

Moreover, communities in remote mining areas, disillusioned by the failure of the State to deliver on its post-nationalisation promises and having lost out with regard to resource rent distribution from the large State mining enterprises of the 70s and 80s, according to our emerging research evidence in South America, are now engaging directly with mining companies in efforts to negotiate immediate benefits – teachers, enterprise support programmes, health schemes, health compensation, water treatment plants etc. They are not waiting for the State to do it for them.

So, while public policy quite clearly provides the framework (not just in terms of pollution prevention regulation or market incentives, but also the criteria for establishing and monitoring my idea of sustainability permits) companies have the capacity, opportunity and responsibility to make the difference and international collaborative research can provide the impetus and arguments to persuade them to make that difference – FAST!

ENVIRONMENTAL MANAGEMENT AND THE EQUIPMENT & TECHNOLOGY MARKET: BUSINESS IMPLICATIONS FOR MINING & METALLURGY IN A GLOBALISED AND 'ENVIRONMENTALLY PROBLEMATIC' AGE.

by F. E. Novaes-Hegenberg[1], for *Ciencia y Tecnologia para el Desarrollo-CYTED* (Spain); *United Nations Industrial Development Organisation-UNIDO* and *Ministério da Ciência e Tecnologia* (Portugal).
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Opening remarks / Abstract

The main purpose of this paper is to discuss a key issue in corporate environmental management - the use of equipment and technologies. In order to provide some concrete examples we will focus on the case of **Brazil** and on the equipment needs for the productive and environmental management in the mineral-metallurgical sectors[2] (citing the use of equipment and technology from **France**, **Germany**, **Sweden**, **Switzerland**, **UK**, and **USA**). This paper argues that sustainable development today is increasingly being considered within a global perspective and involving global corporations. For this purpose, and to provide some concrete examples, the case studies will be those of: **CVRD** (metal mining), **PETROBRAS** (oil & gas mining), and **USIMINAS** (heavy metallurgy). We conclude by considering whether environmental management for the mining-metallurgical industries in Brazil will require greater use of specialised equipment with sophisticated engineering. The equipment aspect of the market (including technology, industrial processes and engineering systems) need to be studied in more detail to uncover the best path for industrial and technological development with environmental and social responsibility.

1.1. Introduction

There is increasing interest within industry in several countries, and in Brazil in particular, in obtaining greater international acceptance of their business practices and products. This is exemplified by the negotiations for obtaining and establishing internationally recognised standards and managerial industrial procedures - as in the case of the drive towards obtaining certification for International Organisation for Standardisation-ISO series (e.g. 9000 / 14000; see ISO websites at the end of the text). The ISO 14000[3] certification negotiations are becoming a very important "enterprise system for environmental management" (Villas Bôas, 1996). This is of particular relevance for the cases of the extractive and basic industries, especially for mining[4] and metallurgy, as these sectors are the focus of increasing environmental and ecological pressure.

In the case of Brazil, the participation of the industrial sector in the negotiations of the ISO 14000 series is still restricted to a relatively small number of enterprises[5]. The industrial sector finances, via the Brazilian Technical Norms and Standards Association (ABNT), the Environmental Standardisation Support Group (GANA). Companies of the mining and metallurgical sectors in Brazil account for around 30% of the total number of enterprises that are financing the GANA. An important aspect of the mineral-metallurgical sector is that these enterprises usually direct a large part of their production to the external market[6] (Pires do Rio, 1996: 12-3; ABNT / GANA, 1995). The most important companies of

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[2] The oil & gas industry is considered here as part of the mineral sector.
[3] The ISO 14000 series are a group of procedures about environmental management that is under the co-ordination of the ISO.
[4] We are adopting here the view that "Resources is a High- Technology Business" (Ellis, 1998: 14).
[5] The ISO 9000 series is already well established in Brazil.
[6] One important exception is PETROBRAS, that is mainly directed for the internal Brazilian market.

these sectors are AÇOMINAS, ALBRAS, CBL, COSIGUA, COSIPA, CSN, CST, CVRD, PETROBRAS, USIMINAS, VILLARES (see **Table**).

When dealing with the concept of 'environmental management' (as stated in the title of this paper), we are considering the broad understanding of its meaning, i.e. an expanded view of the environment, one that includes 'industrial' and 'para-industrial' activities (with its certification needs in order to better compete at the international sphere; operation of productive plants; health & safety issues; industrial relations and stakeholder relations in general)[7]. This follows the approach carried out in Brazil, something that is extensively documented in specialised journals such as *Saneamento Ambiental* ("Journal of Environmental Sanitation")[8], and *Revista Meio Ambiente Industrial* ("Industrial Environment Review"). More and more businesses are seeing the need to comply with international standards in order to grow or even to survive. This means, among other issues, the drive for obtaining certification for the ISO series (e.g. 9000 and 14000), and also for carrying out Environmental Management Systems (EMSs) procedures.

Some of the procedures usually adopted by enterprises in Brazil to obtain ISO certifications include: developing Environmental Management Systems; building Industrial Effluent & Sanitation-Treatment Plants; working towards reducing / preventing accidents with the *Associação Brasileira de Prevenção de Acidentes - ABPA* ("Brazilian Association for the Prevention of Accidents"); and also, depending on the particular characteristics of the projects being carried, development of recycling plants, of pollution control programs, and leaner industrial process technologies (that economise energy and raw material inputs). All these pre-requisites are demanding a greater use of specialised equipment - and it is here that business opportunities are significantly great.

More stringent environmental requirements for developing industrial activities in Brazil came as a result of new laws and regulations established with: (a) the 1981 Law no. 6938 (Brazilian Environmental Policy, regulated by Decree no. 99274 of 1990), (b) the 1986 CONAMA[9] Resolution no. 1 (and also Resolutions no. 9 and 10 of 1990), (c) the 1988 Brazilian Constitution (Article 225), (d) Law 7805 of 1989 (regulated in 1990 by Decree no. 98812), (e) the 1989 Decree no. 97632, (f) the 1990 Standard Regulation no. 01 by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA). These new laws and regulations make the exercise of mining activities in Brazil dependent on some specific government control instruments - Environmental Impact Assessment (EIA) reports, Environmental Licensing (LA), and the Plan for Recovery of Degraded Areas (PRAD). These are important requirements in order to obtain project approval and licensing for the development of new businesses and industrial activities in Brazil. This is resulting in "the emergence of a new and lucrative industry as local and foreign entities involved in selling environmental equipment, engineering and consulting services position themselves to participate in this evolving market" (Sinclair & Sinclair, 1999: 1).

Following the 1992 Rio de Janeiro Earth Summit Conference, there is a high awareness of environmental issues within both the public and corporate arenas. 'Agenda 21' has become an important reference point for both Federal and state governments, with policy being guided by the principles set out in the Agenda. There is now an awareness of the urgency needed to act on environmental issues. This raising awareness relates not only to the major international issues, such as global warming and the destruction of the ozone layer, but also to the problems of pollution control, lack of urban [and industrial] infrastructure and services and the need to preserve habitats in Brazil. During the last 4 years there has been a growing consciousness on the part of government legislators towards the immense environmental problems confronting the country. Increasing global concern for the environment have encouraged subsidiaries of multinational companies and export-oriented manufacturers to implement environmentally-friendly production methods.

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[7] Environmental management deals with a wide range of issues and sectors, such as: pollution control (air, soil, water, noise & vibration); water (extraction, supply, treatment, re-use); waste (recycling, disposal, production of energy from); instrumentation & automation (for environmental monitoring, for industry); energy (production systems, distribution, use); land (e.g. contaminated land and its remediation); services (e.g. certification, health & safety); etc.

[8] *Saneamento Ambiental* is Brazil's leading magazine for the sanitation and environmental pollution control industry; published by Editora Signus Ltda., Fax: +55 (0)11- 813 5534.

[9] CONAMA: Conselho Nacional do Meio Ambiente / National Council for the Environment.

Most of these companies are expected to implement the ISO 14000 environmental norms, which should result in an increased demand for environmental technologies (DTI, 1998: 7)[10].

There are today several companies in Brazil that have achieved, or are in the process of achieving, the ISO 14001 certification, amongst them we will take a closer look at CVRD, PETROBRAS, and USIMINAS (listed in the **Table** at the end of this text). Of these three companies, USIMINAS belongs to the heavy-metallurgy sector. For this company, and for the Brazilian heavy-metallurgical sector as a whole, it can be said that, "starting from 1994, they[11] are undergoing a programme of investment (that was planned to continue at least until the year 2000) where efforts will be undertaken in order to: (a) modernise its technological productive capabilities, (b) improve environmental conditions, (c) enhance product quality, (d) improve human resources via training and professional qualification programmes, and (e) increase installed capacity through productivity increases and plant installation efficiency" (Brasil, 1996: 11-2, In: Hegenberg & Neves, 1998: 37)[12].

But it is not only the heavy-metallurgy sector that is predicted to invest in modernisation, the oil & gas sector (represented here by PETROBRAS) is also going through times of change, and the investments in this sector are expected to reach enormous sums. "The oil & gas market [in Brazil] will probably be responsible for around US$ 20 billion in investment for the period between 1998-2001", said Mr. José Augusto Marques, Marketing vice-president of **Asea Brown Boveri-ABB** in Brazil. Mr. Cedric Mark Lewis, president of ABB, said that: "The privatisation and the concession of public services in infrastructural sectors stimulate the local [Brazilian] growth of ABB" (*Brasil Mineral*, 1998). "The share of natural gas in the country's consumption of energy will rise from the 3.8 percent of today [1997-1998] to 12 percent in 2010, according to the National Bank for Economic and Social Development-BNDES" (p. 53 In: *Brasil 98* by Ícaro, 1998). This clearly indicates that important opportunities for industrial businesses are currently opening in Brazil.

Other sources quote that PETROBRAS, now with its new management (after the departure of its long serving chief Mr. Joel Renno), may open more doors to private capital, speeding up the signing of risk contracts and leading to a reduction in PETROBRAS' non-core assets, particularly in the gas industry (where it dominates distribution, transport, loading and sales). PETROBRAS upstream joint ventures includes names such as **BP**, **ELF**, **EXXON**, **MOBIL**, **NISHO IWAI**, **PENNZOIL**, **SHELL**, **TEXACO** and the opportunities for increasing foreign partnership in the oil & gas sector are greatly increasing. "Officials have projected US$ 53.7 billion-worth of foreign direct investment during the 1998-2010 period" and "December [1998] saw one important concession to foreign companies with the finance ministry agreeing to exempt the temporary import of all types of equipment for prospecting, drilling, and production from tax" (*LAT*, 1999: 10-11).

Although the oil & gas and the metallurgical sub-sectors are more promising in terms of promoting new business ventures, the metal mining sub-sector via CVRD may provide some opportunities within their iron ore pelletisation or gold activities. The Directory of Pelletisation and Metallurgy of CVRD, for example, is responsible for operating six pelletisation plants (all located in Tubarão in the state of Espírito Santo in Brazil). CVRD entirely owns two of these plants and shares ownership of the other four plants with steel makers from **Italy (ITABRASCO)**, **Japan (NIBRASCO)**, **Korea (KOBRASCO)**, and **Spain (HISPANOBRAS)**. Apart from new equipment that CVRD will need to buy to comply with new environmental regulations, opportunities also seems to exist with replacement, improvements and modernisation of these plants.

1.2. The main objectives for environmental planning and management

The main objectives for promoting Environmental Planning & Management (EPM) are (1) environmental protection, (2) reduction of pollution and its implications, and also (3) to work as an instrument to better regulate the relations between producers, distributors,

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[10] Contact: Richard Turner and Valeria Martinez, British Consulate-General (São Paulo), Fax: +55 (0)11-287 7637 and Tel. 287 7722 (see JEMU 1999 in references).

[11] The companies of the Brazilian heavy-metallurgy sector ("siderurgia", as called in Brazil).

[12] The investments in the Brazilian heavy-metallurgy sector for the 1994-97 period were of US$ 10.4 billion. Around US$ 5.3 billion is the estimated expenditure for the 1998-2000 period (Bigarelli, 1998: 18-9).

suppliers, clients and consumers - i.e. all the stakeholders (and considering the entire supply-demand chain). EPM is applied, in theory, in order to provide known and accepted standards of behaviour for industry and, with this, to give a clearer indication to the public in general of what companies can do and what companies are effectively doing to control, reduce and mitigate their impact on the environment (industrial environment included) and on peoples' lives.

The relevance of EPM to businesses is that it stimulates industry to deal with some important "management tools" such as: (a) Environmental Management Systems-EMSs (that includes Environmental Auditing-EA, Environmental Impact Assessment-EIA, Life Cycle Assessment-LCA, and Risk Assessment-RA), and (b) ISO standards (that includes a diversity of series for certification and more stringent control of businesses). The development and application of these management tools require more specialised engineering systems and processes, which in turn, requires greater use of equipment for industrial applications that are supposed to be more efficient, technologically advanced, and also more environmentally friendly.

1.3. Some of the main implications of environmental planning and management

1.3.1. Business strategies and world-class operations needs

Extending the concept of "world class mineral operation" considered by Richardson (1991) to the steel-producing and metallurgical industries and also to the oil & gas industry, is a useful path towards developing and implementing a global industrial analysis of world class strategies to compete within the global materials business. World class mineral and metallurgical operations means having (or searching for) 'world class orebodies' and also having (or developing) 'world class industrial facilities'. As in "world class manufacturing", the considerations regarding performance parameters, production strategies and organisation processes are very important factors towards a *world class status* for production, trade and businesses. This includes e.g. the development of a new concept of value creation, the financial and operating performance parameters, strategies for organisation processes and environmental management.

Drawing upon these ideas and concepts, it is possible to state that world class strategies have to be shaped to meet the unique competitive situation of each corporation, i.e. on improving total factor productivity in an integrated manner: improving '**material productivity**' (by choosing the best mine, the best orebody, the best geological setting, the best plant layout, the best equipment and technology), improving '**capital productivity**' (by the best use of financial resources, continual cost improvement), and improving '**productivity of labour**' (best use of human and management resources, good practice with the "operational philosophy" regarding managerial skills and attitudes). All these three components: (a) material (including land, the mine, the industrial plant and its processes and equipment), (b) labour, and (c) capital, must be constantly subjected to periodic 'performance audits', focusing on the quality of the ore deposits, industrial and financial operations, production volumes and product quality (specifications and uses), and the effects and influence over environmental matters.

1.3.2. The increasing importance of the regulatory and legal systems

Discussions concerning the influence of environmental policies and legislation over the competitiveness of enterprises of the natural resources transformation sector are relevant to predict possible changes in industrial practices (and in the competitiveness of the natural resource sector). One of the main preoccupation concerning competitiveness of natural resources enterprises, that greatly influence their use and buying pattern of industrial equipment (and their related technological processes), is related to the influence of the legislative system regulating issues of the environment (e.g. pollution, health & safety, plant operation). We are considering here 'the environment' including aspects and processes for protection of Nature (ecological resources), and also industrial operations and its implications for workers and other stakeholders. The basic conclusion that we achieve is that the management of the environment is increasingly requiring international standards (such as ISO series and EMSs), and also international presence through the provision of high-tech equipment.

The increasing adoption of ISO series and standards has occurred partially because of the implications brought about by the launching of the Brazilian Quality and Productivity Programme (PBQP) during the period of 1990-92. The PBQP aims to promote business strategies and practices designed to help companies better able to adjust to the environment of greater competition of the domestic economy that was triggered by the attempts of greater international integration and exposure of Brazil and its consequent policy and regulatory changes that were implemented since 1990.

1.3.3. Equipment and technology needs and the forms of its supply

"Technology can be transferred in two basic forms. One form embraces physical items such as drawings, tools, machinery, process information, specifications and patents. The other form is personal contact. Put simply, knowledge is always embodied in something or somebody, the form being important for determining the transfer process and cost" (Hall and Johnson, 1970, quoted in Buckley, 1985, p. 46) when dealing with aspects of transfer process of technology. In the case of several Brazilian enterprises, the costs to them to develop their industrial activities and manage their impact on the environment are associated with the costs of buying engineering equipment, processes and systems.

Among the main implications of adopting EPM that complies with international standards & specifications are those relating to the use of equipment and technology (see *Minério / Minerales*, 1996; and Singhal, 1998). In the case of more advanced mining and metallurgy operations in developing countries [such as in the case of Brazil] this is very clear by observing the widespread use of imported equipment and technology. The main reason for this is because producing companies need to make their products according to the demanding conditions established by international competitiveness. This requires having or developing world class operations.

1.3.4. Consequences for industrial operations: Brazilian examples

In the case of, for example, technologically-advanced productive processes, we can quote the case of **CVRD**'s gold mine Fazenda Brasileiro. The metallurgical process and plant used in this mine "was planned to recover gold from *primary ore* by the hydrometallurgical 'carbon-in-pulp' (C.I.P.) process with an expected recovery index of 90%. The first-stage gravimetric cycle comprises crushing and milling followed by cycloning and jigging. After this stage the mill product (80% of bulk volume) is directed to the thickener and its underflow (50% solids) is pumped to pre-aeration and cyanide solution addition tanks. The gold in solution and the pulp resulting from leaching are pumped to carbon tanks for the gold adsorption stage. Gold-enriched carbon goes to a desorption (elution) unit. The impregnate solution is then pumped to electrolytic cells and gold is electro-deposited on steel wool cathodes which are removed from the cells when saturated. Saturated cathodes are acid washed in order to dissolve impurities. The concentrate obtained is filtered, dried and melted in induction furnaces. The gold bullion is afterwards sent to refineries" (Victorasso et al 1991: 9).

With respect to productive systems, quoting the case of **PETROBRAS** is also useful for understanding the importance for companies to have their industrial activities certified in accordance with international standards. PETROBRAS has already obtained several ISO 9000 certifications; for example, ISO 9001 for development, production and technical assistance relative to oil & lubricators, ISO 9002 for productive, transportation, storage, distribution and commercialisation activities of a diverse range of petrol products, and also for support in materials supply and engineering. PETROBRAS is one important user of advanced productive systems (as exemplified below in our 'case study 2').

In order to better illustrate these issues of environmental planning and management and its related technological character (of industrial operations, engineering systems and processes) - something that is clearly indicated by **the use of specialised and advanced equipment produced by multinational enterprises** - three case studies are presented in the following section of this paper: CVRD, PETROBRAS and USIMINAS.

1.4. Case studies

1.4.1. Case study 1: CVRD:

Address: http://www.cvrd.com.br

Company origin: Brazil (created in 1942).

Products: Diverse range, but the most important being iron-ore.

Market: National and international.

Equipment & Technology: User of know-how and technology from, among others:

-(a) **DATAMINE from the UK** [Datamine Latin America; Tel./Fax: +55 (0)11-866 5366]: Mining industry software's - for exploration, geology, geochemistry, rock mechanics, orebody modelling, etc. CVRD uses, for example, the 'Datamine/NPV Scheduler'.

-(b) **KRUPP from Germany** [Krupp Engenharia do Brasil Ltda. Fax: +55 (0)31-261 3677]: Amongst its products are engineering systems for mining, materials handling and mineral processing. In Brazil Krupp works mainly with the iron-ore sector (with CVRD, but also with MBR, SAMITRI and SAMARCO) and related areas such as installations for ports that handle large volumes of ores (work was already done for the Port of Santos where two ship loading systems were installed by Krupp).
-(c) **ATLAS COPCO from Sweden** [Atlas Copco Brasil Ltda., Fax: +55 (0)11 - 541 7721 / 541 7671 / 541 7567]: Products include a diverse range of equipment such as those for perforation, drilling and demolition of rocks; also transport and maintenance. CVRD uses, for example, drilling equipment for underground mining ('Atlas Copco Boomer H 127').
Perspectives for new businesses: As CVRD is investing in industrial automation, e.g. in the C.I.P. process of Fazenda Brazileiro mine for the controlled addition of cyanide solutions undertaken in *real-time*, this indicates that the 'organised (= formal) sector' of Brazilian mining is promoting more advanced solutions for their operations and that there will probably be more opportunities for suppliers of these cited mining-metallurgical operational systems.

1.4.2. ***Case study 2: PETROBRAS:***

Address: www.petrobras.com.br
Company origin: Brazil (created in 1953).
Products: Oil & gas (exploration, drilling, production, refining, transportation, distribution).
Market: Mainly national.
Equipment & Technology: User of know-how and technology from, among others:
-(a) **SIEMENS from Germany** [Siemens Ltda., Fax: +55 (0)11-836 2565 / 836 2631]: Siemens developed in its Brazilian factory ["Fábrica de Transformadores de Jundiaí" in São Paulo state] the first submarine electric transformer for deep-sea use in the world. With sophisticated engineering, the transformer started to be used in 1998 in the oil Basin of Campos (Rio de Janeiro state) by PETROBRAS. This is part of a Programme for Technological Co-operation for Technological Innovation in Deep Waters between PETROBRAS and SIEMENS ("Programa de Inovação Tecnológica em Águas Profundas e Ultraprofundas" - PROCAP 2000, "Acordo de Cooperação Tecnológica"). The transformers makes possible the distribution of electric energy in the deep sea in depths of until 2,000 meters.
Obs.: SIEMENS is a leading figure for its products and systems in the Brazilian market.
-(b) **ABB from Switzerland** [Asea Brown Boveri Ltda., Fax: +55 (0)11-7084 9983]:
The Swiss enterprise ABB inaugurated in February 1998 a new equipment-producer plant (already with ISO 9001 certification) in Osasco, São Paulo state (transferring its operations from Rio de Janeiro) in order to increase its production capacity for servicing the oil & gas industry. This new plant is already producing "Christmas Trees", "Risers", "Mud lines", and other equipment and systems destined for use in oil exploration and production.
The purpose of ABB was not only to increase their productive capacity, but also to increase their productivity and technological capabilities. As an example of their technological resources, PETROBRAS, during the second semester of 1997, broke the world record in oil exploitation in deep sea, reaching a depth of 1,709 meters under water with a "Christmas Tree" designed and fabricated by ABB.[13]
Perspectives for new businesses: New businesses look particularly promising in the gas sector as the **Bolivia-Brazil Gas Pipeline Project** is being developed; this will leverage the demand for natural gas in Brazil. It is also expected to open up opportunities for new projects to facilitate the integration of energy and industry in the South American region. The 3150 km pipeline span will require a diverse range of equipment and speciality materials to serve 'gas metering stations', 'compression stations' and 'city-gates'. As cited by SBPC (1998) the entire system of pipelines in use in Brazil nowadays (oil & gas) is equivalent to approximately 12,000 km in extension; and the target is to extend this to around 21,000 km by the year 2000 (and this will require massive investments).
Register your company: Companies intending to qualify as a vendor / supplier of equipment and materials for PETROBRAS are advised to register with: PETROBRAS, Purchasing

[13] Since 1997 another world record was achieved on the 25, January 1999, with PETROBRAS' deep water oil production record reaching a depth of 1,853 meters: Roncador field, in the Campos Basin (Rio de Janeiro).

Department, Serviço de Material (SERMAT), Att: DIQUAD / SEHAC, Av. República do Chile, n. 65, 6th floor, Room 601-A, CEP 20.035-900, Rio de Janeiro, Brazil. Fax: +55 (0)21- 534 4248 or 534 3857 and Tel. +55 (0)21- 534 1986.

*1.4.3. **Case study 3: USIMINAS**:*

Address: www.usiminas.com.br

Company origin: Brazil (started operations in 1962).

Products: Heavy Metallurgy; Steel producer.

Market: National and international.

Equipment & Technology: User of know-how and technology from, among others:

-(a) **ALSTOM Group / CEGELEC, from France.**

ALSTOM is represented in Brazil by 'CEGELEC Engenharia S.A.' [Tel./Fax: +55 (0)31-291 2626 and Fax: +55 (0)11-280 2206]; ALSTOM produces electric equipment and industrial controls for mining, metallurgy and infrastructure. USIMINAS contracted work such as "Furnace Signalling System", "Linha de Tesouras LTF1", "Skip Alto Forno no. 1".

-(b) **ROCKWELL from USA** [Rockwell Automation; Fax: +55 (0)11-3879 8986]: Automation electric systems - hardware, engineering and software - for the coiling process of the flat-rolled steel produced by USIMINAS.

-(c) ULSAB Project: USIMINAS participates in the Ultra Light Steel Auto Body project (ULSAB), together with 34 other laminated steel producers from 18 countries for the development of an 'holistic design' for the auto-industry in order to "demonstrate steel's capability to reduce substantially the weight of a vehicle's body structure and ... highly suited for mass production of vehicles" [see website: http://www.ulsab.org/ for more information].

Perspectives for new businesses: There are potential business opportunities from developing recycling plants for metallurgical dross (waste or refuse materials), combustible ashes, 'fly ash' (composed of hematite and magnetite), combustible oils, and acids resulting from the use of sulphuric acid (quoted by Veiga & Paschoal, 1991: 117).

1.5. The operation of corporations in a global context

"If we are to avoid further environmental and social crises, there is no alternative but to change the way in which businesses and markets allocate resources" (Welford, 1999: 9). Welford (1999: 36) also suggests that "many large companies (including some in developing countries) are adopting corporate environmental management strategies and tools. Whilst this is to be encouraged, ... [there are some doubts] ... about the real effectiveness of many of the tools being used. Although companies may perceive themselves to be doing things right, therefore, we must nevertheless ask whether they are doing the right thing. [This author points out that] ... the trend of eco-modernism may not be sufficient if our aim is to bring about a situation consistent with sustainable development".

We must remember that issues associated with sustainable development[14], and the sustainable development debate itself, have a wide range of implications for the way corporations work. The implementation (or not) of 'best-practice' procedures and tools depends not only on the directions which the environmental debate takes us to, but also on the willingness and capabilities of enterprises to take on board the proposed changes and to comply with new policies being designed by national and also by supranational bodies (such as the United Nations (UN), the European Union (EU), the World Trade Organisation (WTO), the Organisation for Economic Cooperation and Development-OECD, etc.). The achievement of 'sustainable development' depends on a social and economic order that can rightly comply with many new ideas and regulations. However, we must first start by defining the main issues and establishing what corporations must do and what they effectively can (or are willing) to do.

A starting point for this could be the a discussion on 'how companies work and what are their main environmental consequences'. The contribution of such study, that can

[14] Sustainable development has come to be part of common language yet few agree on what sustainable development actually means. Often sustainability is used to describe a constellation of ideas. Basiago (1995) stated that "in biology *sustainability* has come to be associated with the protection of bio-diversity. In economics *sustainability* is advanced by those who favour accounting for natural resources. In sociology *sustainability* involves the defence of environmental justice. In planning *sustainability* means alternatively, preservation, conservation or 'sustainable use' of natural resources" (Ahmed & Hardaker, 1999: 75).

provide some concrete examples (from a diversity of countries), would be one route for examining the national and international dimensions of sustainable development. Only by knowing 'how companies are conducting their activities', and also by setting some basic guidelines and definitions of 'what must be done' (to avoid environmental degradation), we will be able to evolve towards sustainable development. If domestic sustainable development practices today are increasingly going to be considered within a global perspective, it implies that national (domestic) corporations will have to adopt 'best-practice procedures and tools' that are recognised to have international standards.

For international standards to be applicable, we must accept some basic guidelines and define 'sustainable development' in the context of mining activities. As a building block for this policy, "sustainable development in the context of minerals and metals is considered as incorporating the following elements: (a) finding, extracting, producing, adding value to, using, re-using, recycling and, when necessary, disposing of mineral and metal products in the most efficient, competitive and environmentally responsible manner possible, utilising best practices; (b) respecting the needs and values of all resource users, and considering those needs and values in government decision-making; (c) maintaining or enhancing the quality of life and the environment for present and future generations; and (d) securing the involvement and participation of stakeholders, individuals and communities in decision-making" (MPWGSC, 1996: 4-5).

In defining sustainable development in the context of minerals and metals, it should be recognised that the mining industry is part of a greater picture that deals with several other industries. Economic and social development will only bring benefits in the long-term if current investments and current activities in human and physical capital take into account present and future generations. This means re-enforcing more and more the role and importance of the environmental industries sector.

The 'environmental industries sector' in a global context today is big business. Data from the Environmental Business Network (EBN, 1999) estimated that this sector was "worth US$ 280 billion in 1997", and predicted that by the year 2000 it will grow to US$ 335 billion (and US$ 640 billion by 2010). There are many reasons for explaining the importance of environmental industries, among them are: increasingly more stringent environmental legislation; consumer awareness (stakeholder pressure); supply chain pressure, and the needs of newly industrialised nations (e.g. Asian and South American countries). Why is all this necessary? ... To obtain "eco-efficiency". "Eco-efficiency is reached by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's carrying capacity" (Nuij, 1999, p. 14).

How are companies going to achieve this? ... By increasingly promoting "eco-design" solutions. This should also mean efficient use of resources and energy and increased industrial efficiency. The parameters that we must take on board for promoting eco-design are: (a) to consider the whole life-cycle of products (e.g. How is the article produced? How is the finished article distributed? Investigate the use of the product, and what happens at disposal?), (b) to look at the mix of materials used, and (c) consider the ways in which components or materials are joined together (EBN, 1999). Huang & Hunkeler (1995: 36) consider that "Today, there is a growing interest in industry to practice Environmentally Conscious Design and Manufacturing (ECDM)".

How will this affect most countries around the world? ... By stimulating them to buy equipment and automation systems from some highly developed corporations (technologically speaking). Most countries (**Brazil** included), and also some countries of the 'First World' (e.g. **Portugal**) do not have their indigenous technological capabilities[15] developed to the required degree of sophistication to produce: (a) their own equipment; (b) quality programmes, and (c) to promote high technology eco-design. They have to rely on other countries' technologies for managing their own 'environment'. This is a critical matter for further analysis, i.e. the reliance on foreign suppliers[16] of equipment, technology and processes for environmental management. Technical and scientific aspects involved in advancing mining activities, is a good area for further research (between Brazil and European countries). A historical perspective for Brazil for the XVIII and XIX centuries was

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[15] Of Science & Technology (S&T) and Research & Development (R&D).

[16] Or equipment produced by MNEs established in a 'host' [= recipient] country; as opposed to equipment coming directly from the 'home' country of the multinational.

provided by Figueirôa (1994); it is now time for reviewing how 'technical & scientific' dimensions affected mining in the 20th century in 'multi-country' study.

1.6. Final remarks

We may consider that there is an increasing tendency in Brazil[17] (ever more so since 1990), as observed in the case of the mineral and metallurgical sectors, of elaborating business strategies that are global with respect to the adoption of international standards (and certification), and to the use of imported equipment[18] for managing the 'industrial environment' (processes, technologies) and 'natural environment' (pollution control and mitigation). This is opening up great business opportunities for suppliers of equipment, technology and industrial processes for the mining (including oil & gas) and heavy-metallurgical sectors in Brazil, and promoting an increasing pattern of international integration of Brazilian enterprises through the use of foreign technologies, tools and processes.

Mining and metallurgy 'per se' are today uninteresting businesses on their own[19]. For mining and metallurgy to be interesting and attract more investment, it needs to be linked to more advanced stages of the production chain; it needs to be useful for industry in providing higher-quality, lower cost, environmentally friendly commodities that may be "adjusted" (e.g. its specifications, performance parameters, physical & chemical characteristics) according to the demands of more advanced stages of industry. Mining & metallurgy will have to adjust more and more by using sophisticated engineering processes, by making products with greater 'quality content' (i.e. with use of ISO and EMSs standards and tools), and with greater use of automation and design technologies.

Although this text gave some specific examples from Brazil, the idea was not only to deal with some specific cases of this particular country, but also to provide concrete evidence of how companies and countries are affected by environmental issues (via technologies, legislation, industrial practices, etc.), and also to highlight that this is a very important area for research. Similar studies must be undertaken for other countries so that more can be known about the business implications of industrial activities. Another line of research that also should be stimulated is that relating to Small & Medium Enterprises-SMEs (which have not been discussed in this paper).

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<u>Table</u>:

Table: Mining & Metallurgical Enterprises registered with GANA.

	Acronym	**Company name** [main sector]
1	AÇOMINAS	Aços Minas Gerais [steel]
2	ALBRAS	Albras Alumínio do Brasil S.A. [aluminium]
3	CBL	Laminação Brasileira de Cobre Ltda. [copper]
4	COSIGUA	Companhia Siderúrgica Guanabara [heavy metallurgy]
5	COSIPA	Companhia Siderúrgica Paulista [heavy metallurgy]
6	CSN	Companhia Siderúrgica Nacional [heavy metallurgy]
7	CST	Companhia Siderúrgica Tubarão [heavy metallurgy]
8	**CVRD**	**Companhia Vale do Rio Doce [mining]**
9	**PETROBRAS**	**Petróleo Brasileiro S.A. [integrated oil company]**
10	**USIMINAS**	**Usinas Siderúrgicas de Minas Gerais [heavy metallurgy]**
11	VILLARES	Aços Villares S.A. [steel]

Source: ABNT / GANA, 1995; Pires do Rio, 1996.

[17] And probably in many other countries around the world (a matter for more research).
[18] Or equipment produced by MNEs established in Brazil.
[19] For some insights in this issue see Houston et al, 1984.

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For more information:

(1) For information on exporting to Brazil (from the UK) see website of the DTI Export Market Information Centre (EMIC): http://www.dti.gov.uk/ots/brazil (with 'market menu' of services).

(2) Brazilian Embassy's website http://www.brazil.org.uk (country information).

(3) Latin America Trade Advisory Group (LATAG): www.latag.com (London based).

(4) http://www.abb.com (ABB).

(5) http://www.alstom.com (ALSTOM).

(6) http://www.atlascopco.com (ATLAS COPCO).

(7) http://www.cegelec.com (CEGELEC; part of ALSTOM since 28 May 1998).

(8) http://www.datamine.co.uk (DATAMINE).

(9) http://www.krupp.com (KRUPP).

(10) http://www.automation.rockwell.com (ROCKEWELL Automation).

(11) http://www.siemens.de (SIEMENS).

(12) For additional information on the Brazilian Machinery and Equipment Industry (basic statistics, producers, addresses, products, services, etc.) please see the website: http://www.abimaq.org.br [internet address of The Brazilian Association of the Machinery and Equipment Industry-ABIMAQ, that works closely with the National Union of the Machinery Industry in Brazil-SINDIMAQ.

Another useful website is that of the 'Sociedade Brasileira de Tecnologia para Equipamentos e Manutenção' (SOBRATEMA) [The Brazilian Society for Equipment Technology]: http://www.sobratema.org.br (São Paulo based).

(13) Some ISO websites:

http://www.iso.ch
http://www.tc207.org/home
http://www.iso14000.com/

(14) http://www.getf.org/vcet/ (Information about the Verification-Certification of Environmental Technology-VCET of the Global Environmental & Technological Foundation-GETF).

(15) http://www.nrcan.gc.ca/mms/sdev/policy-e.htm (Minerals and Metals Sector-MMS of Natural Resources Canada-NRCAN).

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Indicators of Sustainable Development for the Minerals Extraction Industry: Environmental Considerations

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Abstract
Despite numerous actions world-wide which call for adoption of more sustainable strategies, relatively little has been done on practical level so far on the pretext that the issue is too complex and not fully understood yet. This paper follows the argument that it is important that today's decision-makers address the issues of sustainable development, however imperfectly, as ignoring it may only exacerbate the problem for future generations. In particular, the paper concentrates on measuring environmental sustainability of the minerals extraction industry with the aim of further informing the debate in this area. It proposes a framework with a relatively simple, yet comprehensive set of environmental indicators for identification of more sustainable practices for this industry. The indicators include environmental impacts and efficiency, and voluntary environmental actions by companies. The framework is applicable across the industry; however, more specific indicators for different sub-sectors can be defined on a case-by-case basis. A life cycle approach used in this framework ensures that the most important stages in the life cycle and their impacts are identified and targeted for improvements. The framework can be expanded to include economic and social aspects of sustainable development and to provide a link between local and macro-considerations. This framework can therefore assist companies in assessing their environmental performance with regard to goals and objectives embedded in the idea of sustainable development.

1. Introduction

The publication of "Our Common Future"[1] in 1987 prompted numerous actions on both international and national levels, which called on governments, local authorities, businesses and consumers to define and adopt strategies for sustainable development. However, in the midst of all these activities, there is still a lot of confusion as to the exact meaning of sustainable development. While the general concept of "meeting the needs of the present without compromising the ability of future generations to meet their own needs" is accepted and relatively easy to comprehend, the difficulties arise in trying to apply the principles of sustainable development in practice. One of the difficulties is that, to be able to identify and define sustainable actions for different sectors of community, i.e. local and national governments, industry and individuals, we must first be able to measure "the level of sustainability" of the proposed options and strategies. For this, we need to develop indicators of sustainable development (ISD) that will enable the overall assessment of progress towards sustainable development. This is endorsed in Chapter 40 of the Agenda 21[2]. Thus far, a number of different approaches have been proposed to define the indicators for different parts of the community, including industry[3-5]. However, there is still no standardised methodology which defines generic indicators to enable a consistent comparison and identification of more sustainable options.

This paper takes on a challenging task in attempting to develop a generic framework with a simple, yet comprehensive set of environmental indicators for identification of more sustainable practices for the minerals extraction industry. The paper builds on an earlier work[6] and it aims to identify relatively simple ways of measuring the level of environmental sustainability in the first instance and thereby contribute to further understanding of the meaning of sustainable development for this industry.

2. Environmental Indicators of Sustainable Development

Industrial operations associated with the extraction of minerals usually occupy large areas and often have detrimental consequences for the environment. It is therefore important to assess the extent of environmental impacts and identify best strategies for sustainable development of this industrial sector. The key sustainable development objectives are to conserve minerals as far as possible while ensuring an adequate supply, to minimise waste production and to encourage efficient use of materials, to minimise environmental damage from minerals extraction, and to protect designated areas from development[7].

This paper proposes a generic framework to measure the level of environmental sustainability of the minerals extraction industry. The approach is based on life cycle considerations and it follows the Life Cycle Assessment (LCA) methodology[8]. The need to consider the life cycle implications of economic activities in the context of sustainable development is now widely recognised and accepted. The life cycle approach provides a full picture of the interactions of human activities with the environment and identifies the "hot spots" in the system, which can be targeted for improvements. The latter is particularly important as it enables concentrating on the important stages and impacts in the life cycle. There are numerous examples of the usefulness of the life cycle approach and many companies are already using LCA to assess and improve their environmental performance[9].

The environmental indicators proposed in this framework have been classified into three general categories:

- environmental impacts,
- environmental efficiency, and
- voluntary actions.

The environmental impacts indicators include the usual categories considered in LCA. Their definition is given in the Appendix. Although the list of the impacts is fairly comprehensive, it is by no means exhaustive, and can be expanded to include other impacts, specific for each system. The impacts are divided into two categories: those from planned emissions and those from unintentional or accidental releases. Some of the impacts listed in Table 1 have a local effect on the environment (e.g. land use, photochemical smog and eutrophication) while the others are of a more global nature (e.g. global warming and ozone depletion). However, the impacts as defined in LCA at present represent only potential rather than actual effects on the environment. For instance, the impacts are calculated on the basis of the emissions of pollutants, and not on the basis of their fate in the environment. Although there have been some attempts to incorporate environmental fate modelling into LCA[10], there is no agreed methodology at present so that its introduction at this stage may further complicate the issue. It is thus proposed to use the potential rather than "actual" impacts for the environmental indicators. This should not pose a significant problem as long as it is made explicit and the systems are assessed and compared on an equivalent basis.

To facilitate a gradual incorporation of the framework for sustainable development into the organisational structure, it is possible to divide the system under consideration into foreground and background systems (see Fig. 1). The foreground is defined as the set of processes directly affected by the study[11], delivering a functional unit of interest. For instance, the functional unit could be defined as 'operation of the system for one year' or as 'production of 1000 kg of product'. The background is that which supplies energy and materials to the foreground system. For instance, the foreground could be a mine and the associated processing plant for which the environmental impacts are being determined, with the inputs of energy and other materials from the background system. Distinction between foreground and background can also be useful for identifying the direct contributions to the impacts of the activities of the company, compared to the impacts along the whole supply chain. There are a number of examples of application of this approach to the real case studies, e.g. in the mineral[12], water[13], gas[14], and nuclear[15] industries.

Table 1. Environmental indicators of sustainable development

Environmental impacts	Environmental efficiency	Voluntary actions
-Resource use (including land) -Global warming -Ozone depletion -Acidification -Eutrophication -Photochemical smog -Human toxicity -Ecotoxicity -Solid waste	-Material intensity -Energy intensity -Recycling of waste materials (e.g. aggregates)	-Environmental management systems -Environmental improvements above the compliance levels -Assessment of suppliers

In addition to the environmental impacts, further information about the level of environmental sustainability of an activity can be provided by determining its environmental efficiency defined by material and energy intensity and recycling of waste materials. The two former categories determine the total amount of materials and energy used in the life cycle of a minerals extraction facility. Recycling of waste materials to reduce the use of primary resources is another measure of sustainable development proposed here. For instance, to minimise the adverse impacts of aggregates extraction, the construction industry could increase its use of secondary and recycled materials (e.g. from demolition rubble).

Both Environmental Impacts and Environmental Efficiency indicators proposed here are calculated routinely through LCA and, by analogy with LCA, are expressed per functional unit. The wide availability of LCA software packages, which usually come with extensive databases, enables relatively quick and reliable assessments. Therefore, there is no benefit in restricting the number of categories for environmental indicators, as there is little time or resource saving and some important categories could be missed out in this way. Instead, it is better to start the analysis with as many indicators as possible to identify those of greatest concern; less significant indicators can then be dropped in the subsequent analysis.

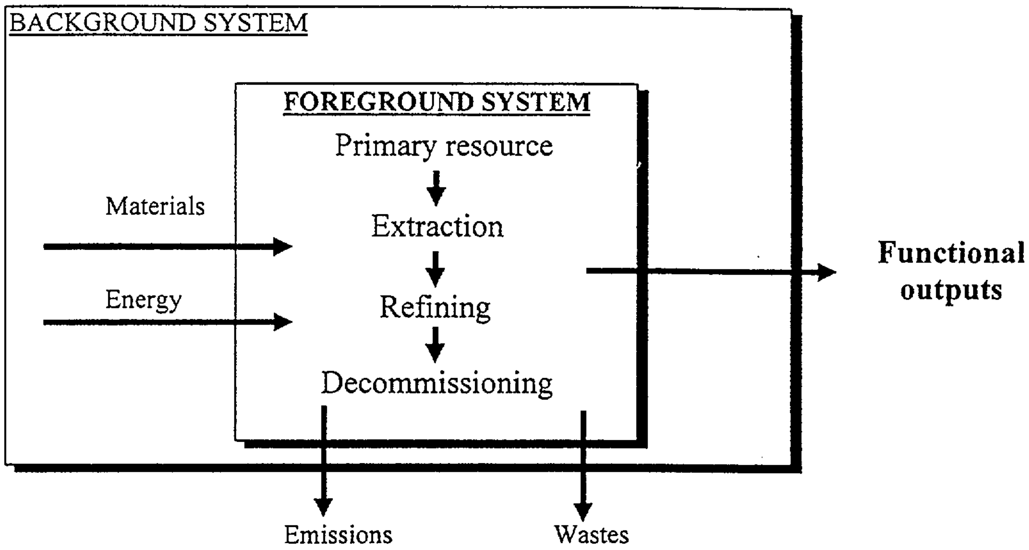

Fig. 1 Life Cycle Stages in a Minerals Extraction System

The third set of environmental indicators proposed in this framework is related to a pro-active response of companies to environmental problems. These indicators are designed to reward business for their contributions to the environment and therefore to the society. Most companies see a business benefit in voluntary environmental actions. If they are merely complying with regulations, then they are the same as all other companies. However, if they can distinguish themselves by being the first to go beyond compliance, they may be able to improve their public image and thus gain a competitive advantage. A proactive approach also enables companies to anticipate regulatory shifts and reduce costs associated with catching-up with legislation.

Three such indicators have been included here: incorporation of environmental management systems (e.g. ISO 14001 or EU EMAS), rate of improvement over the minimum compliance level, and preferential choice of the suppliers based on their environmental performance. There are already a large number of companies which subscribe to some kind of voluntary environmental management systems. Many of them have also cut their emissions beyond the minimum levels prescribed by legislation or ahead of the targets set by government or international organisations. For instance, the Chemical Industries Association and the UK Government have reached an agreement with its members that they undertake to reduce specific energy consumption by 20% of the 1990 level by 2005, a full five years ahead of the

Government's climate change target[16]. The agreement should lead to savings in annual CO_2 emissions of between 550,000 and 900,000 tonnes per year.

More progressive mining companies go further than site-specific considerations and look at the whole supply chain relevant to their activities. They assess the environmental performance of their suppliers and make the appropriate choices on that basis. In the context of life cycle thinking, the right choice of suppliers is directly linked to the company's performance as environmentally better suppliers mean lower impacts overall.

Information on the voluntary actions can be used to further inform the decision-making process when assessing progress of different systems towards sustainable development. Other indicators can also be included, depending on the particular activities that a company is engaged in. As for the metrics of these indicators, they can be treated as either qualitative of quantitative. For instance, if a company reduced their SO_2 emissions by a certain amount below the levels prescribed by legislator, they could express this improvement in terms of percentage decrease per functional unit. The EMS or Assessment of suppliers indicators may be more difficult to express in quantitative terms. They may be included as descriptive statements; the quantitative improvements will in any case be reflected in the reduction of environmental impacts and increase of the efficiency, as expressed by the respective indicators.

The flexibility of the approach proposed here enables inclusion of more specific indicators as necessary; it also allows for a reduced set of categories, if the assessment shows that some are insignificant. The categories included are relatively well defined and many companies and organisations are already using them routinely to indicate their environmental performance[9,17]. The latter provides a further justification for using the proposed indicators, as this may bring us a step closer to the standardisation. However, while there may be a general agreement on the environmental indicators to be considered in the context of sustainable development, the situation is much less clear with the economic and social indicators. These indicators are discussed elsewhere[6].

3. Conclusions

The issue of sustainability is becoming increasingly important for the minerals extraction industry. To respond to the challenge, the industry must be able to measure its progress towards more sustainable development. The generic framework for environmental indicators of sustainable development proposed in this work could be used as a tool for assessing the level of environmental sustainability of industry and for identifying more sustainable options for the future. Most of the indicators included in the framework apply across the industry; more specific indicators for different sub-sectors can be developed separately. The latter have to be considered on a case-by-case basis to reflect specific characteristics of different operations.

In developing the methodological framework, the aim was to use simple and informative indicators with relevance to environmental aspect of sustainable development. The framework proposes three types of indicators: environmental impacts, environmental efficiency and voluntary environmental actions. A life cycle approach has been taken in this work and, like in Life Cycle Assessment, it is proposed that the indicators be standardised according to the function the system delivers. The advantage of this approach, compared to some other approaches, is that it explicitly avoids trying to express environmental performance in monetary terms. This helps avoid the usual bias on the economic aspect of sustainable development, which often attracts criticism from different pressure and consumer groups.

Appendix: Definition of Environmental Indicators

All indicators defined here are expressed per functional unit, related to the function the system delivers.

Environmental impacts

The environmental impacts are defined according to the problem-oriented approach[18] to Impact Assessment in LCA. They can be calculated either for the foreground only or for the whole life cycle of the system. Both planned and accidental releases and their respective impacts are calculated but reported separately, for the transparency of results.

Resource use: abiotic, biotic depletion and land use/restoration

Abiotic resource depletion (ARD) includes depletion of non-renewable resources, i.e. metals and minerals and fossil fuels. The effect score is calculated by:

$$EI_{ard} = \sum_{j=1}^{J} \sum_{l=1}^{L} \frac{B_{l,j}}{e_{ard,j}} \qquad (-) \qquad \text{(A1a)}$$

where $B_{l,j}$ is quantity of resource j used in life cycle stage l; $e_{ard,j}$ represents total estimated world reserves of that resource[19].

Biotic resource depletion (BRD) is related to the use of species threatened with extinction, due to the extraction of minerals. It is calculated as:

$$EI_{brd} = \sum_{j=1}^{J} \sum_{l=1}^{L} \frac{B_{l,j}}{e_{brd,j}} \qquad (yr^{-1}) \qquad \text{(A1b)}$$

where $B_{l,j}$ is the use of species j in a life cycle stage l and $e_{brd,j}$ is the biotic depletion factor for that species. For instance, $e_{brd,j}$ for black rhino is $4 \cdot 10^{-5}$ /yr[19].

Land use is expressed in square meters of land occupied by the whole system:

$$EI_{land} = \sum_{l=1}^{L} B_l \qquad (m^2) \qquad \text{(A1c)}$$

where B_l is the land area used in different stages of the life cycle.

Land restoration (LR) can be expressed as the area of land, *LR*, which has been restored per functional unit in the whole system:

$$EE_{lr} = \sum_{l=1}^{L} LR_l \qquad (m^2) \qquad \text{(A1d)}$$

It is desirable to increase the amount of land restored to beneficial use as soon as possible. Modern planning permissions require restoration and "aftercare" of sites following minerals extraction. Aftercare treatment could include cultivation and application of fertilisers.

Global warming potential (GWP)

GWP represents total emissions of the greenhouse gases, $B_{l,j}$ (i.e. CO_2, N_2O, CH_4 and other VOCs) multiplied by their respective GWP factors, $e_{gwp,j}$:

$$EI_{gwp} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{gwp,j} B_{l,j} \qquad \text{(kg)} \qquad \text{(A2)}$$

GWP factors, $e_{gwp,j}$, are for different greenhouse gases expressed relative to the global warming potential of CO_2, which is therefore defined to be unity. The values of GWP depend on the time horizon over which the global warming effect is assessed. GWP factors for shorter times (20 and 50 years) provide an indication of the short-term effects of greenhouse gases on the climate, while GWP for longer periods (100 and 500 years) are used to predict the cumulative effects of these gases on the global climate.

Ozone depletion potential (ODP)

The ODP category indicates the potential of emissions of chlorofluorocarbons (CFCs) and chlorinated hydrocarbons for depleting the ozone layer and is expressed by:

$$EI_{odp} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{odp,j} B_{l,j} \qquad \text{(kg)} \qquad \text{(A3)}$$

where $B_{l,j}$ is emission of ozone depleting gas j. The ODP factors $e_{odp,j}$ represent depletion potential of the emissions relative to the ozone depletion potential of CFC-11.

Acidification potential (AP)

AP is based on the contributions of SO_2, NOx, HCl, NH_3, and HF to the potential acid deposition, i.e. on their potential to form H^+ ions. AP is calculated according to the formula:

$$EI_{ap} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{ap,j} B_{l,j} \qquad \text{(kg)} \qquad \text{(A4)}$$

where $e_{ap,j}$ represents acidification potential of gas j expressed relative to the AP of SO_2, and $B_{l,j}$ is emission of burden j per functional unit.

Eutrophication potential (EP)

EP is defined as the potential to cause over-fertilisation of water and soil, which can result in the increased growth of biomass. It is calculated as:

$$EI_{ep} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{ep,j} B_{l,j} \qquad \text{(kg)} \qquad \text{(A5)}$$

where $B_{l,j}$ is emission of species such as NOx, NH_4^+, N, PO_4^{3-} and P, and $e_{ep,j}$ represents their respective eutrophication potentials. EP is expressed relative to PO_4^{3-}.

Photochemical smog (PS)

Photochemical smog or photochemical oxidants creation potential, is expressed relative to the PS of ethylene and is calculated by:

$$EI_{ps} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{ps,j} B_{l,j} \qquad \text{(kg)} \qquad \text{(A6)}$$

$B_{l,j}$ is emission of different contributory species, primarily VOCs, classified into the following categories: alkanes, halogenated HCs, alcohols, ketones, esters, ethers, olefins, acetylenes, aromatics and aldehydes; $e_{ps,j}$ are their respective classification factors for photochemical smog formation.

Human toxicity potential (HTP)

HTP is calculated by adding human toxic releases to three different media, i.e. air, water and soil:

$$EI_{htp} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{htp,jA} B_{l,jA} + \sum_{j=1}^{J}\sum_{l=1}^{L} e_{htp,jW} B_{l,jW} + \sum_{j=1}^{J}\sum_{l=1}^{L} e_{htp,jS} B_{l,jS} \qquad \text{(kg)} \qquad \text{(A7)}$$

where $e_{htp,jA}$, $e_{htp,jW}$, and $e_{htp,jS}$ are human toxicological classification factors for the effects of the toxic emission to air, water and soil, respectively. $B_{l,jA}$, $B_{l,jW}$ and $B_{l,jS}$ represent the respective emissions of different toxic substances into the three media. The toxicological factors are calculated using the acceptable daily intake or the tolerable daily intake of the toxic substances. The human toxicological factors are still at an early stage of development so that HTP can only be taken as an indication and not as an absolute measure of the toxicity potential.

Ecotoxicity potential (ETP)

ETP is divided into aquatic and terrestrial ecotoxicity, which are calculated as:

$$EI_{etp_A} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{etp,jA} B_{l,jA} \qquad (\text{m}^3) \qquad \text{(A8)}$$

$$EI_{etp_T} = \sum_{j=1}^{J}\sum_{l=1}^{L} e_{etp,jT} B_{l,jT} \qquad \text{(kg)} \qquad \text{(A9)}$$

where $e_{etp,jA}$ and $e_{etp,jT}$ represent ecotoxicity classification factors of different toxic substances and $B_{l,jA}$ and $B_{l,jT}$ are their respective emissions to the aquatic and terrestrial ecosystems. ETP is based on the maximum tolerable concentrations of different toxic substances in water and soil. Similar to the HTP, classification factors for ETP are still developing, so that EP can only be used as an indication of potential ecotoxicity.

Solid waste (SW)

SW is expressed in kg per functional unit:

$$EI_{sw} = \sum_{l=1}^{L} B_l \qquad \text{(kg)} \qquad \text{(A10)}$$

where B_l is the amount of solid waste generated in the life cycle of the system.

Environmental efficiency:

Material intensity (MI)

MI represents the sum of all raw materials used in the system and can be calculated as:

$$EE_{mi} = \sum_{j=1}^{J} \sum_{l=1}^{L} M_{l,j} \quad \text{(kg)} \qquad \text{(A11)}$$

where $M_{l,j}$ is the amount of raw material j used in life cycle stage l.

Energy intensity (EN)

EN is the total amount of energy and is determined as:

$$EE_{en} = \sum_{j=1}^{J} \sum_{l=1}^{L} EN_{l,j} \quad \text{(MJ)} \qquad \text{(A12)}$$

where $EN_{l,j}$ is the amount of energy type j used in the life cycle.

Recycling of waste materials (RW)

This indicator could be expressed as the amount of recycled waste material (e.g. aggregate) per functional unit:

$$EE_{rw} = \sum_{j=1}^{J} \sum_{l=1}^{L} RW_{l,j} \quad \text{(kg)} \qquad \text{(A13)}$$

Voluntary actions

Environmental Management Systems (EMS)

This is a qualitative indicator which is included as a statement; the quantitative benefits of incorporation of the EMS are reflected in reduced environmental impacts and increased environmental efficiency.

Environmental improvements above the compliance levels (ICL)

This indicator can be expressed as an average percentage of decrease in environmental burdens for either the prescribed substances or substances that are of general environmental concern, but are not regulated. For instance, a company would be credited for a voluntary reduction of emissions of CO_2 below the target levels set by the Government or an international organisation. ICL could be calculated as:

$$EE_{icl,j} = \frac{\sum_{c=1}^{C} \frac{AL_j - B_{c,j}}{AL_j}}{C} \cdot 100 \quad (\%) \qquad \text{(A14)}$$

where $B_{c,j}$ is a level of burden j from company c in the life cycle of the system and AL_j is a prescribed local or national level, or accepted target for that burden. For companies that do not have environmental improvements above the compliance levels, this indicator is zero.

Assessment of suppliers (AS)

Like EMS, AS is also a qualitative indicator and can consist of a statement which describes the procedure of the assessment; for instance if the company requires their suppliers to have an EMS in place or perhaps if they use LCA for their activities.

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Design of an integrated resource management system for supplying and processing of metals: the examples of aluminium and copper

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1 Introduction

The Collaborative Research Center 525 "Resource-orientated analysis of metallic raw material flows – design of methods and their application" was established in 1997 at the Aachen University of Technology and is funded by the Deutsche Forschungsgemeinschaft (DFG). The long-term goal of the research program is the identification of options for a resource-sensitive supplying and processing of metallic raw materials in the area of conflict of technical developments and economic and ecological aims. An integrated resource management system for important metallic raw materials is to be designed and tested by the CRC 525 with regard to the applicability of this framework in order to provide useful and efficient tools for decision makers.

The challenges of sustainable development facing the minerals and metals industry require a comprehensive, integrated and multi-disciplinary approach based on shared decision-making, close co-ordination and co-operation, a reliable information base, and the consideration of the competing interests of all shareholders including aspects of intra- and inter-generational equity. The integrated approach of the CRC 525 offers the opportunity to address and cope with these challenges by supporting sustainable development-based decision-making.

The first phase of the research program (1997 – 1999) was focused on aluminium and aluminium alloys. In the second phase (2000 – 2002) copper will be included into the resource-orientated analysis of metallic raw materials.

2 Scope of the Analysis

The scope of analyses carried out by the CRC 525 reaches from deposit valuation to extraction over processing and smelting of mineral resources to manufacturing and utilisation. The recycling processes for supplying secondary resources ensuing the use phase are also analysed and assessed as an integral part of the raw materials supply. Transportation processes, processes of energy supply and utilisation or disposal processes of the most important waste flows arising in any of the sub-processes along the entire process chain are included in the investigation. This procedure makes it possible to analyse the influence of the technical process chain on the environment as well as economic and social aspects.

The complexity of interdisciplinary questions arising from such a topic were taken into account when selecting the participating scientists and the scientific institutions and by choosing close, co-operative working methods.

The CRC 525 is divided into 9 sub-programs with 12 participating institutes of the Aachen University of Technology and 1 institute of the Forschungszentrum Jülich. The thematic link-up between these 9 sub-programs is represented in figure 1.

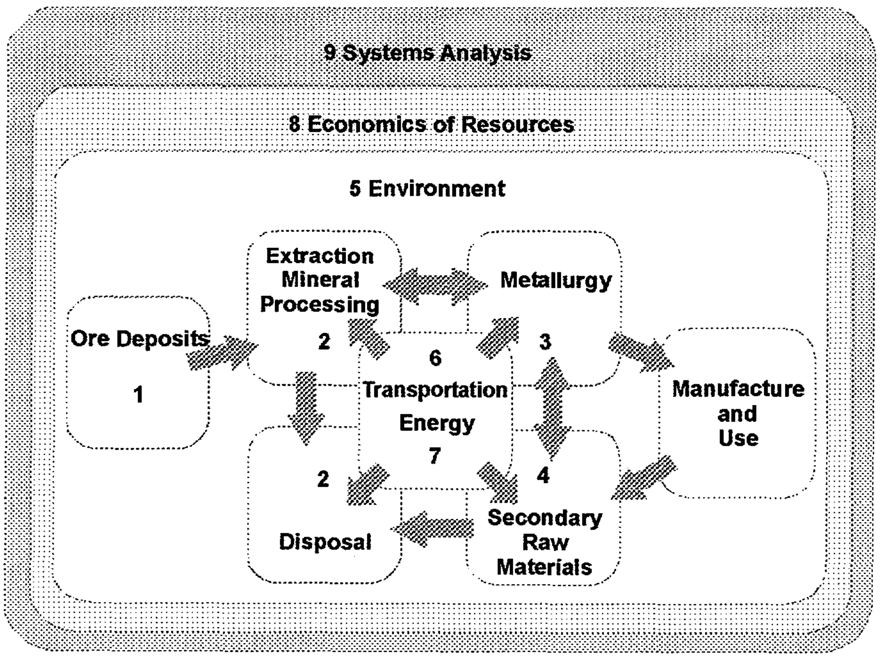

Figure 1: Link-up of the sub-programs of the CRC 525

3 Design of an Integrated Resource Management System

In the first phase (1997 - 1999) preliminary work was conducted on the design of an **integrated resource management system**. The developed framework will be deepened and put in concrete terms in the second phase (2000 – 2002) by means of adaptation and application of the different methodological approaches. The integrated resource management system (figure 2) is based on practical experiments and computer-aided **tools**, which can be divided into:

- sub-program-specific information systems
- an overall information system
- sub-program-specific models
- overall process chain models and economic models

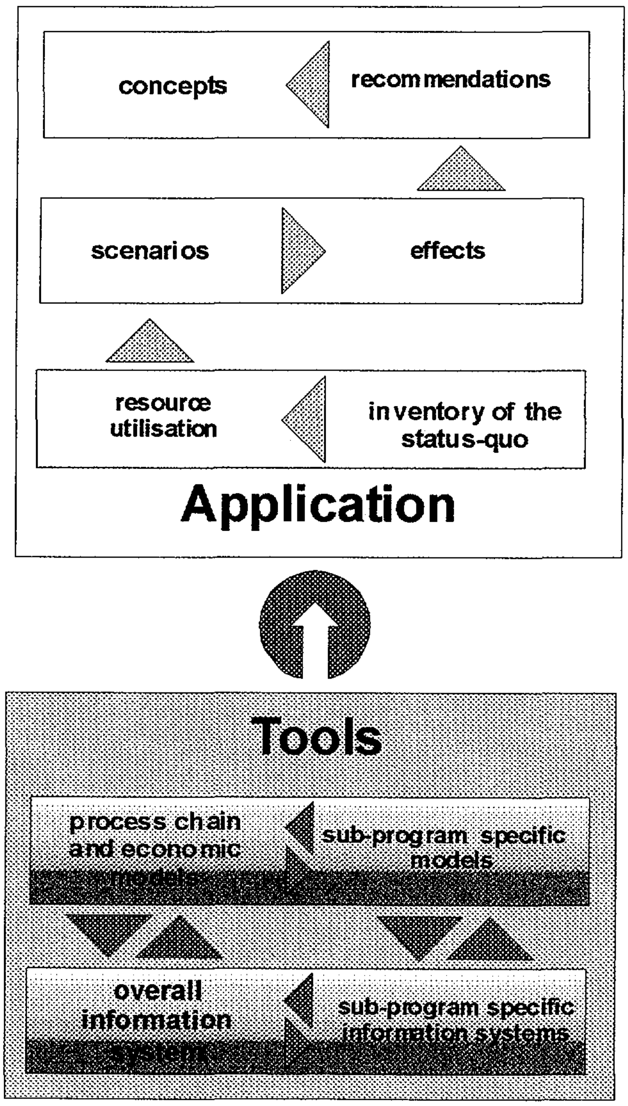

Figure 2: Design of an integrated resource management system

The tools support the detailed **inventory of the status-quo** of the material flows of metallic raw materials. The description of the state-of-the art will be carried out for:

- processes
  (e.g. a comparison of different electrolysis processes),
- products
  (e.g. an inventory analysis and an environmental impact assessment for different aluminium foils in the packaging sector),
- product systems
  (e.g. an analysis of the effects of the substitution of unalloyed primary aluminium by alloyed secondary aluminium considering open and closed loop recycling processes),
- industrial sectors
  (e.g. an analysis of the global distribution and merchandising of Aluminium).

Main focus of the attention is always placed on the **resource utilisation** of materials, energy, environment, work force and capital.

Starting from the inventory of the status-quo and the analysis of the corresponding resource utilisation, **scenarios** will be designed in which the reference trend of technical and organisational progress is compared with goal-orientated scenarios considering external interventions, i.e. by political decision makers. The potential **effects** on the material flows, on the energy utilisation, on the location choice of mining and processing plants and on the resource productivity will be examined for all scenario designs.

The results of the investigations will be discussed with representatives of the scientific community, of industrial associations, of main companies and other relevant interested parties. Following the discussion an expert panel consisting of CRC-internal and external members will be able to draw conclusions and to give **recommendations** for a sustainable supplying and processing of primary and secondary metallic raw materials. The recommendations are expected to have either a normative or an operational or a strategic character. The proposed options for decision making deriving from the conclusions and recommendations can be the starting point for goal-orientated **concepts** in terms of a sustainable utilisation of metallic raw materials. The concepts are meant to be practice-orientated, adequate and as far as possible consensual. The resulting instrument claims to consider the competing interests of directly and indirectly involved actors.

3.1 Methodological approach of sub-program 2 "Mining and Disposal"

The methodological approach chosen for sub-program 2 "Mining and Disposal" is illustrated in figure 3. The scope of the investigation was defined in co-operation with the other sub-programs and according to the scope of the CRC 525. In a second step an intensively, systematically and thoroughly data collection was carried out.

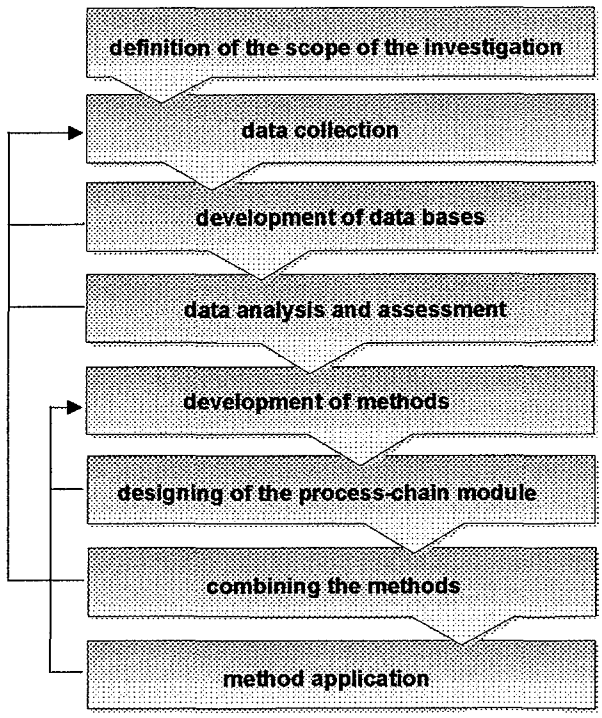

Figure 3: Methodological approach of sub-program 2 "Mining and Disposal"

For each of the two parts (mining and disposal) a computer-aided data base has been developed. The mining data base includes data from 70 extraction sites and is named WORLD BAUXITE EXTRACTION DATA BASE (WOBEX). The disposal data base includes data from 71 red mud disposal sites and is named ALUMINIUM WASTE DATA BASE (ALWA). The principal structure of the two data bases is shown in figure 4.

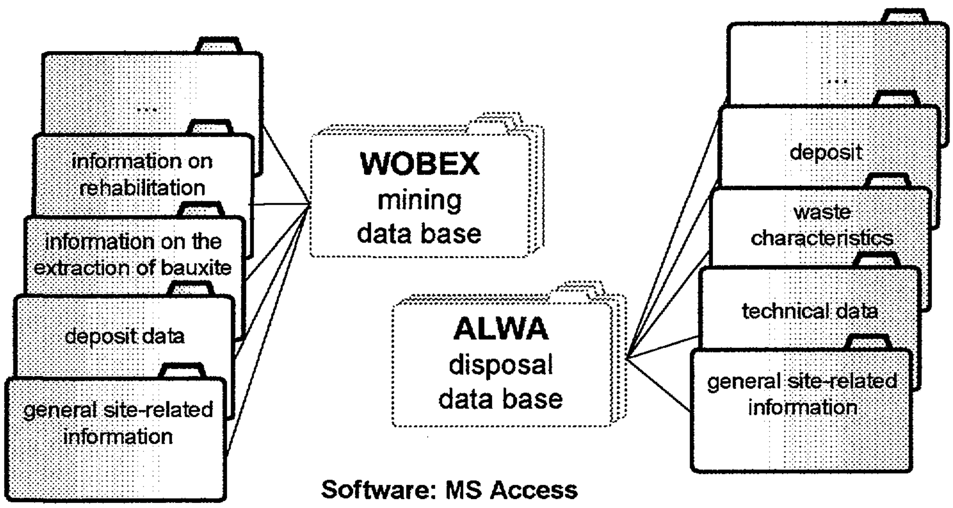

Figure 4: Principal structure of the data bases WOBEX and ALWA

With the assistance of the two data bases, methods were elaborated, which allow the validation of the recorded data and, moreover, the calculation of missing data.

Figure 5 shows the data-sheet of the bauxite mining site Weipa as an example of the WOBEX data base.

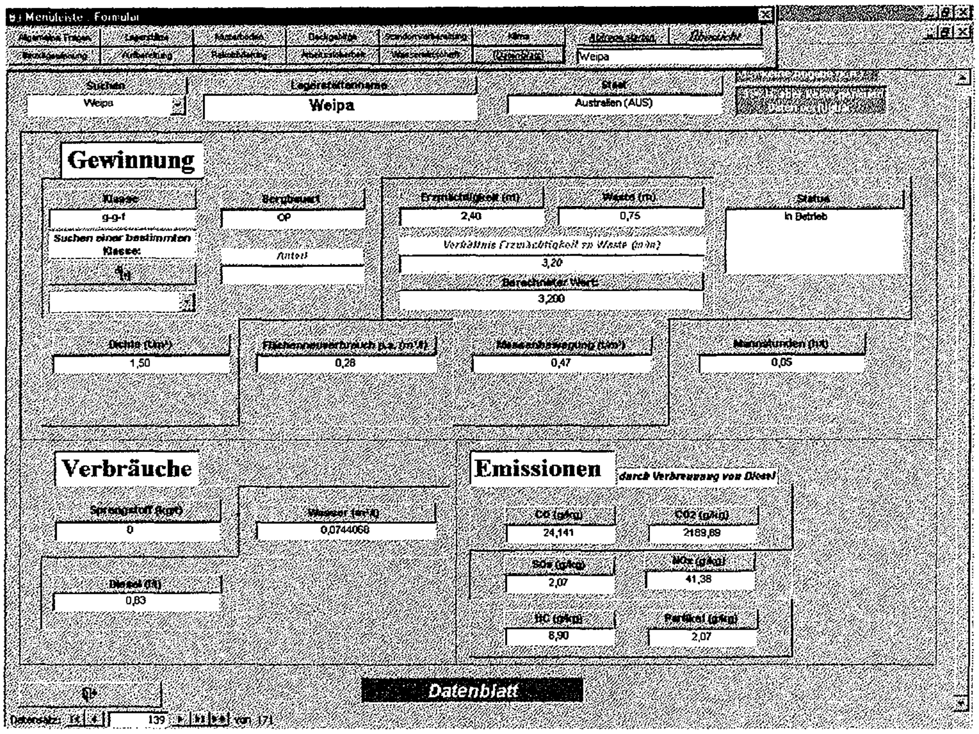

Figure 5: Screen-shot of one WOBEX data sheet

Figure 6 shows the data-sheet of the alumina production site in Sao Luiz, Brazil.

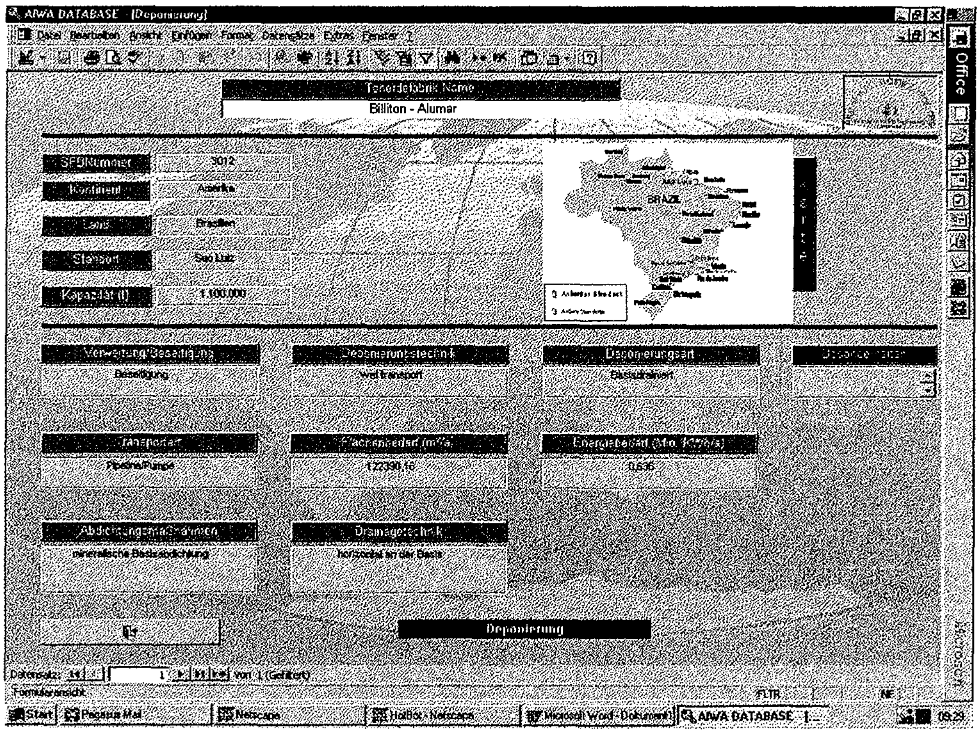

Figure 6: Screen-shot of one ALWA data sheet

To simplify the procedure of the entire process chain analysis, classification systems for bauxite mining sites and disposal methods were built up. The bauxite mining sites were classified according to:

- thickness of overlying rock,
- thickness of bauxite,
- deposit geometry.

For the currently exploited bauxite mining sites, 13 extraction modules were established and average values as well as the scope of e.g. land use, diesel consumption, mass flows etc. were allocated.

The disposal methods used for red mud and other residues of the primary aluminium industry were classified according to:

- hazard potential,
- sealing methods,
- physical and chemical properties of waste,
- deposit geometry.

This results in 18 disposal modules, and average values of e.g. land use, water utilisation, energy utilisation etc. were assigned to each module.

All these modules were integrated into the entire process chain analysis of the aluminium production.

Moreover, the elaborated methods and the classification systems could be seen as scenario tools, which permit predictions to be made on (for example):

- mass flows,
- energy demand,
- land use,
- water consumption.

for future mining and/or disposal sites.

4 State-of-the-Art and Outlook

The design of the computer-aided tools and the methodological approaches of the framework are fairly advanced for the example aluminium. Parting from this basis a description of the status-quo has been worked out in the first phase of the project (1997-1999). Preliminary trends and scenarios have been derived from the inventory analysis and the set of tools has been used for simulations, which have already been presented to experts and specialists with subsequent discussions.

In the second phase (2000 – 2002) the description of the state-of-the-art for aluminium will be concluded soon. The inventory of the status-quo will be finished by integrating the use-phase, the environmental impact assessment and the resource-orientated evaluation into the process chain analysis. Further scenarios will be designed from which conclusions and recommendations as well as options for decision making will be drawn.

Furthermore, in the second phase copper will be included into the resource-orientated analysis of metallic raw materials. Besides adapting the methodological approaches the computer-aided instruments have to be extended in order to take into consideration the copper-specific aspects. The mineral processing is far more complicated for copper than for aluminium due to the complex mineral paragenesis of the copper ores which may include metals like gold, silver and zinc. While toxicological aspects were not considered in the case of aluminium, toxic effects of copper and its by-products are widely discussed in the present and therefore should be included in the impact analysis. As in the case of aluminium, the inventory of the status-quo will be followed by the designing of scenarios and the drawing of conclusions and recommendations.

The long-term goals of the CRC 525 cover the following aspects:

- Adapting the methodological approaches for the resource management system to the material flows of further metallic raw materials
- Finishing the design of methods and instruments for the description of material flows of metallic raw materials
- Designing a general guideline for a resource-orientated analysis of the material flows of further mineral resources
- Initiating a sustainable resource management by means of practise-orientated concepts

4.1 Outlook for sub-program 2

In the second phase (2000 – 2002) the data bases WOBEX and especially ALWA will be expanded. The methodological approaches used for the modelling of bauxite mining and of the disposal of aluminium-related wastes are transferred to other metallic raw materials at the example of copper. The mining modules have to be expanded for underground mining and open pit mining on hard rock. The disposal modules have to be adapted for other waste materials and resulting disposal tracks and techniques.

5 Internal and External Networking

In order to pursue the objectives of the CRC 525 a successful networking and promoting of partnerships inside and outside the research program is essential. The interdisciplinary team working and the development of a common language, which is necessary due to the wide variety of scientific disciplines participating in the project, is guaranteed by several organisational measures like:

- meetings of the members
- work groups
- workshops and symposia (with external participants of the interested parties)
- excursions and field-trips (on a global scale)

The external relationships of the CRC 525 are focused on other national and international research centres, associations, companies and non-governmental organisations. The communication and co-operation is meant to take place in congresses, symposia, trade fairs and visits and is based on questionnaires, interviews and dialogues as well as on publications and presentations.

6 References for more Information about the CRC 525

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THE PROBLEM OF MINE TAILINGS DISPOSAL

(Presented at the CYTED XIII Conference in Porto on October 27, 1999)

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INTRODUCTION

In the last 30 years, I have worked as a Mining Engineer and as a manager in a number of mining operations and, I must say that the my personal view when dealing with mine tailings problems has gradually evolved from focusing on minimising cost to focusing on environmental impact.

I am sure that most of my professional colleagues in this audience have personal experience on the increasing environmental awareness of society, whereby the conflict between mining activity and environment has intensified. Nowadays, in Spain, Portugal, and elsewhere in Europe and in all other developed countries, new mining proposals are greeted with strenuous opposition from some sections of the community.

Governments and Public Institutions have followed a similar path. Until the seventies, the level of government concern and legislation in relation with mine tailings disposal systems was relatively low. During the seventies and the eighties, technical and legislative attention to these problems steadily increased, mainly due to the initiative of leading industrial countries and multinational organisations such as the EEC, OECD, NATO, UN, etc.

Future challenges of mine tailings disposal are directly related with this shift of social perception of mining activities. The view of society has evolved from considering mining as a social benefit bringing wealth and economic development to perceiving mining as risk to environment which must be minimised and, against which, the community must be properly insured.

THE PROBLEM OF TAILINGS DAMS

The tailings impoundment generated in 1999 by the mineral industry including coal power generation and excluding waste rock dumps, amounts to approximately 5,200 million tonnes of solids, equivalent to 3,500 million m3 of impounded volume, with the following distribution:

Coal (wash plant slimes and power plant fly ash)	2.300
Iron ore and industrial mineral tailings	550
Milling of base and precious metals	2.350
Total (Mill. Tonnes)	5.200

On cumulative bases, the volume of tailings impounded on earth to date may be 25 times the above estimate, or 87,5 Million m3, and may occupy a surface of some 1,5 million hectares, more than 1 m2 per land hectare on earth.

Clearly, Mining is unique in the sense that very large volumes of material must be removed and transformed to achieve a saleable product. In this process, solid waste in amounts many times larger that the volume of sales are generated and disposed of to waste dumps and tailings dams.
To exemplify the above, one ton of copper produced from an open pit mine with 0,5 % copper grade and 5:1 strip ratio, would generate 1,250 tonnes of rock waste, 245 tonnes of mill tailings and 5 tonnes of smelter slag.
To study the problem of mine tailings disposal, one must try to forecast the changes produced on key aspects such as site selection, design and decommissioning, by the foreseeable evolution of social perception of mining activities, technological developments and the minerals market.

SITE SELECTION AND DESIGN METHODS

In a not too distant past, the mining industry attitude towards tailings disposal was usually not based on sound engineering principles. Instead, site and design methods for tailings disposal were selected and developed with a minimum engineering and capital.
In recent years, tailings dam design has become an increasingly greater part of the design and construction budget and today, permitting regulations in most countries have been developed to ensure that mining companies are required to select the site and design method having the least effect on the environment.

Present practice

The most common practice is the on-land disposal of tailings in locations not farther than 2 km from the mill site. The location is generally selected trying to find an area (i.e: a valley bottom or hillside) where capital cost may be minimised by maximising the storage capacity per unit volume of dam wall.

Other less frequent alternatives are:

* Disposal under water (lake or sea bottom). This is normal practice in Canada and in countries having deep lakes where tailings may be deposited at depths greater than 50 metres, well below the depth of turbulence and wave effect. This type of disposals may be very economical and environmentally favourable since tailings are invisible and are not subject to oxidation reactions involving metal leaching and acid generation.

* Disposals in an abandoned pit or underground mine as backfill. This alternative should be regarded as environmentally effective and also economical. In bulk underground mining scenarios, consolidated backfill using mill tailings have been extensively used to provide ground control, increase metal recovery and reduce impact to landscape.

* A combination of on land and underwater, when a pervious dam is build across a lake, across the mouth of a bay or a water inlet and the area behind the dam is filled with tailings and treated as a land disposal site.
In many cases, this alternative is adopted as a compromise between under water and land disposal when neither one is fully acceptable.

Regarding the selection of the design and engineering methods there are three main methods :

* Disposal of tailings in the form of a low density tailings-water pulp with 20% to 30% solids using water dam design methodology. In this design method the dam may be build using borrowed rock or mill tailings or a combination of both, may be built-up in stages using the upstream, downstream or centre line methods but, in all cases, the dam is designed to be impermeable and to withstand the hydrostatic pressure of liquefied tailings.

* Disposal of tailings in the form of a low density tailings-water pulp with 20% to 30% solids using pervious tailings as the dam construction material. In this design method the dam is normally built using the coarse, high percolation size fraction of the mill tailings, obtained by cyclonning or through spigotting discharge. In this case, the dam is built-up in stages as tailings become available using the upstream, downstream or centre line methods, and the dam is designed to be permeable and maintain the phreatic level away from the downstream slope of the dam.

* Disposal of dewatered tailings in the form of dewatered sands with more that 80% solids by weight, a material which behaves as a solid waste and may be handled and dumped where no retaining walls are required and reclamation and tailings disposal may be simultaneously performed.

Trends

At present and for the foreseeable future, tailing generation per unit weight of product from mining will continue to increase as the result of processing lower ore grades at larger rates. A good example of this trend is the Escondida mine, where over 750,000 tonnes/day of tailings are generated.
Permitting for tailings disposal solutions will have to be managed for acceptance by local community, government agencies and environmental groups and, as the result of this, time and cost for tailings disposal will increase and will have to be reflected as a higher capital an operating cost and a higher financial risk in their feasibility studies.
Government regulations will react to social pressure by introducing the concept of "acceptable risk" on the bases of sustainable economic effort, whereby mining and other alternative business may be compared on the bases of economic benefit and human and environmental risk.
Technology will continue to focus on the development of cost efficient large scale tailings transportation and dewatering systems allowing for the increase of economically feasible transportation of tailings to sites far away (80-100 km) from local communities, focusing on achieving social acceptance at an acceptable cost.Tailings dam design end engineering method will have to be based on highly sophisticated "Quantified Risk Assessment" models, where both the probability of failure and the magnitude of loss will be evaluated.
As the result, site selection and design criteria for tailings disposal systems will be governed by size, storage capacity and public acceptance considerations, rather than distance to mill and cost efficiency.

In the above scenario, the following trends may be expected:

i) Sites with larger capacity in unpopulated areas at increasing distance from the mill.

ii) An increase number of mining projects will select dewatering of tailings and its handling and disposal using bulk materials handling systems, with higher processing cost but less demanding in terms of site selection and control of human end environmental risk.

iii) The capital and operation cost of mine tailings disposal and the time required for mine project permitting will increase and this will have a significant reflection on cut-off grades and/or price of mineral commodities.

iv) The preparation of detailed Baseline study by mining companies will become of much higher importance for mining companies. This baseline studies will be required by government and by the insurance companies to provide insurance for environmental risks. Also, baseline studies will serve to define the most environment sensitive aspects of the project and to set up a standard against which future environmental impact may be quantified.

LAND RESTORATION AND DECOMMISSIONING

Many definitions of the word "restoration" and other commonly used words such as reclamation, rehabilitation etc.
Following the British Department of Environment, we define restoration as "the whole complex operations which follow the extraction of mineral up to the time the land is fully established once more in an acceptable environmental condition".
Decommissioning may be defined as "the implementation of measures, which are necessary to ensure long term environmental monitoring and control of the restored land after abandonment".
Restoration and decommissioning has been almost non-existing until recent years. As an example, In the Iberian Pyrite Belt which we are visiting tomorrow contains world class ore bodies, such as Neves Corvos, Rio Tinto and Tharsis, and many medium and small-sized massive sulphide ore bodies, no restoration has been performed until very recently and a large proportion of its mining land remains damaged and derelict.
As for site selection and design, the mining industry attitude towards restoration was that of dedicating the least engineering effort and the minimum amount of money and after mines were closed, dams were left to become an eyesore and a dust nuisance.

Present practice

In recent years, mining companies have become progressively aware of the need to restore the land affected by mining operations and the technological progresses in waste management and pollution abatement techniques was impressive. Today, no tailings disposal system can receive a permit unless a suitable restoration and abandonment plan is presented by the mining companies.

When referring to a tailings dam facility today, the following restoration works are normally required:

* Geotechnical stabilisation, reshaping of tailings surface and regrading of dam slopes

* Sealing of tailing surfaces and dam slopes with a layer of clayish materials to reduce infiltration and seepage to a minimum.

* Slope protection measures preventing erosion and weathering and shape deterioration

* Monitoring and drainage systems to provide full control over the phreatic levels in tailings and slopes and to prevent the accumulation of water on the restored surface.

* Replacing the layer of topsoil and revegetating.

Prior to abandonment, several decommissioning measures must be implemented:

* A perimetral seepage collection system and effluent treatment system to collect and treat liquid effluent as required prior to discharge to public watercourses.

* Design and implementation of a long-term inspection, monitoring and control program providing full control over the main environmental parameters such as the slope stability, quality and volume of effluents, phreatic levels, air emissions, flora and fauna, etc.

* Preparation and approval by the Authorities of a Emergency Plan, including a definition and assessment of all possible environmental and Human risk scenarios and a detail procedure for the information, control and remediation action to be performed for each emergency scenario.

* Providing environmental liability insurance or cash deposit that guaranties full compliance with the maintenance program and other abandonment conditions over an agreed period of time.

* Typically, the mining company is expected to carry out the maintenance program for a period of 5 years, but its environmental liability with regard to environmental effectiveness of the plan may be extended to 25 years or longer.

Trends

Social and political pressure will cause mine waste management regulations to become more restrictive and demanding. In order to gain acceptance by local community and environmental groups the permitting Authorities will increase their requirements for environmental control after abandonment. The reporting, technical requirements and capital demands to obtain an official permit of a tailings dam facility will increase and the coverage of environmental liability will become more time consuming and expensive.

Technology and engineering development in this field will focus on:

* Development of processes for the chemical stabilisation of tailings, especially in the fields of acid mine drainage, radioactive tailings stabilisation.

* Increased R&D work on the long-term adverse effects of tailings dams on the environment and on human heath to comply with increasingly demanding regulations on mineral waste disposal.

* Hydrogeological modelling to be used in the evaluation and control potential impact of effluent seepage into aquifers, specially applicable to tailings containing potentially toxic substances.

* R&D work on environmentally safe underwater disposal of tailings to comply with increasingly restrictive regulations for marine dumping.

* R&D work on potential utilisation of tailings as a secondary source of mining products to comply with increasingly restrictive regulations for restoration and resource conservation.

* Increased effort to develop new technologies allowing for the secondary recovery of metals from the reclamation of abandoned tailings dams of increasingly lower grades.

In the above scenario, the following trends may be expected:

i) Mining activity will continue its geographical shift towards less developed countries with less demanding environmental regulation. In Europe, North America and other developed countries, mining activity will keep declining until market conditions are such that the increasing cost of restoration and environmental control may be transferred to commodity prices. The mining of massive sulphide orebodies such as those encountered in the Iberian Pyritic Belt will be subject to ever increasing social and environmental pressure.

ii) The use of abandoned mines for tailings disposal will become more attractive even at the cost of increasing transportation distances and cost.

iii) Governments will have to face the problem of the proper control and restoration of tailing dams in old mineral regions (i.e.: Iberian Pyritic Belt, etc). This will probably be done through subsidising mining companies involved old tailings reclamation and stabilisation activities.

iv) In the long term, metallurgical processes will be developed for in plant chemical stabilisation processes to deal with reactive tailings before disposal, and this will be included as part of the reclamation and abandonment plans.

THE AZNALCOLLAR CASE

The Aznalcollar tailings dam failed in the morning of April 25th 1998, causing the spill of tailings and tailings water estimated at 1.3 and 5.5 million cubic metres, respectively. I worked in the team of professionals which carried our the investigation of the failure and I had the unique opportunity to work with some of the top world experts in the field.

It is not the purpose of this conference to explain to you the results of the investigation although I have planned to present a video animation which was released by Boliden land which, in many aspects, is self explanatory of the failure mechanism where the main factor was a progressively failure of the overconsolidated clay foundation, overstressed by construction induced pore pressures past the peak strength. However, due to the large dimension of this incident and the worldwide interest generated in the public and among the mining professionals, the Aznalcollar failure will probably represent a milestone in the evolution of the perception of the problem of mine tailings by the mining companies and the society.
I believe that in Spain and probably in the rest of the world there will be a "before" and an "After" to the Aznalcollar case, and the experience gained by mining industry in this case will have a very positive influence in the long term. It is in this context that I considered that a reference to Aznalcollar was important for my paper and for this audience.

CONCLUSIONS

It can be stated that mining is unique in the sense that very large volumes of material must be removed and transformed to achieve a saleable product. In this process, solid waste in amounts many times larger that the volume of sales are generated and disposed of to waste dumps and tailings dams.
Society is evolving from considering mining activities as an economic and social benefit to perceiving it as a risk to environment, against which, the community must be properly insured.
Mining activity will continue its move towards less developed countries with less demanding environmental regulation until market conditions are such that the increasing environmental control cost may be transferred to commodity prices. The mining of massive sulphide orebodies in the Iberian Pyritic Belt will be subject to ever increasing social and environmental pressure.
Future trends in site selection will aim towards sites with larger capacity in unpopulated areas at increasing distance from the mill. Also, an increase number of mining projects will select dewatering of tailings, with higher processing cost but less demanding in terms of site selection and control of human end environmental risk.
In the long term, reclamation and abandonment plans will tend towards the use of processes for in-plant stabilisation of tailings prior to disposal.
Governments will have to face the problem of the proper control and restoration of tailing dams in old mineral regions (i.e.: Iberian Pyritic Belt, etc).
The capital and operation cost of mine tailings disposal and the time required for mine project permitting will increase and this should be expected to have a reflection on the prices of mineral commodities.

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Sustainable Development and Non-Ferrous Metals: Challenges and Opportunities

Patrick Hurens
International Copper Study Group
www.icsg.org

International Copper Study Group

- Intergovernmental organization
- 24 member countries and EC, representing copper producing and consuming nations
- Promote international cooperation
- Global forum for discussions
- Increase market transparency

Work Program

- Statistics
  - Production, consumption, trade
  - Directory of mines, smelters, refineries
- Environmental and Health
  - International regulatory issues
  - Surveys of legislation
  - Workshops, seminars, conferences
- Economics
  - Market studies
  - Commodity development

Changes in Doing Business

- Globalization of business
- Increased focus on environment
- Increasing influence of ENGOs
- Internationalization of regulatory framework
- Challenges and opportunities for metals industry

"Environmental" Issues

- Past, simple
- Site specific
- Focus on air, water, soil, wastes

- Now, more complex
- Climate change
- Soil conservation
- Biodiversity
- Transboundary movements
- Sustainable development

Sustainable Development

- Resource depletion
- Process and product efficiency
- Eco-efficiency
- Recycling
- Energy consumption

- Emissions, wastes
- Environmental impacts
- Jobs
- Wealth
- Standard of living

Threats

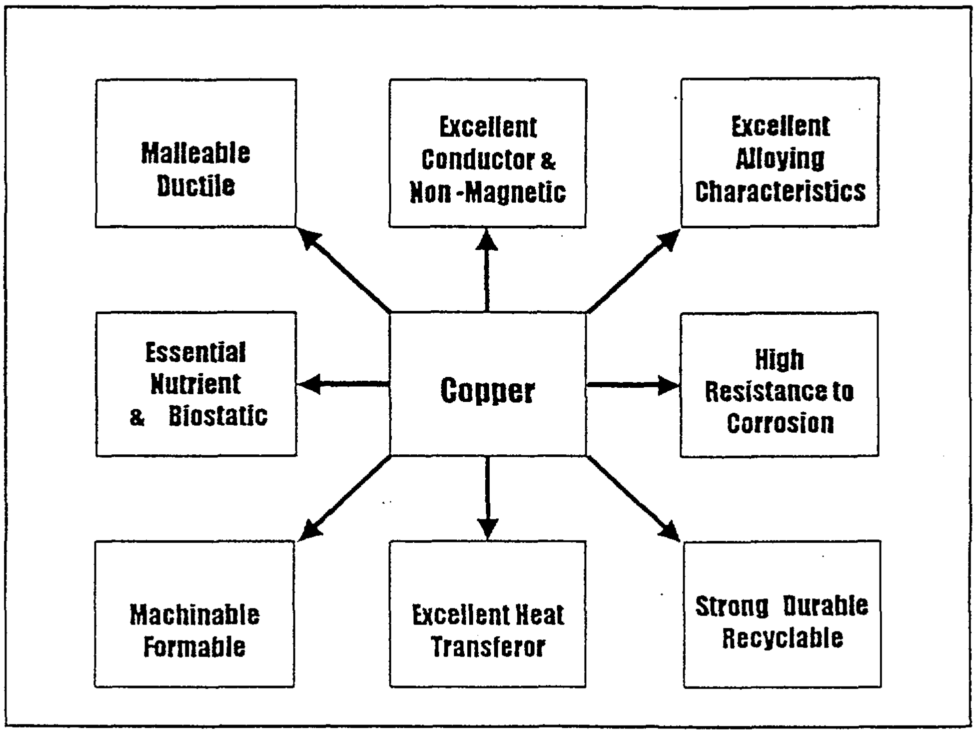
- Misconceptions
- Perceptions
- Lack of, or poor science
- Competing visions
- Unbalanced regulations
- Public and ENGO pressure
- Accidents
- Fringe operations

Challenge

- Processes have changed
- Environmental / SD Policies
- Performance
- Research
- Communication/Dialogue
- Best available technologies/processes
- Needs and expectations of downstream industries and consumers

Metals in Society

- Metals are fundamental
- Contribute to sustaining and improving society
- Wide array of applications: infrastructure, transportation, communications, consumer goods, power and electrical distribution

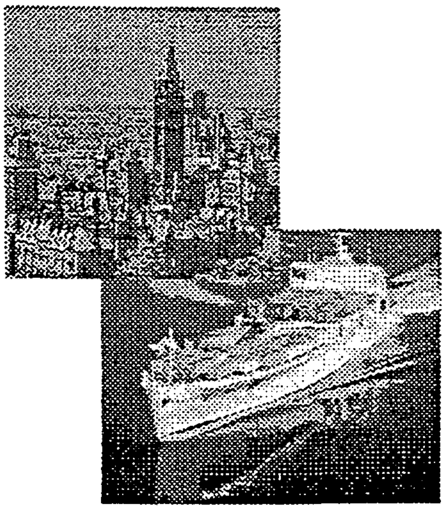


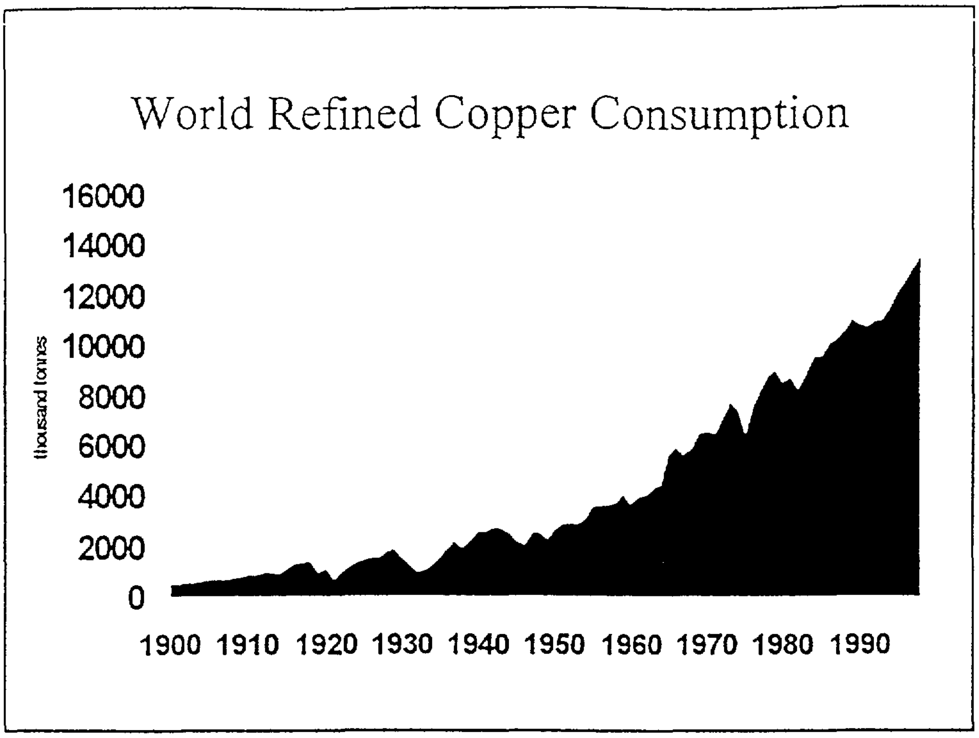
Electrical, Electronics, Communications

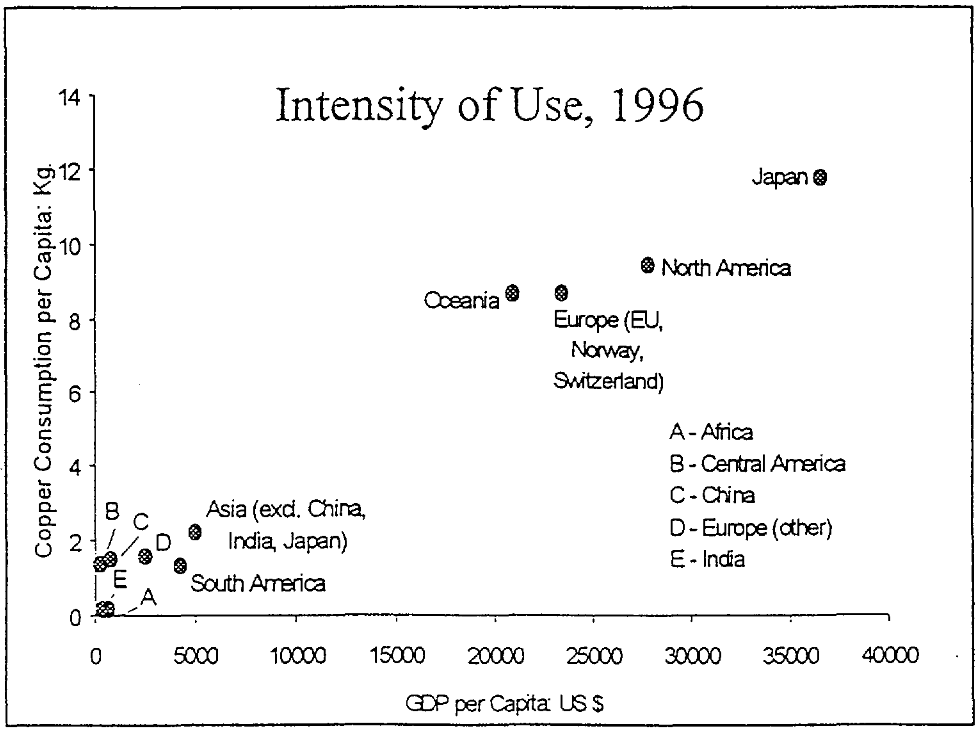
- Essential component of energy efficient motors and transformers
- Preferred carrier for last mile
- High-tech applications

Construction & Transportation

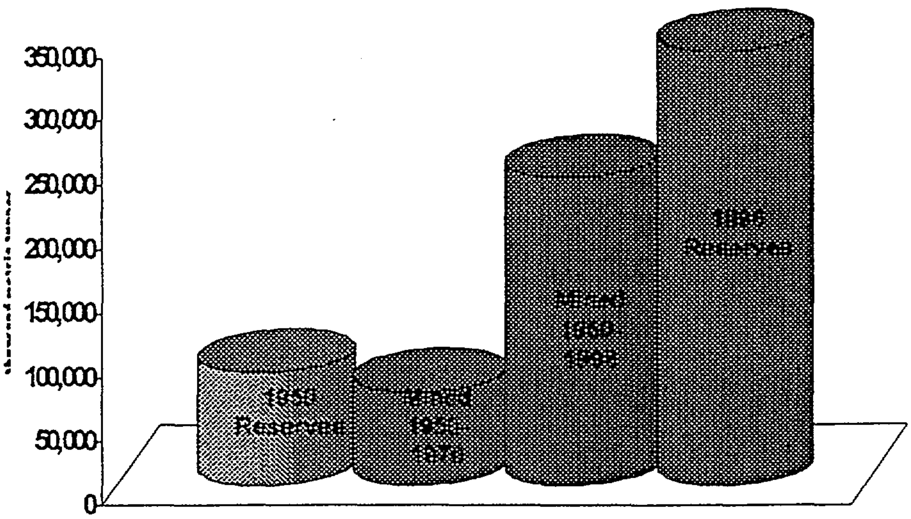
- Protection
- Water distribution
- Reduce biofouling
- Superior heat transfer
- Industrial equipment
- Food, livestock, crop supplement




World Refined Copper Consumption
thousand tonnes
16000
14000
12000
10000
8000
6000
4000
2000
0
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990

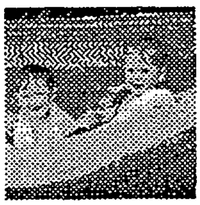

Intensity of Use, 1996
Copper Consumption per Capita: Kg.
14
12
10
8
6
4
2
0
Japan
North America
Oceania
Europe (EU, Norway, Switzerland)
A - Africa
B - Central America
C - China
D - Europe (other)
E - India
Asia (excl. China, India, Japan)
South America
B
C
D
E
A
0 5000 10000 15000 20000 25000 30000 35000 40000
GDP per Capita: US $

Reserves and Mined Copper



Copper and Health

- Essential to plant, animal and human health
- Under certain conditions and levels can be toxic
- Deficiency greater risk than excess
- Populations at risk, those with poor diet
- Natural biostatic properties

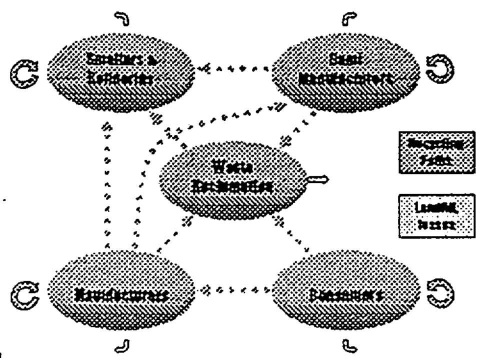


Copper and the Environment

- Present naturally and as a result of human activity
- Most copper introduced into environment poses no risk
- Risk assessment/management tools for evaluating dangers
- Society needs to take action when and where required

Copper and Recycling

- 37% recycling rate (30 year average)
- Recycling extends the efficiency of use of copper
- Recycling is an economic activity with environmental benefits. Or is it?



Cu and Sustainable Development

- Copper is essential for society's development
- Demand will continue to be met through exploration, technological improvements, efficient design and recycling
- Copper production and consumption is important to mature, newly developed and developing economies
- Copper will continue to contribute to society's development well into the future

Opportunities

- Metals are vital
- Research for sound science
- Policy formulation
- Industry must be responsive and engaged
- Metals are part of the solution to SD

ENVIRONMENTAL SUSTAINABILITY OF MINE WASTE FACILITIES IN SEMI-ARID CLIMATES: CHALLENGES FOR TECHNOLOGY AND POLICY

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JORNADAS CYTED-XIII y IMAAC COPPER FORUM
de 25 de outubro a 03 de novembro de 1999
Departamento de Engenharia dos Materiais da Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
Ciencia y Tecnologia para el Desarrollo (CYTED), Ministério da Ciência e Tecnologia da República Portuguesa, y
United Nations Industrial Development Organization (UNIDO), International Materials Assessment and Application Center

ABSTRACT

The environmental sustainability of mining is in question in part due to the occurrence of acid rock drainage (ARD) and the associated affect on surface and groundwater resources. The prevention of ARD from waste rock facilities situated in arid and semi-arid climates presents unique and complex challenges to both technology and policy. For waste rock facilities situated in arid and semi-arid climates, it is currently not technically possible, nor economically feasible to limit the infiltration of oxygen into the waste rock, a primary catalyst in the production of ARD. Technology however, does exist to limit the infiltration of water to very low rates for even the large-scale mining operations. The technology and policy challenges are rooted primarily in the following issue. Reclamation and closure strategies designed to limit only water infiltration into waste rock facilities can eliminate environmental loading for a significant period of time (i.e., until seepage occurs from the base of the facility and migrates to groundwater which may range in time from many tens to many thousands of years); however, recent studies show that the environmental loading may return to a level dictated by the overall oxidation rate in the waste rock facility with no long-term benefit realized by the closure strategy. With the size of waste rock facilities at large-scale mining operations now approaching billions of tons and the realization that many of these facilities are situated in arid and semi-arid climates, the critical nature of this challenge is evident.

Effectively addressing this challenge will require the marriage of state-of-the-art technology and policy tools. The main challenges to technology are limiting the infiltration of oxygen into the waste rock facilities over the long term, improving the ability to limit water infiltration, and improving in-situ acid treatment technologies. The challenge to policy is to provide concise technical guidance in light of technical uncertainty. This paper details the technical aspects of this challenge and presents technology and policy tools that can be applied to address it.

CONTENTS

1.0 INTRODUCTION

The interdependence of the world's economy and environment is today's reality, born out of an acceptance that critical global thresholds are now being approached and even exceeded (MacNeill et al. 1991). It has been noted that "human activities have become so huge that in many circumstances they are of the same scale as fundamental natural processes (MacNeill et al. 1991)." Based on this realization and a realization of humankind's need for continued global development and prosperity, the notion of sustainable development, as introduced by the World Commission on Environment and Development in 1987 (Our Common Future), has surfaced as the logical path to take.

Mining is a large-scale human activity that can literally move mountains and create new water bodies. Mining is one of the true global industries, one in which "the potential for mine development, operation and closure occurs on virtually every continent and in every region of the planet, including oceans and arctic terrain (Wilson 1999a)." It has the ability to accelerate both economic and social development for a given region provided that significant financial benefits do remain local. The mining industry was an integral component of the economic engine that helped drive the North American economy through the twentieth century to its current prosperous state. Inherently, large-scale environmental impacts will accompany large-scale human activities, and mining is no exception.

The environmental sustainability of mining has come into question in part due to the occurrence of acid rock drainage (ARD) and the associated effects on surface and groundwater resources. The financial liability of ARD has been estimated in excess of $2 billion in Canada alone (The Financial Post 1992). New technology has made large scale open pit mining operations economically feasible, but given the enormity of the land disturbance combined with the potential for ARD, the environmental sustainability is now being assessed in greater detail.

The major land disturbances associated with mining include pit lakes, waste rock, tailings and heap leach facilities. Open pits are often generated that are several square miles in extent and in many instances result in the development of lakes with unacceptable water quality that can affect surrounding surface and groundwater resources. Massive amounts of waste rock are removed from the open pit to expose ore bearing strata. These amounts can typically approach hundreds of millions of tons and in some operations, billions of tons. The extraction process produces tailings and heap leach piles on a slightly smaller scale but with similar potential effects on water resources.

This discussion focuses on the long-term environmental sustainability of mine waste facilities and in particular, waste rock facilities situated in arid and semi-arid climates (hereafter termed "dry"). In wet climates, technology is now available to reduce ARD from mine waste facilities to acceptable levels through the use of sub-aqueous disposal techniques (MEND 1995) and saturated engineered soil cover systems that limit the infiltration of both water and oxygen into the waste, the two components required to catalyze ARD. However, in dry climates, it is currently not technically possible, nor economically feasible to limit the infiltration of oxygen into waste rock facilities. Technology however, does exist to limit the infiltration of water to very low rates for even the largest scale mining operations. The underlying conundrum that differentiates waste rock facilities situated in dry climates from those situated in wet climates is this: closure strategies designed to limit only water infiltration into the waste rock will reduce environmental loading for a period until seepage occurs from the base of the facility and migrates to groundwater (which may range in time from many tens of years to many thousands of years; PTI and WESTEC 1997, Swanson et al. 2000); however, the environmental loading is likely to eventually return to a level dictated by the overall oxidation rate in the facility (Ritchie 1994) and no long-term benefit realized by the closure strategy.

Despite the obvious challenges posed by this unique problem, such as developing technology to limit the infiltration of oxygen and drafting policy guidelines for dealing with the uncertainty in light of the need for development, the large time frames involved (many tens to many thousands of years for environmental loading to occur) bring forth other challenges. Challenges such as the ability to predict and measure low water infiltration rates, the long-term integrity of engineered soil covers, and the extrapability of predictive model input parameters to such a large time frame (i.e., changes in climate). The challenges for technology and policy required to address this problem are daunting, but given the diverse technology and policy tools available, an acceptable solution can only be a matter of time.

As summarized on Figure 1, the ensuing discussion identifies and details the challenges facing the environmental sustainability of waste rock facilities in dry climates and presents state-of-the-art technology and policy tools that can be applied to address these challenges.

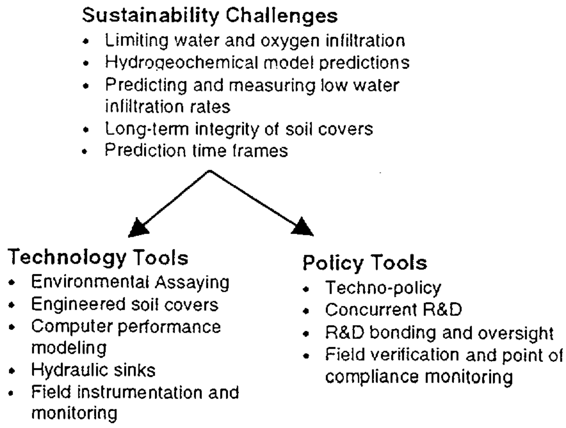

Figure 1. Summary of environmental sustainability challenges for waste rock facilities in dry climates and the pertinent technology and policy tools available to address the challenges posed.

2.0 TECHNICAL BACKGROUND

A conceptual technical understanding of environmental performance as it pertains to waste rock facilities is necessary to understand the challenges posed to technology and policy in ensuring environmental sustainability of waste rock facilities. Pertinent to understanding these challenges is a concept that will be referred to as the environmental time lag and also the uncertainties associated with environmental loading in dry climates in the absence of oxygen limiting technologies.

At wet sites where annual precipitation rates are high (i.e., greater than 250 mm per year) surface and/or subsurface environmental loading from waste rock facilities typically occurs during the operating life of the mine and is mitigated at that time using combined cover and collect-and-treat technologies. However, in dry climates (where annual precipitation rates are less than 250 mm and annual evaporation exceeds annual precipitation) environmental loading is not likely to appear during the operating life of the mine. In fact, for sites with annual precipitation rates less than 250 mm per year, it may take anywhere from many tens to many hundreds of years for the available moisture storage to be depleted and for a drop of water to seep from the base of a facility (Hutchison and Ellison 1992; PTI and WESTEC 1996; Swanson et al. 2000). This lag between when a facility is constructed and when environmental loading (i.e., seepage of ARD to surface/and/or groundwater) first occurs from the facility can be referred to as the environmental time lag.

Recent studies conducted in Australia highlight the importance of controlling the infiltration of oxygen into waste rock facilities. Ritchie (1994) put forth that if the oxidation rate is not controlled by limiting oxygen infiltration and if the concentration of pollutants in the pore-water of the waste rock are not limited to some maximum concentration due to geochemical reactions, the environmental loading will be independent of the infiltration rate through the facility. In other words, as illustrated on Figure 10, if pollutant concentrations in the pore water are not limited, it is possible that closure strategies designed to limit only water infiltration may reduce the environmental loading for the period until seepage occurs from the base of a facility, but the environmental loading will eventually return to a level dictated by the overall oxidation rate in the facility (Ritchie 1994) and no long-term benefit realized by the closure strategy.

The following paragraphs present a comprehensive conceptual understanding of unsaturated zone hydrology and sulfide oxidation as they relate to the issues just described. In summary, when sulfide minerals are present in waste rock, the infiltration of both water and oxygen will result in the generation of ARD. The presence of oxygen results in the oxidation of sulfide minerals and the infiltration of water provides the mechanism for transporting the oxidation products (i.e., sulfate, acidity etc.) through and from the waste rock. An accurate prediction of environmental loading from a waste rock facility requires a coupling of the hydrology and oxidation components.

2.1 Conceptual Understanding of Unsaturated Zone Hydrology

As illustrated on Figure 2, the environmental time lag for waste rock facilities situated in dry climates is a factor of the net infiltration at the surface, the percolation rate through the waste rock (governed by the inherent moisture storage potential of waste rock, i.e., the ability to soak up water), the partitioning of seepage at the base of the facility (i.e., lateral or vertical) and the downward migration velocity of seepage emanating from the base of the facility. The current conceptual understanding of these factors and their influence on the environmental time lag are discussed in the paragraphs to follow.

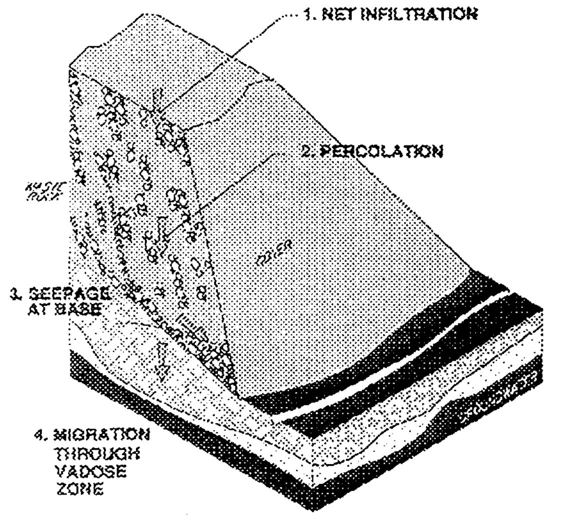

Figure 2. Conceptual hydrologic model of a waste rock facility (from Swanson and O'Kane 1999).

Precipitation in the form of rain or snowmelt either infiltrates at the soil surface or moves laterally as runoff (Figure 3). Water that infiltrates the soil surface is stored in the soil pores. This water can be removed from the soil by surface evaporation and plant transpiration. The amount of water that is removed via evapo-transpiration is a function of climate and the soil properties (soil-water characteristics and hydraulic conductivity). Water that is not extracted via surface evaporation and plant transpiration moves through the active soil zone and infiltrates into the underlying waste rock (commonly referred to as net infiltration).

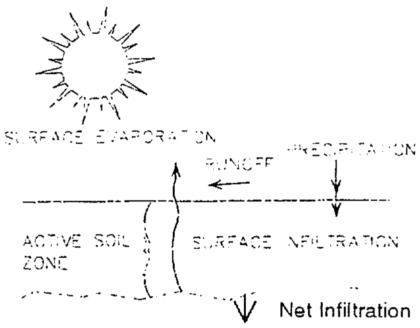

Figure 3. Components of net infiltration (from Swanson and O'Kane 1999).

There can be little dispute that waste rock facilities in dry climates are indeed wetting, albeit at a low rate. Consider the relationship between predicted net infiltration and climate for uncovered waste rock facilities situated in dry climates in the United States as presented on Figure 4. The relationship indicates a logical trend of decreasing net infiltration as the ratio between evaporation and precipitation increases. The fact that these net infiltration rates are non-zero, indicate that wetting is likely occurring in uncovered facilities.

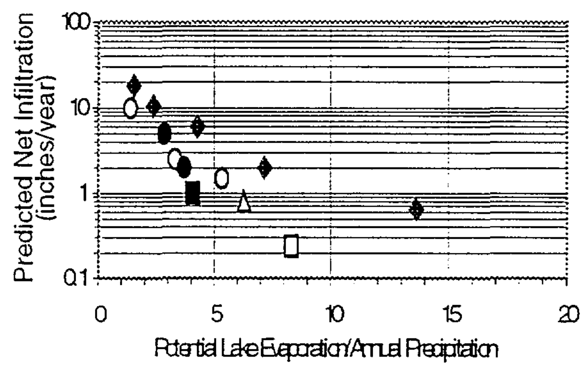

Figure 4 Predicted net infiltration versus climate for uncovered waste rock facilities in dry climates (from Swanson et all. 2000)

Waste rock is typically stockpiled in a dry state and has an inherent moisture storage potential that may take tens to hundreds of years to deplete. Water that infiltrates through the active soil zone percolates through the waste rock facility, gradually wetting it over time. As illustrated on Figure 5, waste rock facilities typically consist of an inter-fingered and bedded system of coarse to fine-textured waste rock (i.e., waste rock containing appreciable fines surrounding larger particles) that dip at the angle of repose (Herasymuik 1996).

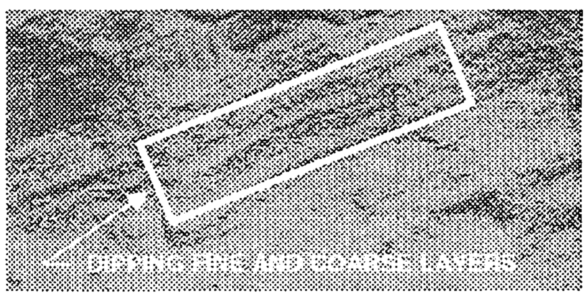

Figure 5. Internal structure of a waste rock facility (from Swanson and O'Kane 1999).

Under unsaturated flow conditions typical in dry climates, water will flow primarily through fine-textured waste rock rather than through the coarse waste rock (Newman et al. 1997 and Swanson et al. 1998). This preferential flow is demonstrated in the two-dimensional flow simulation shown on Figure 6 and supports observations made by Horton and Hawkins (1965) and Newman et al. (1997).

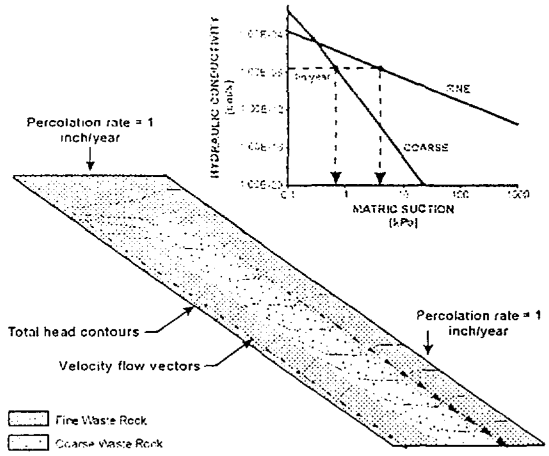

Figure 5. Preferential flow through a waste facility (from Swanson et al, 2000).

The estimated time required to deplete the available moisture storage for waste rock facilities at a metal mine situated in a dry climate of southwest United States is illustrated on Figure 6. The relationship between moisture storage depletion time and facility thickness shown in the figure indicate that for the climatic and soil conditions considered in the estimations, moisture storage depletion times can range from approximately 30 to 180 years for facilities ranging in thickness from 50 to 300 feet.

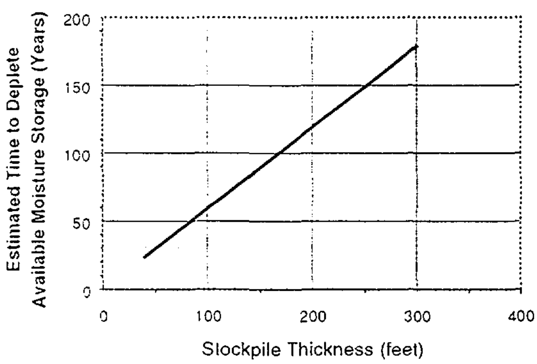

Figure 6. Estimated time to deplete available moisture storage potential for waste rock facilities situated in a dry climate of southwest United States (from Swanson et al. 2000).

When the moisture storage potential of the waste rock has been depleted, seepage will begin to occur from the base of the facility at a rate equivalent to the net infiltration at the surface. Seepage from the base of the facility will seep laterally above the native foundation contact, and/or seep vertically downward. Lateral and vertical seepage will depend on the percolation rate through the waste rock and the saturated/unsaturated hydraulic properties of the waste rock and the native foundation.

In dry climates, the time required for seepage emerging from the base of a waste rock facility to migrate to an underlying aquifer might be considerable. The timeframe for this migration is dependent on: (1) the vertical seepage rate from beneath the facility; (2) the moisture storage potential of the underlying native foundation material; and (3) the depth to the water table. For example, as shown on Figure 7, the average migration time to groundwater for waste rock facilities at a metal mine situated at a site in southwest United States was estimated to range from 100 years to in excess of 1,000 years for depths to groundwater ranging from 50 to 500 feet (Swanson et al. 2000).

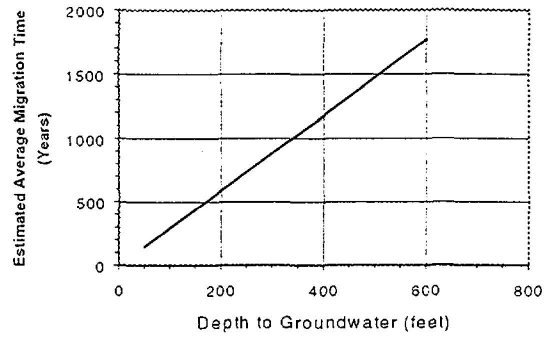

Figure 7. Estimated time for seepage emanating from the base of a waste rock facility to migrate to groundwater (from Swanson et al. 2000).

2.2 Conceptual Understanding of Sulfide Oxidation

Recent studies conducted in Australia highlight the importance of controlling the infiltration of oxygen into waste rock facilities. Ritchie (1994) put forth that if the oxidation rate is not controlled by limiting oxygen infiltration and if the concentration of pollutants in the pore-water of the waste rock are not limited to some maximum concentration due to geochemical reactions, the environmental loading will be independent of the infiltration rate through the facility. In other words, if pollutant concentrations in the pore water are not limited, it is possible that closure strategies designed to limit only water infiltration may reduce the environmental loading only for the period until seepage occurs from the base of a facility, and the environmental loading will eventually return to a level dictated by the overall oxidation rate in the facility (Ritchie 1994) and no long-term benefit realized by the closure strategy.

A conceptual model for sulfide oxidation in waste rock facilities for dry climates was described by Peterson et al. (1998) and is shown on Figure 8. Peterson et al. put forth three main mechanisms for the oxidation of sulfides in a waste rock facility both during and after material placement:

- Consumption of initial pore-space oxygen;
- Diffusion of oxygen into active placement faces; and
- Diffusion of oxygen into inactive placement faces.

Oxygen may be transported to sulfide minerals in waste rock facilities by diffusion, thermal convection or advection driven by changes in atmospheric pressure (Harries and Ritchie 1985; Bennett et al. 1994; Ritchie 1994). However, as described by Peterson et al., most researchers believe that the diffusive transfer of oxygen controls the rate of sulfide oxidation in waste rock (Davis and Ritchie 1986; David and Nicholson 1995). In large waste rock facilities, convection is limited to the edges, which is a small fraction of the total facility volume. Studies conducted by Ritchie (1994) have also shown that convection is not a significant transport mechanism unless the air permeability of the facility is large. Advective transport of oxygen results from variations in atmospheric pressure, producing oxygen concentrations on a daily time scale. However, the time frame of interest for environmental loading is on the order of tens to thousands of years; therefore, daily oxygen fluctuations are insignificant (Peterson et al. 1998).

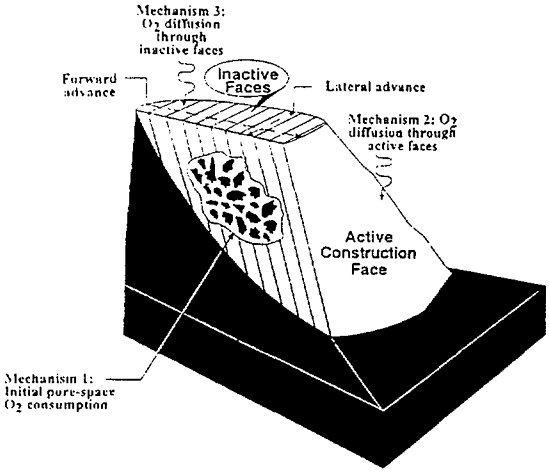

Figure 8. Conceptual model of sulfide oxidation in a waste rock facility (from Peterson et al. 1998).

As the waste rock is mined, oxygen is introduced into the pore space at atmospheric concentrations (20.9 percent) and is consumed as the sulfide minerals oxidize. During placement of the waste rock, oxygen can also diffuse into the active faces (i.e., where placement is occurring) on the sides of the facility as shown on Figure 8. Some of the waste rock will be exposed to the atmosphere for only minutes before being covered by more rock, while other areas may not be covered for weeks, allowing oxygen to diffuse into the waste rock. After the facility is completed, oxygen can diffuse into the inactive faces (i.e., where placement has ceased) from the top and the sides, and if coarse rubble material is present at the bottom, oxygen may diffuse upward from the bottom of the facility. To obtain an accurate estimate of the total amount of oxidation products generated, each of the three mechanisms that result in sulfide oxidation should be considered.

The ensuing summary of the geochemistry of pyrite oxidation is from Exponent (1999). The oxidation of pyrite (FeS_2) and subsequent formation of Fe^{2+}, SO_4^{2-} and acidity is governed by the following reaction (Exponent 1999):

$$FeS_2(s) + \frac{7}{2}O_2 + H_2O \leftrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

Additional acidity (H^+) is produced as ferrous iron (Fe^{2+}) oxidizes to form ferric iron (Fe^{3+}) and precipitation of hydrous ferric oxide (HFO) occurs:

$$2Fe^{2+} + \frac{1}{2}O_2 + (5+x)H_2O \leftrightarrow 2Fe(OH)_3 \bullet xH_2O + 4H^+$$

The release of additional constituents can also occur when sulfides oxidize. Trace metals bound as sulfide minerals (i.e., copper, zinc, nickel, lead and arsenic) are liberated when pyrite is oxidized. Acidity produced by pyrite oxidation can react with carbonate minerals, simultaneously dissolving carbonate minerals and consuming acidity (i.e., raising the pH). In addition to raising pH, the dissolution of calcite increases the concentration of bicarbonate and calcium, leading to an increase in the concentration of constituents that are not contained within the sulfide mineral itself.

Other minerals, such as hydroxides, silicates and carbonates that are present in the sulfide bearing rocks may also dissolve in the presence of ARD. This dissolution may, in turn, release other constituents such as aluminum, sodium, manganese and silica. Once these constituents dissolve, they may interact with other products of the sulfide oxidation and acid neutralization process to form new minerals. For example, if a sufficient quantity of calcium is released to exceed the solubility of gypsum, calcium and sulfate can be removed from solution. The rate at which these interdependent reactions occur is dependent on many factors including temperature, biotic reactions and solution chemistry.

3.0 IDENTIFICATION OF KEY CHALLENGES

One of the most critical problems pertaining to the environmental sustainability of waste rock facilities in dry climates is the potential for environmental loading to occur to groundwater at some point in the future. Technology has not yet advanced sufficiently to limit the infiltration of oxygen into waste rock to acceptable levels over the long term. However, technology does exist to limit the rate of water infiltration using engineered soil covers that have the potential to maintain integrity for significant time frames. The benefits to applying such a design are the reduced volume rate of seepage from the base of a facility or runoff from the surface of a facility and the environmental time lag that results from the low rate of water infiltration. However, the long-term benefits of designing to limit only water infiltration are uncertain in light of recent hydrogeochemical modeling studies that predict environmental loading.

The large time frames involved (many tens to many thousands of years for environmental loading to occur) give rise to other challenges such as the ability to predict and measure low water infiltration rates, the long-term integrity of engineered soil covers, and the extrapability of predictive model input parameters to such a large time frame (i.e., changes in climate). These challenges are discussed in the sections to follow.

3.1 Limiting Water and Oxygen Infiltration

Limiting both water and oxygen infiltration into waste rock facilities in dry climates has presented a technical challenge. This is mainly due to the fact that technologies developed at sites situated in wet climates (technology typically comes from the wetter climates that experience the problems sooner and to a greater magnitude) are not always directly transferable to sites situated in dry climates. For example, engineered soil covers to control ARD must specifically address the role of local climatic factors on cover performance. There is an increasing concern that design paradigms developed for one climate not be transferred directly to new sites where the climatic conditions are quite different.

Cover systems for wet climates typically consist of a compacted layer covered by an additional layer to provide erosion protection and support vegetation. The low saturated hydraulic conductivity of the compacted layer promotes surface runoff and limits infiltration. These systems usually incorporate a capillary break below the compacted layer to prevent it from draining and keep it saturated, so that it also acts as a barrier to oxygen diffusion (Yanful et al. 1994; Nicholson et al. 1989).

Low-permeability barriers such as clay however, are not necessarily the most effective covers for limiting water infiltration in dry climates (Swanson et al. 1997). This is due to the high potential for drying and cracking, which results in water bypassing the soil matrix (Morris et al. 1992; Daniel and Wu 1993). In addition, a layered compacted clay cover design that may have proven effective at remaining saturated to limit oxygen infiltration in a wet climate may not remain sufficiently saturated in a drier climate (i.e., Figure 9). The end result can be a failed cover system.

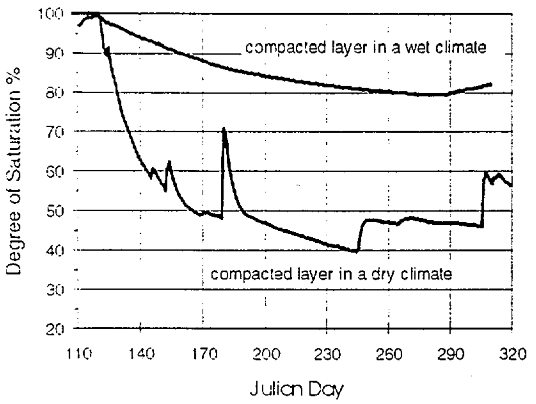

Figure 9. Comparison of the changes in the degree of saturation for a compacted clay cover for a wet and a dry climate (from Swanson et al. 1997).

3.2 Uncertainty in the Hydrogeochemical Prediction of Environmental Loading

The uncertainty in the long-term geochemical composition of waste rock pore water poses both technical and policy challenges and is of specific concern for closure alternatives such as engineered soil covers designed only to limit water infiltration and not oxygen infiltration. In such cases, the volume and rate of seepage from a waste rock facility may be reduced several orders of magnitude and the environmental time lag increased accordingly as illustrated on Figure 10.

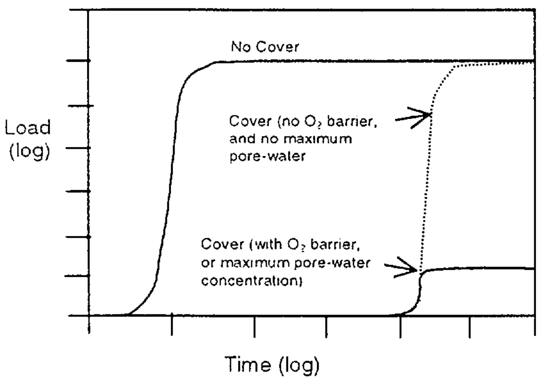

Figure 10. Environmental loading from a waste rock facility for conditions not limiting and limiting pollutant concentrations in the pore water.

However, as studies reported by Ritchie (1994) indicate, if the concentration of pollutants in the pore water of the waste rock are not limited geochemically, and the oxidation rate is not controlled by limiting oxygen infiltration, then the environmental loading will be independent of the infiltration rate through the facility. In other words, as illustrated on Figure 10, if pollutant concentrations in the pore water are not limited, closure strategies designed to limit only water infiltration may reduce the environmental loading for the period until seepage occurs from the base of a facility, but the environmental loading will eventually return to a level dictated by the overall oxidation rate in the facility (Ritchie 1994) and no long-term benefit realized by the closure strategy.

The challenge this problem presents affects both technology and policy. For example, closure strategies designed to limit only water infiltration reduce seepage volumes which is of benefit for situations where the seepage can be collected. If the seepage cannot be collected then the closure strategy becomes one of assessing the environmental time lag. For example, if water infiltration is limited such that environmental loading is not likely to occur for 2,000 years, then policy defines whether this is an acceptable closure strategy. If policy defines a design life of 100 years for the facility, the design would be acceptable. But would such a policy defend the true spirit of sustainable development. This aspect will be addressed further in Section 6, Policy Solutions.

3.3 Predicting and Measuring Low Rates of Water Infiltration

The required accuracy of net infiltration predictions using computer performance models presents a technology and policy challenge, as does the need for measuring low rates of water infiltration to verify the computer model predictions.

The low rate of water infiltration presents a challenge in terms of what degree of accuracy is required when predicting the net infiltration rate in the design of soil covers. For example, a design prediction may give a net infiltration rate of 0 inches per year. Based on this result it may be concluded that there is no net infiltration through the cover. However, if the result were reported to more significant digits, the actual predicted net infiltration rate may in fact be 0.2 inches per year. Although this may not appear to be an important issue, it is indeed significant when the value is used to predict the environmental time lag. Technology must provide the guidance to policy in order for policy guidelines to be established to standardize the prediction accuracy for engineered soil covers.

An important aspect of any design is monitoring to ensure that the design is operating as planned and to have in place contingency plans in the event the design does not operate as planned. Such should be the case for the design of engineered soil covers and perhaps even more so in light of the fact that design of natural systems are not as predictable as other types of designs (i.e., building construction). At present, policy guidelines do not typically require long-term monitoring of engineered soil covers to verify predicted performance and nor do they require sound contingency plans. The challenge to technology lies in the difficulty in measuring the low water infiltration rates that are characteristic of properly designed soil covers in dry climates. The science of unsaturated zone hydrology that defines the monitoring technologies is established (Fredlund and Rahardjo 1993; Guymon 1991; Swanson et al. 1999), but has not yet seen widespread application in the mine waste management.

3.4 Long-Term Integrity of Engineered Soil Covers

The ability of closure strategies to remain effective over the long term (i.e., the integrity of the closure strategy) poses a technical challenge to the environmental sustainability of mine waste facilities. Most notably are issues pertaining to the long-term integrity of engineered soil covers.

Factors that affect the long-term integrity of engineered soil covers include physical, chemical and biological factors (Figure 12). Physical factors typically have the greatest effect on the long-term integrity of engineered soil covers and altering the hydraulic conductivity and/or the moisture retention capacity of the cover material. As shown on Figure 11, physical factors include desiccation (cracking due to drying), erosion, freeze/thaw, consolidation and dispersion (loss or addition of fines).

Physical Factors	Chemical Factors	Biological Factors
• Desiccation • Erosion • Freeze/Thaw • Consolidation • Dispersion	• Dissolution • Osmotic consolidation • Sorption • Precipitation • Mineralogical transformation	• Root growth • Worm holes • Animal burrowing

Figure 11. Factors affecting the long-term integrity of engineered soil covers.

The process of erosion can destroy a cover by washing away the fine fraction of a cover or by reducing the thickness of the cover. Dispersion of fines from a fine-textured cover layer and transport into a capillary barrier layer can clog the pores of the barrier and damage the integrity of the barrier. Freeze-thaw cycling can result in an increase in hydraulic conductivity of compacted clay covers of up to 1.5 orders of magnitude (Wong and Haug 1991). Desiccation can affect cover integrity by increasing hydraulic conductivity and reducing the degree of saturation of oxygen barriers. For clayey soils, if desiccation is severe cracking can occur causing an increase in hydraulic conductivity as infiltration bypasses the soil matrix and flows through the cracks to the underlying waste (Morris et al. 1992; Daniel and Wu 1993; Bronswijk 1991).

3.5 Prediction Time-Frames

The reliability of long-term computer model predictions has been the subject of debate in the design of deep underground repositories for high-level radioactive waste and has seen recent discussion in the mining industry pertaining to pit-lake water quality and seepage from waste rock facilities (Kempton and Atkins 2000).

Regulatory policy for nuclear waste facilities requires that computer model predictions be performed to 1,000 years. Of primary concern is the applicability of model input parameters such as annual precipitation and evaporation that are based on limited historic data and extrapolation over the entire timeframe of the prediction. And if it is not applicable, then what is? Similarly, it has been proposed that input parameters, such as hydraulic conductivity and moisture storage potential of waste rock, may change over time due to physiochemical weathering. How should computer models account for these changes in input parameters when the necessary long-term physical data does not apparently exist?

These questions pose a challenge to both technology and policy. Technology must advance to narrow down the uncertainty in the measured values for the input parameters and policy must also advance to put forth guidelines that are based on the most current technology.

4.0 TECHNOLOGY TOOLS

There are a number of technical tools now available that are being applied to mine sites around the world that help improve the environmental sustainability of waste rock facilities. These tools were previously summarized on Figure 1 and include:

- Environmental Assaying;
- Engineered Soil Covers;
- Computer Performance Modeling;
- Designing for Closure Using Concurrent Reclamation;
- Hydraulic Sinks; and
- Field Instrumentation and Monitoring.

4.1 Environmental Assaying

Environmental assaying refers to the geochemical characterization of waste rock conducted during the exploration phase of a mining project. A paradigm shift is occurring in that the need to characterize the "waste body" is becoming as important as characterizing the "ore body". Many regulatory frameworks now require that material handling plans be submitted and approved before operating permits are issued. These plans must characterize the acid generating potential and constituent release potential of the waste rock and must propose a means of stockpiling such that discharge of pollutants to surface and groundwater resources does not occur.

An effective means of storing and analyzing environmental assay data is using the mines geologic block model (GBM). The GBM is commonly used to describe the economic value of ore bodies and to develop plans for their extraction. This innovative approach to waste characterization was described by Bennett and Kemtpon (1997) for a gold mine in the state of Nevada, United States. At this site, approximately 7,000 acid-base accounting tests were conducted by the operator using LECO furnace to determine sulfide and carbonate contents on samples obtained during development drilling. The waste body was then characterized based on net neutralizing potential (NNP) using kriging with lithologic controls or by rock type averaging. The results of the GBM waste characterization was used to develop a material handling plan which assessed blending and encapsulations strategies for the facilities using probabilistic modeling techniques (Kempton et al. 1997). Bennett and Kempton (1997) also discuss methods for adding environmental assay data to existing GBMs for situations where such data was not collected during exploration and development.

4.2 Engineered Soil Covers

Engineered soil covers have been used at mine sites in wet and dry climates to limit the infiltration of water and/or oxygen into waste rock facilities. The site-specific nature of cover design is now being recognized and accounted for in the reclamation and closure of mine waste facilities (Wilson 2000). Compacted clay cover systems have been successfully applied at wet sites to limit both water and oxygen infiltration. Store-and-release cover systems have been designed and successfully applied at drier sites where the integrity of compacted clay cover systems would be in question due to the potential for desiccation cracking. Technology advancements have been made in the last decade in the area of computer performance modeling that have allowed for more efficient and effective soil cover design for both wet and dry climates.

The performance of compacted clay cover systems has been documented at a number of sites situated in wet climates

(Johnson et al. 1983; Collin and Rasmuson 1990; Woyshner and Yanful 1993; Yanful and Aube 1993; Yanful et al. 1994; O'Kane et al. 1995). For example, Wilson et al. (1997) reported on the successful field performance of a cover system at a waste-rock facility in British Columbia, Canada. The cover consisted of 50 cm of compacted glacial till overlain with 30 cm of loosely placed glacial till, to support vegetation and provide erosion protection. Field measurements at this site showed that the compacted layer maintained a degree of saturation in excess of 90 percent throughout the year, and infiltration averaged approximately 4 percent of annual precipitation. Results of computer modeling for the cover system reported by Swanson et al. (1995) showed that oxygen fluxes would be reduced by 98.4 percent under extreme dry conditions, and infiltration rates would be reduced to 3 percent of annual precipitation under extreme wet conditions.

At dry sites successful store-and-release cover systems have been designed that do not incorporate a low-permeability compacted layer (PTI and WESTEC 1996; GSM 1995; Swanson 1995). These cover systems, illustrated on Figure 12, store infiltrating waters in the root zone long enough to allow evapotranspiration to remove the majority of water before it percolates into the waste. PTI and WESTEC (1996) reported on a cover system consisting of 1.5 m of alluvium (silty, clayey gravel with sand), used for waste-rock dumps at a site in Nevada. The U.S. EPA's HELP model was used to estimate infiltration rates through the cover once vegetation was established. Model results revealed that infiltration rates were likely to range from 0.3 to 7.9 mm/yr (0.1 and 3.9 percent of annual precipitation). At this rate, it was predicted to take 600 to 1600 years for the waste-rock dumps to reach hydraulic equilibrium and for water to percolate from their bases.

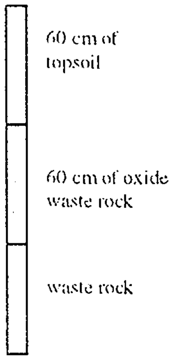

Figure 12. Store-and-release cover system constructed at a mine site situated in a dry climate.

Similar infiltration rates were reported for a layered cover system consisting of 60 cm of topsoil (20% silt and clay, 15% sand, and 65% gravel) underlain with 60 cm of oxide waste rock (10% silt and clay, 10% sand, and 80% gravel) at a site in Montana (GSM 1995; Swanson 1995). Infiltration rates were predicted using three different hydrological computer models. Results showed that infiltration rates through the cover ranged from 2.5 to 6.3 mm/yr (GSM 1995). Model results were supported by moisture contents measured in field test plots over a 3-year period. It was also predicted that oxygen fluxes would not be significantly reduced by construction of the cover system.

4.3 Computer Performance Modeling

Advances in computer processing speed combined with advances in the understanding of hydrologic and geochemical processes in the last decade have led to the development of computer modeling technologies that are seeing application in the design of engineered soil covers and prediction of environmental loading from mine waste facilities. These technologies have been of significant benefit in improving the environmental sustainability of mine waste facilities and are improving continuously.

<u>Soil-Atmosphere Modeling</u>

Soil-atmosphere hydrologic models are used for the analysis and design of engineered soil covers at waste management facilities. In dry climates, net infiltration rates can be significantly overestimated if the predictive method is not climate-specific (Hutchison and Ellison 1992). The use of a physically based hydrologic model that is capable of accurately simulating upward unsaturated flow is recommended for dry climates (Hutchison and Ellison 1992). A physically-based model is a numerical model that solves the partial differential equations that describe the flow of water and heat in a porous media.

For example, the HELP model is a semi-empirical model (i.e., that uses simplified solutions of the physical process of water flow) and is a useful tool for the rapid identification of mean and extreme climatic years from multiple sets of annual data, but the model does not implicitly account for upward unsaturated flow, which is a dominant water transport mechanism in dry climates.

The SOILCOVER model is an example of a physically-based hydrologic model and is capable of accurately simulating upward unsaturated flow. It has been successfully applied to mine sites in dry climates in Australia, Canada and the United States (Swanson et al. 2000; Swanson et al. 1995; Williams, et al. 1997 and Machibroda, et al. 1993). In addition, such physically-based models consider both liquid and vapor transport within the soil profile to provide a more accurate quantification of surface evaporation. Model results are compared to field data to evaluate the accuracy of the model predictions. For example, Figure 13 shows a comparison of predicted and field measured moisture contents for a mine site in the southwestern United States.

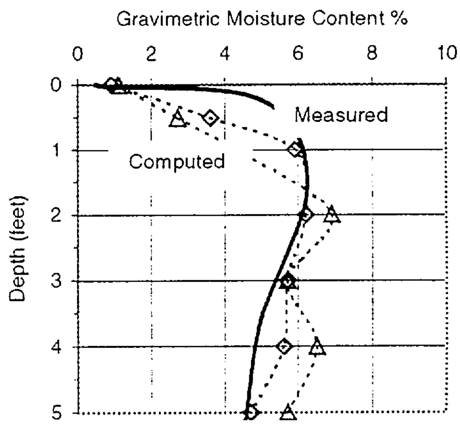

Figure 13. Computed moisture contents using a physically-based soil-atmosphere computer performance model.

Advances have also been made in the computer programs used to estimate soil hydraulic properties that are required as input into soil-atmosphere models. The duration for laboratory testing to measure one of the key soil hydraulic properties, the soil-water characteristic curve (SWCC), can range from several weeks to several months for typical mine soils. Feasibility studies and preliminary analysis and design projects at mine sites can be subject to deliverable times that therefore preclude laboratory measurement of the SWCC. Due to the lengthy testing times, computer programs based on theoretical models are sometimes used to predict the SWCC using the readily measured particle size curve (i.e., Gupta and Larson 1979; Tarnawski and Wagner 1991). The most recent approach to predicting the SWCC combines theoretical models with a knowledge-based systems approach (Fredlund 1996). This combined approach allows the user to calibrate theoretical predictions to available laboratory SWCC data as a means of improving the accuracy of the theoretical prediction (applied by Swanson et al. 1999a) This new technology provides a means for expediting analysis and design; however, final design should always be based on direct measurement of the pertinent properties.

Hydrogeochemical Modeling

Hydrogeochemical models are models that combine the hydrology of water flow with the geochemistry of sulfide oxidation to predict the generation and transport of ARD pollutants. Advances have been made in the technology of this modeling due to both advances in the technical understanding and increased computer processing speed. Models such as ACIDROCK (Schaer et al. 1994) and FIDHELM (Pantelis 1993) are examples of such hydrogeochemical models, but are not sufficient for making detailed predictions of ARD chemistry (MEND 1995).

The most recent and perhaps complete of these types of models is MINTOX (Wunderly et al. 1995). MINTOX is a reactive transport model that couples a saturated/unsaturated finite element flow model, an equilibrium-geochemical model and a diffusion limited pyrite oxidation model. The MINTOX model was used to simulate the occurrence of ARD from a tailings impoundment in Ontario, Canada. The tailing impoundment was treated with limestone and had been allowed to oxidize for approximately 12 years before site data was collected for modeling purposes. The model accurately reproduced the distribution of pH, aluminum and other metals in the tailings. Although this model may be the most complete of the hydrogeochemical models, it has limitations for simulating environmental loading from waste rock facilities in dry climates. This is primarily due to the inherent numerical instability in the geochemical simulation of high concentrations of constituents resulting from low infiltration rates and high oxidation rates typical of waste rock facilities in dry climates.

4.4 Designing for Closure

The benefits of designing a waste rock facility with final closure and reclamation in mind are now being recognized. Design features such as location (i.e., sub-aqueous and in pit disposal), order of placement (i.e., blending and encapsulation) and method of placement (i.e., compaction/concurrent reclamation) are being applied to facilities in wet and dry climates.

In wet climates where natural water bodies are plentiful, placement of acid generating waste rock directly beneath a water surface (i.e., sub-aqueous disposal) is an effective control measure for limiting ARD (SRK 1988). This method is attempted in drier climates with waste rock being deposited dry into adjacent open pits and the water table allowed to rebound to either partway or completely above the waste rock. Successful application of this method has not been documented. Sub-aqueous disposal case studies in wet climates have been reported by Senes (1995), Golder (1994) and MEND (1995). General observations from these studies indicate that deposition of waster rock immediately beneath water cover is the most common practice and that a barrier is typically constructed above the waste rock to prevent diffusion to the lake above. Some examples of in pit disposal of waste rock in dry climates in which the water table was to rebound only midway through the waste rock facility have been reported (BLM 1986; Water Management Consultants 1996); however no long-term monitoring data or observations of performance are yet available. Studies conducted by Peterson et al. (1998) indicate that such disposal techniques (i.e., dry deposition followed by water table rebound) are likely to result in an initial release of constituents due to the oxidation of waste rock during placement (resulting from the consumption of initial pore-space oxygen) and during the time until water cover occurs (resulting from the diffusion of oxygen through active placement faces).

Blending and encapsulation of acid generating waste rock with acid neutralizing waste rock have been documented for large-scale mining operations in North America (Kempton et al. 1997) and Australia (O'Kane et al. 1999). These specific sites involve the handling and placement of over a billion tons of waste rock over the life of the mine. Due to the climatic conditions at these sites, it was not deemed feasible to limit oxygen infiltration. Rather, the limiting of water infiltration was a design objective along with geochemical isolation of the acid generating waste rock. Kempton et al. (1997) reported on the application of probabilistic modeling techniques to assess the effectiveness of blending and encapsulation strategies on limiting the environmental loading of ARD from the base of a waste rock facility at a gold mine situated in a semi-arid climate of the United Sates. The probabilistic modeling indicated that for this particular dry climate, a blending strategy would provide more complete in-situ acid neutralization. O'Kane et al. (1999) reported on the encapsulation of acid generating waste rock at an iron ore mine in Australia. A unique component of this project was the application of a Global Positioning System (GPS) technology to control the placement of acid generating waste rock. The location of each haul truck is continually monitored using GPS interfaced truck dispatch software and is accurate to within 5 meters. The GPS material handling method allows for accurate implementation of the waste rock facility design.

Concurrent reclamation is a process whereby the waste rock facility is continually engineered during its construction with the objective of limiting environmental loading from the final facility configuration. Concurrent reclamation can include the following strategies:

- Compaction of the surface of individual lifts to slow the rate of water infiltration through the facility;
- Increasing the moisture storage potential of the waste rock by increasing the percentage of fines through modification of the blast hole spacing during excavation of the waste rock; and
- Limiting or enhancing surface water runoff through modification of surface topography.

Concurrent reclamation strategies are the subject of extensive research for potential application at uranium mines in Northern Canada (Barbour and Wilson 1999).

4.5 Field Verification and Long-Term Alert Level Monitoring

Technology has developed in recent years to allow direct and indirect measurement of water and oxygen infiltration into waste rock facilities. This information is necessary to verify computer performance model predictions and to monitor long-term performance of the facility design. Although typically policy does not require monitoring of the unsaturated waste rock facility and the underlying vadose zone, such monitoring can provide early warning of performance failures. Due to the slow nature of unsaturated water flow, this early warning can be on the order of several tens to several hundreds of years. Contingency measures can then be initiated well before impacts to surface and/or groundwater resources occur. Field monitoring technology has been developed and employed for measuring water and oxygen infiltration through both covered and uncovered waste rock facilities as described below.

Field monitoring of engineered soil covers has been used at mine sites situated in both wet and dry climates around the world (Durham 1999; Wilson 1997; O'Kane 1999; GSM 1995). Durham et al. (1999) report on a state-of-the-art field instrumentation and monitoring program for the design of an engineered soil cover at a mine site in a semi-arid region of Australia. To address the problem of ARD, the Kidston Gold Mine in North Queensland, Australia implemented a research program with the University of Saskatchewan, Canada to design a store-and-release soil cover system for the waste rock facilities. The first phase of the program, as described by Bews et al. (1997), consisted of characterizing the waste rock and cover materials, designing cover alternatives using the numerical model SoilCover (USG, 1997), and building and instrumenting two field test covers. The second phase included evaluation of the field performance of the two cover systems, model calibration, and the design of a final closure system based on the wettest year recorded at the mine site since 1984. The instrumentation for the test covers and the field performance evaluation included engineered zero tension lysimeters described by Bews et al. (1997), thermal conductivity (TC) sensors for the measurement of soil matric suction and temperature and water content sensors using frequency domain reflectometry (FDR). The sensors were wired to a datalogger to provide automated data collection on a daily basis (Figure 14). In order to measure actual evapotranspiration on the cover, a Bowen Ration system was installed. This system indirectly measures evapotranspiration based on the vapour pressure and temperature gradient between two points as described by Bowen (1926).

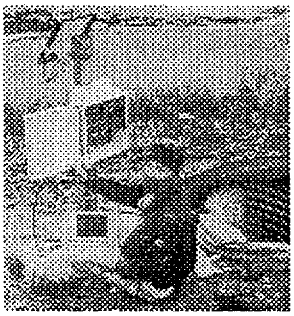

Figure 14. Example of field automated measurement of soil matric suction and moisture content in an engineered soil cover.

4.6 Hydraulic Sinks

The excavation of an open pit mine can cause a depression in the regional groundwater table during mining operations as a result of mine dewatering and, in dry climates, after mining as a result of a net evaporative loss from the water surface of the open pit. Groundwater within the groundwater depression (i.e., the capture zone) will flow to the open pit. This system is referred to as a hydraulic sink. Any discharges from a waste facility at the ground surface that occur within the capture zone will flow into the open pit and will not effect other surface and our groundwater resources. Although this does transfer the discharge to a pit lake creating environmental concerns that must be dealt with appropriately, the hydraulic sink can be an effective form of passive containment.

The hydraulic sink is considered a form of best available demonstrated control technology (BADCT) under Arizona Revised Statutes (A.R.S. 49-243.G) provided that "the mine pit creates a passive containment that is sufficient to capture the pollutants discharged and that is hydrologically isolated to the extent that it does not allow pollutant migration from the capture zone. Passive containment means natural or engineered topographical, geological or hydrological control measures that can operate without continuous maintenance. Monitoring and inspections to confirm performance of the passive containment do not constitute maintenance." In addition, the statute requires that "the discharging facility employs additional processes, operating methods or other alternatives to minimize discharge."

The presence of a hydraulic sink can be predicted using numerical groundwater flow and transport modeling. The most common tool applied to mine sites is the United States Geologic Survey MODFLOW model (MacDonald and Harbough 1999). MODFLOW is modular three-dimensional finite difference groundwater flow model and is the recognized standard model used by courts, regulatory agencies, universities, consultants and industry. Groundwater flow and transport modeling of open pits have been reported for several mines situated in the dry climates of the United States (i.e., PTI 1992; HCI 1996; SMI 1995).

5.0 POLICY TOOLS

Policy tools that can be applied to address the challenges facing the environmental sustainability of mine waste facilities in dry climates are characterized by their ability to incorporate state-of-the-art technology and to provide concise guidance in light of technological uncertainty. Examples of such policy tools include:

- Techno-Policy;
- Concurrent Research & Development;
- Research & Development Bonding and Oversight; and
- Field Verification and Point of Compliance monitoring.

5.1 Techno-Policy

Techno-policy guidance refers to policy guidance that incorporates state-of-the-art technology. More specifically, it is a framework that provides direct technical guidance to allow for application of standard (i.e., widely accepted) technology that can expedite permitting, but is flexible enough to allow for the incorporation of new state-of-the-art and innovative technology. Such a framework is crucial in today's rapidly advancing technological environment.

A good example of techno-policy is the Best Available Demonstrated Control Technology (BADCT) program administered through the state of Arizona's Aquifer Protection

Permit (APP). The state of Arizona, situated in the southwestern United Sates immediately north of the Mexican border, is the nation's major copper producer and administers an effective regulatory framework for mine waste management. The APP process is administered by the Arizona Department of Environmental Quality (ADEQ) and through the BADCT program, provides flexibility to incorporate new technology into the permit process. The regulatory framework is summarized below.

The Arizona Revised Statutes require an APP for any person who discharges or who owns or operates a facility that discharges (A.R.S. 49-241.A). A "discharge" is defined as the direct or indirect addition of any pollutant to the waters of the state from a facility, and for purposes of the aquifer protection permit program prescribed by A.R.S. 49-241, discharge means "the addition of a pollutant from a facility, either directly to an aquifer or to the land surface or the vadose zone, in such a manner that there is a reasonable probability that the pollutant will reach an aquifer (A.R.S. 49-201.11)." Waste rock facilities that have not been subjected to mine leaching procedures are not considered "discharging" facilities under A.R.S. 49-241; however, before a waste rock facility is deemed exempt from the APP, a technical report (referred to as a Determination of Applicability) must be submitted by the operator demonstrating that the facility is, in fact, non-discharging.

The BADCT program, defined under A.R.S. 49-243.B.1, states that a "facility will be so designed, constructed and operated as to ensure the greatest degree of discharge reduction achievable through application of the best available demonstrated control technology, processes, operating methods or other alternatives, including, where practicable, a technology permitting no discharge of pollutants. Site specific hydrologic and geologic characteristics and other environmental factors, the opportunity for water conservation or augmentation and economic impacts of the use of alternative technologies, processes or operating methods on an industry-wide basis are all considered in determining a BADCT. A discharge reduction to an aquifer achievable solely by means of site specific characteristics does not, in itself, constitute a BADCT." The ADEQ may establish, by rule, presumptive best available demonstrated control technology, processes, operating methods or other alternatives, for a class of facilities. Once presumptive controls are established by rule for a particular class of facilities the ADEQ will review those rules every five years and, if appropriate, revise the rules for that class of facilities.

A BADCT can either be "prescriptive" or "individual". The "prescriptive" BADCT includes a list of designs to choose from that are based on widely accepted technology (i.e., the use of a double-lined leachate collection and removal system for process solution ponds). The prescriptive BADCT minimizes the level of site investigation and engineering evaluations that the operator is responsible for, saving both time and money in the design and regulatory review process. The "Individual" BADCT allows the operator to "evaluate and compare alternatives that combine site characteristics with demonstrated control technologies (ADEQ 1999)." The "individual" BADCT provides a "method for an operator to incorporate water quality protection characteristics that may occur due to climate, vadose zone conditions beneath the facility, operational procedures and other factors (ADEQ 1999)."

In relation to techno-policy, the prescriptive BADCT provides the mechanism for expediting the permit process using standard technology and the individual BADCT provides the mechanism that allows for site-specific application of new and innovative technology. It can be seen via this process, that technology introduced through an individual BADCT may, in due time, become a standard technology included under prescriptive BADCT.

5.2 Concurrent Research & Development

Developing policy guidelines to address environmental performance in the presence of uncertain technology is perhaps the key policy challenge facing the environmental sustainability of mine waste facilities. Concurrent research & development (R&D) is one method to address this challenge.

Concurrent R&D is a framework by which R&D is directed toward addressing a key technological uncertainty that might otherwise prevent permit issuance, but which the environmental time lag is sufficient such that there is reasonable likelihood of developing a technological solution before the environmental impact is realized. For example, consider the primary technological uncertainty identified in Section 3: limiting oxygen infiltration into waste rock facilities in dry climates. At this time it is not technologically possible, nor economically feasible to limit the infiltration of oxygen into acid generating waste rock facilities. Limiting the infiltration of water is technologically possible; however, current studies suggest that limiting the infiltration of water and not oxygen, may not impose any long-term reduction in environmental loading. The environmental time lag for this environmental loading can be significant depending on site-specific factors such as the net infiltration rate and the thickness of the vadose zone underlying the facility.

Concurrent R&D applied to the above situation would initiate an R&D program with the goal of solving the key technological uncertainties in a defined timeframe. The technological uncertainties of primary focus in the R&D program could include such aspects as determining maximum pore-water concentrations of constituents of concern and/or developing economically feasible engineered cover designs capable of limiting oxygen infiltration.

Such programs have evolved outside of an official regulatory policy framework and are born out of good long-term vision on the part of the mine operator and good identification of key issues on the part of the regulatory agency. An example of this is Placer Dome Canada, Inc.'s cover modeling R&D program conduced jointly with the Unsaturated Soils Group (USG) at the Department of Civil Engineering, University of Saskatchewan (Wilson et al. 1997). This five-year R&D program was conducted at the Equity Silver Mine situated in a wet climate of north central British Columbia (B.C.), Canada. The B.C. government regulatory agency required that Placer Dome Canada post a $32 million (Aziz and Ferguson 1997) bond to cover the long-term costs associated with the collect-and-treat system used to mitigate ARD prior to discharge to a local surface water resource. In setting the bond, the B.C government built in the flexibility to reduce the bond if Place Dome Canada could demonstrate that a recently installed cover system could result in a decrease in the cost of the collect-and-treat system. The R&D program was initiated by Placer Dome Canada and the USG with the goal of determining the effectiveness of an engineered soil cover constructed over acid generating waste rock in terms of limiting the infiltration of both water and oxygen to the underlying waste rock. During the course of the five-year R&D program a state-of-the-art soil-atmosphere model, SOILCOVER, was developed and used to predict the long-term performance of the constructed cover system. To aid in the development of the computer program and to calibrate and verify the model predictions, a comprehensive field instrumentation and monitoring program was also initiated. The combined computer modeling and field instrumentation and monitoring R&D program demonstrated that the constructed cover system at Equity Silver Mine was likely to reduce collect-and-treat costs at the mine and in response, the B.C. Government reduced the bond by approximately $10 million (Aziz and Ferguson 1997). In this example, initial R&D goals were achieved in a relatively short time-frame and resulted in the development of cover modeling technology and methods that are currently being applied all over the world.

5.3 R&D Bonding and Oversight

One method of funding a concurrent R&D program is through a bond posted by the operator at the time of permit issuance in a somewhat similar as described previously for the cover modeling R&D program at Equity Silver Mine. The amount of the bond could be based on the estimated cost of the R&D program and would be separate from any bonding associated with carrying out contingency measures in the event significant environmental loading occurs after mine closure. The R&D bonding could incorporate incentives for conducting focused and productive R&D. For example, as in the case of the cover modeling R&D program at Equity Silver Mine, bond reductions could be scheduled in response to achieving intermediate and primary R&D goals. For such incentives to be effective, the R&D program would be best implemented under the direction of the mine operator. A regulatory oversight committee could be employed to oversee the R&D in an effort to coordinate with other concurrent R&D programs to eliminate redundancy and foster sharing of technological advancements.

Canada's innovative Mine Environment Neutral Drainage (MEND) program acted in a similar oversight capacity during its eight-year tenure and provides a good model for the cooperation of government and industry in the development of new technology. The MEND program began with representation from the mining industry, the Canadian Center for Mining and Energy Technology (CANMET), Environment Canada and other provincial bodies. The program was initiated with the objective to:

- "Provide a comprehensive, scientific, technical and economic basis for the mining and government agencies to predict with confidence the long term management requirements for reactive tailings and waste rock: and
- Establish techniques that will enable the operation and closure of acid generating tailings and waste rock disposal areas in a predictable, affordable, timely and environmentally acceptable manner (Feasby et al. 1997)."

With an initial operating budget of $18.5 million and over 200 projects initiated, it has been estimated that the MEND program has reduced environmental liability in Canada by $340 million for five mine sites alone (Young and Witshire 1996). The program has resulted in a much greater common understanding of issues and solutions, reduced environmental liability and increased diligence by regulators, industry and public (Young and Witshire 1996).

5.4 Point of Compliance Monitoring

Point of compliance monitoring using groundwater sampling wells is an integral component of all regulatory frameworks to provide early warning of a facility design failure. However, such monitoring is typically not required for engineered soil covers and within the vadose zone to verify predicted performance nor to provide an early warning system for design failures. As described in Section 4.5, the technology exists for field instrumentation and monitoring of engineered soil covers and to monitor moisture movement within the waste rock and the underlying vadose zone. Due to the slow nature of unsaturated water flow, point of compliance monitoring could provide early warning on the order of several tens to several hundred years. Contingency measures could then be initiated well before impacts to surface and/or groundwater resources occur.

Existing policy frameworks for groundwater point of compliance monitoring are well suited for application to unsaturated zone point of compliance monitoring. For example, the Arizona Revised Statutes require the designation of a point or points of compliance for each facility receiving an APP permit (A.R.S. 49-244). The point of compliance is the "point at which compliance with aquifer water quality standards shall be determined. The point of compliance shall be a vertical plane downgradient of the facility that extends through the uppermost aquifers underlying that facility (A.R.S. 49-244)." An alternative point of compliance may be considered provided that such a request is "supported by an analysis of the volume and characteristics of the pollutants that may be discharged and the ability of the vadose zone to attenuate the particular pollutants that may be discharged, including such factors as climate, hydrology, geology and soil chemistry (A.R.S. 49-244.2(a))." An example of an alternate point of compliance is monitoring of a leachate collection and removal system (LCRS) for a double-lined process solution pond. Monitoring of the LCRS could be requested provided that an appropriate alert level is established for the LCRS and that a discharge potential assessment is provided.

The policy procedure for determining an appropriate alert level under the regulation of the Arizona Revised Statutes includes (ADEQ 1999a):

- Delineation of the pollutant management area (A.R.S. 49-244.1);
- Identification of constituents of concern;
- Characterization of the discharge waters;
- Establishment of a "use protection level" at the point of groundwater use;
- Determination of an "alert level" through "consideration of the fate and transport of the pollutant to insure that the use protection level is not exceeded at the downgradient point of groundwater withdrawal"
- Identification of contingency plans that will be triggered upon exceeding the alert level.

The above policy procedures could be adapted for unsaturated zone point of compliance monitoring using the technology tools described in Section 4.5 to verify the predicted hydraulic performance of engineered soil covers and to provide early warning of waste rock facility design failures.

6.0 ADDRESSING THE CHALLLENGES

One of the primary challenges facing the environmental sustainability of mine waste facilities in dry climates is the long-term potential for ARD emanating from waste rock facilities to impact surface and groundwater resources. Effectively addressing this challenge will require the marriage of state-of-the-art technology and policy tools. The challenge to technology is limiting the infiltration of oxygen into the waste rock facilities over the long term and improving the ability to limit water infiltration. The challenge to policy is to provide concise technical guidance in light of technical uncertainty.

The large time frames involved (many tens to many thousands of years for environmental loading to occur) give rise to other challenges such as the ability to predict and measure low water infiltration rates, the long-term integrity of engineered soil covers, and the extrapability of predictive model input parameters to such a large time frame (i.e., changes in climate).

6.1 Addressing Technology Challenges

The tools available to address the technology challenges range from innovative methods for characterizing the potential for ARD (i.e., environmental assaying) to computer performance modeling. The technology tools described previously in Section 4 include:

- Environmental Assaying;
- Engineered Soil Covers;
- Computer Performance Modeling;
- Designing for Closure Using Concurrent Reclamation;
- Utilization of Hydraulic Sinks; and
- Field Instrumentation and Monitoring.

Environmental assaying using geologic block modeling can be used to accurately characterize the ARD potential for large-scale mining operations and to provide the basis for designing for closure. Engineered soil covers, such as store-and-release cover systems are a sustainable means of limiting water infiltration into the waste rock facilities in dry climates. The potential exists, through continued R&D, to combine the key components of a store-and-release cover design with a saturated clay cover layer design to produce an engineered cover system capable of limiting oxygen infiltration in a dry climate that and maintaining long-term integrity. Advances in the state-of-the-art of computer performance modeling and field instrumentation and monitoring provide the mechanism for dealing with the challenges associated with the ability to predict and measure low water infiltration rates. Designing for closure is a concept that is proving beneficial based on current R&D and is seeing practical application at mine sites. The use of computer data bases and GIS technology allow the analysis of large amounts of data on climate and engineering properties of mine waste which provides a means for evaluating the extrapability of computer model input parameters over large time frames.

6.2 Addressing Policy Challenges

The tools available to address policy challenges are characterized by their ability to incorporate state-of-the-art technology and to provide concise guidance in light of technological uncertainty. Policy tools described in Section 5 include:

- Techno-Policy;
- Concurrent Research & Development;
- Research & Development Bonding and Oversight; and
- Field Verification and Point of Compliance monitoring.

Techno-policy provides a framework for concise technical guidance to allow for application of standard (i.e., widely accepted) technology that can expedite permitting, but is flexible enough to allow for the incorporation of new state-of-the-art and innovative technology. Examples of such techno-policy are currently part of some regulatory frameworks. Concurrent R&D provides a mechanism for addressing environmental performance in the presence of uncertain technology and has proven effective in advancing the state-of-the-art of engineered cover design. R&D bonding and oversight is required to fund and operate a concurrent R&D program and when incentives are incorporated (i.e., bond reductions for reaching intermediate and primary R&D goals) can focus the program significantly. In addition, concurrent R&D and the associated bonding and oversight can provide a means for fueling local economy and introducing new technical and labor skills to a developing region. Finally, application of field verification and point of compliance monitoring policy frameworks already developed for groundwater systems to the unsaturated zone can provide effective early warning systems for potential long-term environmental loading and also provide a direct means for evaluating new and innovative technologies.

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Environmental Policy and Sustainable Development: Implications for Materials and Mining

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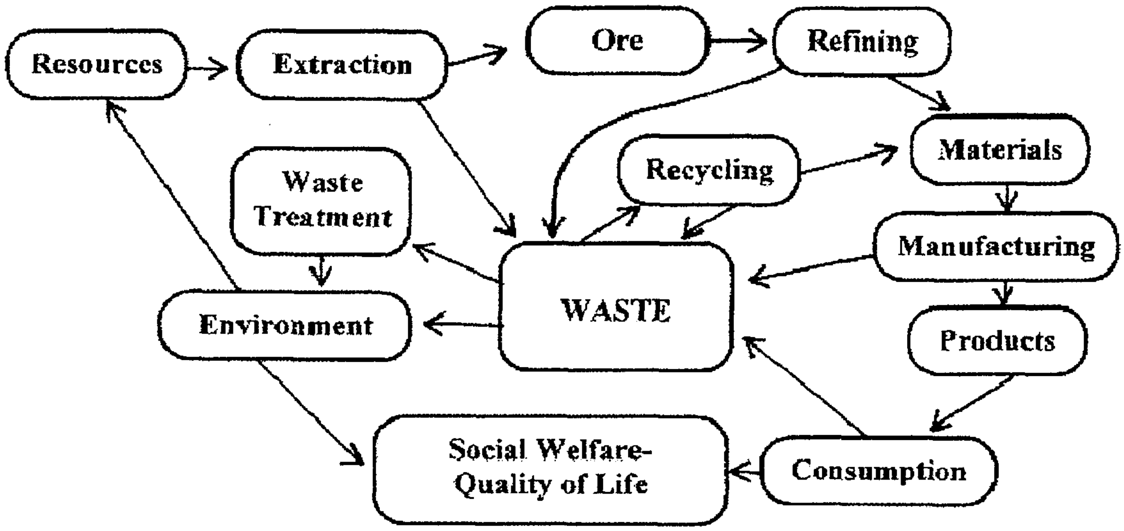
1.0 Introduction

Mining and materials use has important implications for sustainability. As illustrated in Figure 1, every single step of the "materials cycle" generates wastes which find their way into the environment. In addition to these wastes, these processes often alter the landscape, causing loss of habitat, impacts to surface and ground water and other environmental impacts. This paper looks at the nexus of exhaustible resource extraction and use, environmental degradation and sustainability and exams policy options for promoting environmental protection and sustainability.

Figure 1 THE CIRCULAR NATURE OF MATERIALS USE



The conventional economic approach to sustainability has been to look at the role of exhaustible resources in the production of output. Since sustainability implies an infinite stream of output, this approach looks at the conditions under which an infinite stream of outputs can be generated in the case where an essential input (extractable resources) are finite. Barnett and

Morse (1963) emphasize the role of technological innovation and substitution in by-passing the seeming finiteness of exhaustible resources. Hartwick (1993) develops a simple economic model in which sustainability will occur if the economic rents (revenues minus extraction costs) associated with extractable resources are completely reinvested in human made (artificial capital).

The term and concept of sustainable development has received much attention since the late 1980's, when it became the global theme for a long-term perspective on economic growth. The definition of the terms has been molded to fit different situations since then, but has mostly retained the original thrust behind which sustainable development is driven. Generally, the interpretation relates 'improving the prospects of the current generation without reducing the prospects of future generations' (Brundtland Commission 1987)

This definition implies a particular path for society's stock of capital assets, where assets can be broadly defined to include the stocks of human-made capital, human capital, extractable resources and environmental resources. In order to allow for an increasing standard of living, the aggregate stock of capital assets must be increasing as well, especially in the face of increasing population. Specific treatments of sustainability generally have not looked at all four types of capital stocks mentioned above, and have made restrictive assumptions about substitutability among different types of capital. We attempt to broaden the discussion of sustainable development by simultaneously examining the role of all types of capital assets.

A particularly important aspect of our approach[1] will be to differentiate between extractable resources (such as minerals and fossil fuels) and environmental resources (such as ecosystems). Environmental resources provide a broad range of ecological services such nutrient cycling, habitat protection, carbon sequestration and watershed protection. The importance of this

[1] This approach is based on Franceschi and Kahn (1999b)

distinction between extractable resources and environmental resources, as discussed later in the paper, is that artificial (human-made) and human capital are likely to be good substitutes for extractable resources, but none of these types of capital are likely to be close substitutes for environmental resources.

2.0 Sustainability and Exhaustible Resources

The conventional treatment of exhaustible resources in terms of sustainability dates back to the early works of Thomas Malthus and David Ricardo, where resource scarcity and diminishing returns dominated the analysis. These models focused on finite resource supply and whether continued economic growth was possible as resources became more scarce. Work by Barnett and Morse (1963) built on these ideas by emphasizing the inevitable development of and switching to good substitutes for the resources that become characterized by increasing scarcity. Utilizing a model based on the free substitution of inputs (labor, artificial capital and exhaustible resources), Barnett and Morse found that technological innovation in discovery, extraction and production techniques lowered the costs of extractable resources, greatly outweighing the cost- increasing effects of depletion. These influential findings largely refuted the previously held notion that Malthusian limits to growth existed and would constrain or collapse current consumption and development rates. Barnett and Morse's conclusions have served as the point of embarkation for further exploration of the relationship between sustainability and exhaustible resource use, including works by John Hartwick (1977,1993, 1994) and John Pezzey (1989).

The assumption of substitutability between inputs is not an inconsequential one. The fundamental premise underlying the work of Barnett and Morse work is the interchangeability between labor (human capital), artificial capital, and extractable natural resources as inputs to the production process. Two issues regarding substitution to achieve sustainability in these models are of concern.

The most important issue is that the models do not incorporate the environmental or ecological resources as inputs to the production process. As discussed earlier, ecological resources provide an array of important services to a variety of different production processes, day to day living and other ecological systems. However, the inclusion of environmental resources or ecological services into the production function is not in itself sufficient to rectify the shortcomings of these economic models of sustainability. In addition, one must consider the notion of complete substitutability among the different types of capital.

Kahn and O'Neill (1999) argue that at the large scales defined by the current level of economic activity, artificial capital can not provide an adequate substitute for environmental resources, as it is completely infeasible for human activity to provide the ecological services at the level of natural activity. For example, although artificial capital can be used to process point source wastes in sewage treatment plant, it would be completely infeasible for all the non-point sources of nutrients (both natural and anthropocentric) to be processed by treatments plants. Perhaps the best example of the inability of human-made capital to substitute for natural capital can be found in flood protection in the Mississippi River flood plain. Flood protection was provided by environmental resources in terms of wetlands which acted as giant sponges, absorbed sudden large influxes of rainwater, storing them, and gradually releasing them to be carried downstream over a prolonged period of time. As wetlands were converted to farmland and other economic purposes, systems of dikes and levees were developed to try to control the flooding problem, however they were not capable of doing so. In fact the 'one hundred year flood' which occurred in the mid 1990s was generated by a '20 year' rainfall, indicating a vast reduction in flood control protection, despite the provision of the artificial capital devoted to the production of flood control.

Further, the traditional approach to the rationing of exhaustible resources is based on the premise that the market can allocate supply and usage through the pricing system. In the classic literature of resource scarcity, including the work by Barnett and Morse, as an exhaustible resource or mineral resource stock becomes depleted, prices rise. The rise in price is primarily the response of increased costs of extraction of the relatively less abundant source (relative in the sense of the deposit being less rich than deposits of the past). As price of one product rises, either firms find better extraction technology to control costs or buyers switch to another product that can satisfy their needs at a lower price. In the case of environmental or ecological resources, the market is unable to ration usage. Most often ecological systems do not have prices associated with their services, because they are external to markets. The public goods nature of ecosystems, which includes the properties of non-rivalry and non-excludability creates conditions which lessen the likelihood of sustainable long term usage. Again, the fact that these systems are external to markets heightens the need for their explicit inclusion in the formula for sustainability.

In another paper, the authors (Franceschi and Kahn, 1999b) revisit the Hartwick model, and include ecological services as one of the explicit inputs to economic production and do not assume perfect substitution between ecological services and other inputs. Our findings are consistent with the Hartwick rule in the sense that they also imply that investment in artificial capital is needed. However, out results have further and different implications in that they stress that at the same time that one invests in artificial capital (and human capital) one must take steps to reduce the decline in the stock of environmental services which provide ecological services. In other words, a development strategy which does not focus on the maintenance of environmental capital can not be sustainable.

3.0 Environmental Policy Instruments

The preceding section has illustrated the importance of maintaining our stock of environmental resources and the flow of ecological services due to their essential role in maintaining both quality of life and economic productivity. Sustainable development requires the maintenance of these stocks and flows, yet Figure 1 illustrates the potential of mining and materials use to interrupt these flows of ecological services. Therefore, it is critical to develop environmental policy to protect these stocks of environmental resources and flows of ecological services. This section of the paper focuses on alternative methods of control of pollution and other forms of environmental degradation. The literature in environmental economics[2] detail two major categories of environmental policy instruments. These include direct controls (often called command and control regulations) and economic incentives.

3.1 Direct Controls:

Direct controls are the policy instruments most used in actual environmental regulation, but least favored by environmental economists. Direct controls consist of restrictions on input or output levels of firms. Examples of input controls would be requirements for use of certain abatement equipment (such as catalytic converters in cars or scrubber stacks in coal-burning

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[2] See Baumol and Oates (1988), and Kahn (1998) for summaries of this literature.

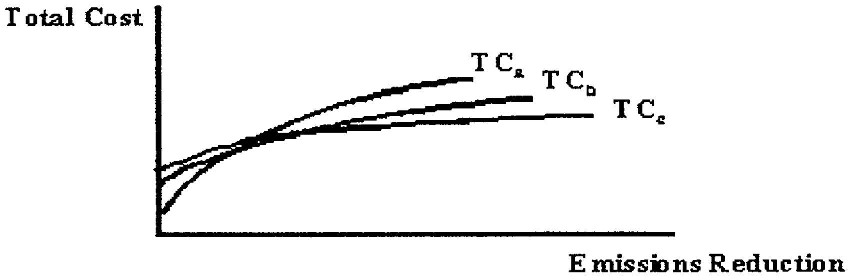
boilers) or restrictions on the sulfur content of fuels. Examples of output controls would include limitations on the level of emissions of a certain pollutant, or requirements to restore the land after surface mining.

Direct controls have been the basis of environmental regulation in North America and Europe, although there has been some movement towards economic incentives in recent years. The primary advantages of direct controls consist of greater administrative ease of implementation and greater certainty of attaining the target level of pollution. However, economists are critical of direct controls because they raise the cost of attaining the target level of pollution.

The excessively high cost associated with direct controls is generated by the way the direct controls affect the abatement decisions made by the individual polluter and also by the way the abatement activities are allocated across polluters. In addition, direct controls and economic incentives generate very different incentives for technological innovation in emissions abatement technology. Each of these factors will be individually discussed below.

There are many different technologies available to the firm to abate emissions, where abatement can take place by choosing an alternative production technology (such as a more energy efficient technology) or by choosing alternative 'end-of-pipe' abatement technologies, or both. The alternative technologies are represented by the cost-functions (TC_a, TC_b , and TC_c) in Figure 2. In each case, abatement is achieved as a result of the application of fixed inputs (capital equipment) and variable inputs (energy, labor, materials). For lower levels of abatement, it is likely that there the least cost abatement technology would have a relatively higher level of variable costs and a relatively lower level of fixed costs. For higher levels of abatement, it is likely that the least cost abatement technology would have relatively higher fixed costs and relatively lower variable costs. A lower envelope of these total cost functions can be constructed which shows the minimum cost of attaining a given level of emissions abatement. Each level of emissions abatement will be associated with a least-cost technology.

Figure 2: Total Costs of Emissions Reductions



This illustrates one of the major problems associated with the government choosing the abatement technology for the polluter. The government may not know the least cost technology for the firm. If the direct control takes the place of both technology restrictions and restrictions on emissions levels, then the regulatory agency must simultaneously choose the technology and the restriction level. Given the many different types of economic activities which contribute to each emissions problem, it is highly unlikely that the regulatory agency will have the appropriate knowledge of the many different types of technologies necessary to make these cost-minimizing choices. In other words, it is likely that the direct controls will increase a firm's cost of attaining a given level of emissions reductions.

Direct controls also drive the cost of attaining a given level of environmental quality above the minimum achievable level through their impact on the allocation of emissions reductions across polluters. It is a well-established result[3] that in order for the cost of achieving the target level of pollution to be minimized, the marginal cost of abatement must be equated across polluters.

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[3] See Baumol and Oates, for example.

Direct controls can only accomplish this if the regulator knows the shape of all the alternative marginal abatement cost functions.

One other cost-related disadvantage of direct controls is that they provide little incentive for technological innovation. Technology-based standards provide no economic incentive to develop alternative abatement technologies, and restrictions on emissions provide limited incentives to innovate. In this case, innovation would reduce the cost of meeting the restrictions on emissions, but there is no economic pay-off to reducing emissions levels below the current level, so there is not as high an incentive to innovate as there would be with pollution taxes or marketable pollution permits. This point is further discussed below when pollution taxes are discussed.

It should also be pointed out that direct controls have some strengths in addition to the weakness of not minimizing costs. If monitoring and enforcement is difficult, if there are stochastic events (such as thermal inversions or droughts which require more stringent control immediately), or if the substance is extremely harmful and its release should be completely banned, then direct controls are probably the best environmental policy[4].

3.2 Economic Incentives:

Economists view pollution as an economic problem caused by a disparity between the private costs of an activity and the social costs. Firms or individuals compare the private costs and private benefits of their activities in maximizing their profits or welfare. Pollution and other types of environmental insults constitute social costs, but not private costs since the damages from the

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[4] See Baumol and Oates and Kahn (1998) for a discussion of the conditions under which direct controls perform better than

pollution one individual creates, falls upon others. Economic incentives such as pollution taxes attempt to eliminate the disparity between the private cost and social cost of pollution. This is often referred to as internalizing the pollution externality, because the tax increases private costs, and an optimally designed tax will equilibrate private cost and social cost. Pollution taxes do not eliminate pollution, rather they reduce pollution and if properly constructed can reduce pollution to the socially optimal level where the cost of reducing pollution another unit is exactly equal to the benefits from reducing pollution another unit.

Economic incentives include pollution taxes, materials and packaging taxes, fuel taxes, marketable pollution permits, deposit/refund systems, pollution-reduction subsidies, liability systems and performance bonding systems. This paper will focus on taxes and marketable pollution permit systems, which are the most widely discussed types of economic incentives. In addition, the paper will examine performance bonding systems which can be applied to environmental problems which are generally difficult to address with pollution taxes or marketable pollution permits.

Pollution taxes:

Conceptual writings in economics often talk of pollution taxes in terms of achieving the optimal level of pollution. However, in practice, the information requirements associated with determining the optimal level of pollution are severe. Therefore instead of pursuing the optimal level of pollution, a target level of pollution is identified through other types of legislative or administrative processes. Even though the opportunity to achieve the optimal level of pollution is generally not present, pollution taxes can minimize the cost of achieving the target level of pollution. This cost-minimizing response to the pollution taxes takes three forms.

First, the polluter will seek to minimize the total costs associated with pollution. This total cost is the sum of costs of reduction and taxes which must be made. The polluter will respond to the tax by choosing a technology and abatement level which minimizes this sum of costs. As a part of this optimization process, the polluter will choose the technology associated with the minimum cost of attaining a given level of pollution.

Second, the tax allocates pollution reductions across polluters in a fashion which minimizes the total cost of achieving the target level of pollution. Each individual polluter will reduce his pollution level until the cost of reducing another unit (the marginal abatement cost) is just equal to the tax. If all polluters face the same tax, the marginal abatement cost will be equal across polluters which minimizes the total abatement cost of achieving the target level of pollution.

Finally, pollution taxes will encourage more technological innovation than direct controls. If direct controls take the form of specifying the allowable technology for a given process, there is virtually no additional incentive (other than reducing cost of producing the output) for a firm to invest in research and development of new cleaner technologies. If the direct control takes the form of a maximum emission standard, then the firm has incentive to innovate because they can reduce the cost of meeting their standard. However, if there is a per unit pollution tax instead of a direct control, there is an additional incentive to innovate. As with direct controls, there is an incentive to reduce their cost of abatement. However, the technological innovation can generate even greater savings under a tax system, because the polluter can lower emission levels in response to the lower cost of abatement and reduce their tax liability in addition to lowering their abatement costs. These additional benefits of technological innovation under a tax system give an even greater incentive to invest in new technologies, which will further reduce the cost of achieving the target level of pollution.

In the original conception of the pollution tax, a fixed tax is charged for every unit of pollution emitted. However, the tax could be constructed in a variable fashion, which could give even greater incentive to technological innovation. This is the case for several types of pollution in Sweden, including sulfur dioxide, nitrogen oxides, and carbon dioxide. In this case, the pollution tax is based on a fixed per unit charge multiplied by the level of emissions, just as in the conventional case. However, the Swedish system has the added incentive of a refund of the tax based on the polluters relative share of industry economic output (ratio of individual firm output to total industry output). The incentive properties of this modification of the tax are quite straight forward. Firms that are more efficient than average in turning inputs into economic outputs (less pollution per unit output) will receive a refund of their pollution taxes which is actually greater than the amount they paid in the first place. Firms that are less efficient than average will receive a refund of their taxes that is less than the amount they actually paid. This system lessens the financial impact to firms of the tax system (since taxes are rebated) and creates competition among the firms to engage in technological innovation to develop cleaner technologies, as a firm that becomes 'greener' than its competition will receive a greater proportionate share of the tax refunds.

Pollution taxes have an additional advantage in that they may create a 'double dividend.'[5] The first dividend is the social benefit associated with lowering pollution towards a more desirable level. The second benefit is that the pollution taxes may be used as a revenue substitute for distortionary taxes such as income or sales taxes. In other words pollution taxes are imposed on something that is bad for society while income taxes are imposed on something that is good for society. Therefore, substituting pollution taxes for income taxes in meeting public revenue needs

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[5] See Pearce (1991), Kahn and Farmer (1999)

will improve social welfare, *ceteris paribus.*[6]

Materials, Packaging and Fuel Taxes:

One way of attacking environmental problems is to discourage the excessive use of materials and packaging. Holding everything else constant, the more efficient is industry in converting inputs to useful economic outputs, the less inputs will be needed and the less pollution and wastes will be generated. A packaging and materials tax could be constructed along the lines of the Swedish environmental tax system. Firms could be taxed based on the volume or mass of materials used, and the tax could be refunded based on the efficiency of materials use in comparison with other firms in the industry. In general, it would be better to tax the pollution directly, but when that is administratively difficult, the materials or packaging tax could be employed. A similar argument could be developed for taxing fuel consumption if it was too difficult to tax the pollution arising from fuel use.

Marketable Pollution Permits:

Several European countries are focusing on pollution taxes as a way to improve the economic efficiency of their environmental policies, but in contrast, the small amount of movement seen in the United States away from direct controls has been in the direction of marketable pollution permits. Marketable pollution permits share the cost-minimizing properties of environmental taxes, but do so by creating a market price for pollution, rather than through setting a tax.

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[6]This proposition is not without controversy in the economics literature. For example, Bovenberg and Goulder (1996) argue that pollution taxes will increase the distortion in the labor market, however Kahn and Farmer point out that the structure of the model imposed by Bovemberg and Goulder generates this result. Kahn and Farmer argue that under a more general (and more realistic model), the double dividend is likely to be positive.

Marketable pollution permits work by setting a target level of pollution emissions, and then issuing permits for this emissions. The permits are sometimes referred to as 'offsets' or 'allowances' and can be allocated to firms according to historical pollution levels, proportionate to their share of economic output, or by auction. Once the permits are allocated, the polluters must have a permit for each level of pollution they emit, but are free to buy or sell permits as their needs dictate. Firms who can reduce their pollution levels rather cheaply will do so, and sell permits to firms who have a higher cost of pollution reduction. Firms will buy (sell) permits as long as the market price is less than (greater than) their cost of reducing pollution. Therefore, the buying and selling of permits will result in each firm generating a level of emissions reduction at which the marginal cost of abatement is equal to the price of the permit. This equates marginal abatement costs across polluters and minimizes the total social cost of achieving the target level of pollution. Similarly, marketable pollution permits will have identical effects to taxes with regard to both choosing the cost-minimizing technology and spurring technological innovation.

The primary application of marketable pollution permits in the United States has been to sulfur dioxide emissions of electric power generation in the Eastern United States. These policies were adapted in response to the acid rain problems in the Quebec, New England and the Appalachian Mountain region. Sulfur dioxide emissions trade on a one-for-one basis regardless of the location of the emissions.

4.0 Environmental Taxes, Marketable Pollution Permits and a Global Climate Change Agreement

Much of the discussion of marketable pollution permits and environmental taxes takes place in the context of limiting emissions of greenhouse gases. Much of the discussions of economists focus on marketable pollution permits, as the economists see the opportunities for trades between developing countries (which are viewed to have a low cost of reducing emissions) and developed countries (which are viewed to have a high cost of reducing emissions). However, the outcome of negotiations among nations may not result in a trading system or a quasi-trading system such as joint implementation. A system such as the Clean Development Mechanism may develop where developed nations that do not meet their emission targets contribute to a fund which is used to finance development projects in developing countries that would lower greenhouse gas emissions.

It makes little sense to have a domestic market pollution permit system for greenhouse gases if the international system is based on the Clean Development Mechanism. If this is the case, domestic controls of greenhouse gases should be based on emissions taxes and then these funds can be used to develop an internal clean development fund, or used to fund other social policies in full or partial replacement of income or value-added taxes.

5.0 Performance Bonds:

Performance bonding has been used in many contexts to assure a desired type of behavior. In terms of environmental policy, its most common use has been in the case of surface mining. Firms involved in surface mining must post an environmental performance bond before beginning operations. This bond is placed into an escrow account, and returned to the firm if they satisfactorily restore the land to the legally stipulated condition after surface mining is completed in that area. If restoration is not attempted or completed, the government can confiscate the performance bond and contract with a third party to restore the land to the legally stipulated condition.

Performance bonding has several advantages as an environmental policy instrument. First, the performance bond gives a greater certainty of compliance, particularly in comparison to command and control policies. Since the government has control of the money before the potentially destructive activity begins, there is a greater certainty of environmental compliance. Problems of moral hazards are dramatically lessened, as the potential for 'hit and run' activities is eliminated.

Another advantage of performance bonding is that even if compliance does not occur, the performance bonding system creates a financial resource with which to conduct restoration activities. Finally, as long as the interest earned by the performance bond is a market rate, the performance bond need not create a financial hardship for the regulated firms.

there are several problems associated with performance bonding. First and foremost, performance bonding tends to be reactive and focused on restoration of damages, rather than being pro-active and focused on prevention of damages. In many cases, prevention of damages is much less expensive than restoration. More importantly, many types of environmental impacts are irreversible (e.g. the release of persistent pollutants such as DDT, heavy metals, and CO_2, the destruction of rainforests or the extinction of a species). Second, performance bonding tends to be focused on achieving a minimum acceptable level of environmental quality, rather than being directed at obtaining the optimal level of environmental quality. Finally, performance bonding is generally structured as a discrete policy instrument, rather than as a continuous tool. If the environmental standard is met, all the bond is returned, and if the standard is not achieved, all the bond is forfeited. In particular, if the firm does not achieve the standard and the performance bond is forfeited, the firm might as well continue to degrade the environment as there are no additional penalties for poorer environmental performance. Similarly, there is no reward to encourage a firm that meets the standard to exceed the standard.

It is possible to define environmental characteristics which can calibrate a continuous instrument for defining environmental success and for returning a proportion of the performance bond. For example, in the tropical forestry case, Kahn, McCormick and Nogueira (2000) defined two ratios as the calibrating environmental characteristics. These were the ratio of the length of the edge of the disturbed area to the surface area of the disturbed area, and the ratio of the amount of undisturbed area to the amount of disturbed area.

It is also possible to define a minimum acceptable level of the characteristic and an optimal level of the characteristic. The minimum safe acceptable level would correspond to the minimum safety criterion defined by Bishop, which is the level that, with a reason margin of safety, prevents the collapse of the system. The optimal level of the characteristic would be that level at which the cost of improving the characteristic is just equal to the benefit of increasing the level of the characteristic. In order to give an incentive for the firm to leave the ecosystem at the optimal level of the characteristic, the performance bond should be at least as large as the total cost to the firm of attaining the optimal level of the characteristic.

This determines the size of the performance bond, but how should it be returned in a way that gives the firm the proper environmental incentives. If the entire bond is forfeited for missing the optimal level by a small amount, there is no incentive to avoid further degradation. Missing the optimal level by a small amount should result in a small penalty, while missing it by a large amount should result in a large penalty.

If Ca is the level of the characteristic that the firm leaves after its activities are over, Cm is the minimum acceptable level of the characteristic and Co is the optimal level of the characteristic, the following function can be written which defines the proportion of the performance bond which is actually returned to the firm.

$$P = \frac{C_a - C_m}{C_o - C_m}$$

If the actual level of the environmental characteristic (Ca) is equal to the minimum acceptable level (Cm) then the numerator of the fraction is equal to zero and the whole performance bond is forfeited. If the actual level of the environmental characteristic is equal to the optimal level, then the numerator is equal to the denominator, and the entire performance bond is returned to the firm.

There are many additional implementation issues associated with the construction of a performance bond. For further discussion of these issues, see Kahn, McCormick and Nogueira and Franceschi and Kahn (1999a).

6.0 Environmental Regulation of Small-Scale Activities:

In developing countries, the activities of small scale entrepreneurs are among the most difficult to regulate by environmental policy. Many of these activities are operating at the periphery of legality, are very mobile and difficult to monitor and they do not have direct incentives to comply with environmental directives. It is very difficult to enforce a regulation by threat of fine or penalty on an activity where the operators have little or no assets that would be available for the government to seize.

More importantly, the idea of internalizing external costs and OECD's 'polluter pays' principle may not be as appropriate for small scale activities in developing countries as for multi-national corporations in developed countries. Since these scale small activities are economically fragile, and since the people involved (especially the labor force) are economically disadvantaged, imposing additional costs may be counterproductive to the development efforts of a developing country.

However, this does not mean that these small scale activities should be ignored by environmental policy, as they can be responsible for significant and often irreversible damage to the environment. For example, in Brazil, small scale farmers are responsible for much of the deforestation in states such as Acre, Rondonia and Para. Small scale gold miners (garimpeiros) are responsible for mercury contamination of aquatic ecosystems, as well as sedimentation, deforestation and other environmental problems. However, to be effective, policy must positively encourage environmentally friendly technologies, rather than negatively discouraging the damaging technologies.

For example, Caviglia, Kahn and Greene (1999) discuss the use of demand side policies to increase the demand for (and price of) agricultural outputs which are produced using sustainable agroforestry techniques which do not result in deforestation. Similar techniques can be used to encourage aquaculture to reduce the demand for, and depletion of, wild stocks of fish.

Direct subsidies for environmental improvement must be judiciously crafted, because (Baumol and Oates) subsidies can encourage entry into the industry. Even if subsidies reduce the environmental damage per firm, subsidies can increase the number of firms and environmental damage could increase in the aggregate. Although this will increase the amount of economic output and the number of jobs, the development strategy of a particular country might be better served by subsidizing industries which are both less environmental damaging, and have other positive social impacts such as improving the quality of the workforce and developing higher quality jobs instead.

6.1 Performance Bonds in the Context of Small-Scale Activities

Many small scale activities, particularly in the mining and forestry sectors, create the type of environmental damage which would be best prevented and/or mitigated through the use of performance bonds. However, giving the economic standing and the asset position of many of these small scale enterprises, the enterprises are incapable of posting a bond which would be of significant magnitude to ensure compliance with the environmental standard. While the government could establish a performance 'bonus', where firms meeting the standard would receive a significant payment following the satisfactory completion of their activities, this creates two problems. First, the government must develop the funds for the bonus, which would compete with other economic and social development projects. Second, the bonus could lead to the problems of excess entry of firms which was described above.

We suggest a compromise system where a performance fund is established with funding from three sources. First, the government would generate a fund for performance bonuses. Second, environmental non-governmental organizations (NGOs) would be asked to match the government contributions to the fund. Finally, firms would be required to post a performance bond. Under this system, if the firm meets the environmental standard, then they are returned their performance bond, plus their proportionate share of the funds from the government and the non-governmental organization. In other words, if the firm complies with the environmental standard, the firm is not penalized and in addition, receives a performance bonus. If the firm does not comply with the environmental standard, then they forfeit their performance bond, and do not receive any bonus from the government and NGO funds. The performance bonus fund could be linked to environmental characteristics in a continuous fashion, using the methods which was previously discussed for the case of performance bonds

7.0 Conclusions

Sustainable development requires an expansion of our stocks of artificial capital, human capital, and natural resources, while maintaining the stocks of environmental capital which provide ecological services. Thus, environmental policy is a critical component of economic development policy. While there is substantial experience with environmental policy in North America and Western Europe, developing countries must be careful not to repeat the mistakes made in the developed countries and construct narrowly conceived policies based on direct controls. Rather, a mix of direct controls and economic incentives can achieve a greater degree of environmental compliance at a lower opportunity cost and promote sustainable development of the economy. Innovative policies such as performance bonds should be part of the policy arsenal, and careful attention must be paid to the different economic, social, environmental and cultural factors which differentiate developing countries from developed countries.

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