Asia-Pacific
Economic Cooperation

INTERNATIONAL WORKSHOP
"IMPROVING ENERGY EFFICIENCY IN THE APEC MINING INDUSTRY"

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Santiago Chile

Session 2: New Developments on Energy Efficient Mining Technologies

WORKSHOP ON IMPROVING ENERGY EFFICIENCY IN THE MINING INDUSTRY OF THE APEC COUNTRIES

MINING AND ENERGY: "THE RIGHT TO ENERGY EFFICIENCY"

BY FERNANDO SÁNCHEZ ALBAVERA[1]

I will begin this presentation by the following statement: the right to energy efficiency should be established in our civilization. The point of departure for this proposal is the assumption that the exploitation of energy sources and their application to change the production patterns must not erode the overall heritage of societies or humanity, in general. This is not just a moral imperative for safeguarding the well-being of future generations, but also a premise that can yield significant benefits for the business world and is directed at improving the current population's quality of life.

For the purposes of this presentation, we will focus exclusively on the natural component of societies' overall heritage; in other words, on the natural elements and processes found in a given geographical area.[2] These elements and processes have an intangible usefulness as well as a tangible one. Everything that exists in the natural heritage has value, and this value is permanent. The use of the natural heritage and their comparative advantages are relative over time, being dependent on the progress of science and technology.

In the process of changing production patterns, it must be recognized that natural advantages are dynamic rather than static because, inter alia, knowledge concerning the natural heritage has a relative dimension of history and time.[3] In fact, the accumulation of knowledge and the use of natural resources form part of substantive social processes that determine specific cultural and material ways of relating to the natural heritage. The comprehensive view of the natural heritage and the increasingly effective management of negative externalities are signs that humanity and its forms of community life have reached a higher stage of advancement. Thus, given the progress of applied science and technology, we are now at a moment in human history when it is possible to use energy more rationally, optimising the productivity with which it is harnessed for the purpose of changing production patterns and reducing production costs. Having in mind the improvement of the well-being of producers and consumers, by a more efficient use of the energy and using more those that cause less damage to the environment.

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[2] This concept includes the soil, subsoil, air, water and biotic and ecosystemic diversity, including all their interrelationships and capacities for self-reproduction and self-sustenance. Each physical space contains a set of elements and laws of configuration and operation that define existing natural systems.

[3] From the standpoint of science and technology, the outstanding feature of the benefits of the natural heritage is their constant relativity, and the paramount goal is to accumulate more and more knowledge about the natural heritage. It should be pointed out, however, that knowledge of the natural heritage consists of not only knowledge of the variety of natural elements and processes, but also knowledge of how to manage and use them sustainably.

A new approach that has gradually been gaining ground is one that seeks to strengthen the interrelationships between natural elements and processes, thus ensuring that negative externalities can be avoided or neutralized more effectively.[4] In this regard, the stock of available science and technology and its absorption and incorporation into strategies for changing production patterns are essential for guaranteeing that energy management is compatible with the care of the natural heritage.

Sustainability demands are increasing as knowledge of the natural heritage advances and accumulates. We have seen evidence of that at this workshop, as significant technological advances have been presented for saving energy in mineral and metallurgical processes.

Considering that the relationships between changing production patterns and the satisfaction of human needs have evolved significantly, it is important to note that the use of mineral reserves has led to build-up a considerable environmental debt, which was more harmful when mineral exploitation reflected only the interests of imperial expansion.

The Latin American mining sector reveals a significant accumulation of environmental debt. For many years, our natural heritage was undervalued by the developed countries, as the monetary wealth derived from mineral exploitation was absorbed by the imperial powers, while the negative externalities affecting the natural heritage were left in our territories.

Unquestionably, minerals and energy continue to be very important inputs for the worldwide process of changing production patterns. Although their share of total world trade fell from 29% to 13% between the 1980s and the 1990s, it is interesting to note that the value of world trade in fuels increased by some US$ 112 billion, amounting to about US$ 600 billion in 2000. Meanwhile, total world trade in minerals and metals grew by about US$ 97 billion, reaching a value of nearly US$ 200 billion at the dawn of the twenty-first century. It should also be borne in mind that fuels (45%) and metals (15%) account for 60% of global commodity trade.

The developed countries are the main consumers and exporters of both fuel and metals. At the start of the new century, they accounted for 32% of world fuel exports and 56% of world mineral and metal exports.

[4] Today there is an entire institutional framework that endorses this concept. Among the international legal instruments related to sustainable development, the most relevant ones in this context are, among others, the Vienna Convention for the Protection of the Ozone Layer (1985), the United Nations Framework Convention on Climate Change (1992), Agenda 21 of the United Nations Conference on Environment and Development (1992) and the Kyoto Protocol (1997); this last instrument recently entered into force upon its ratification by the Russian Federation.

Table 1: *GROWTH IN THE CONSUMPTION OF REFINED COPPER*
(Average growth rates, in percentages)

	1970-1979	1980-1989	1990-1999	2000-2002
Developed countries	1.9	1.2	2.1	-6.5
Europe	1.5	1.1	2.1	-5.2
Germany	2.0	1.3	2.0	-9.7
France	-0.7	0.1	2.0	-1.1
Italy	3.0	2.8	2.8	-0.1
Belgium	9.9	2.5	-1.7	-10.8
United States	0.9	1.4	4.1	-9.7
Canada	0.5	1.7	5.5	0.3
Australia	0.5	-0.8	4.9	6.8
Japan	4.8	1.5	-1.9	-7.1
Developing countries	10.4	8.0	9.3	1.1
Africa	9.2	0.9	3.0	19.3
Latin America	9.8	1.4	9.7	-9.6
Asia	11.8	14.2	9.2	4.4
Republic of Korea	33.3	12.2	9.9	4.2
Chinese Taipei	26.4	16.8	8.2	2.2
Indonesia		12.2	5.1	34.8
Soviet Union	4.3	-1.3		
Russian Federation			-9.1	28.0
China	7.5	5.4	11.8	18.0
World total	3.1	1.8	3.3	-0.4

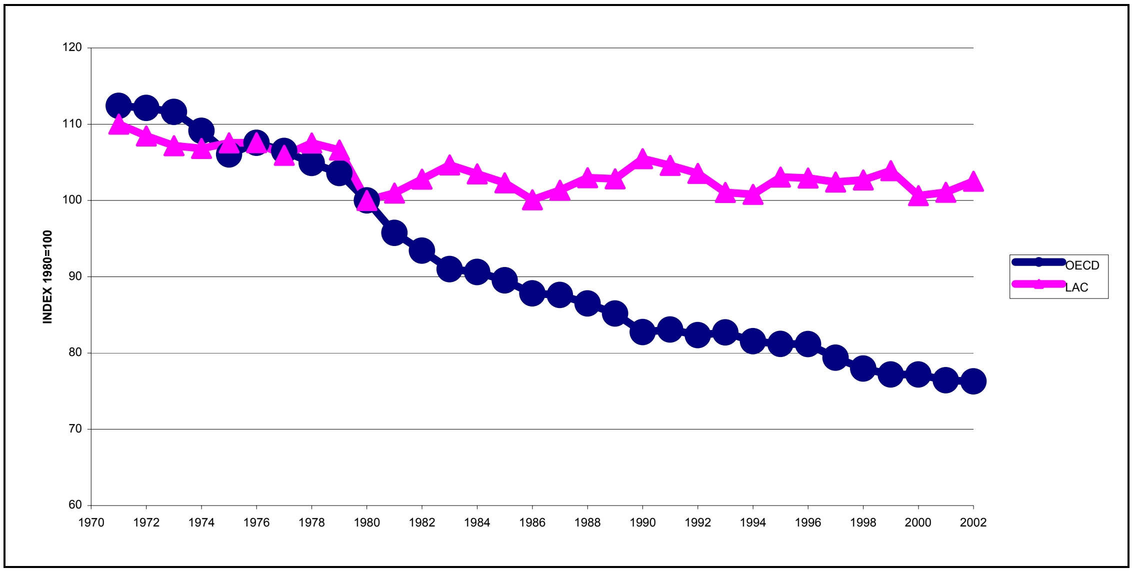
Source: *ECLAC, on the basis of figures from Metallgesellschaft Aktiengesellschaft, "Metal Statistics", and World Bureau of Metal Statistics, "World Metal Statistics".*

The extent to which a country uses both energy and minerals and metals reflects the degree of industrialization it has reached. The developed countries have increased their productivity in both of these categories. Thus, in countries at an advanced stage of industrialization, growth in the consumption of metals is slower and energy use is more productive.

Table 1 shows that growth in copper consumption has been very moderate in the developed countries since the 1970s, and even declined in the initial years of the twenty-first century. This behaviour contrasts with the vigorous growth observed in China, which has become a driving force in the world copper market. Figure 1 shows that energy intensity has decreased in the OECD countries but has stayed virtually constant in the Latin American countries.

In both cases, the unequal development inherent in the globalisation process is evident. The market is based on creative inequality, which implies that the productivity obtained from factors of production will be higher in some countries than in others.

Figure 1: TRENDS IN ENERGY INTENSITY



Source: *ECLAC, on the basis of figures from the International Energy Agency.*

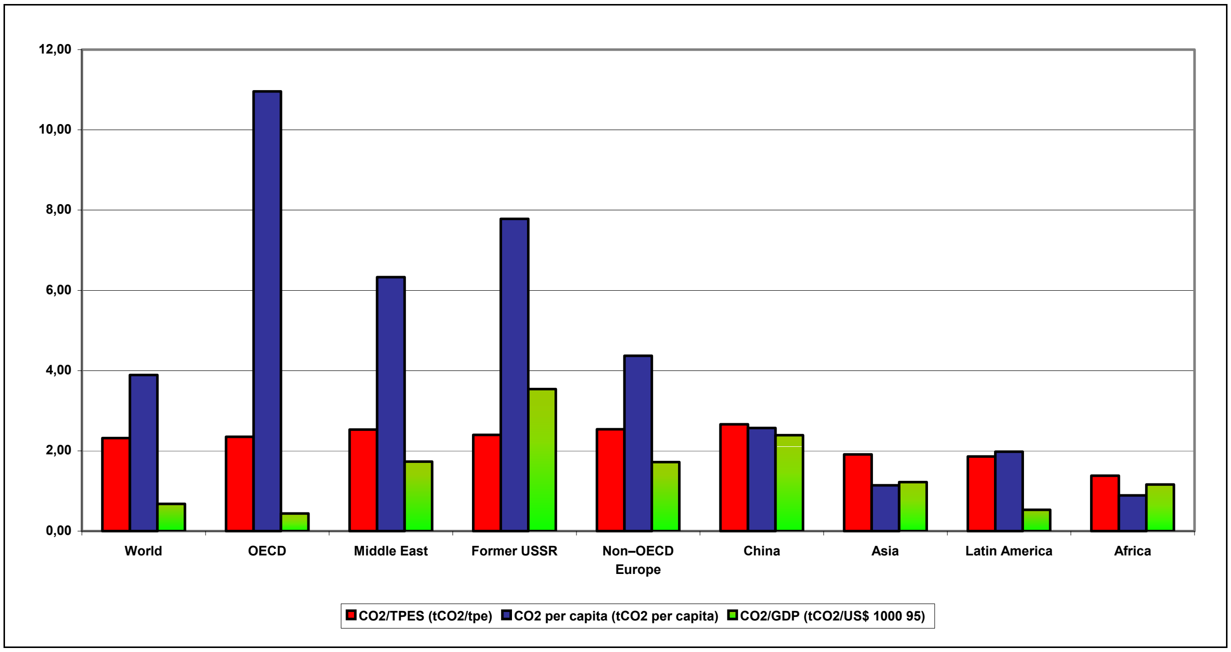
It is this very inequality that determines competitiveness. Productivity differentials generate winners and losers in a capitalist system. In addition, this system grows and accumulates wealth on the basis of what Schumpeter called "creative destruction": technological change destroys and then creates competitive advantages, either natural or knowledge-based. In the case of natural advantages, it can be seen that, since the 1970s, there has been a change in patterns of metal consumption, as shown by the reduction in metal content per unit of product. In many cases, this reflected the miniaturization of metal-containing products and the replacement of metals with other materials (in household appliances, cars, etc.).

The different degrees to which technological advances are incorporated reflect the unequal development of different economies and, in turn, differences in quality of life related to energy consumption. For example, per capita GDP in most of the Latin American economies is very far from the worldwide average, which is estimated at US$ 5,700. Moreover, per capita electricity consumption is almost six times lower in Latin America and China than it is in the OECD economies, and nearly 16 times lower in Africa. Per capita energy consumption is undoubtedly an indicator of the population's quality of life.

It should be stressed that responsibility for the emission of pollutants has been unequal and, in consequence, a compensatory mechanism is needed for making adjustments that are consistent with the purposes of sustainable development.

The developing countries need to consume more energy to improve their quality of life, but they must do so in a more productive way, while developed countries must continue to reduce their energy intensity. In part, these aims, which are ineluctable if the challenges proposed in the Kyoto Protocol are to be met, arise from the logic of the market itself.

Figure 2: *EMISSIONS INDICATORS*



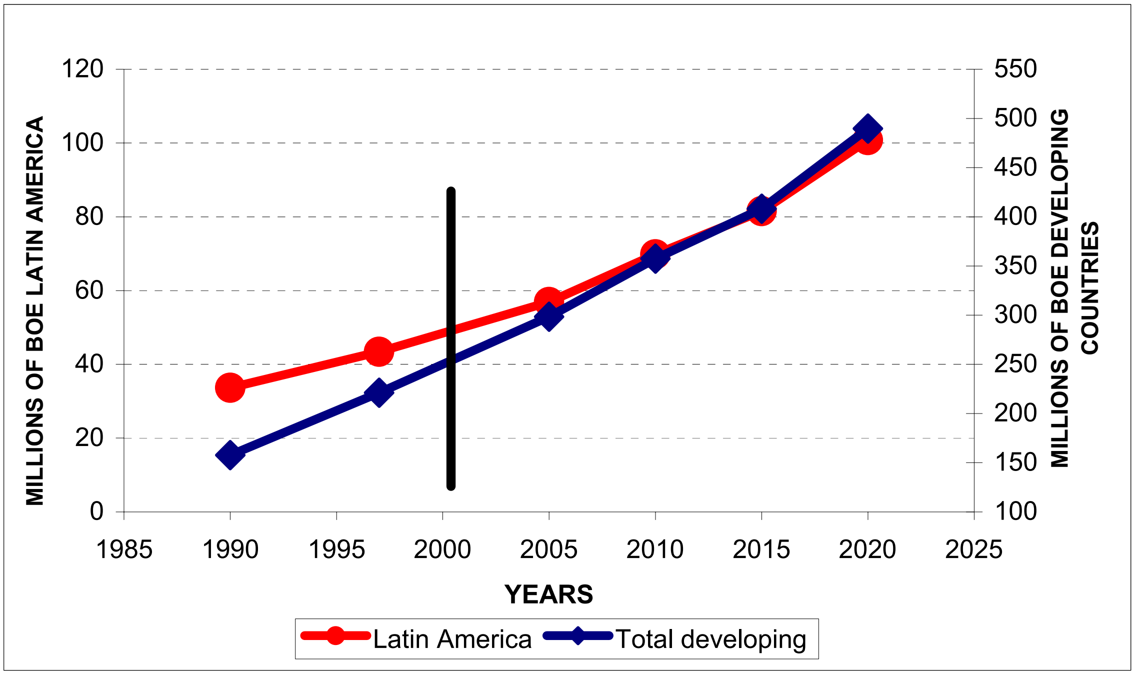
Source: *ECLAC, on the basis of figures from the International Energy Agency.*

Mining, as an energy-intensive activity and an international price taker, should undoubtedly incorporate concentration and refining technologies that substantially improve energy productivity, as an aspect of good corporate governance.

It is important to bear in mind that the mining sector manages costs, not prices. Mining profits are determined by the difference, or spread, between costs —which are the fruit of each company's efforts and creativity— and international prices. These prices do not depend exclusively on the actual physical supply of and demand for the metal concerned, since metal exchanges, which set international benchmark prices, involve participation by not only producers, but also many investors seeking to increase the value of their holdings by speculating on the basis of financial expectations in world markets. For example, it is estimated that only a third of the transactions on the London Metal Exchange are actual operations between producers and consumers. The rest is pure speculation.

Mining is an activity that must necessarily take a long-term view. The useful life of the mine concerned is crucial, and investments in this sector are affected by price volatility. This is why it is so important for companies to rigorously manage their costs, of which energy costs are a major component.

Figure 3: PROJECTED ENERGY DEMAND OF THE LATIN AMERICAN COUNTRIES AND THE DEVELOPING COUNTRIES



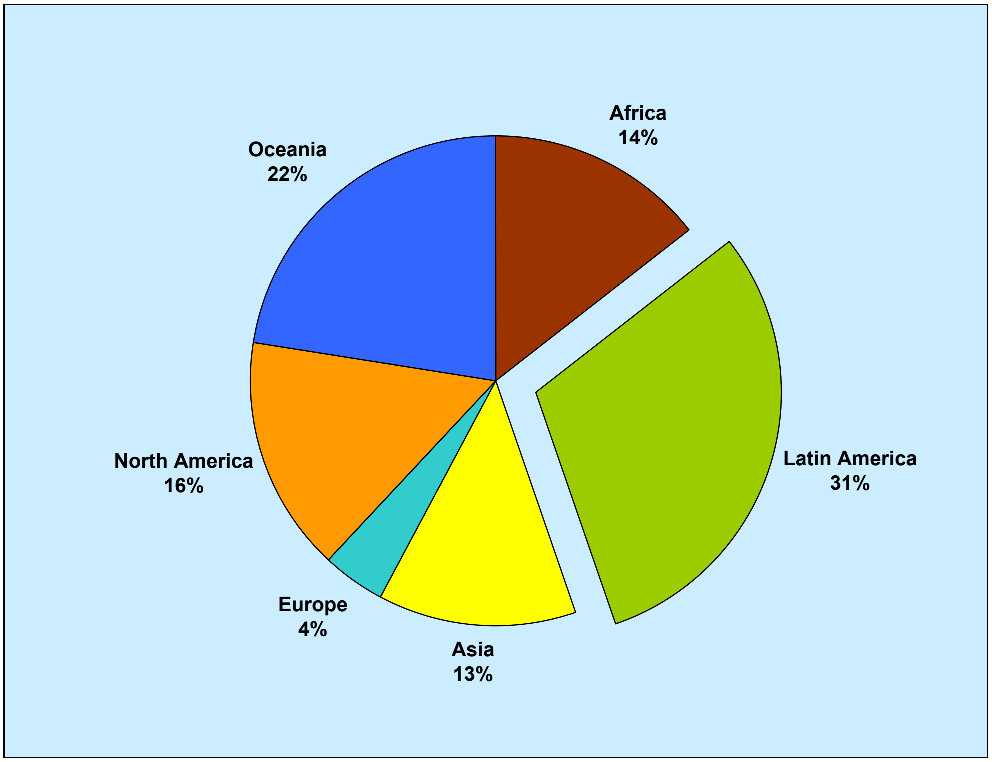
***Source**: United States Department of Energy.*

The key determinants of profitability are the real values expressed by international mineral prices. A comparison between the prices prevailing in the initial years of the current century and those observed in 1990 reveals a loss of potential profits on the order of US$ 7 billion. In other words, Latin American producers failed to receive this sum of US$ 7 billion because prices fell in the course of this period.

I believe the foregoing considerations provide a sufficient basis for affirming that mineral producers should no spare efforts to promote energy efficiency, since it is part of their responsibility to their shareholders. However, the prices quoted on metal exchanges do not internalise environmental costs, even less the improvements in energy use. Whatever earnings are generated by market forces —driven by producers, consumers and speculators—, it must be used to defray the costs that mining companies are compelled to incur if they wish to avoid being accused of damaging the environment. Furthermore, environmental protection standards are becoming more and more stringent, and compliance with them has become a prerequisite for obtaining project financing.

Since the use and usufruct of mineral resources must not compromise the natural and cultural heritage or the quality of life of future generations, any negative externalities that may arise must be carefully managed. While exploitation practices must always be consistent with the state of technological progress, this is particularly crucial with respect to energy, which is one of the leading cost components.

Figure 4: *PROJECTED MINING INVESTMENT, BY REGION*
US$ 76 billion in the period 2002-2007



Source: *ECLAC, on the basis of Engineering & Mining Journal (2003).*

Producers and consumers share responsibility for the sustainable development of mining operations. A projection up to 2007 indicates that worldwide mining investment could reach some US$ 76 billion, 86% of which will probably be located in APEC countries. This investment must be made in such a way as to avoid disturbing the environment, meaning that mining sites, tailings and waste must be properly managed and, especially, that energy must be used efficiently.

At this point, I would like to raise what I feel is a key issue: the desirability of opening a debate, within the current institutional framework of world markets, on what responsibility should be assigned to consumers and to investors or speculators for the care of the environment and the efficient use of energy.

It seems to me that these actors should bear part of the cost of absorbing the technological advances required for this purpose. It is therefore important to devise a mechanism, such as a tax on the transactions conducted on metal exchanges, to create a global fund that could be drawn upon for this purpose on preferential terms. The biggest problem with mining-derived environmental debt is finding ways to remedy the ravages of the past and improve the management of small and medium-sized mining enterprises, especially artisan mining entities, which often cause significant environmental harm.

Another issue that should be emphasized is the need to provide incentives for energy efficiency. As long as oil is cheap, there will be insufficient stimuli for the development of energy-saving technologies. As in the case of metals, it seems appropriate to promote an adjustment in world oil prices, in line with the purposes of the Kyoto Protocol.

The aim would be to ensure price stability within a band that would reflect environmental costs and stimulate efforts to save fossil fuel energy. The adoption of such a system would require the relevant actors to agree that, since worldwide environmental protection goals are higher purposes that must be pursued by all of humanity, the oil market must be regulated to curb price volatility, promote the geopolitical stabilization of the principal supplier areas, rein in speculators and guarantee stable prices to oil-producing and oil-importing countries. Of course, this process would have to be introduced gradually, as it would involve spreading the principles of a new energy civilization based on renewable sources.

The International Conference for Renewable Energies, held in Bonn from 1 to 4 June 2004, was a milestone in this regard, but international negotiations are needed to adjust the market to facilitate the growing incorporation of renewable energies. The idea is to ensure that the prices of conventional energies reflect the negative externalities generated by their use. This is undoubtedly a complex issue that calls for the commitment of key actors such as the United States.

In sum, I would like to round out these considerations by returning to my initial remarks on the urgency to incorporate the right to energy efficiency into our civilization.

Energy use generates externalities that can harm the natural heritage and, ultimately, the quality of life of humanity. Energy suppliers should carry out their activities in conditions that substantially reduce negative impacts, and consumers should use energy in the proper proportion to generate the highest possible productivity. The energy supply should reflect the rational use of energy sources and natural potential, and conditions conducting to the inclusion of renewable sources should be created. Lastly, users and consumers have the right to be educated on how to meet their energy needs in a manner that does not harm the environment or, consequently, the overall well-being of humanity.

These proposals dovetail with efforts to enhance firms' competitiveness and corporate social responsibility. Companies fail to demonstrate such responsibility when they are indifferent to the generation of negative externalities that affect society's overall heritage (natural, cultural, historical, social, etc.). At the same time, companies' actions should be governed by a general framework that allows them to meet their long-term growth aspirations. This calls for public policies and for what economists refer to as "global public goods and services", which, in turn, require a degree of "energy governance" in the globalisation process.

While interaction between States and enterprises is essential, the generation of international cooperation mechanisms is particularly important for adapting world markets to suit the purposes of sustainable development.

WORKSHOP ON THE IMPROVEMENT OF ENERGY EFFICIENCY IN THE MINING ECONOMIES OF THE APEC COUNTRIES

MINING AND ENERGY: RIGHT TO ENERGY EFFICIENCY

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DIRECTOR DIVISION OF NATURAL RESOURCES AND INFRASTRUCTURE

ECLAC, UNITED NATIONS

CONTENTS OF PRESENTATION

- Introduction
- Minerals and fuels in world trade
- Creative inequality and destructive creation
- Mining potential and sustainable development
- Right to energy efficiency
- Challenges

MINING AND PATRIMONIAL INTEGRITY

- Use of mineral resources should not involve natural, cultural patrimony and life quality of future generations: management of externalities.
- Maximum development of internal potentials
- Exploitation should always be compatible with technical progress to guarantee sustainability.

MINING AND PATRIMONIAL INTEGRITY

- Mining policies should promote sustainable development of mining
- Sustainability is a dynamic concept and therefore relative and variable within time.
- In mining costs are managed.
- Without profit no resources are available towards sustainable development.

THE CONCEPT OF ENVIRONMENTAL MINING LIABILITY

- The concept of environmental mining liability implies a patrimonial loss that is generally cumulative in time. The damage continues if it is not confronted.
- The problem lies in how can damage be valued and in who must assume same. An endogenous sanction and capacity for valueing is needed.
- Negative impacts (changes in surroundings, pollution, accumulation of residuals, emissions) caused by operations must be identified and valued (impact on water resources, land, fauna, flora, etc.) by authorities indicating responsiblities and mechanisms for repairing damage caused.

STRUCTURE OF WORLD TRADE (Thousands of millions of dollars and percentages)

Productos	1980	%	2000	%	Incremento	Contribución al incremento
Primarios	869	43	1322	22	453	11%
Combustibles	481	24	593	10	112	3%
Minerales y metales	93	5	190	3	97	2%
Materias primas agrícolas	74	4	118	2	44	1%
Alimentos	221	11	421	7	200	5%
Manufacturas	1085	55	4660	76	3575	85%
Otros sin clasificar	46	2	198	2	200	4%
Total	2000	100	6180	100	4180	100%

Source: Based on UNCTAD, *Handbook of Statistics*, 2002.

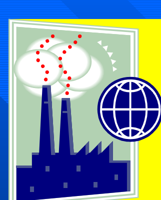
STRUCTURE OF WORLD TRADE OF PRIMARY PRODUCTS

(Thousand of millions of dollars and percentages)

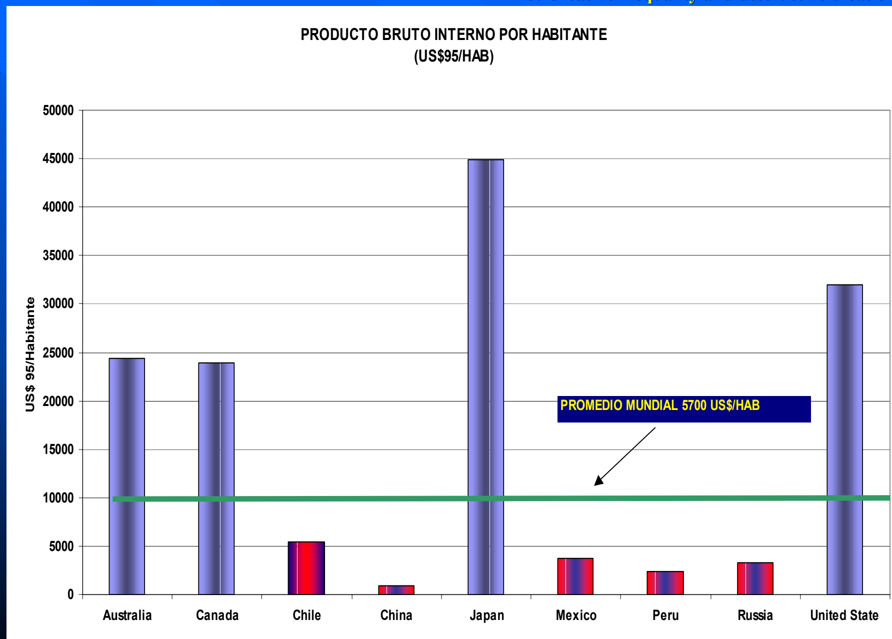
Productos	1980	%	2000	%
Combustibles	481	55	593	45%
Minerales y metales	93	11	190	14%
Materias primas agrícolas	74	9	118	9%
Alimentos	221	25	421	32%
Total	869	100	1322	100%

Source: Based on information from *Handbook of Statistics*, UNCTAD, 2002

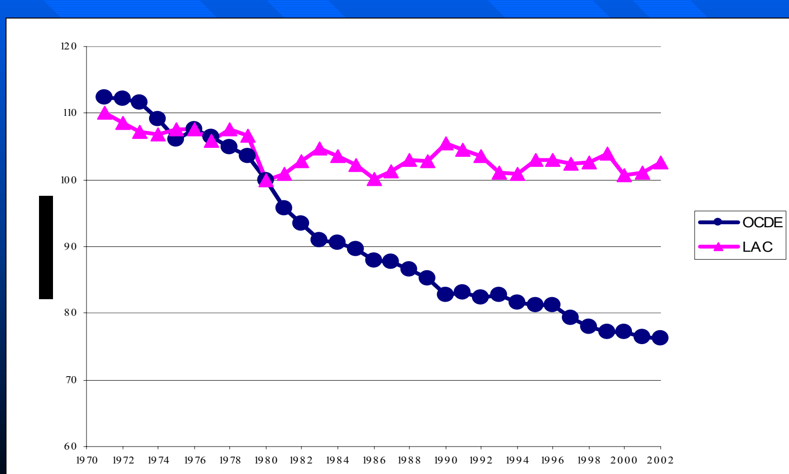
MARKET IS BASED ON UNEQUAL AND DESTRUCTIVE CHANGES

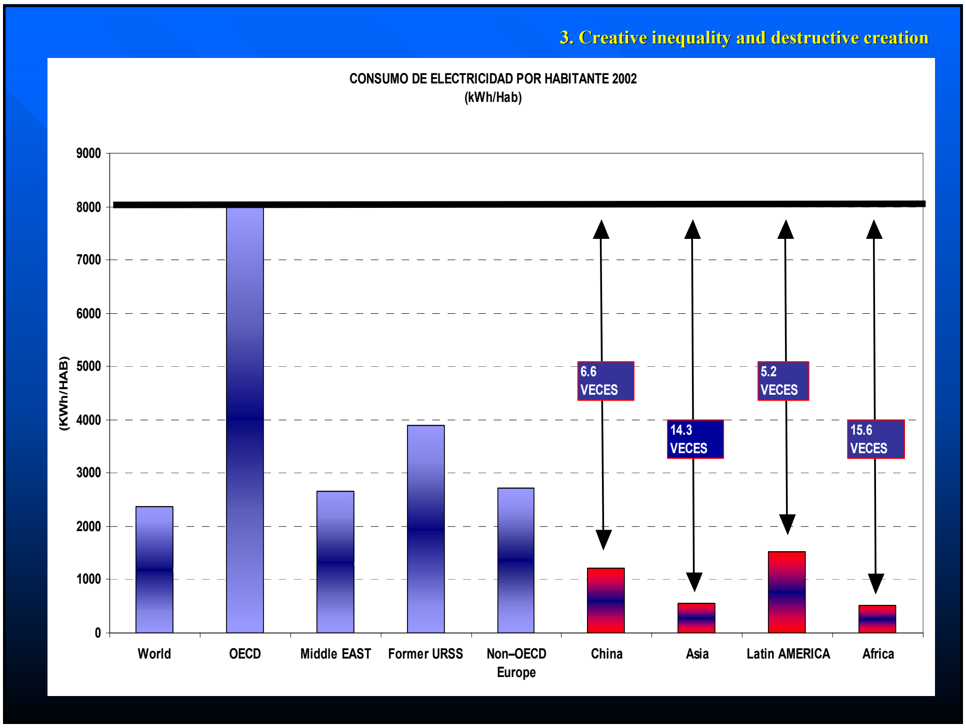


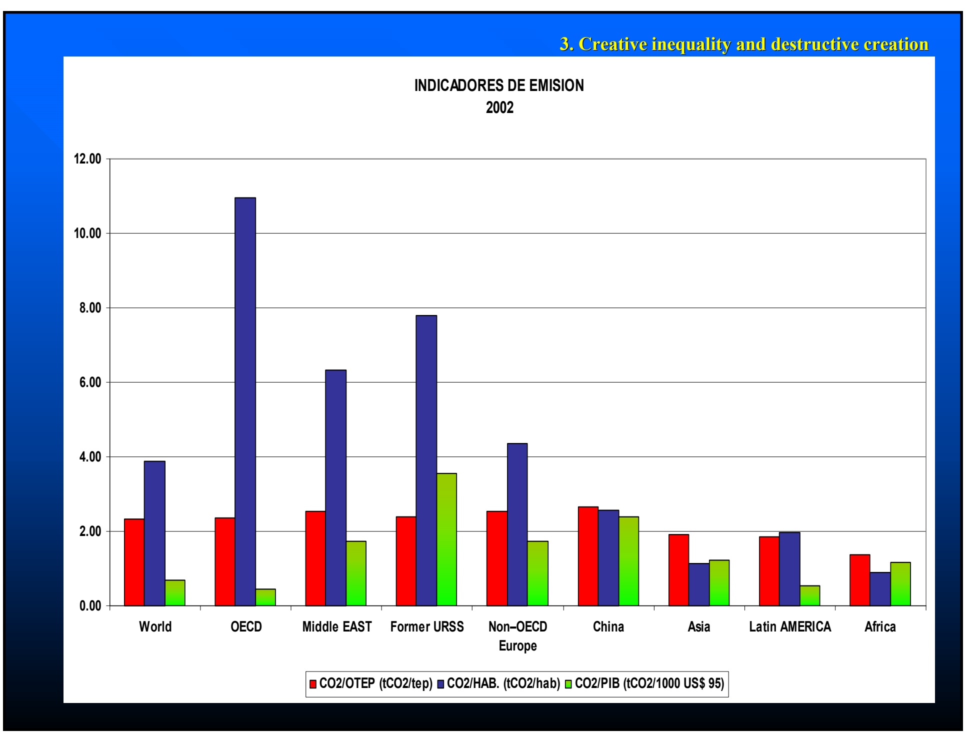
- Natural Resources supply is different and allows economy complementarity.
- Different productivity in the use of factors allows consumers to benefit from the value generated by more efficient tenders
- Energy use shows both the potential productive capacity and its efficiency as well as available life quality to mankind.

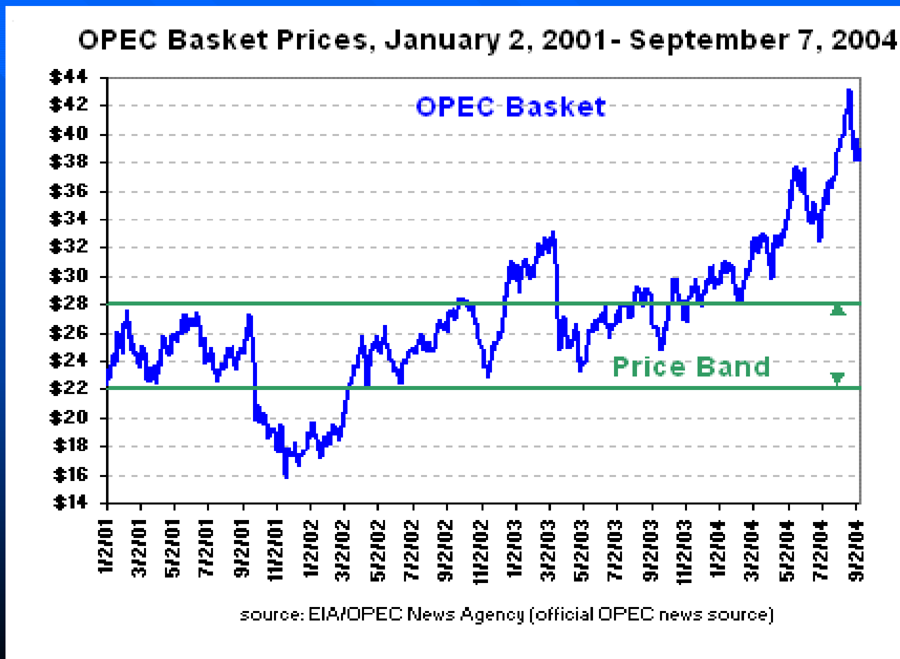


EVOLUTION OF ENERGY INTENSITY

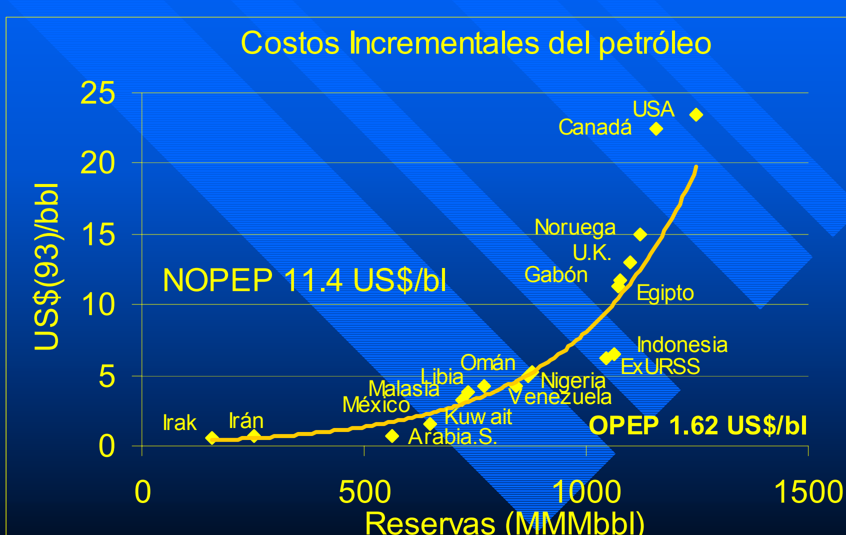


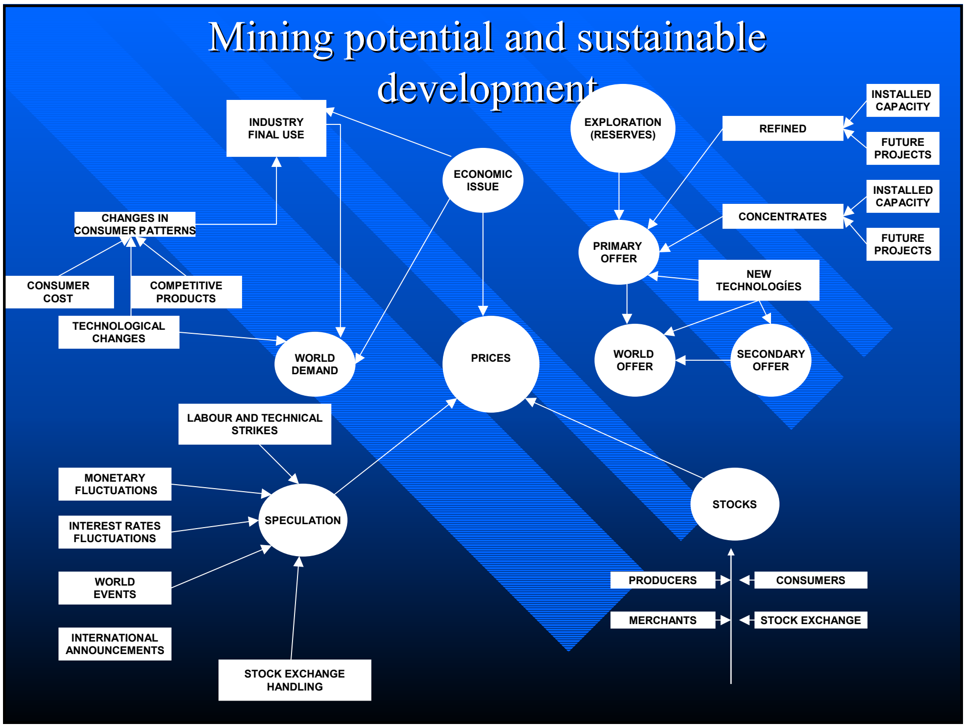

3. Creative inequality and destructive creation
CONSUMO DE ELECTRICIDAD POR HABITANTE 2002
(kWh/Hab)
(KWh/HAB)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
6.6 VECES
14.3 VECES
5.2 VECES
15.6 VECES
World
OECD
Middle EAST
Former URSS
Non-OECD Europe
China
Asia
Latin AMERICA
Africa


3. Creative inequality and destructive creation
INDICADORES DE EMISION
2002
12.00
10.00
8.00
6.00
4.00
2.00
0.00
World
OECD
Middle EAST
Former URSS
Non-OECD Europe
China
Asia
Latin AMERICA
Africa
CO2/OTEP (tCO2/tep)
CO2/HAB. (tCO2/hab)
CO2/PIB (tCO2/1000 US$ 95)

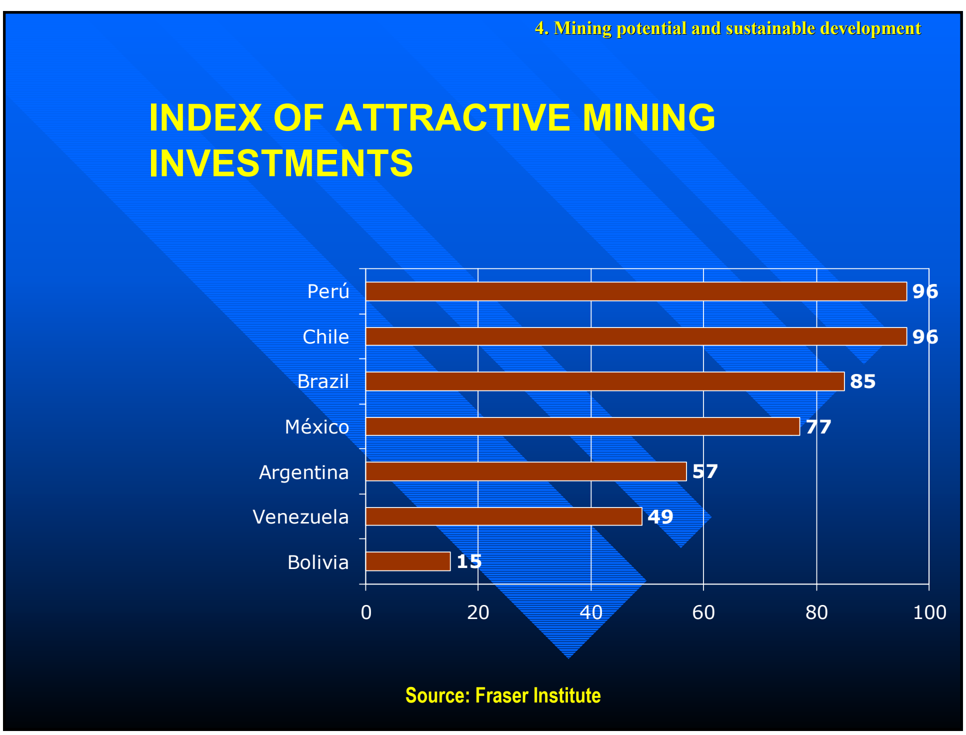


WORLD OIL MARKET



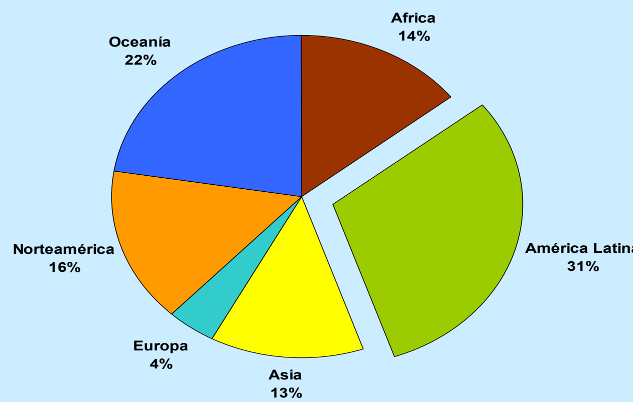


Mining potential and sustainable development
INDUSTRY FINAL USE
ECONOMIC ISSUE
EXPLORATION (RESERVES)
REFINED
INSTALLED CAPACITY
FUTURE PROJECTS
CONCENTRATES
INSTALLED CAPACITY
FUTURE PROJECTS
CHANGES IN CONSUMER PATTERNS
PRIMARY OFFER
NEW TECHNOLOGİES
CONSUMER COST
COMPETITIVE PRODUCTS
TECHNOLOGICAL CHANGES
WORLD DEMAND
PRICES
WORLD OFFER
SECONDARY OFFER
LABOUR AND TECHNICAL STRIKES
MONETARY FLUCTUATIONS
SPECULATION
INTEREST RATES FLUCTUATIONS
STOCKS
WORLD EVENTS
PRODUCERS
CONSUMERS
MERCHANTS
STOCK EXCHANGE
INTERNATIONAL ANNOUNCEMENTS
STOCK EXCHANGE HANDLING



4. Mining potential and sustainable development
INDEX OF ATTRACTIVE MINING INVESTMENTS
Perú
Chile
Brazil
México
Argentina
Venezuela
Bolivia
96
96
85
77
57
49
15
0
20
40
60
80
100
Source: Fraser Institute

WORLD MINING INVESTMENT: 2002-2007

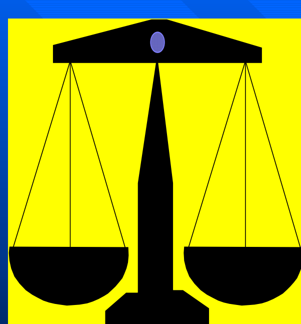


TOTAL: 76 thousand million dollars

Source: Raw Materials Group, January 2003

4. Mining potential and sustainable development

SUSTAINABILITY FACTORS



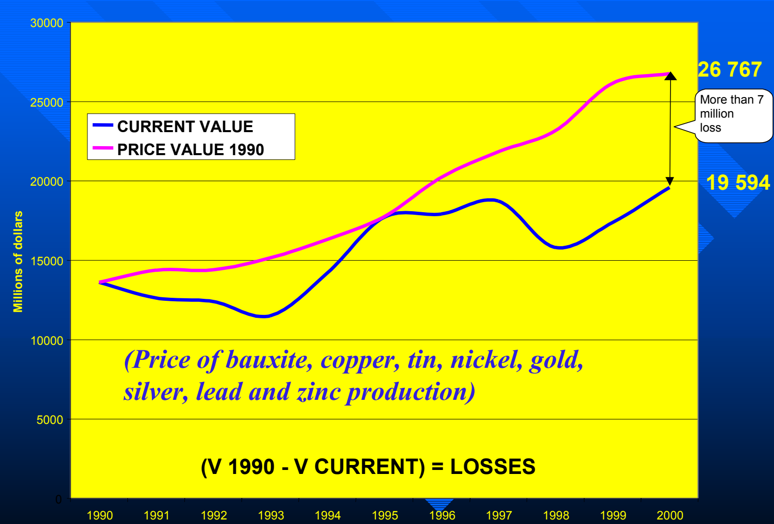
- Financial volatility
- Growth and competitiveness
- Social equity
- Patrimonial integrity
- Consensus

SUSTAINABILITY AND COMPETITIVENESS

- Mining is an “international price taker”.
- Public policies should not affect costs.
- Public policies should stimulate and support reduction of costs (energy auditing, credit lines)

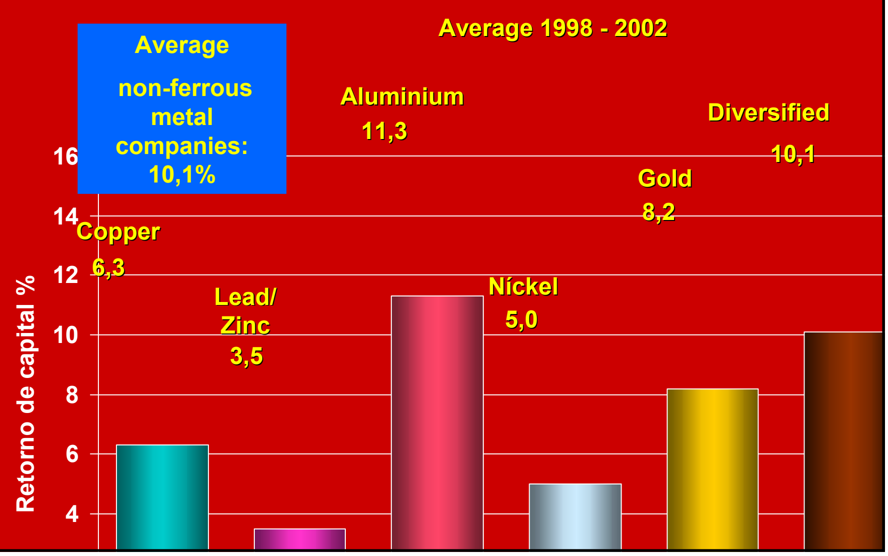
4. Mining potential and sustainable development

LATIN AMERICA: POTENTIAL LOSS DUE TO PRICE DETERIORATION



Source: ECLAC.

CRU: PROFIT FROM CAPITAL INVESTED



STRATEGIC ORIENTATION OF MINING ENTERPRISES

- **Major capital capture in stock markets.**
- **Concentration of interest of stockholders: short-term benefit**
- **More selection of investment decisions**
- **More concern for mineral market management (cuts in production)**
- **As “taker of international prices”, mining impulses technological innovation towards cost reduction.**

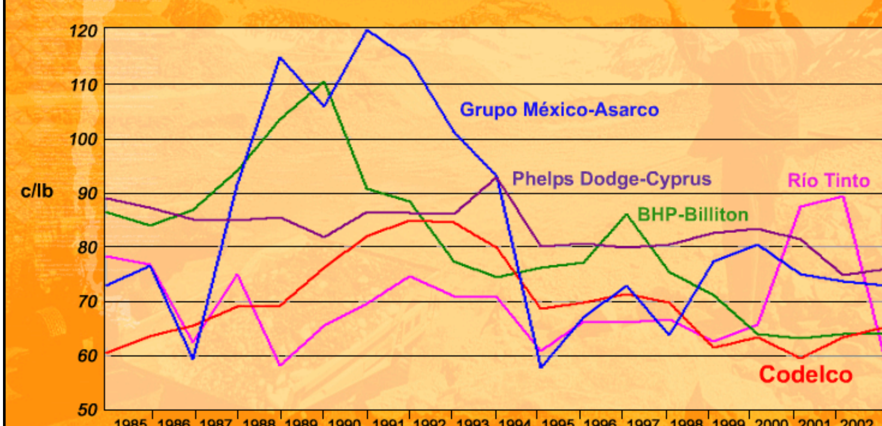
ENERGY INDICATORS OF THE MINING COPPER INDUSTRY OF CHILE

Energía eléctrica			Año	
Área	Unidad	Producto	1995	2000
Mina rajo abierto	MJ/TMF	en mineral	750	452
Mina subterránea	MJ/TMF	en mineral	1,024	1,195
Concentradora	MJ/TMF	en concentrados	5,564	6,144
Fundición	MJ/TMF	en Blister	2,900	3,277
Refinería	MJ/TMF	en cátodos ER	1,066	1,087
Tratamiento de sulfurados	MJ/TMF	en catodos ER	9,531	10,508
Tratamiento de óxidos	MJ/TMF	en cátodos EO	10,816	10,096
Servicios	MJ/TMF	total producido	583	510
Total	**MJ/TMF**	**total producido**	**8,680**	**9,870**

CODELCO
Produciendo Futuro

Costo Neto a Cátodo, Empresas Seleccionadas de la Industria

(c/lb, Moneda 2003, IPM-USA)



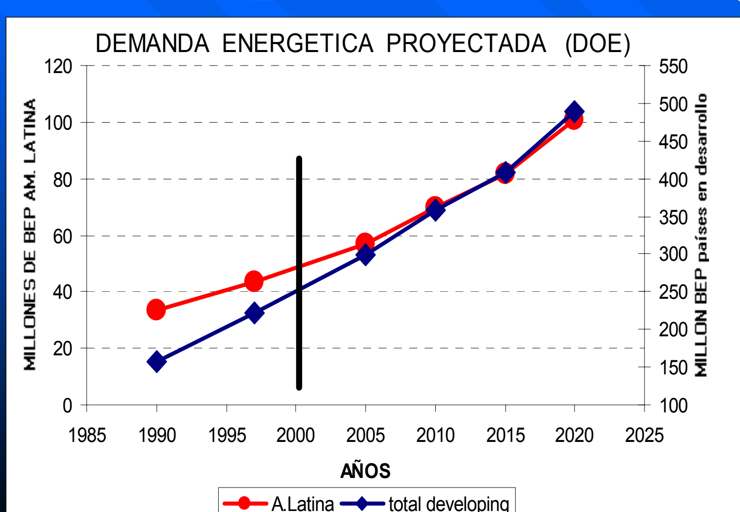
Gestión de Activos | Desarrollo Humano | Sustentabilidad

SOCIETY RIGHT TOWARDS ENERGY EFFICIENCY

- The use of energy generates externalities that can affect natural patrimony and therefore well-being of mankind.
- Those who offer energy must do so under such conditions that negative impacts may be reduced substantially; while those making use of it must do it adequately so as to generate more productivity.

Sustainable replacement of energy demand

social coverage   energy intensity



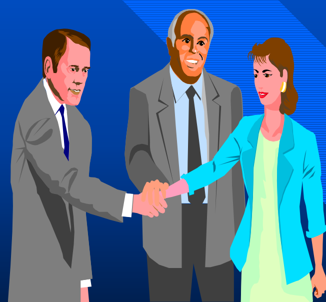
SOCIAL ENTREPRENEURIAL RESPONSIBILITY

- The concept of social responsibility has different interpretations but it must be necessarily associated to the concept of sustainable development.
- In other words, we speak of social responsibility in respect of behaviour related to wealth creation and growth; protection of society's patrimony as a whole and social equity, which are the three pillars of sustainable development.
- Social responsibility has a strong ethic component. However, when put into practice it cannot be liable to subjective criteria.

PUBLIC-PRIVATE INTERACTION RESPONSIBILITIES

- Identify and manage sustainability tendencies
- Evaluate gaps, risks and opportunities
- Propose policies and public actions
- Identify emerging subjects and put forward effective answers
- Create a reliable and sistemic data base
- Establish indicators of achievement and mechanisms for evaluation and action.

NEED FOR CONSENSUS



- Mining is of public interest
- The enterprises and community recognize as theirs the reasons for public interest
- Mining is acknowledged as a progress factor.

CHALLENGES

- Given the type of offer, based on non renewable and polluting energies, there is a need for valueing negative externalities in order to stimulate efficiency and to incorporate renewable sources.
- A world energy adjustment is needed. Low price energy is not compatible with sustainable development.
- Responsibility of metal consumers towards sustainable development achievement.
- There is a need to redefine the world commodities' market at the institutional level.

THE INFLUENCE OF SHELL, GRATE AND PULP LIFTERS ON SAG MILL PERFORMANCE

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1 ABSTRACT

Today's high capacity semiautogenous grinding (SAG) mills expend vast amounts of energy and in doing so consume tons of shell liners and steel balls, while processing ore. The energy efficiency of these high throughput grinding mills can be attributed to the field of breakage and slurry discharge system. The charge motion and breakage of particles inside the mill depends on the shell lifters design, while the discharge of ground particles is controlled by the grate and pulp lifters. The limitations imposed by poor grate and pulp lifter design become increasingly apparent with increasing size of ag/sag mills and their operation in closed circuit. The design of these mill components has been largely based on trial and error and hence varies considerably between manufacturers. This paper discusses the use of two state of the art design tools - Millsoft™ and FlowMod™. Millsoft™ is an effective tool to design the shell lifters and optimize charge motion, whereas FlowMod™ simulates the slurry discharge system to design grate and pulp lifters. The application of these simulators will be discussed using case studies of full scale mills.

2 INTRODUCTION

Many large mining operations around the world have one or more semi-autogenous (SAG) mills doing bulk of the work in their size reduction operation. The SAG mill is usually followed by a ball mill to finish the size reduction prior to the concentration step. In the past when primary, secondary and tertiary crushers fed material directly to large ball mills, the energy efficiency of the concentrator was determined for the most part by the ball mill operation, whereas now the energy efficiency of a plant often rests largely on the SAG mill operation. As a result mines have shifted their emphasis in optimization from ball mills to SAG mills.

There are a number of SAG mills in operation around the world whose diameter reaches up to 40 ft. These operations continually invest in new technologies to improve their energy efficiency and capacity in their SAG circuit. Commercial SAG mill performance is determined by a large number of variables, both mine site variables and mill variables. In many cases these variables dictate production capacity seemingly randomly. Therefore a number of operating philosophies, each specific to a plant, have arisen. In almost all concentrators the SAG operation is a continually evolving operation. Every year, ways and means are sought to increase capacity, decrease energy consumption and prolong lifter and liner life, ore blending, newer designs of lifters, recycle crushing and redesign of grates and trommel screens are a few routes taken at considerable expense.

2.1 Operation of SAG Mills

Major components of a sag mill are schematically shown in Figure I and described below.

1. Feed trunnion: assembly through which solids and water enters into the mill.
2. Mill Shell: main chamber where ore particles are broken due to tumbling action of the mill.
3. Grate: screen, which allows the ground ore particles and water to pass through in the form of slurry.
4. Pulp lifter: lifts the slurry, which passes through grate into the discharge trunnion.
5. Discharge trunnion: assembly through which mill product discharges.

Once slurry has made its way via the grinding media charge its first stage of discharge is via the grates. Hence in the absence of any subsequent restriction the maximum flow capacity that can be obtained for a given mill is determined by the grate design in terms of open area and position of holes. The driving force for slurry transport from the mill shell through the grate holes is the difference in pressure head across the grate.

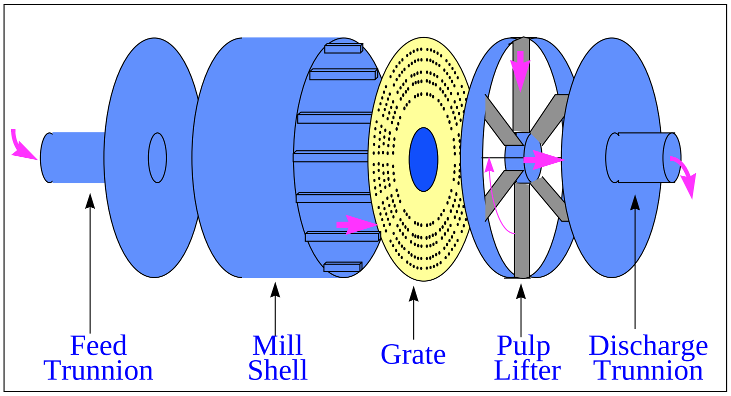


Figure I: Schematic of a typical sag mill.

2.2 SAG Mill Efficiency

The efficiency of SAG mills depends on the breakage rate of particle sizes present in the mill. The breakage rate in turn depends on the power draft of the mill for the simple reason *work done (in fracturing ore particles) is directly proportional to energy input*. The power delivered to the mill should be efficiently transferred to the bed of ore particles in the mill to achieve maximum efficiency. There are four principal operational factors that influence this power delivery. They are: *Mill filling, Mill rotational speed, Design of Shell lifters, and Slurry transport through the grate and pulp lifters.*

There are mainly two kinds of models that have been proposed and currently in use in the industry: *Semi-empirical, and Discrete* element method (Rajamani et.al., 1996,1997a,1997b and Mishra and Rajamani 1994a 1994b,). The empirical models predict the power essentially based on the principle torque-arm, i.e, the torque required to sustain the load dynamically. However, these models do not incorporate the influence of the other two important factors- *shell lifter design and slurry transport through grate and pulp lifters*.

The energy efficiency of tumbling mills can be directly examined by looking at the motion of rocks and steel balls inside the mill. The make-up of the charge and the lifter bars attached to the inside of the mill shell can be designed particularly to maximize the mass of ore fractured per unit of energy spent. At the same time, the unnecessary collisions of steel balls against the mill shell can be reduced. Furthermore, the cascading charge flow can be altered in such a way as to maximize grinding efficiency. First, the shell lifters are designed in such a way the motion is fully cascading and that part of cateracting motion is made to strike in the vicinity of the toe. In such a charge motion regime both shearing action and impacts are fully utilized in grinding the ore. The major factors that affect the energy efficiency of sag mills are shown in Figure II and are discussed further.

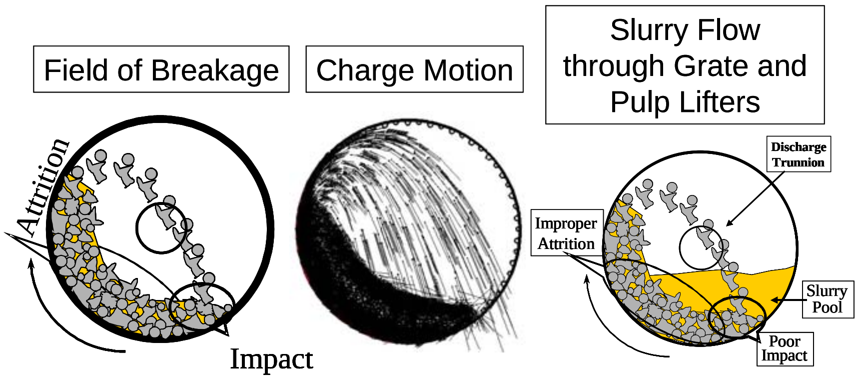


Figure II: Three important factors that affect the energy efficiency of sag mills

2.2.1 Field of breakage

The motion of charge or rocks and balls in SAG mils can be viewed as a field of breakage generated as a result of the internal profile of the lifters and the rotational speed of the mill shell. The ore entering through the feed port is ground by this field and, if it is sufficiently ground to the grate slot size, the slurry leaves through the slots in the grate. The field of breakage influences the rock mass in the SAG mill. Should the incoming ore be harder and the field of breakage insufficient to reduce the size, the ore stays in the mill longer since it is unable to pass through the grate. The net effect is an increase in rock mass, and the feed rate to the mill must be decreased appropriately to maintain rock to ball ratio. On the other hand, when the ore is soft, the field of breakage reduces the ore size rapidly and hence the rock mass decreases. To sustain a set rock mass, the feed rate must be increased. The complicating factor in this concept of field of breakage is that the incoming rocks themselves constitute the field.

2.2.2 Charge motion

In a concentrator, all of the auxiliary equipment-pumps, conveyers, screens and hydrocyclones - and two primary resources-steel and electricity-serve primarily to maintain grinding action in the belly of the SAG mill. It is this action that dictates capacity. The energy efficiency of these mills can be directly examined by looking at the motion of rocks and steel balls inside the mill. The make-up of the charge and the lifter bars attached to the inside of the mill shell can be designed particularly to maximize the mass of ore fractured per unit of energy spent. At the same time, the unnecessary collisions of steel balls against the mill shell can be reduced. Furthermore, the cascading charge flow can be altered in such a way as to maximize grinding efficiency. First, the shell lifters are designed in such a way the motion is fully cascading and that part of cateracting motion is made to strike in the vicinity of the toe. In such a charge motion regime both shearing action and impacts are fully utilized in grinding the ore.

2.2.3 Flow through the grate and pulp lifters

Discharge grates and pulp lifters play an important role in performance of the autogenous (ag), semi-autogenous (sag) mills. The performance of the pulp lifters in conjunction with grate design determines the flow capacity of these mills. The function of the pulp lifters is simply to transport the slurry passed through the discharge grate into the discharge trunnion. Their performance depends on their size and design, the grate design and mill operating conditions such as mill speed and charge level. The difficulties associated with slurry transportation in ag and sag grinding mills have become more apparent in recent years with the increasing trend to build larger diameter mills for grinding high tonnages. This is particularly noticeable when ag/sag mills are run in closed circuit with classifiers such as fine screens/cyclones.

The performance analysis of conventional pulp lifter designs have shown that a large amount of slurry flows back from pulp lifter into the mill (Latchireddi, 2002, Latchireddi & Morrell, 2003a, 2003b), which depends on the size and design of the pulp lifters. The performance analysis of conventional designs of pulp lifter has shown that a large amount of slurry flows back from pulp lifter into the mill (Latchireddi, 2002). This is because the back face of the pulp lifter is the grate itself, which allows the slurry to flow back into the mill. The field of breakage diminishes when excessive slurry is present in the mill.

The key issues discussed above largely depend on the two important design factors such as the shell lifters and grate-pulp lifters. Both these design factors undergo periodic changes, usually once or twice a year, toward more optimal design. The design of these two important mill components has been largely based on trial and error and hence varies considerably between manufacturers.

The research work carried out by Rajamani and Latchireddi over the years has led to the development of two important tools – Millsoft™ and FlowMod™, to help the designers and engineers to analyze and understand the influence of the internal components of sag mills – shell lifters, grate and pulp lifters respectively. The following sections will discuss the basic principles and application of these two simulators with case studies.

3 Millsoft™ - Discrete Element Simulation of SAG Mills

The SAG mill is made up of cylindrical shell with two conical shells attached on both ends. Lifter elements are attached in both the cylindrical and conical shell sections. As the SAG mill rotates, typically around 10 rpm, the internal flat walls of the lifter and shell imparts momentum to balls and rocks. The momentum is primarily transferred to particles in direct contact with the plate elements. These particles in turn impart their momentum to adjacent layers of particles. In this manner the motion of the entire charge evolves resulting in what is commonly referred to as cascading and cataracting charge.

The discrete element method embedded in MillSoft™ replicates the evolution of charge motion as described above. In the simulation the exact dimensions of lifters, plates and balls are used. First, the mill shell is constructed with a series of flat planes joining together to form cylindrical shell and conical shell. Next, a series of planes are constructed on the shell to duplicate shell lifters and end lifters. Next, the grinding balls and rock particles are generated. Usually the rock particles are constructed as spherical particles for ease of computations. The number of spheres so constructed would correspond to 25% filling with 12% filling for grinding balls. In three dimentional simulation, the number of spheres may be in the range 200,000 to 1,000,000 depending on the size distribution and size of the SAG mill. In two dimensions, the number of spheres is in the 3000-8000 range. Now, in the numerical computational point of view, a complex polygonal assembly of rectangular plates encloses a large number of spheres. These spheres have different collisional properties which depend on their size and material make-up.

The critical aspect of DEM is the modeling of the collision between any two spheres or the sphere and a plate element. At the contact point a force develops which sends the sphere in a direction away from the point of collision and also there is deformation of the metal or fracture of the rock particle. To account for these two events the collision is modeled by a pair of spring and dashpot. The spring models the opposing force and the dashpot models the dissipation of the force. Force is dissipated as a result of deformation of the material at the point of collision. The spring and dashpots in the model are placed in the normal direction as well as the tangential plane of the collision point. Thus after collision forces are calculated, the acceleration and velocity of the pair of spheres are computed with the familiar laws of physics. It is clear then that in this method the forces of collision and the dissipation of energy are calculated at a greater level of detail than any other available models.

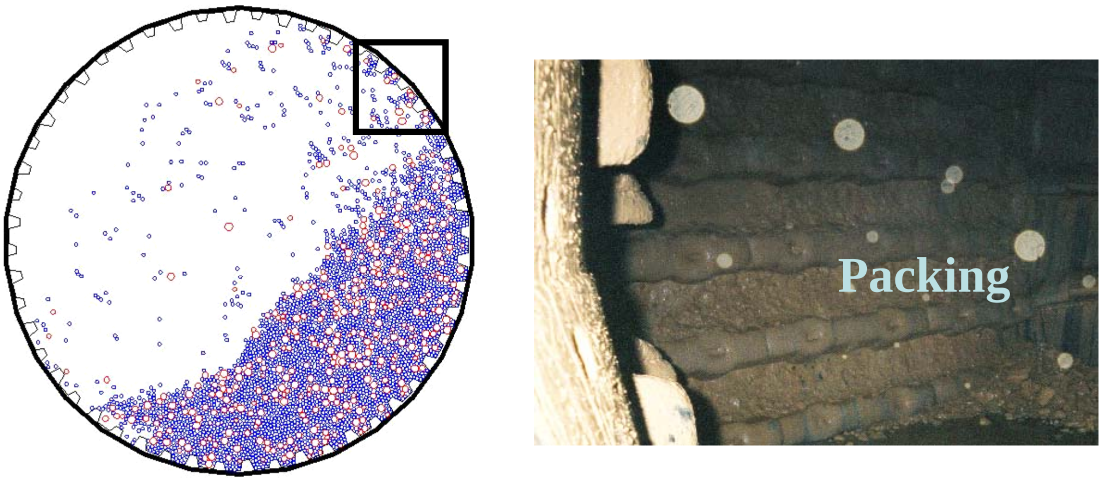
MillSoft can be used affectively to show the effects of different lifter configurations, mill loading, mill speed, and other operating conditions. Unlike single-particle trajectory programs which show only the worse-case condition of a particle path, MillSoft takes into account the entire charge, you can effectively see the "kidney" shape of the charge, the dead zone, toe and shoulder of the charge, and areas of high-impact on the mill lifters.

Millsoft can also be used to follow lifter wear, shell plate wear and particle breakage. Most importantly, the location and the intensity of impacts on lifter bars can be computationally recorded and a corresponding metal abrasion at that location can be worked out. In a like manner, the energy of impact can be used to fragment the rock particles in the simulation. However, the distribution and number of fragments produced overwhelms the computational task.

3.1 Shell lifter design and charge motion analysis with Millsoft™

A typical example of charge motion analysis with Millsoft™ is illustrated in this section. The SAG mill under consideration is a 26x16 ft mill drilled for 52 shell lifters. Therefore, the mill can be fitted with 26 high and 26 low lifter sets. The total charge is 27% with 12% balls. The mill is expected to draw 2.5-3 MW power. The mill speed is set at 76% critical speed. The snapshots of the charge motion at different conditions are shown in Figure III.

Figure IIIa shows the SAG mill fitted with traditional lifters. The high lifters are the 17 degree release angle. Due to small release angle, considerable amount of rock and ball particles are thrown against the mill shell. The ball-to-liner strike zone extends as high as 8 O'clock mark. The mill may not reach design capacity, especially with hard ore type. Furthermore, considerable damage to liners is imminent within four months of operation. A close look near the shoulder position reveals that packing between the lifters is a strong possibility. This has been proved when packing was seen after the mill was crash stopped as shown in Figure IIIb. Broken liners were also observed during the inspection.



(a) New (17^o release angle) (b) Packing between lifters

Figure III: Snap shots of charge motion and packing between the lifters.

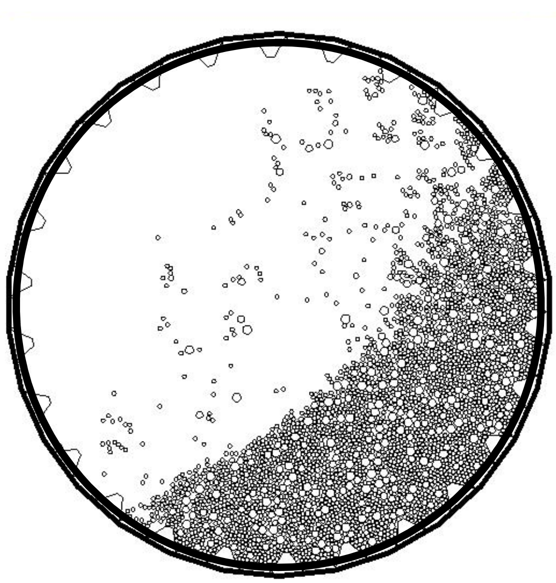


Figure IV: Snap shot of the charge motion with 26 high lifters.

To overcome the problem of packing and ball strikes on liners a new design of liners were proposed based on Millsoft™ simulations. These new liners consist of only 26 high lifters in place of 26 high and 26 low lifters. The snapshot of the charge motion animation is shown in Figure IV. The liners are partially covered deliberately due to confidentiality. The cataracting charge lands within the toe of the charge. This type of charge motion is ideal for SAG, for it to preserve the lifters. The mill speed may be increased without fear of damaging liners. Several mines exploited this concept to increase production and the results are summarized below.

3.2 Industrial case studies on shell lifters

In recent years, with increasing mill size whose power draw has reached over 20MW, emphasis has been diverted towards the design of shell lifters to increase the grinding efficiency. Lifters are not only consumables for protection against wear, but also critical machine elements. They transfer power to the mill charge and govern the pattern of energy distribution inside the mill, including affecting the grinding kinetics. The performance of liners changes with time, as their shape changes by wear. A good design must take these restrictions into consideration and optimize the performance of liners for the full duration of their useful life. The attainment of expected useful life of a set of lifters depend not only on their initial shape, material and quality of fabrication but a good matching between expected and real operating conditions inside the mill. The main issue is the direct impact of balls on the lifters in the absence of the damping effect of a bed of mineral ore and ball charge. The capacity increase achieved with newer shell lifter designs using Millsoft or other methods are summarized in Table I.

Table I: Summary of the case studies on shell lifters.

Mine	Original	First Change	Millsoft	Throughput
Collahuasi (32x15 ft)	6 deg	11 deg	30 deg	11% increase
Alumbrera (36x15 ft)	72 rows 10 deg	48 rows 25 deg	36 rows 30 deg	50,000 to 96,000 tpd
Candelaria (36x15 ft)	72 rows 10 deg	20 deg	36 rows 35 deg	15% increase
Los Pelambres (36x17 ft)	72 rows 8 deg	-	36 rows 30 deg	10,000 tpd increase

4 FlowMod™ – A Tool for Grate and Pulp Lifter Design

Recently, much attention has been focused on the grate/pulp lifter assembly, as the objective has been shifted to maintain very high throughput in closed circuit SAG mill operations. This has emphasized the operational problems in removing high volumes of slurry and pebbles via the grates and pulp lifters.

Pulp lifters (also known as pan lifters) are an important component of these mills whose function is to transport the slurry flowing through the grate holes into the discharge trunnion and out of the mill as shown in Figure 1. Although pulp lifters are obviously important in determining the ultimate discharge flow capacity, very little work has been reported either on their performance or on their influence on mill efficiency.

The design of grate/pulp lifters in SAG mills has a substantial impact on the behavior of the mill. If sufficient grate open area and pulp lifter capacity is not available, they will provide a high resistance to flow of slurry resulting in excessive amount of slurry resulting in slurry pool formation inside the mill. If the amount of slurry exceeds a level past where efficient grinding occurs, the mill will "go off the grind" (Moys, 1986 and Austin et.al, 1984). Build-up of large volumes of slurry will have serious problems by reducing the effective density of the submerged media to a low level, which reduces the inter-media forces that are responsible for grinding of finer particles. The presence of slurry pool tends to reduce the power draw and grinding performance.

The design of both grate and pulp lifters have been largely based on trial and error and hence vary considerably between manufacturers. FlowMod™ is a steady state simulation software has been developed to estimate the slurry hold-up inside the mill and its profile with respect to the charge profile at any given operating condition (Figure Vb). It takes all the important mill design and operating parameters (Figure Va) into consideration while computing the slurry hold-up-discharge rate relation. It allows the user to study the effects of different grate designs (open area and position of slots), pulp lifter design (size and shape), mill loading, mill speed, solids concentration and other operating conditions. It also shows the slurry pooling and its effect on mill power draw.

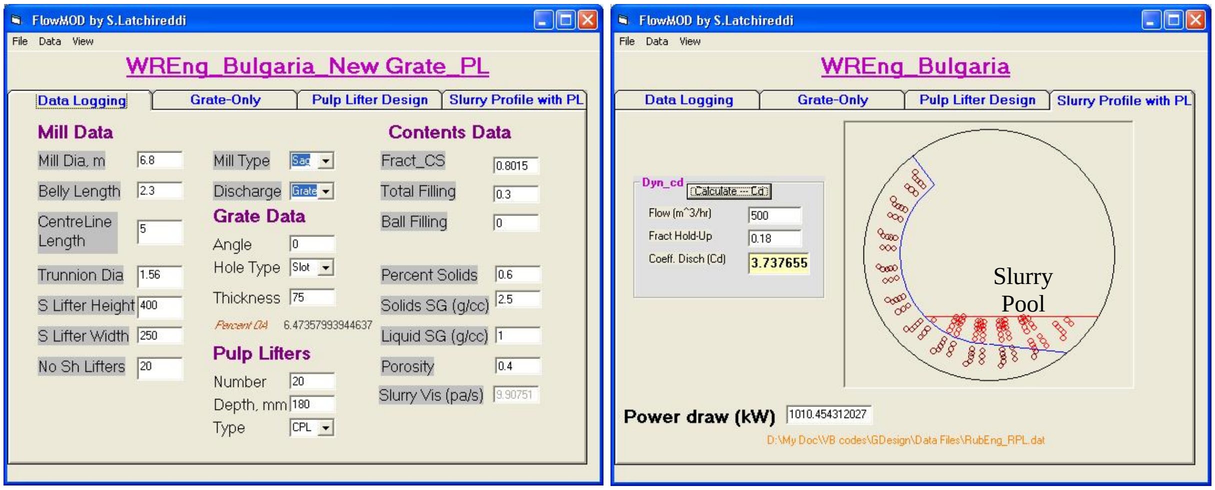
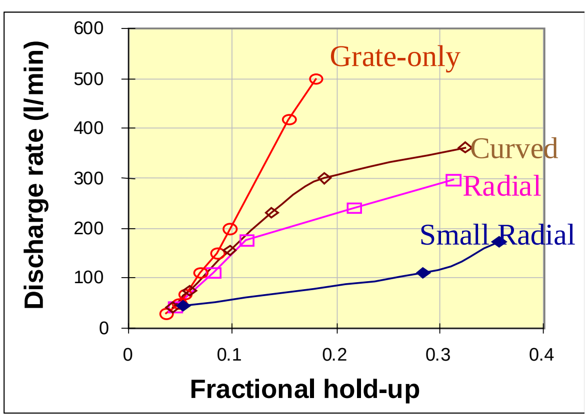


Figure V: FlowMod's a) user interface and b) slurry hold-up and its profile.

4.1 Performance of pulp lifters

A detailed investigation by Latchireddi (2002), Latchireddi and Morrell (1997, 2003a and 2003b) on impact of the discharge grate and pulp lifters on slurry transport in SAG mills revealed the limitations of the conventional designs of pulp lifters (Radial and Curved) on slurry transport in SAG mills. The performance of pulp lifters in transportation of slurry passed through the discharge grate are illustrated in Figure VI. For an efficient slurry transport though the mill, the discharge capacity of pulp lifters should match with the discharge capacity of grate-only at any given slurry hold-up.



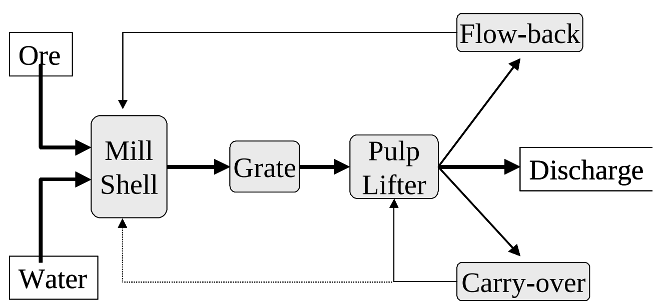


Figure VI: Comparison of flow through pulp lifters. Figure VII: Process of slurry transportation in SAG mill

The reason for the significantly inferior performance of the conventional pulp lifters is the Flow-back phenomena. The flow-back of slurry from pulp lifters into the main grinding chamber through the grate can be as high as 60% depending on the design and size of the pulp lifter assembly. The fraction of slurry remained in the pulp lifter gets carried over to the next cycle as carry-over fraction; however, this occurs in mills operating at higher speeds. The overall slurry transportation process in AG/SAG mills is summarized in Figure VII.

The excess slurry due to flow-back process accumulates near the toe region resulting in slurry pool formation (Figure Vb). This slurry pool softens the ball strikes at the toe of the charge which inhibits the impact breakage of particles. It also diminishes the shearing action in the cascading charge which reduces the fine particle grinding. Both these aspects adversely affect the grinding efficiency thus reduce the mill capacity. Furthermore, the slurry pool applies a counter torque in the mill effectively reducing the power draft. Therefore, the operator either increases the feed rate or increases the critical speed to increases power draft, the power draft increases at first but decreases later, thus giving a false indication.

4.2 Development of new pulp lifter design

The only way to overcome the restrictions imposed by the conventional designs which restricts the flow capacity of mills is to ensure no flow-back of slurry occurs once the slurry has entered the pulp lifter. This has been achieved by developing a new design of pulp lifter called the Twin Chamber Pulp Lifter -TCPL (Latchireddi 1996 and Latchireddi & Morrell 1997b) a schematic of which is shown in Figure VIII.

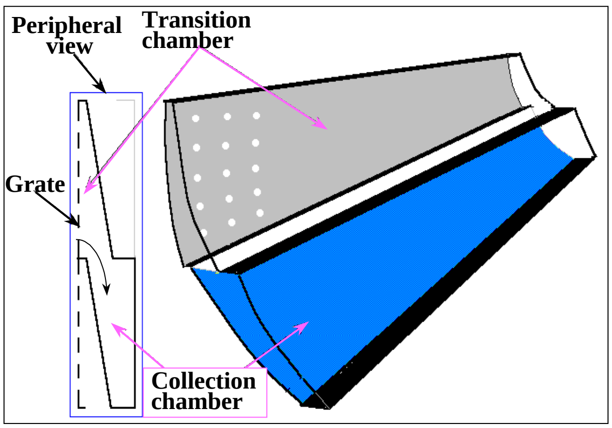


Figure VIII: Schematic of the Twin Chamber Pulp Lifter (TCPL).

The slurry will enter the section exposed to the grate - called the transition chamber, and then flow into the lower section - called the collection chamber which is not exposed to the grate. This mechanism ensures that the slurry is unable to flow or drain backwards into the mill, and hence the flow-back process is prevented up to the capacity of the collection chamber.

The TCPL can be precisely designed to handle the designed flow capacity of the mill whose dimensions depends on the operating conditions such as mill speed and number of pulp lifter segments.

4.2 Influence of grate open area and charge volume on performance of TCPL

Besides overcoming the major problem of flow-back, which is unavoidable in case of conventional pulp lifter designs, the unique design of TCPL offers many other advantages. The most important one is that its performance does not get affected due to variations in:

- grate open area, and
- volume of grinding media (charge) inside the mill

In ag/sag mills the volume of the grinding media (balls & coarse ore) tends to change with the type of ore which also has strong interaction with grate open area and influences the performance of pulp lifter. To illustrate these points the variation in mill hold-up-discharge rate relation with change in grate open area and charge volumes are shown in Figure IX and Figure X respectively for RPL and TCPL.

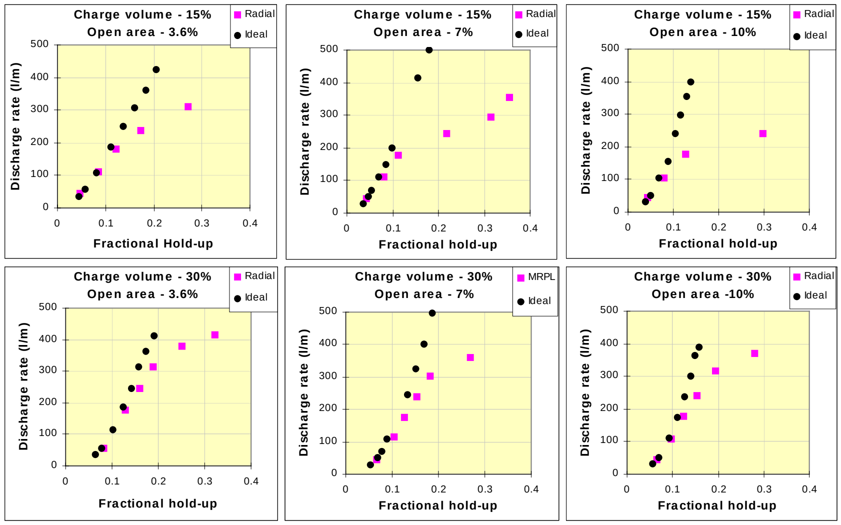


Figure IX: Performance of RPL with variations in charge volume and open area.

The observation of decreasing discharge rates with increasing grate open area is in accordance to the statement made by Rowland and Kjos (1975), that if the pulp lifters do not have enough capacity, the typical approach of increasing the grate area does not improve the situation but makes it worse by allowing the slurry to flow back into the mill, causing it to run too wet. The presence of excessive slurry pool inside the mill reduces the grinding efficiency.

Contrary to the observations made from the RPL results shown in Figure IX, it may be seen from Figure 9 that the performance of the TCPL is not adversely affected by changes in grate open area and charge volume. This observation is clearly seen up to the discharge capacity of the collection chamber. This is because once the slurry flows into the collection chamber it is not exposed to the grate holes. However, the influence of the charge volume and open area, which is similar to that in the RPL, can be seen at discharge rates exceeding the capacity of the collection chamber.

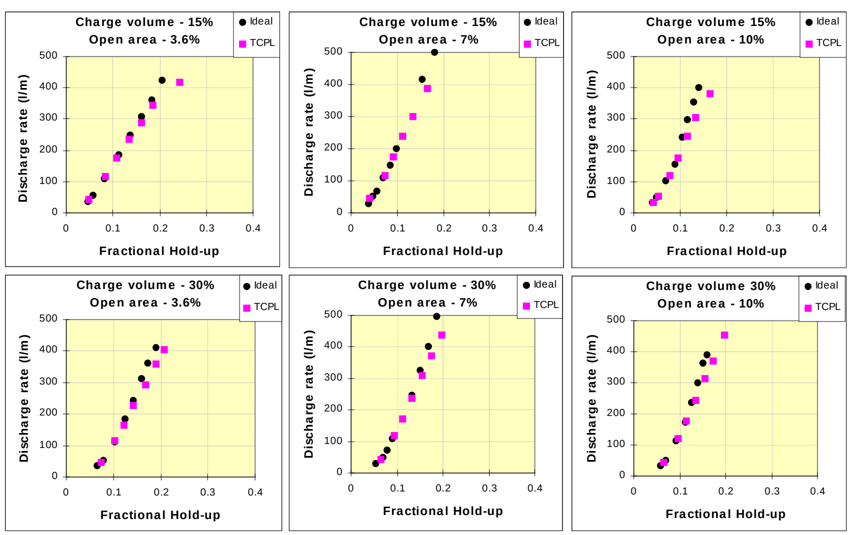


Figure X: Performance of TCPL with variations in charge volume and open area.

Comparing Figure IX with that of Figure X, it is quite evident that up to the capacity of the collection chamber, the performance of TCPL is not adversely influenced by changes in grate open area and charge volume inside the mill.

4.3 Industrial trials of twin chamber pulp lifter

The clear ability of the TCPL to achieve a higher discharge flow rate, closer to the maximum flow capacity of the mill, for a given hold-up prompted Alcoa World Alumina Australia to trial this design in one of its 7.7 m diameter sag mills at its Wagerup Refinery in Western Australia in August 1999.

To assess the effect of the TCPL over the existing RPL, a complete survey around the sag mill circuit was conducted both before and after the installation. For the survey prior to installation the mill was running at its maximum capacity, at which point slurry just starts to overflow out of the feed end of the mill. This was followed by running the mill at different throughputs to estimate the maximum capacity that could be achieved under the prevailing operating conditions. All the surveys were followed by a crash stop of the mill to measure the instantaneous charge and slurry volumes.

Prior to the TCPL installation the maximum throughput was 390 tph and the slurry hold-up was almost 20% by volume. When the mill was crash stopped a slurry pool of more than 0.7 meters deep was measured above the charge level. After installation of the TCPL the hold-up reduced to 6% and the slurry pool disappeared. This resulted in a higher throughput being achieved which increased from 390 to 450 tph. Despite the 15% increase in mill throughput, the product size distribution has remained unaffected (Denis et al, 2001).

5 CONCLUSIONS

It is shown that the design of both shell lifters and grate-pulp lifter assembly are crucial for optimal performance of the ag/sag mills. The design of shell lifters, which control the charge motion thus the breakage field, can be optimized using Millsoft™ - a discrete element numerical method. It can be used affectively to show the effects of different lifter configurations, mill loading, mill speed, and other operating conditions. It can also be used to follow lifter wear, shell plate wear and particle breakage. FlowMod™ is a steady state simulator to optimize the design of grate and pulp lifters to handle the given flow through the mill. It estimates the slurry hold-up inside the mill and shows its dynamic surface at any mill operating condition. The program allows changes in grate open area, position of holes, size of pulp lifter and its shape besides the operating parameters.

6 ACKNOWLEDGMENTS

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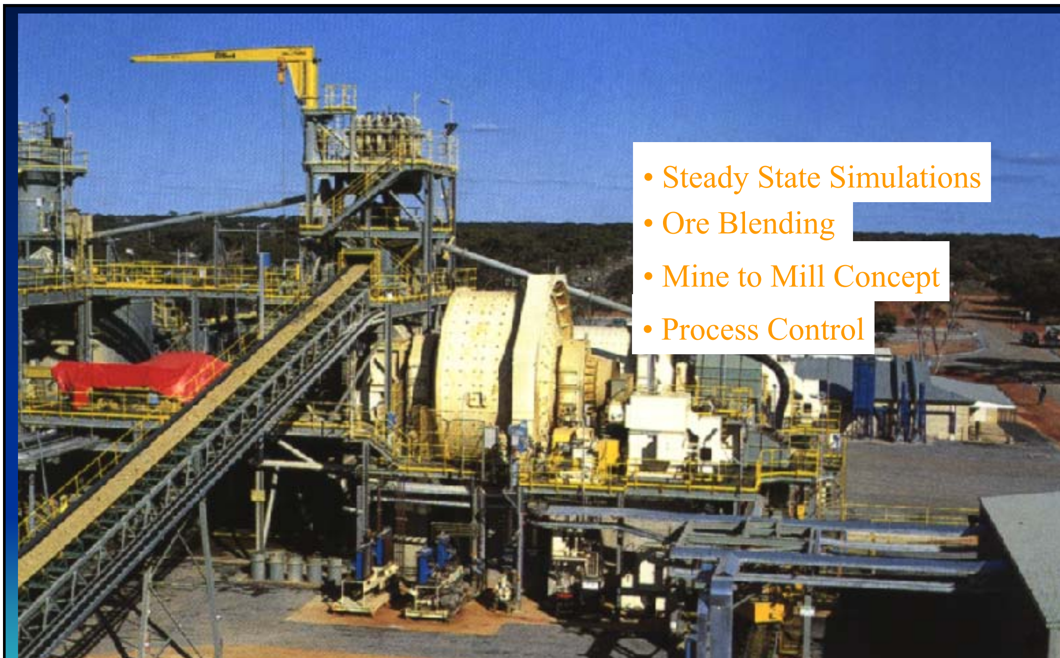


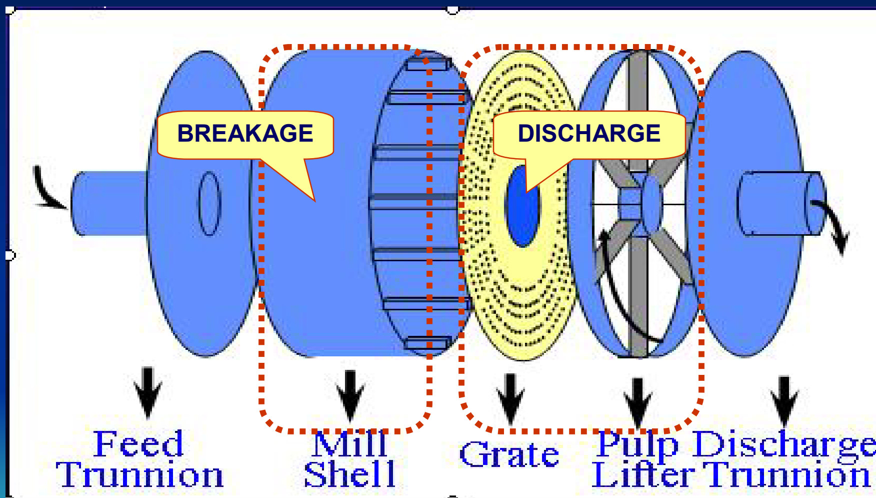
- Steady State Simulations
- Ore Blending
- Mine to Mill Concept
- Process Control

HOW DO WE ENSURE

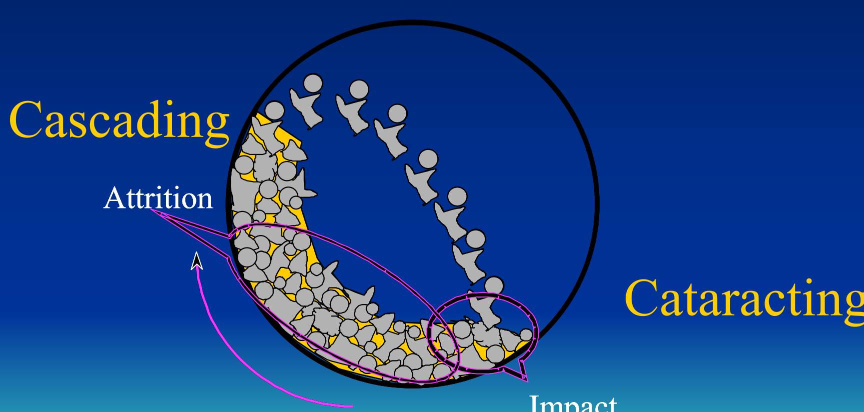
INCREASING ENERGY EFFICIENCY IN SAG MILLS

Sanjeeva Latchireddi and Raj K. Rajamani
Department of Metallurgical Engineering
University of Utah
Salt Lake City, USA

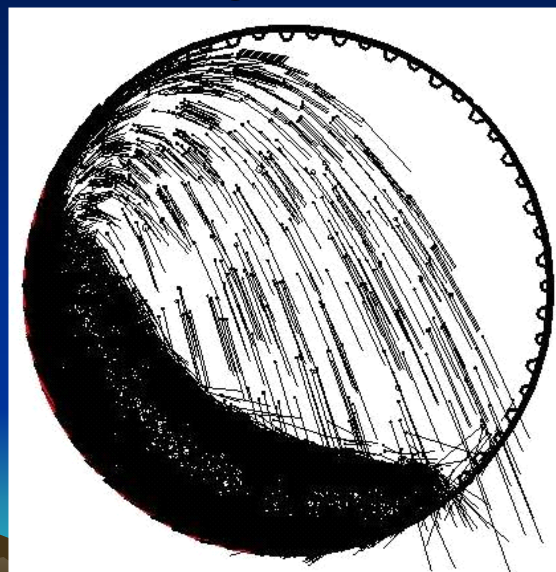
Components of SAG mill



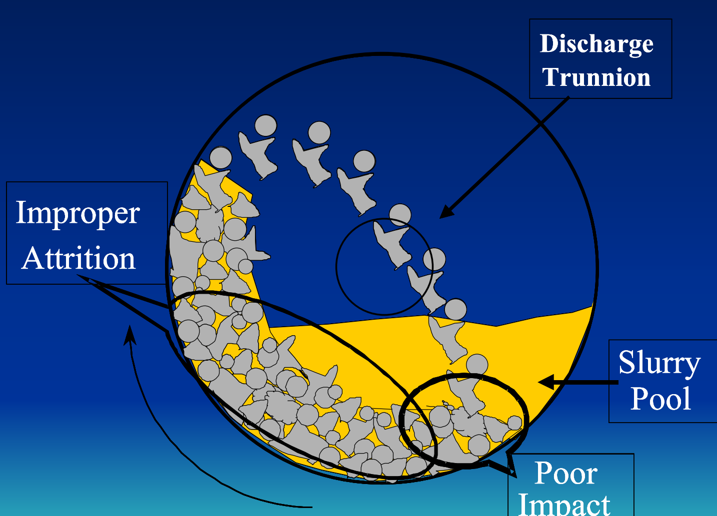
Breakage Process

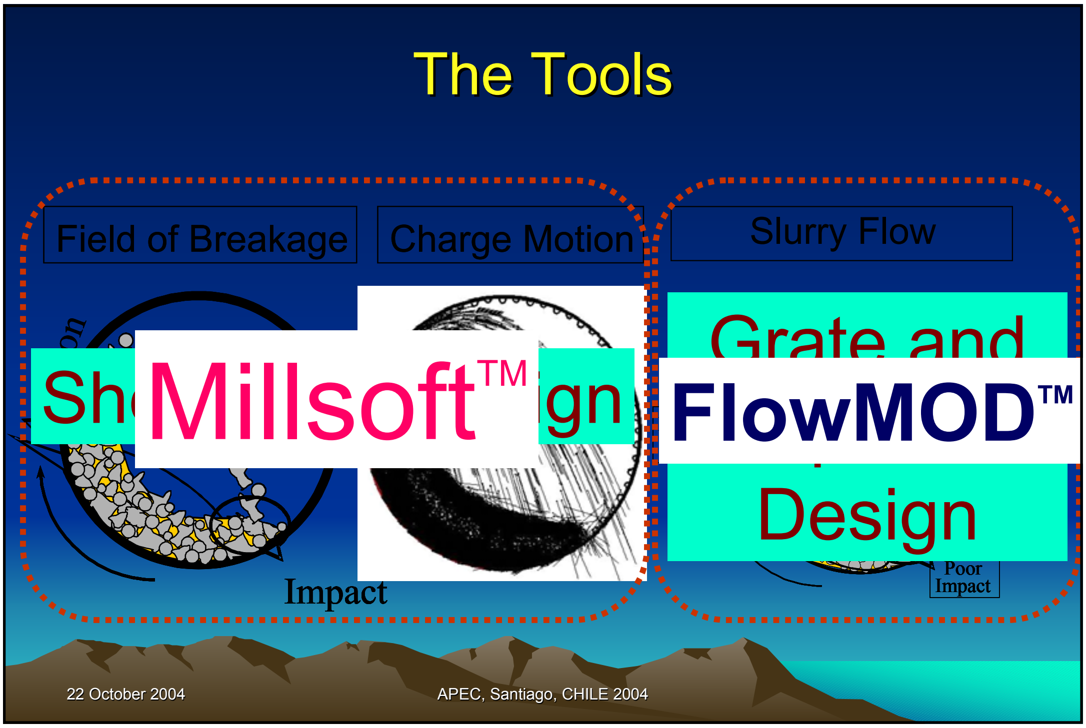


Charge Motion



Slurry Flow

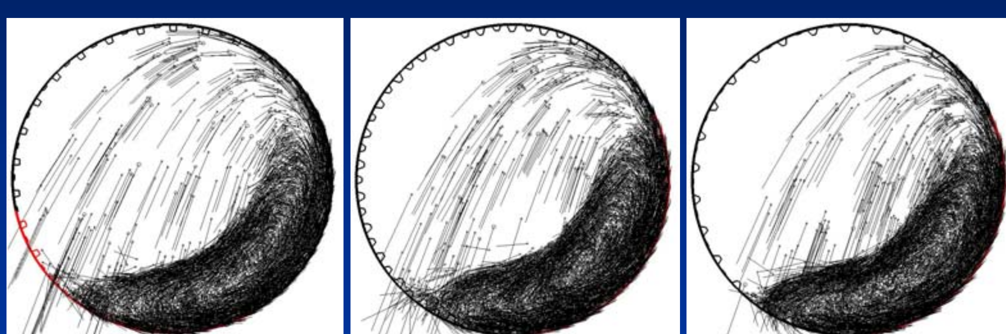



The Tools
Field of Breakage
Charge Motion
Slurry Flow
Millsoft™
FlowMOD™
Design
Impact
Poor Impact
22 October 2004
APEC, Santiago, CHILE 2004


Charge Motion using Millsoft(TM)
22 October 2004
APEC, Santiago, CHILE 2004

Millsoft - parameters

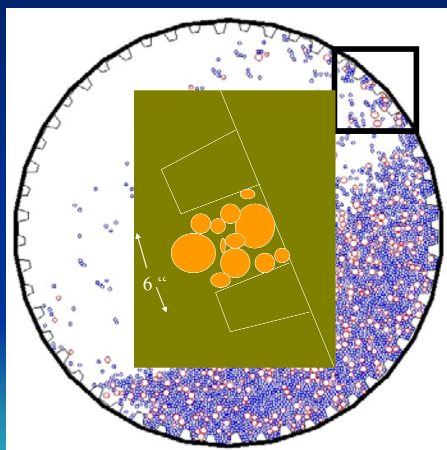
Charge motion



38x24 ft SAG Mill

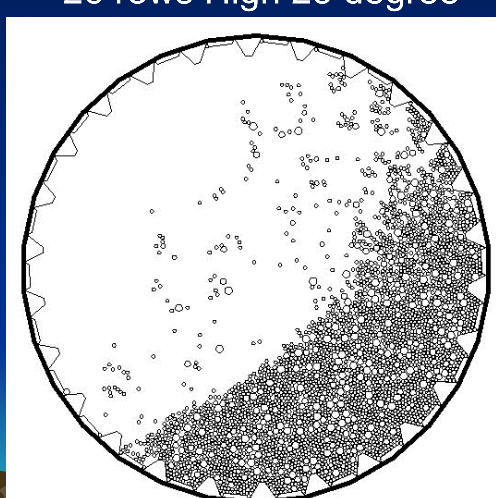
Case study I

52 rows High-Low 17 degree



Case study I (18 Sept 2004)

26 rows High 25 degree

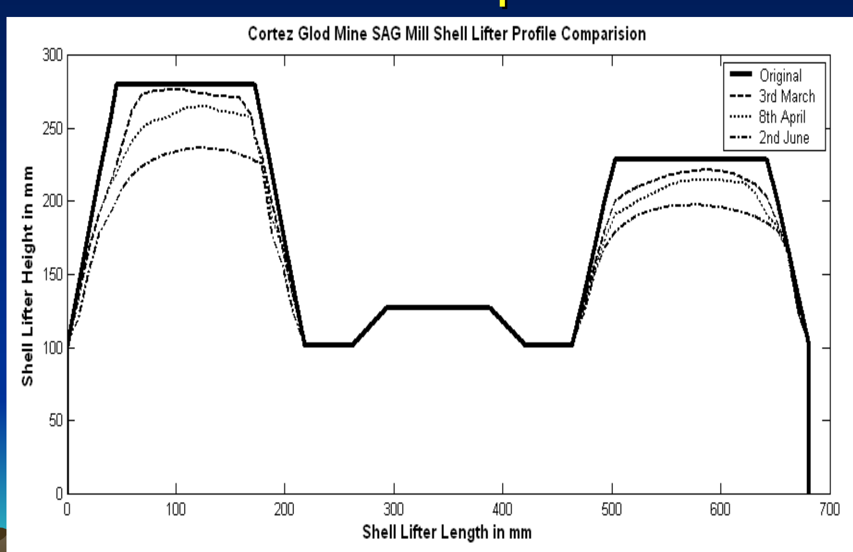


10% less sag power draw.

Industrial Results

Mine	Original	1st Change	Millsoft	Throughput
Collahuasi	6 deg	11 deg	30 deg	11% increase
Alumbrera (36x15 ft)	72 rows 10 deg	48 rows 25 deg	36 rows 30 deg	50,000 to 96,000 tpd
Candelaria (36x15 ft)	72 rows 10 deg	20 deg	36 rows 35 deg	15% increase
Los Pelambres (36x17 ft)	72 rows 8 deg	-	36 rows 30 deg	10,000 tpd increase

Lifter wear profile



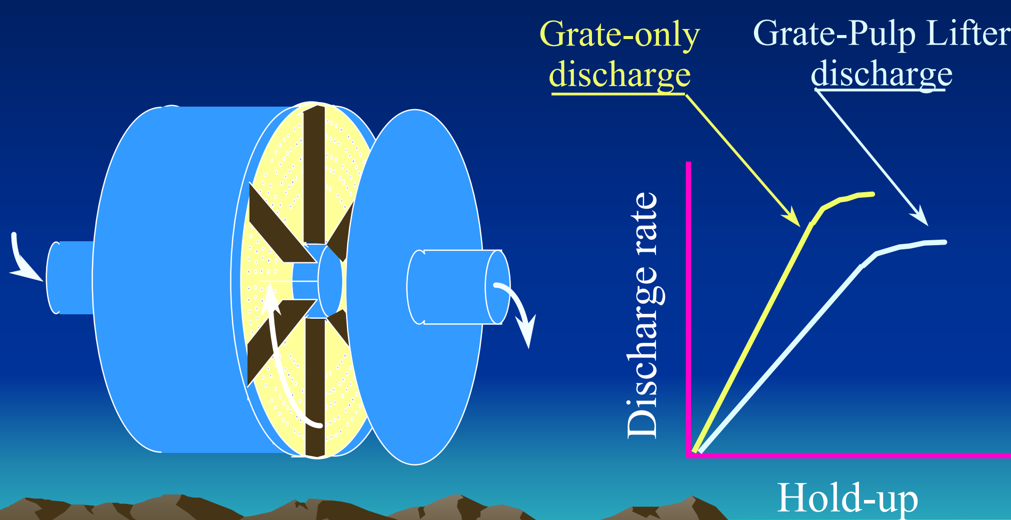
Current Trend

Increase mill speed
Draw more power
Get more throughput
………….Shell lifter design

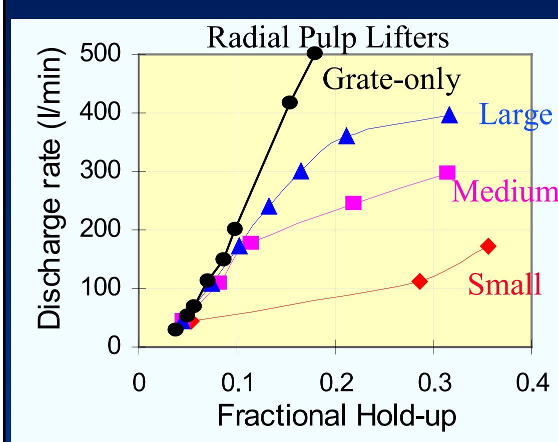
But, what does pulp lifter say?

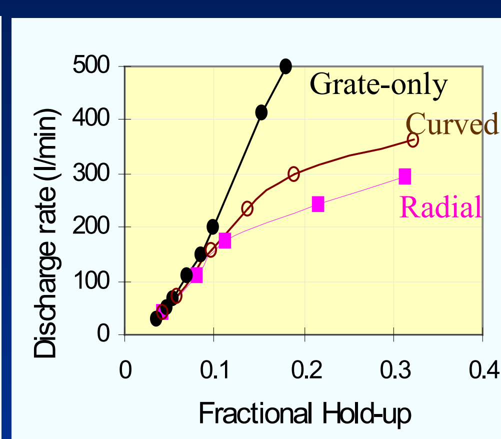
Discharge Grate and Pulp Lifters

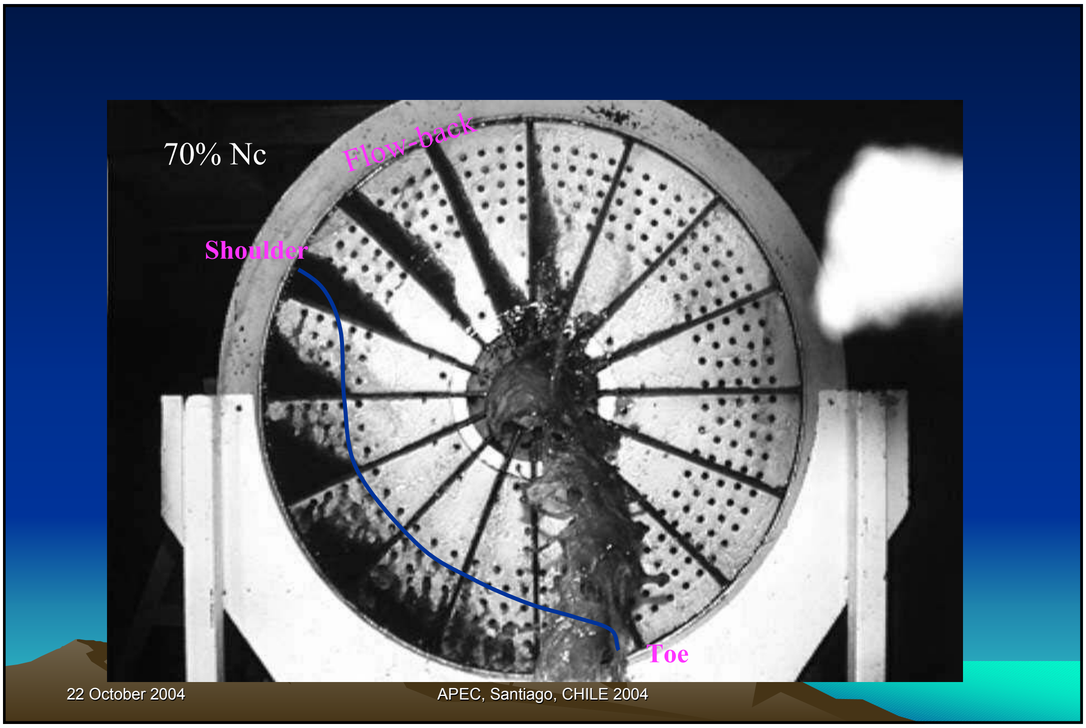
The Concept

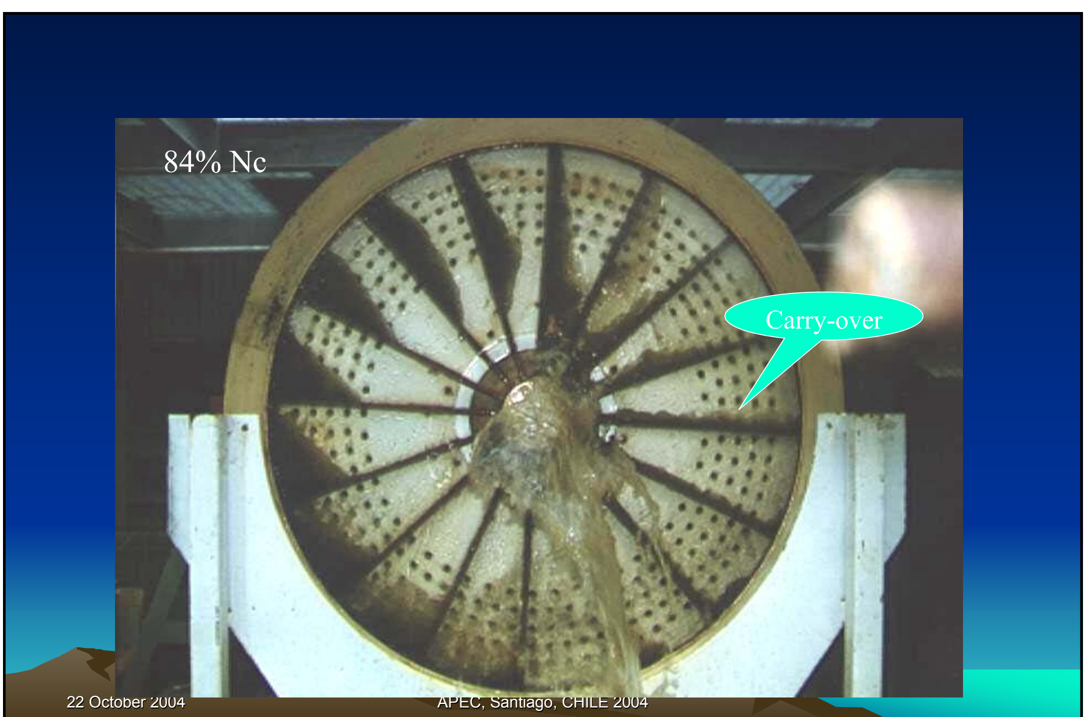


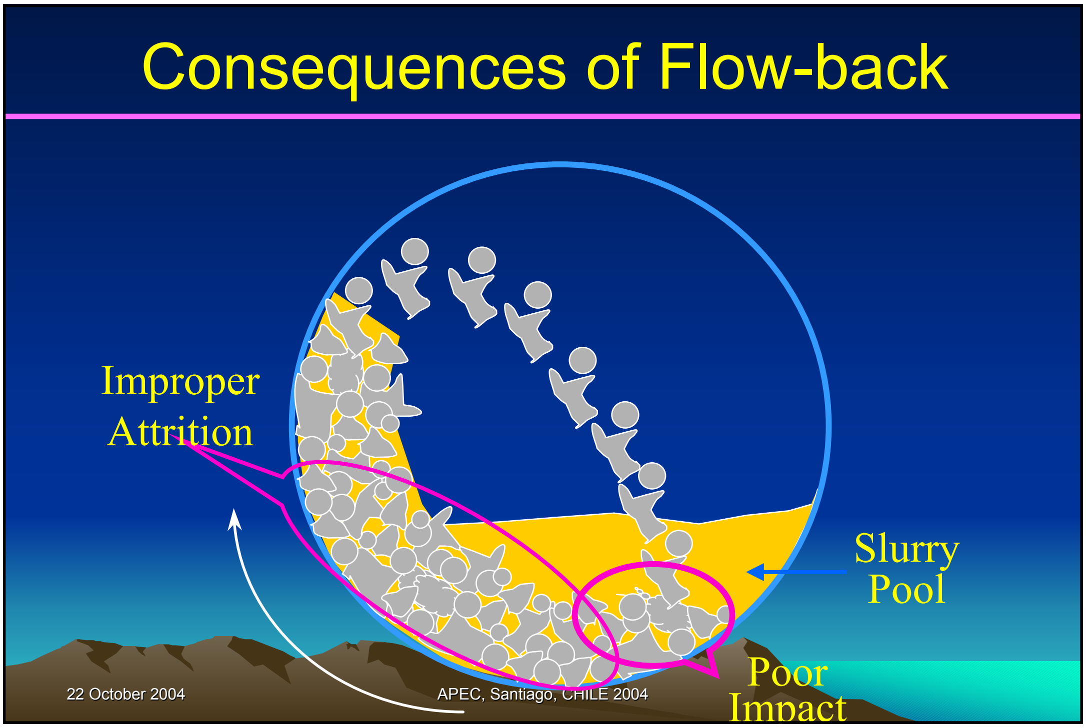
Response of Conventional Designs



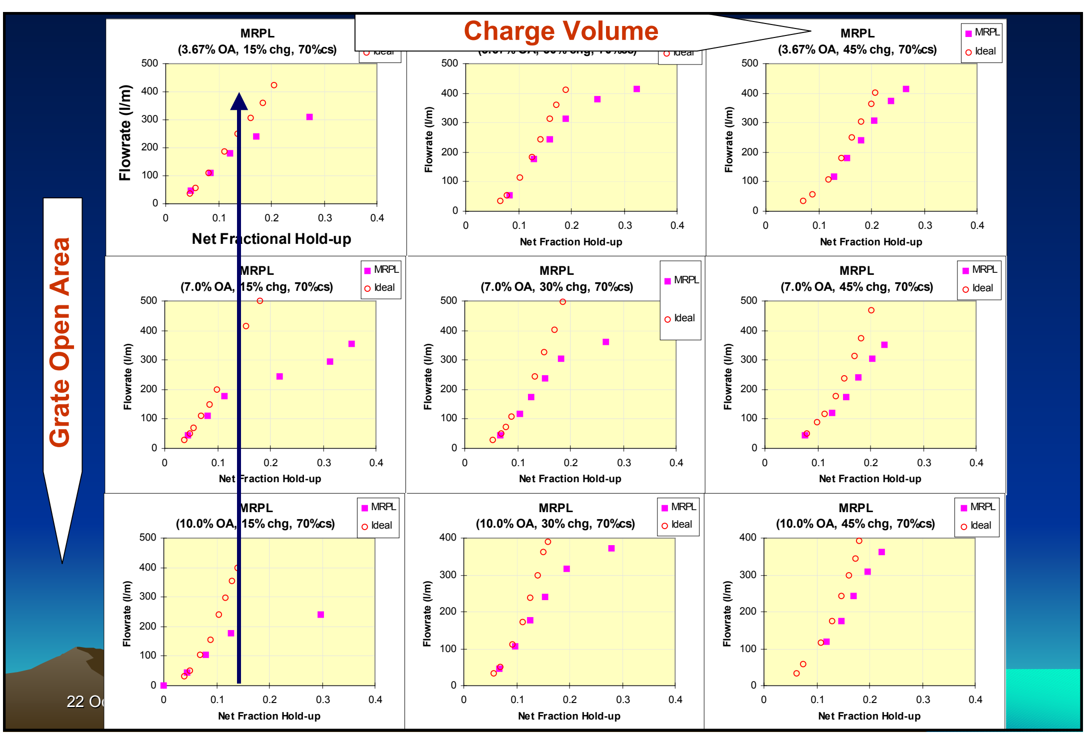



70% Nc
Flow-back
Shoulder
Toe
22 October 2004
APEC, Santiago, CHILE 2004


84% Nc
Carry-over
22 October 2004
APEC, Santiago, CHILE 2004



Consequences of Flow-back
Improper Attrition
Slurry Pool
Poor Impact
22 October 2004
APEC, Santiago, CHILE 2004



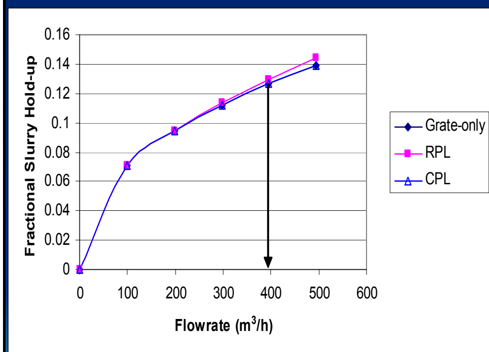
Charge Volume
Grate Open Area
MRPL (3.67% OA, 15% chg, 70%cs)
MRPL (3.67% OA, 45% chg, 70%cs)
MRPL (7.0% OA, 15% chg, 70%cs)
MRPL (7.0% OA, 30% chg, 70%cs)
MRPL (7.0% OA, 45% chg, 70%cs)
MRPL (10.0% OA, 15% chg, 70%cs)
MRPL (10.0% OA, 30% chg, 70%cs)
MRPL (10.0% OA, 45% chg, 70%cs)
MRPL
Ideal
Flowrate (l/m)
Net Fractional Hold-up
Net Fraction Hold-up

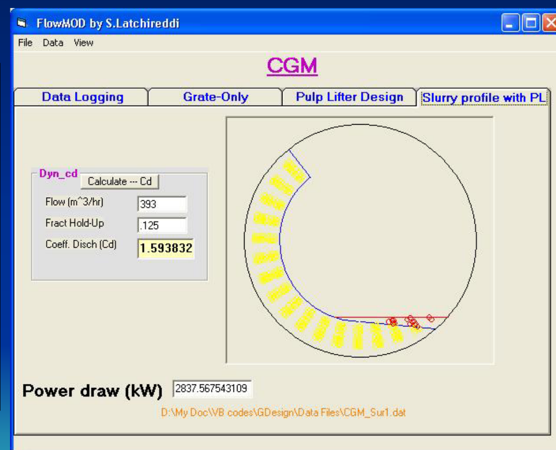
Case Study - 1

Diameter x Length, ft	26x16
Open area %	6.9
Mill speed, rpm	11.6

Crash stop – Normal ore

Slurry profile – Normal ore

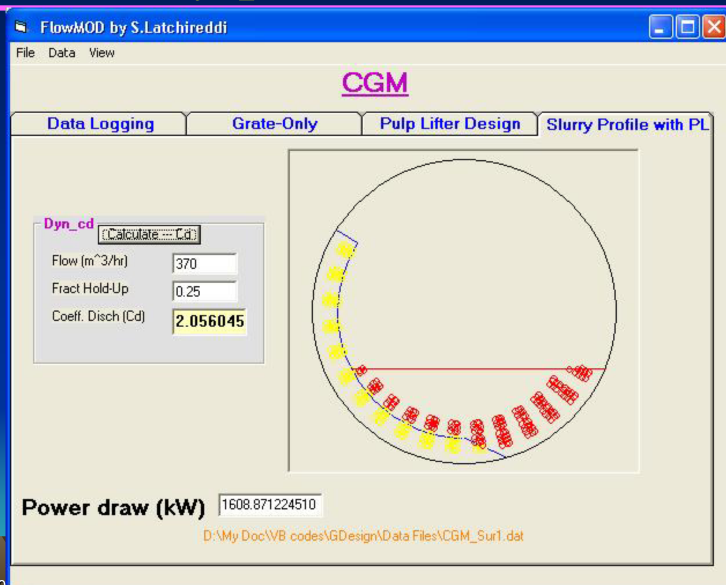




Sandy ore

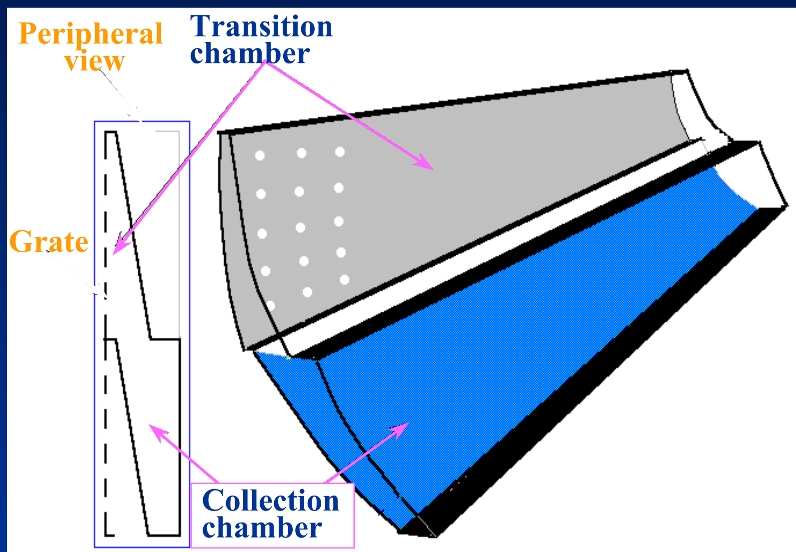
	Normal	Sandy
Bearing Pressure (feed)	460	462
Bearing Pressure (discharge)	482	477
Power (mW)	2800	1530
Sag feed rate, tph	473	423

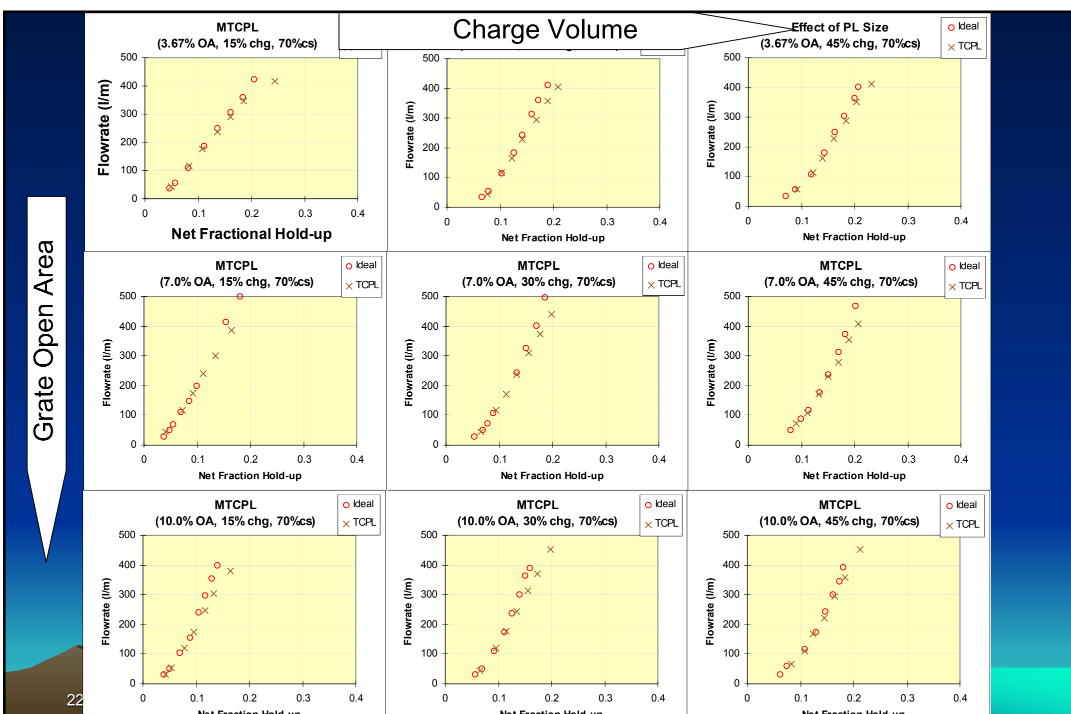
Slurry profile–sandy ore



Ensuring good grinding conditions

Twin Chamber Pulp Lifter



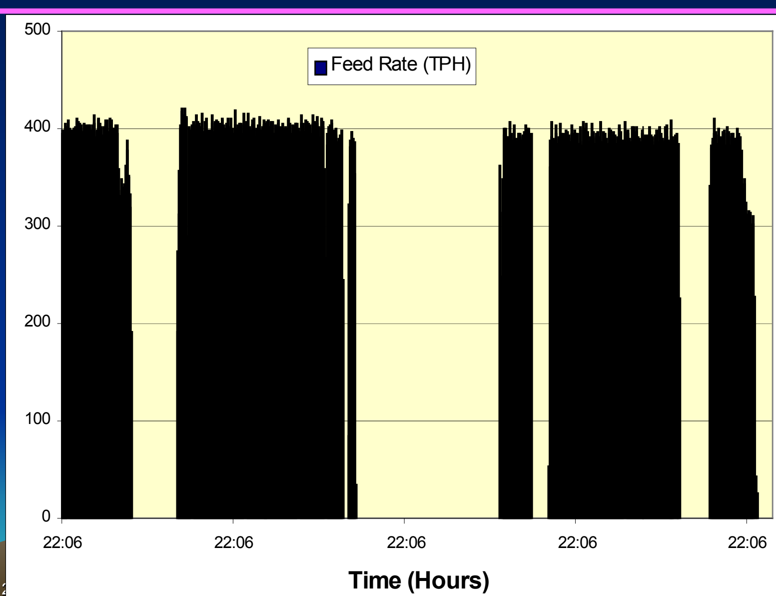


Case Study

Ensuring good grinding conditions

Diameter x Length, ft	26x12
Open area %	8.5
Mill speed,	75% cs

Mill Throughput

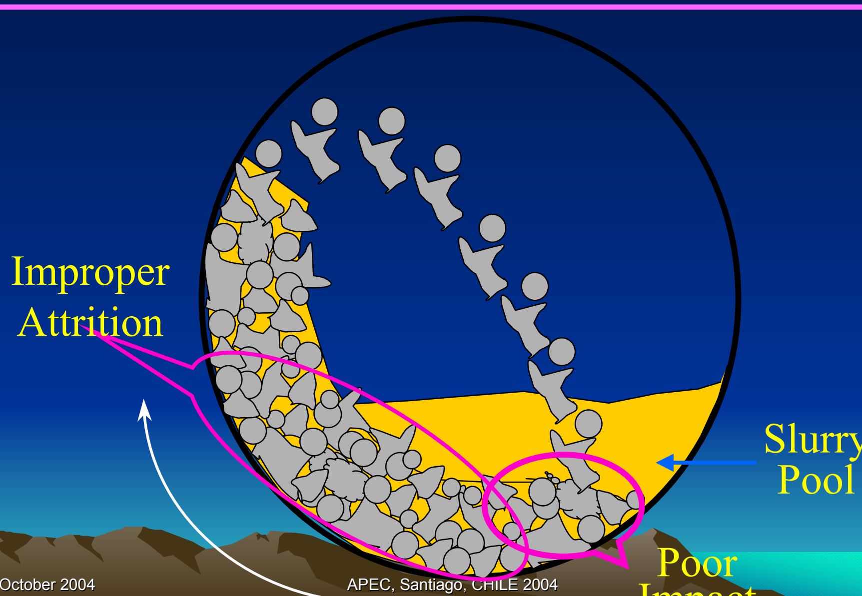


Mill Contents (Pre-installation)

Total Volume -37%

600 mm deep slurry

Mill operation (with RPL)

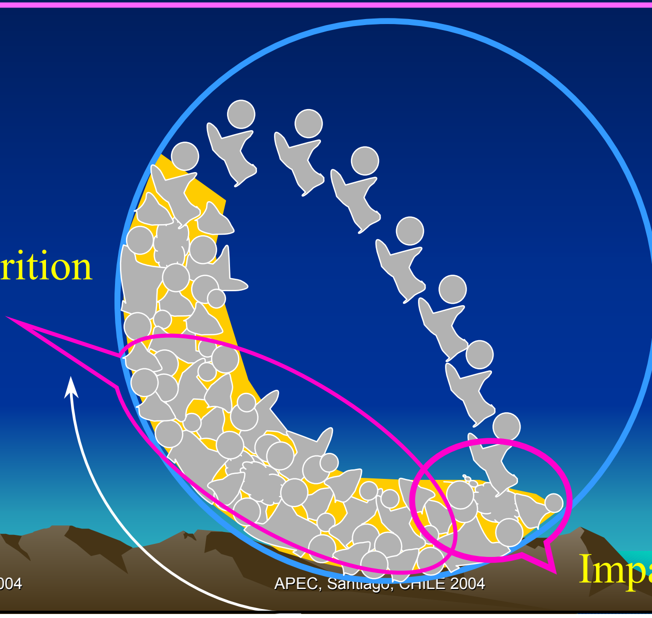


Mill Contents (Post-installation)

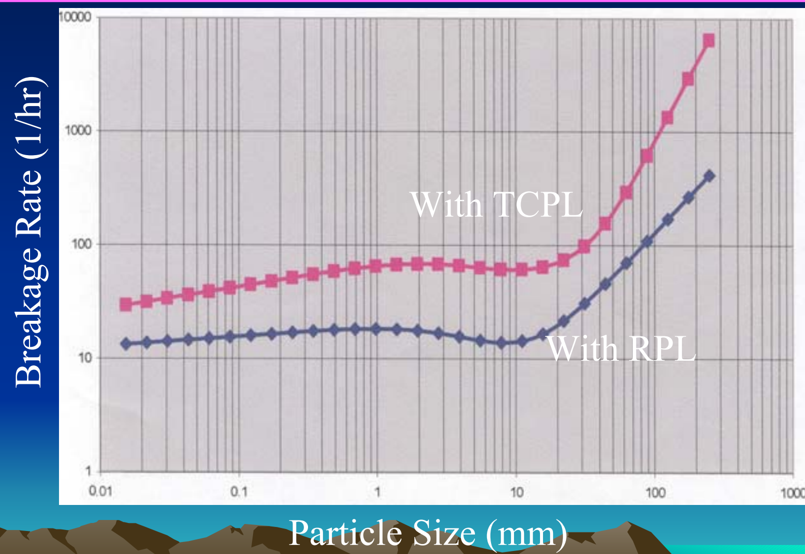
Total Volume -17%

No excess slurry

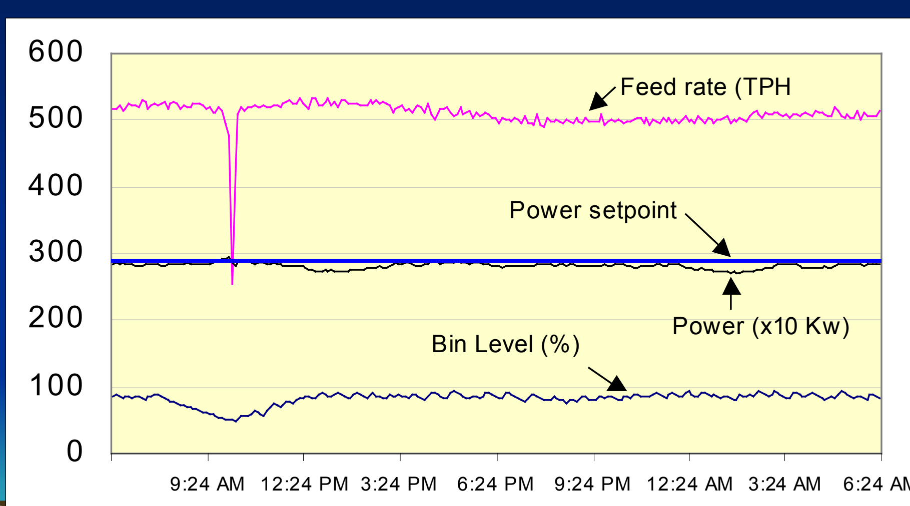
Ideal Grinding with TCPL



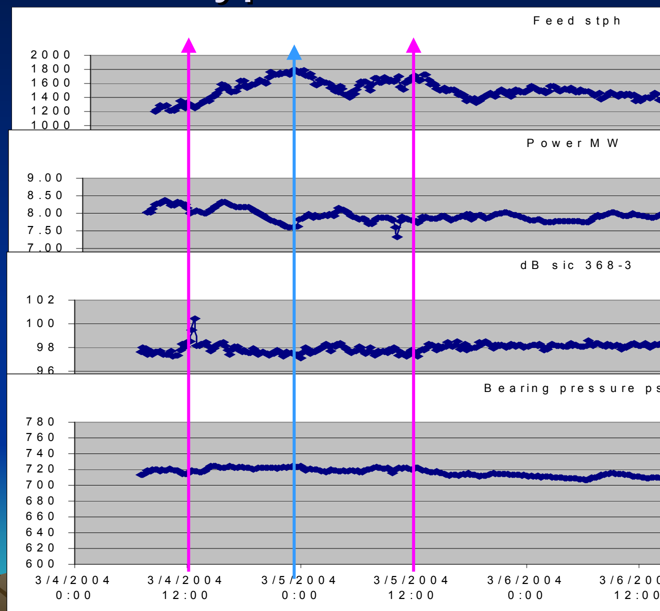
Breakage parameters



Mill Performance with TCPL



Typical trends



Benefits of TCPL

Current Installations – 11 since 1999

- ***On average 15% increase in Mill Capacity***
- ***Power Consumption reduced by 15%***
- ***Reduced maintenance***
- ***Significantly improved wear-life of PL (not changed since 1999)***
- ***Made mill control easy***

Conclusions

Shell Lifters, Grate and Pulp Lifters play a critical role on SAG mill performance

Millsoft and FlowMOD are the effective and proven tools for design optimization of Shell Lifters, Grate and Pulp Lifters

TCPL always ensures the best grinding conditions inside the mill thus allowing the mill to operate at maximum capacity

ACHKNOWLDEGEMENTS

DOE Project : **DE-FC26-03NT41786**

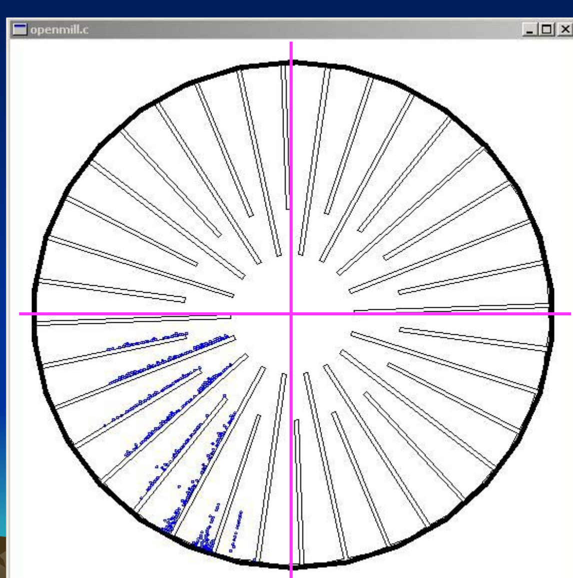
Improving Energy Efficiency via Optimized Charge Motion and Slurry Flow in Plant Scale SAG Mills

Industry partners
Outokumpu Technology
Weir Rubber Engineering
Cortez Gold Mines
Kennecott Utah Copper Corporation
Process Engineering and Resources Inc.

Pebbles Motion in Pulp Lifters

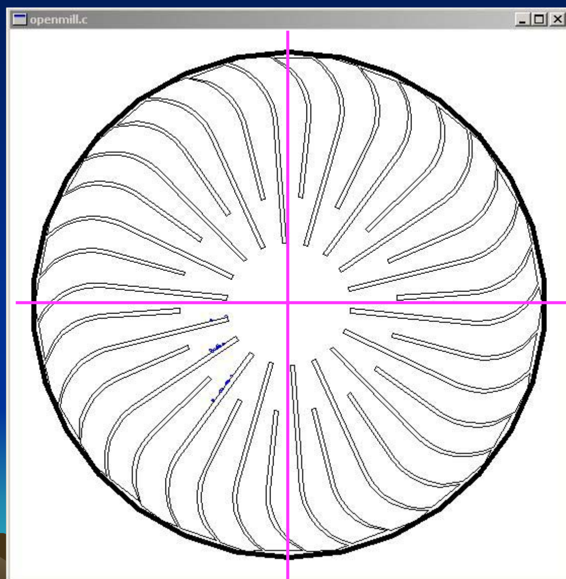
- Radial Pulp Lifter design
- Curved Pulp Lifter design

Flow of pebbles in radial pulp lifters

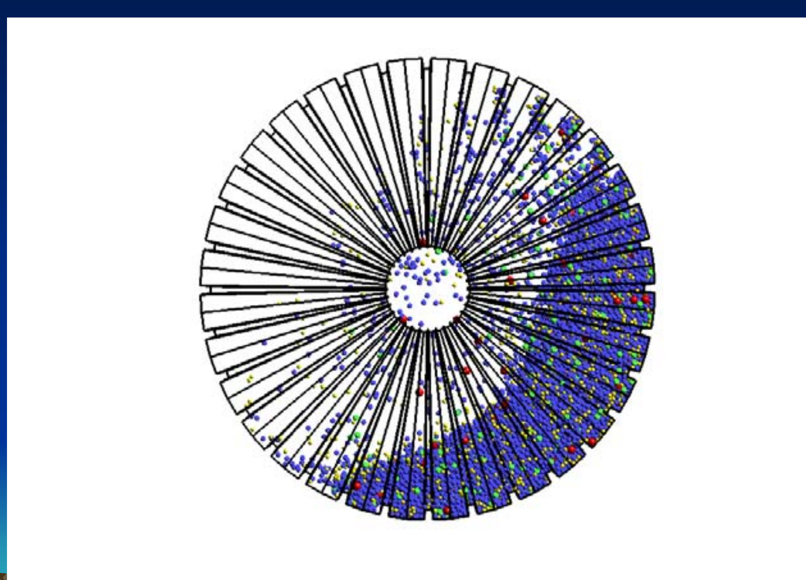


40 ft dia mill
74% CSpeed
63.5 mm pebble size
980 tph pebbles

Flow of pebbles in curved pulp lifters



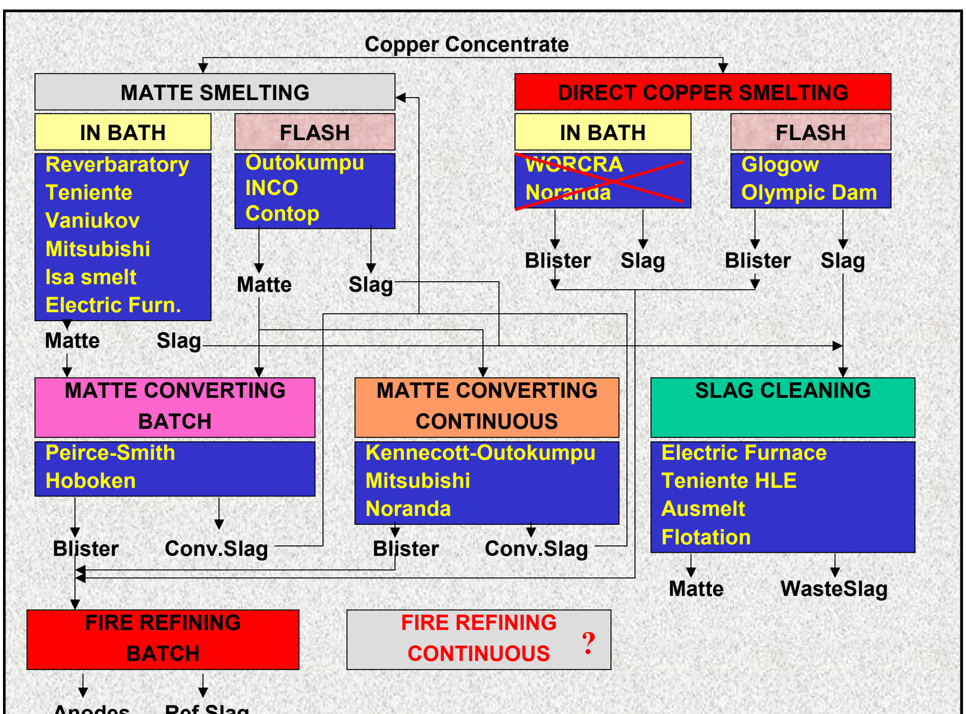
40 ft dia mill
74% CSpeed
63.5 mm Pebbles
980 tph Pebbles



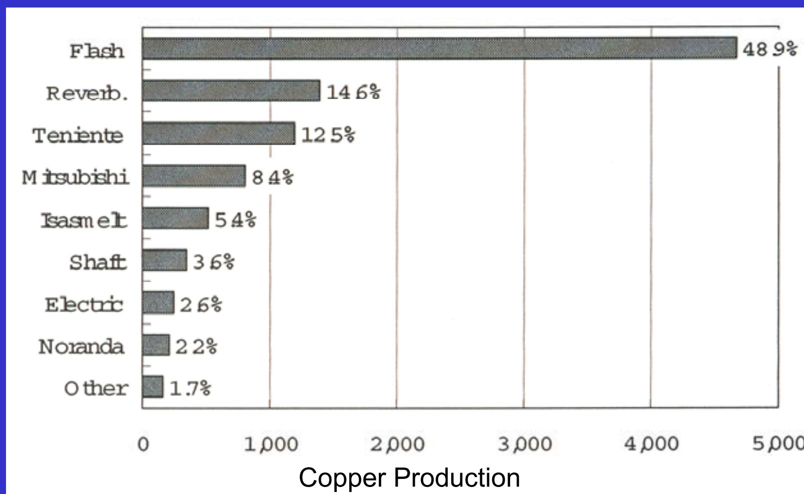
UNIVERSIDAD DE CHILE
FACULTAD DE CIENCIAS FISICAS Y MATEMATICAS
DEPARTAMENTO INGENIERIA DE MINAS

Andrzej Warczok and Gabriel Riveros

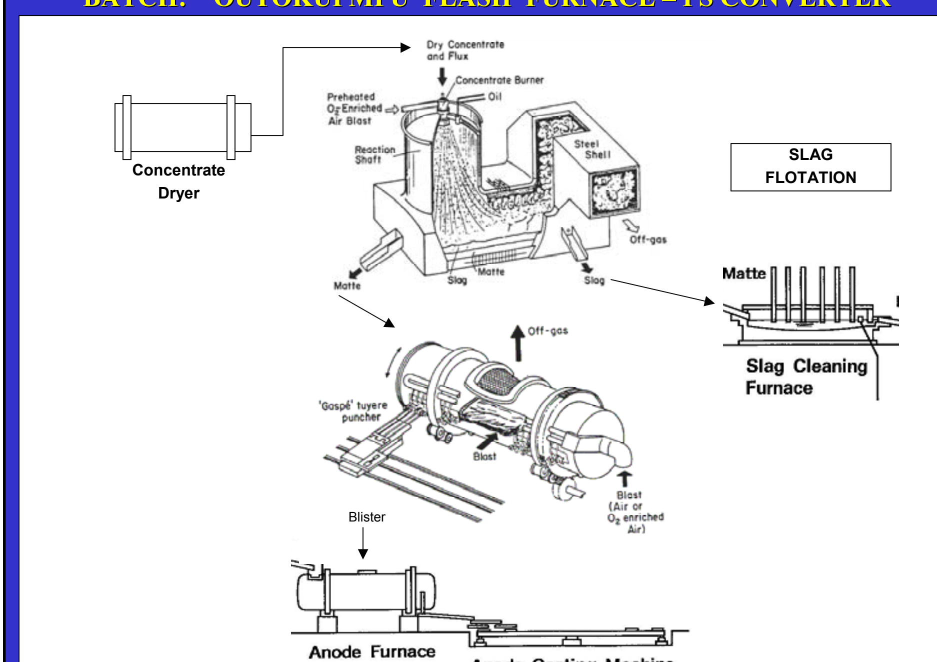
ENERGY EFFICIENCY IN BATCH, CONTINUOUS AND ONE-STEP COPPER PYROMETALLURGICAL PROCESSES



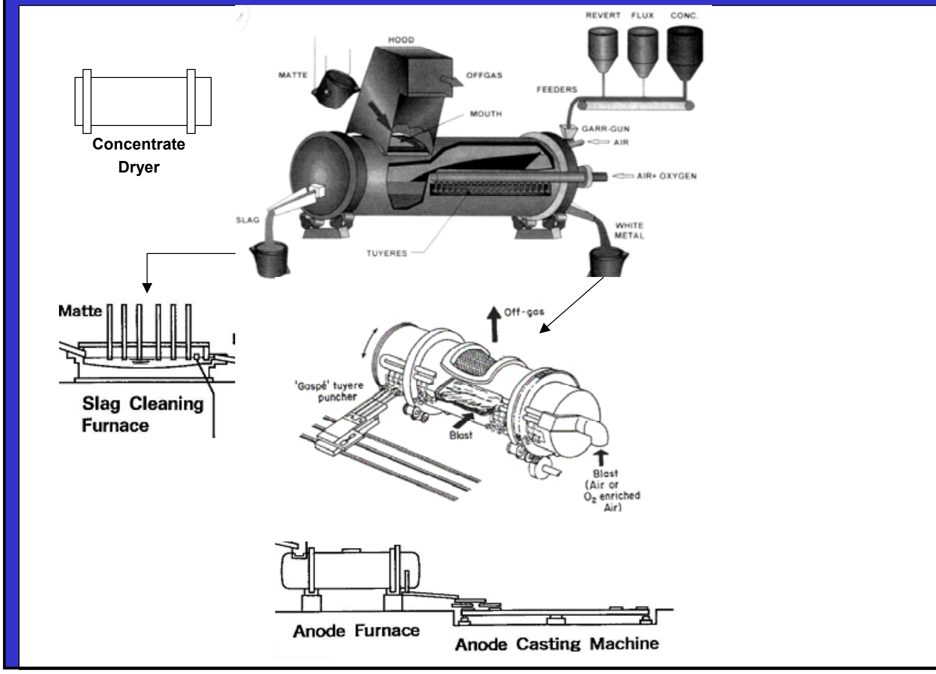
World Copper Production
Classified by Smelting Process



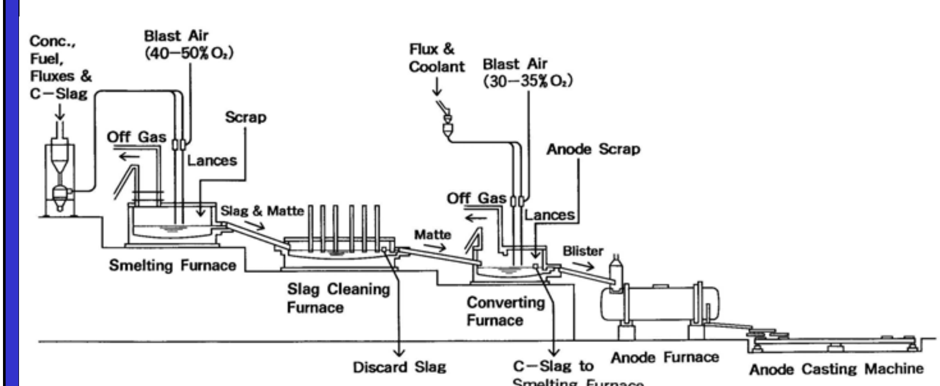
BATCH: OUTOKUPMPU FLASH FURNACE – PS CONVERTER



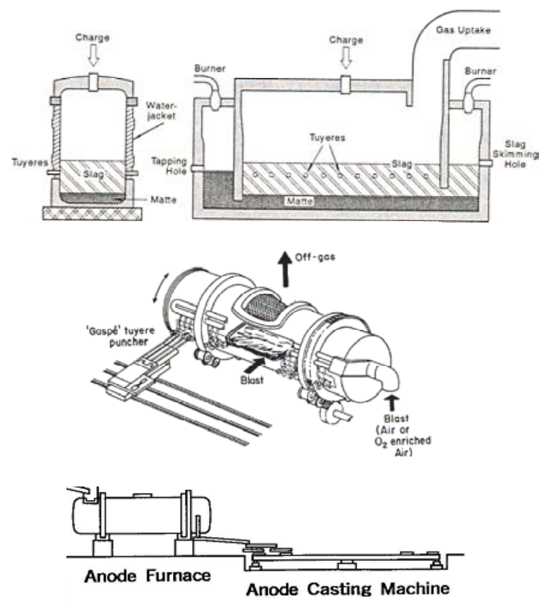
BATCH: TENIENTE CONVERTER – PS CONVERTER



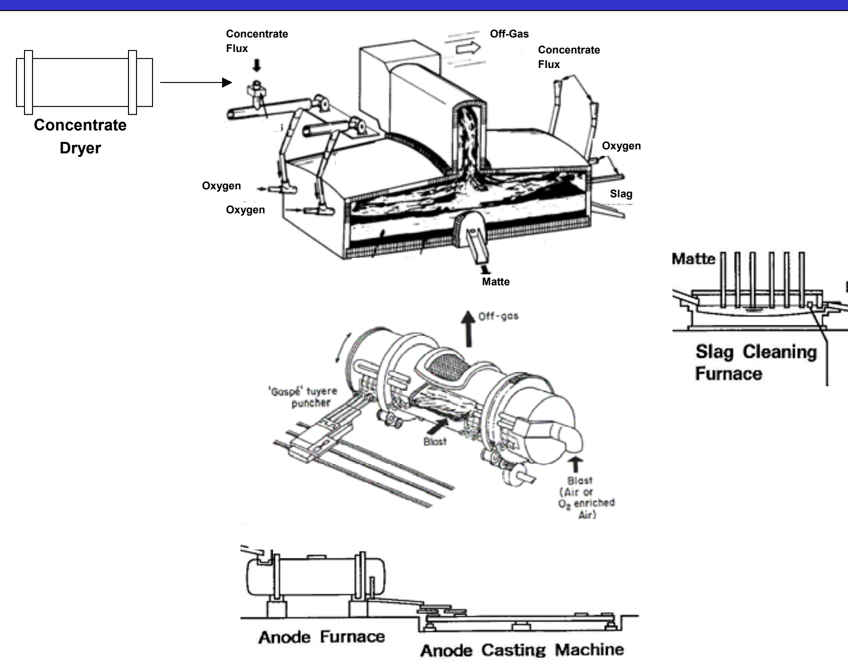
CONTINUOUS: MITSUBISHI PROCESS



BATCH: VANIUKOV FURNACE – PS CONVERTER



BATCH: INCO FLASH FURNACE – PS CONVERTER



ENERGY CONSUMPTION

Energy requirements vary for the different pyrometallurgical processes.

The table compares the energy requirements for seven smelter types, including the energy equivalents of the materials consumed by each process.

Flash furnaces make the most efficient use of the thermal energy released during the oxidation of sulfides; they generate sufficient heat to provide a large proportion of the thermal energy for heating and melting the furnace charge.

Electric furnaces use electrical energy efficiently because of the low heat loss through the effluent gas, they make limited use of the heat produced during oxidation of the sulfide minerals, and their energy costs are high because of the high price of electricity.

Energy Requirements for Pyrometallurgical Processes (GJ/ton Cu)

Process	Teniente Converter	Reverb-dry charge	Electric furnace	INCO flash	Outokumpu flash	Noranda reactor	Mitsubishi reactor
Materials handling	0.70	0.77		0.77	0.60	0.83	0.70
Dry or roast	0.85	0.70	2.82	1.86	1.23	0.80	1.29
Smelting:							
Fuel	4.25	14.50			0.80	3.72	6.46
Electricity	0.64	0.64	19.03	0.05		1.26	1.58
Surplus steam		–4,35			–3.43	– 1.82	–8.00
Converting:Electricity	0.40	1.26	2.92	0.94	0.64	0.37	1,42
Fuel	0.54	0.32	3.58	0.09	0.25		
Slag Cleaning	1.10				1.49	1.31	1,35
Gas cleaning:							
Hot gas	0.8	2.83	0.78	0.59	0.42	0.69	0.86
Cold gas		0.40	2.21	0.31	0.21		0.32
Fugitive emissions	3.5	3.57		3.57	3.57	3.57	0.89
Acid plant	3.2	3.87	4.74	3.19	3.86	3.10	4,08
Water	0.10	0.10		0.10		0.10	0.10
Anode furnace	5.82	5.82	5.10	5.82	5.82	5.82	5.82
Materials:							
Miscellaneous					0.04	0.65	0.63
Oxygen				3.53	3.04	3.17	1.29
Electrodes			0.86				0.16
Fluxes	0.04	0.03	0.12	0.02	0.01	0,02	0.06
Water	0.08	0.08		0.08	0.08		0.08
Anode furnace	0.47	0.47	0.51	0.47	0.47	0.47	0.47
Total	**22.49**	**30.93**	**42.52**	**21.26**	**18.92**	**24.01**	**19.77**

SOURCE: Charles H Pitt and Milton E. *Wadsworth, An Assessment of Energy Requirements in Proven and New Copper Processes*, report prepared for the US Department of Energy, contract no EM-78-S-07-1743

CONTINUOUS SMELTING AND CONVERTING PROCESSES

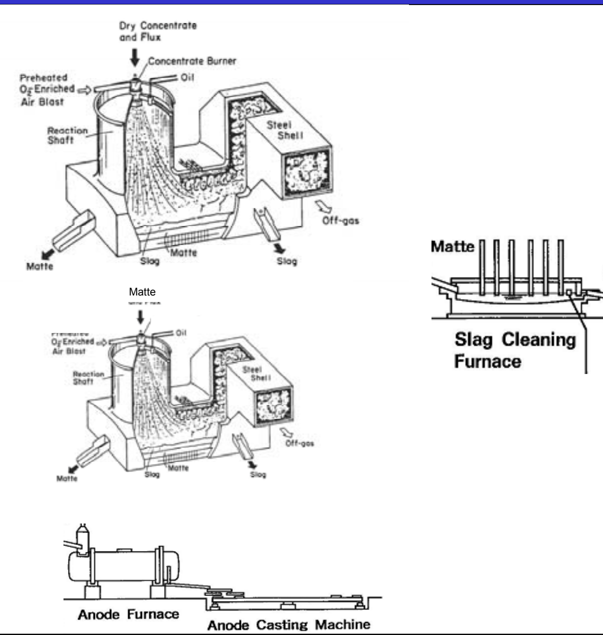
Continuous smelting and converting processes would be more energy efficient than conventional smelting and converting because heat loss in transferring the matte to the converter and the slag to slag cleaning unit would be eliminated or reduced.

The potential for heat loss in fugitive emissions also would be reduced.

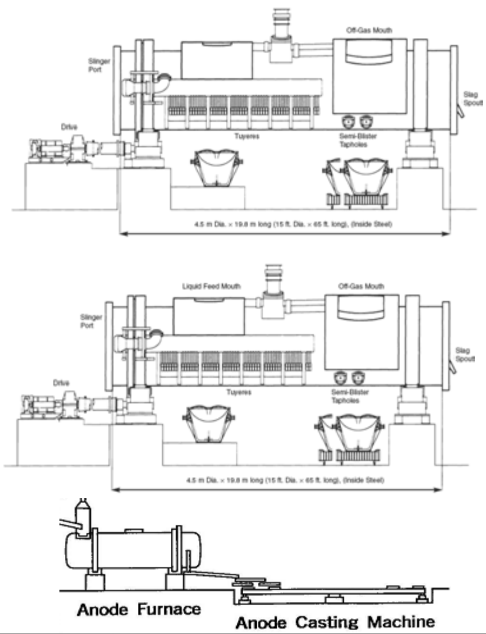
However, continuous Kennecott-Outokumpu flash converting process requires matte quenching and milling, what affects the total energy efficiency.

"In bath" continuous Noranda matte converting process can produce only semi-blister, which requires final blow. Currently, the process operation is stopped.

CONTINUOUS: OUTOKUMPU FLASH SMELTER – KENNECOTT-OUTOKUMPU FLASH CONVERTER



CONTINUOUS: NORANDA SMELTING AND CONTINUOUS CONVERTING



ONE STEP COPPER SMELTING

A window on the future of pyrometallurgy is provided by metal making directly from mineral concentrate in a single, closed, continuous oxygen converter. The impossible dreams of continuous metalmaking directly from mineral feed have a long history.

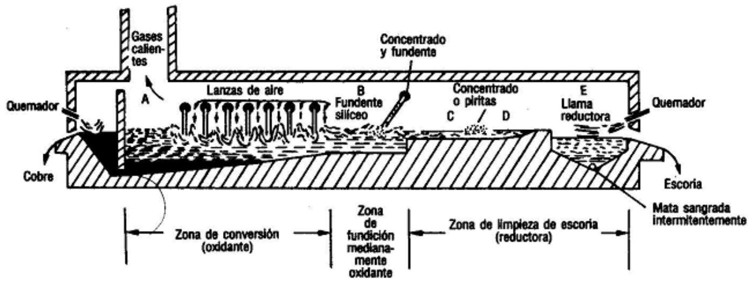
In 1896, Oliver Garretson described a logical process for continuous copper smelting, converting, and slag cleanup, but it remained in two dimensions.

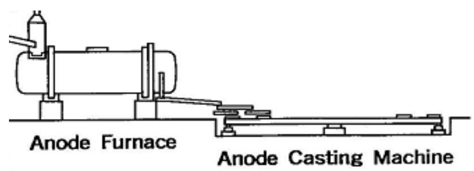
In 1968, Horward Warner described his WORCRA concepts, "which seek to maximize energy conservation" by "direct smelting-converting *in one furnace* in which both smelting, dispersed-phase refining and slag conditioning and settling are combined in distinct but communicating zones or branches."

The genuine merit of his thinking was demonstrated in years of pilot-plant operations, but commercial operations did not follow.

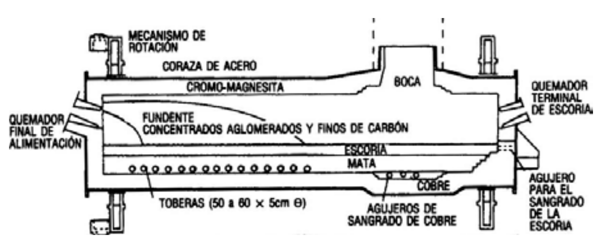
A genuine one-step process could result in a savings of 10 to 20 percent of the energy used in smelting and converting.

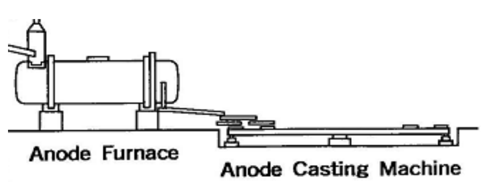
ONE STEP COPPER SMELTING : WORCRA PROCESS





ONE STEP COPPER SMELTING : NORANDA PROCESS

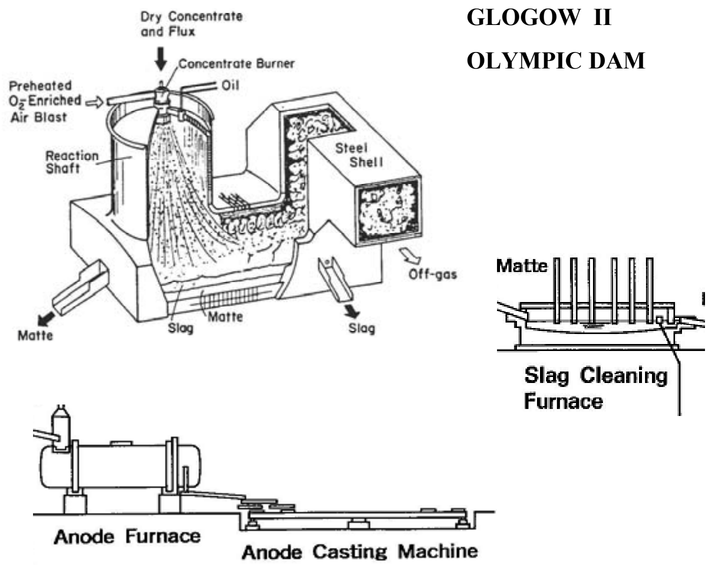




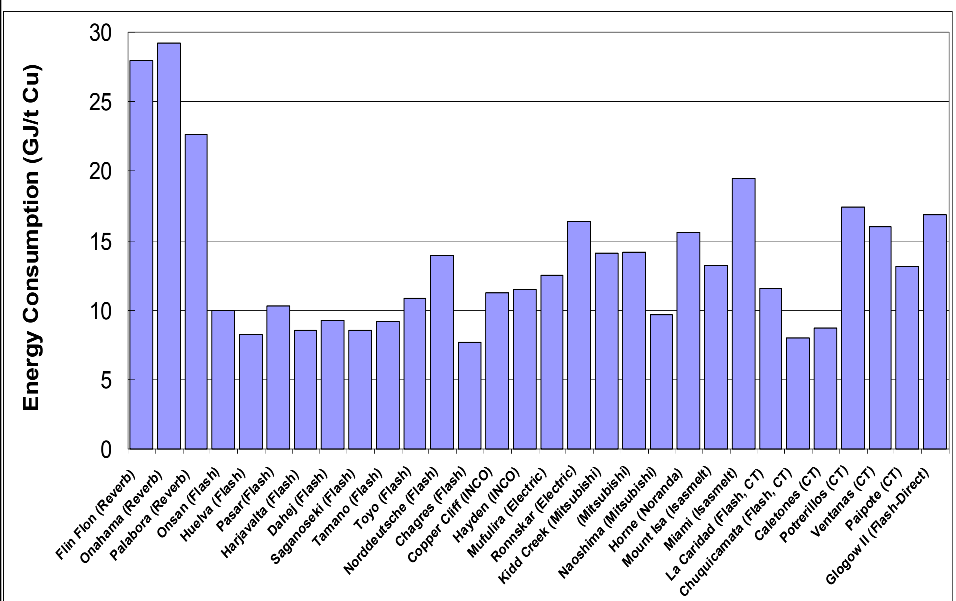
ONE STEP COPPER SMELTING : OUTOKUMPU FLASH PROCESS

GLOGOW II

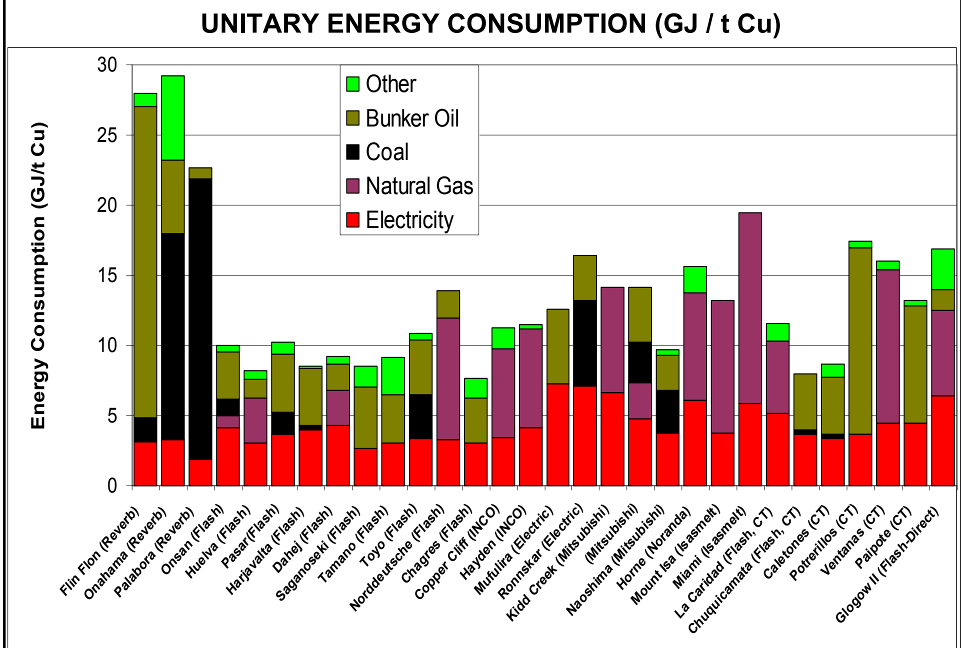
OLYMPIC DAM



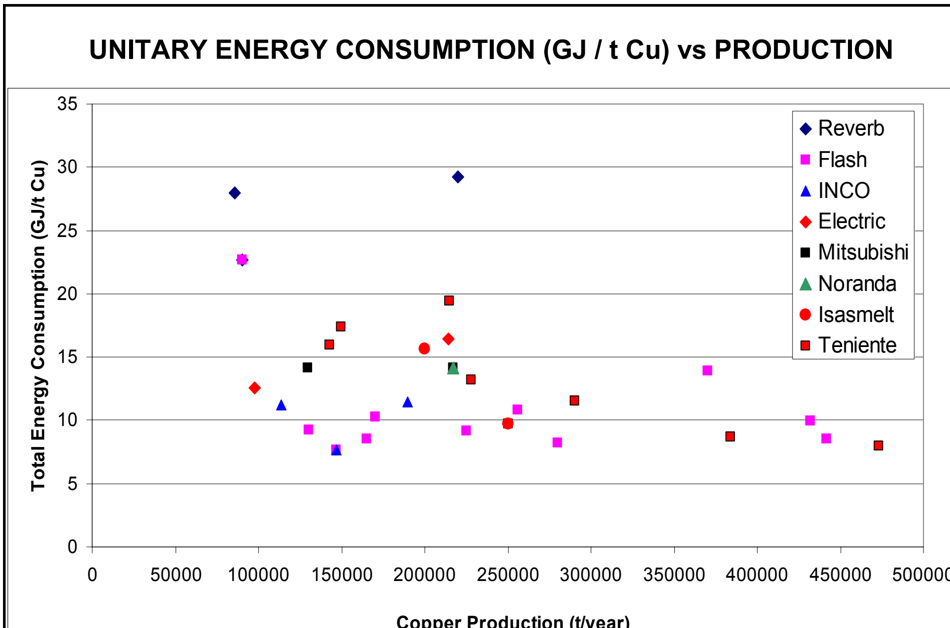
UNITARY TOTAL ENERGY CONSUMPTION (GJ / t Cu)



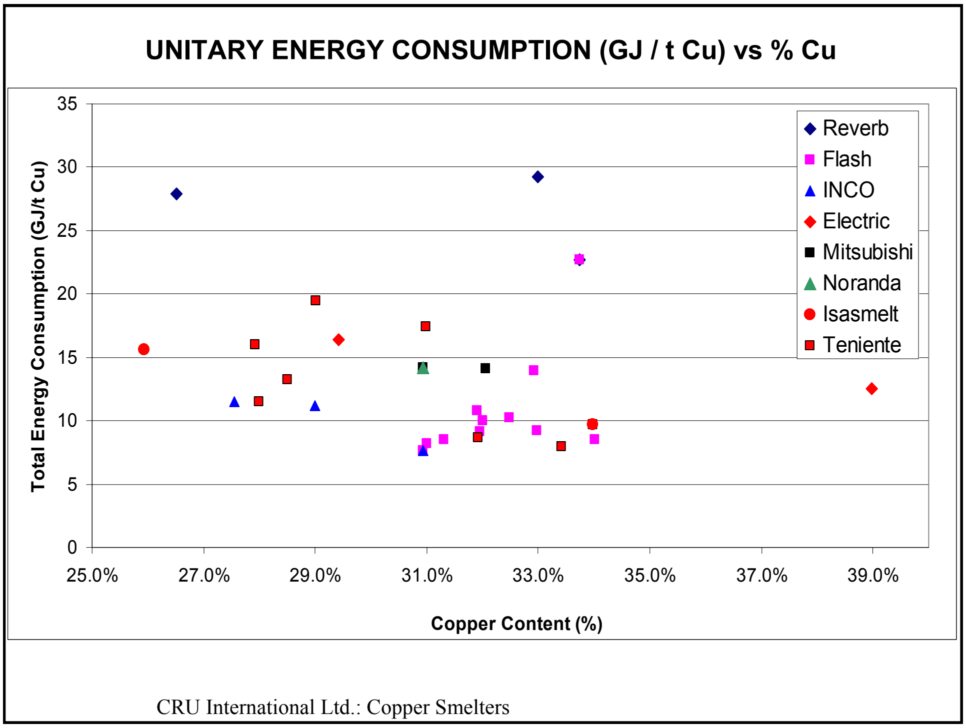
CRU International Ltd.: Copper Smelters



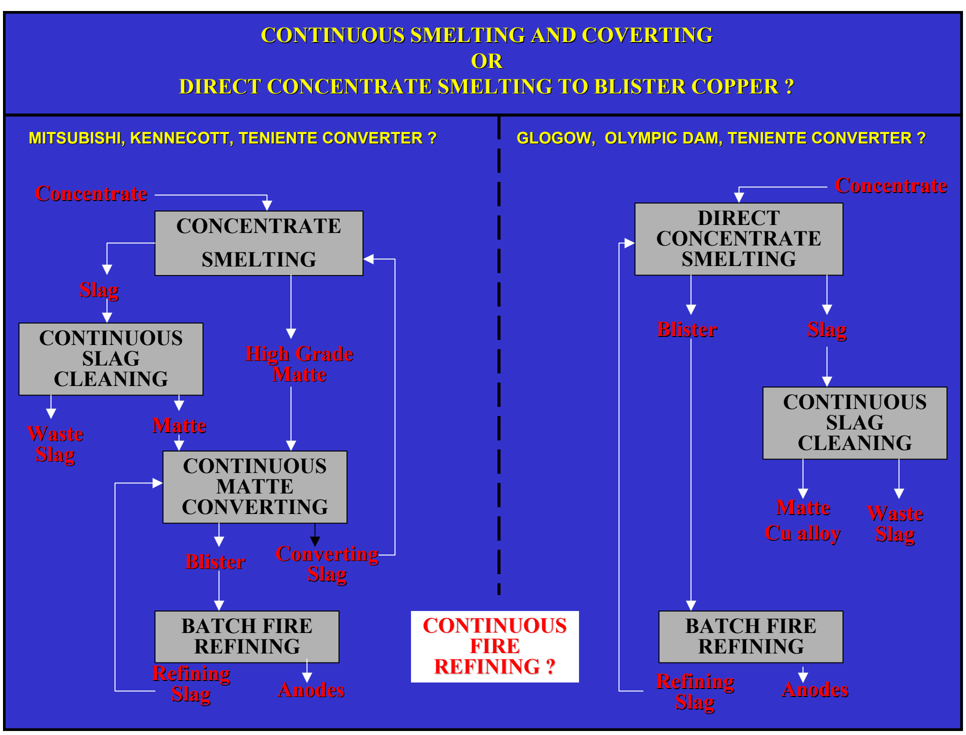
CRU International Ltd.: Copper Smelters



CRU International Ltd.: Copper Smelters



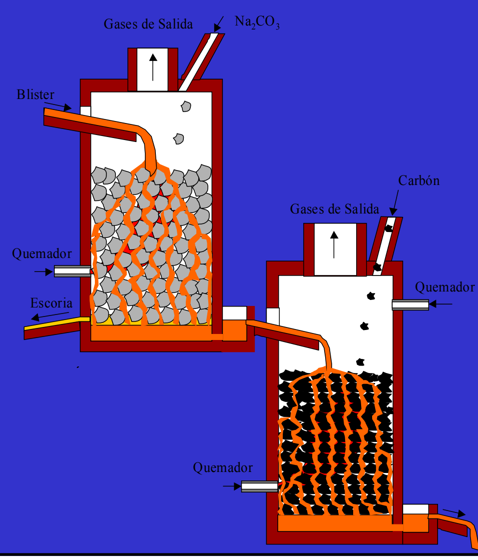
UNITARY ENERGY CONSUMPTION (GJ / t Cu) vs % Cu
Total Energy Consumption (GJ/t Cu)
Copper Content (%)
35
30
25
20
15
10
5
0
25.0%
27.0%
29.0%
31.0%
33.0%
35.0%
37.0%
39.0%
Reverb
Flash
INCO
Electric
Mitsubishi
Noranda
Isasmelt
Teniente
CRU International Ltd.: Copper Smelters



CONTINUOUS SMELTING AND COVERTING
OR
DIRECT CONCENTRATE SMELTING TO BLISTER COPPER ?
MITSUBISHI, KENNECOTT, TENIENTE CONVERTER ?
Concentrate
CONCENTRATE SMELTING
Slag
CONTINUOUS SLAG CLEANING
High Grade Matte
Waste Slag
Matte
CONTINUOUS MATTE CONVERTING
Blister
Converting Slag
BATCH FIRE REFINING
Refining Slag
Anodes
CONTINUOUS FIRE REFINING ?
GLOGOW, OLYMPIC DAM, TENIENTE CONVERTER ?
Concentrate
DIRECT CONCENTRATE SMELTING
Blister
Slag
CONTINUOUS SLAG CLEANING
Matte Cu alloy
Waste Slag
BATCH FIRE REFINING
Refining Slag
Anodes

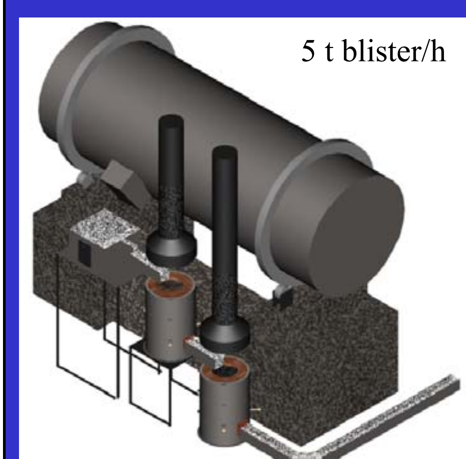
FONDEF ENAMI RHI REFRACTORIES

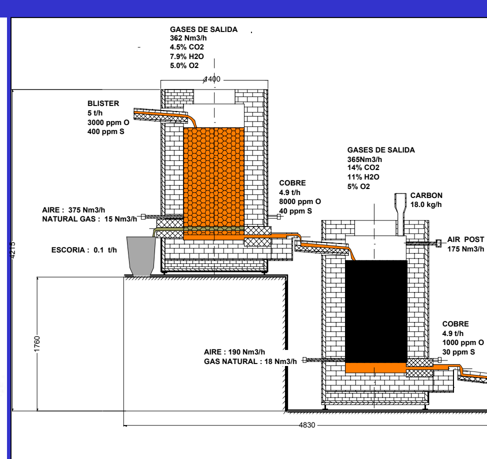
CONTINUOUS FIRE REFINING



FONDEF ENAMI RHI REFRACTORIES

CONTINUOUS FIRE REFINING – PILOT INSTALLATION





SUMMARY

Strong trend for growing prices of energy carriers will result in growing participation of energy costs in copper production.

The increase of energy efficiency of pyrometallurgical processes can be achieved by:

1. Optimization of existing continuous smelting , batch converting and refining processes.

2. Development of continuous matte converting and blister refining processes;

3. Development of one-step copper smelting processes combined with continuous fire refining;

Optimization of existing continuous smelting , batch converting and refining processes.

1. <u>GENERAL</u>

a) Minimization of reverts generation;

b) Recycling of liquid, hot reverts;

c) Utilization of the heat of matte converting for scrap melting;

d) Synchronization of batch processes (converting, fire refining) with continuous smelting – reduction of waiting time of converters and anode furnaces;

2. <u>SMELTING</u>

a) High oxygen enrichment in smelting unit;

b) Decrease of heat losses – optimization of slag composition, less intensive refractories cooling;

c) Minimization of generation of flue dust;

d) Heat recovery from off-gases;

e) Utilization and recovery of the heat of SO_2 oxidation in acid plant;

Optimization of existing continuous smelting , batch converting and refining processes.

3. ***CONVERTING***

a) *Utilization of excess heat for scrap melting;*

b) *Oxygen enrichment in the blast;*

c) *Optimization of compressors use;*

d) *Optimization of hood, dumper and fan operation;*

e) *Heat exchanger air/gas –use of preheated air for concentrate drying;*

3. ***FIRE REFINING***

a) *Intensification of oxidation and degasification by the use of porous plugs;*

b) *Optimization of burner operation;*

c) *Heat recovery from off-gases: waste heat boiler or gas/air heat exchanger;*

Optimization of existing continuous smelting , batch converting and refining processes.

4. ***SLAG CLEANING***

a) *Development of continuous slag cleaning processes consisting of two zones or two reactors of intensive slag reduction and quiet settling;*

b) *Development of new processes combined electric furnace with reductant/fuel injection;*

c) *Optimization of smelting slag composition and properties.*

Technological Challenges in Copper Mining

Fernando Geister Bühlmann
Director de Desarrollo Tecnológico
Gerencia Corporativa Investigación & Innovación
Vicepresidencia de Desarrollo y Proyectos
Santiago, 22 Octubre 2004

Content

- Current Research and Development
- Opportunities and Challenges in medium Term
- Exploring future Challenges

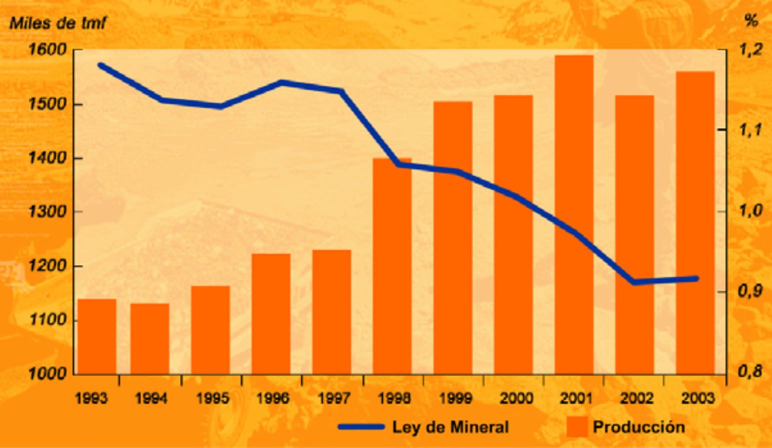
R&D in Codelco

- **Competitiveness Handles**
- **Innovation Model**
- **Results**

CODELCO
Produciendo Futuro

Competitiveness Handles

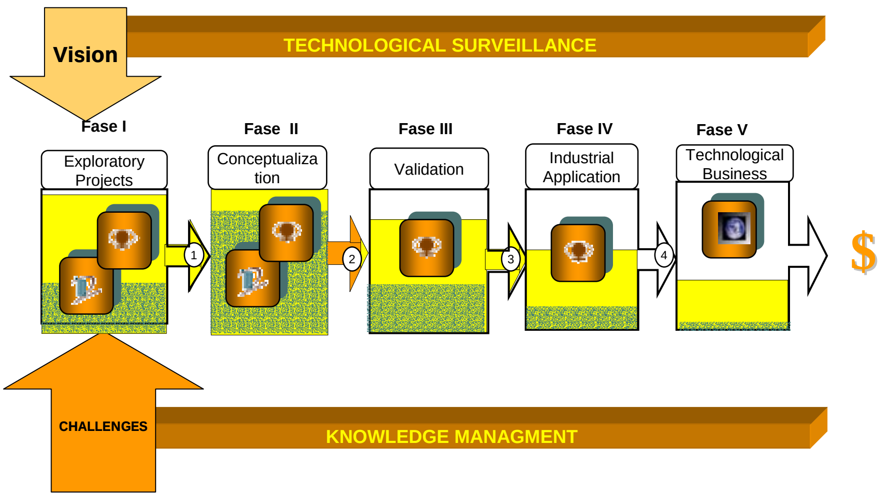
Producción y Ley de Mineral



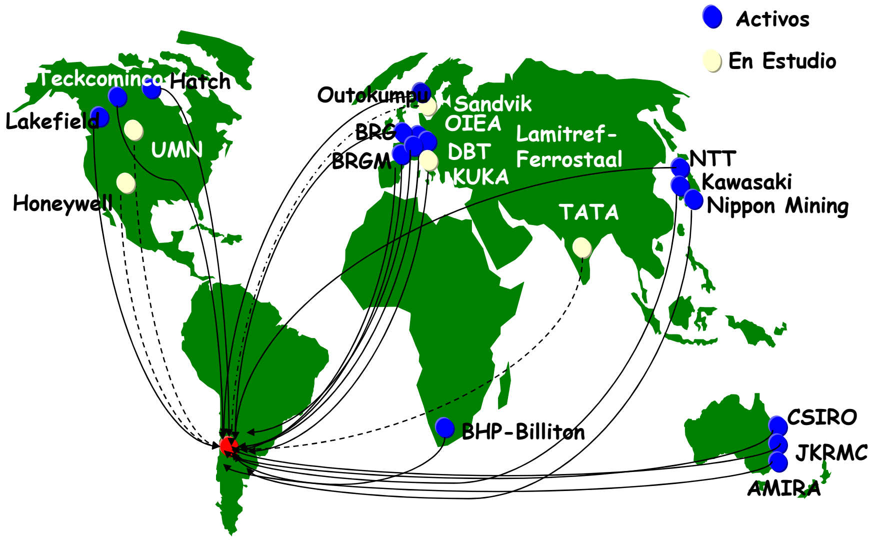
Competitiveness Handles

- **Resources of high complexity**
- **More difficulties in Mining:**
  - **Open Pit: Deeper Mining, longer tramming distance**
  - **Underground: Harder Rock, Stability problems**
- **Process of Complex Resources**
- **Human Resources**
- **Sustainable Development**

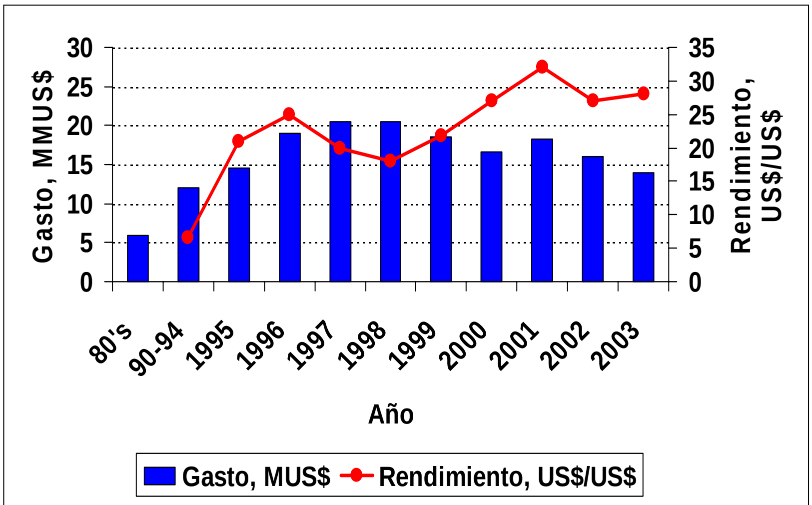
R&D Model



R&D Model
International Networking

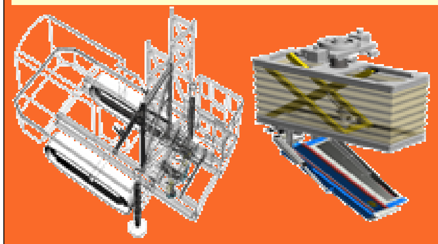


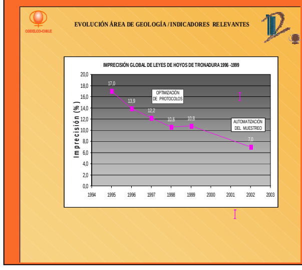
R&D Model
Results



R&D
Surface mining

Automatic Blasting Holes Sampler



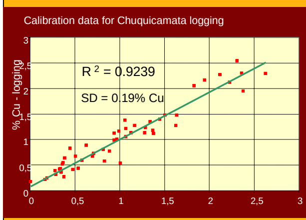


Benefits:

- Higher precision
- Lower analysis Cost
- Impact on short term planning

Nuclear sensors

Grade in Production holes



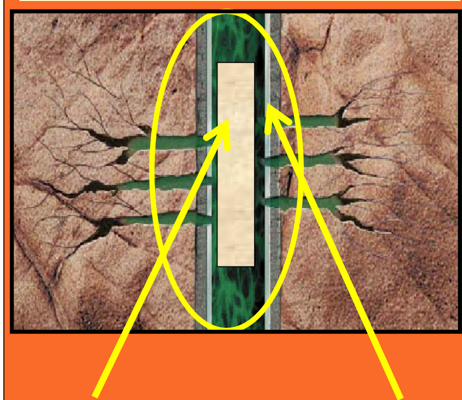
Equipment Development

- **Light Hopper**
- **Higher capacity**
- **Automated Trucks**

Precise Blasting Technology

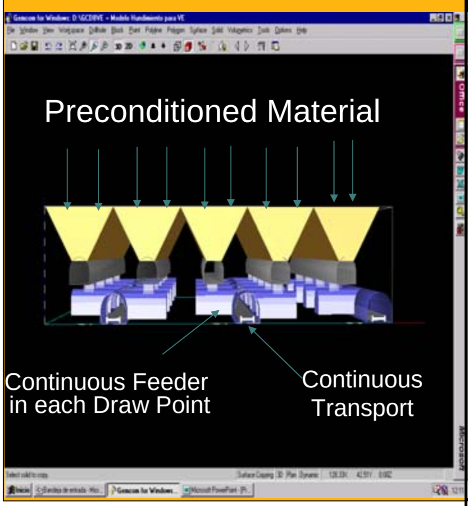
R&D
Underground Mining

Ore Body Preconditioning

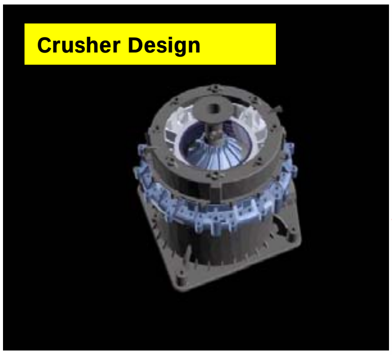


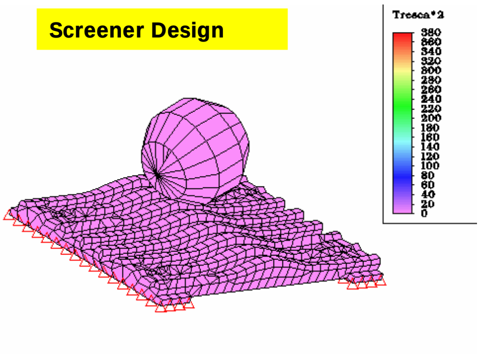
Hidraulic Fracturing **and / or** **Industrial Explosives And Precise Detonation**

Continuos and Automated Material Handling



R&D
Mineral Processing





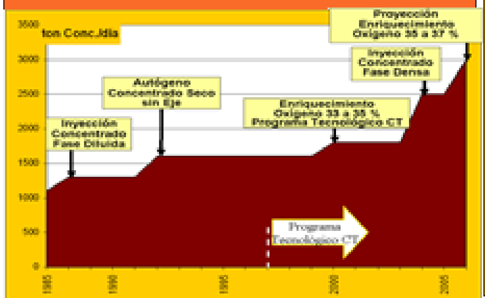
- **800.000 t/unit**
- **1.160.000 t/unit**

Result:

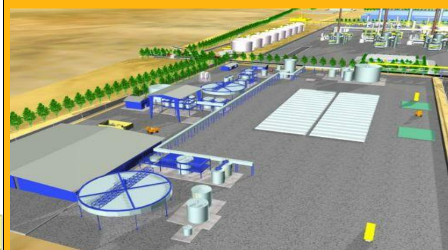
- 38% longer life

R&D
Smelter

Teniente Converter



Effluent Treatment Plant



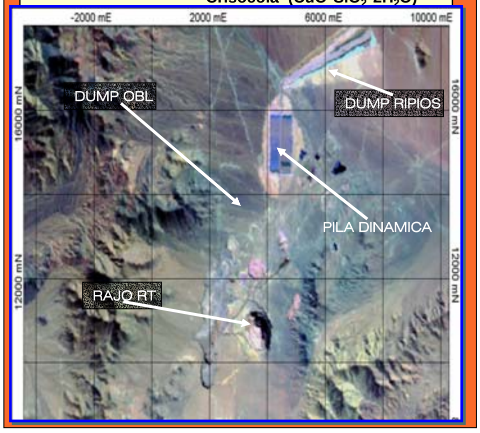
Benefits:

- Arsenic effluents treatment
- Arsenic confinement as scorodite
- Copper content recovery
- Accomplish Environmental regulations

R&D
Electrowining

Leaching of oxide ore

Reserva de óxidos : 802 M. Tons
Ley media : 0.59% Cu Total
Principales minerales: Atacamita ($CuCl_2*3Cu(OH)_2$)
Crisocola ($CuO*SiO_2*2H_2O$)

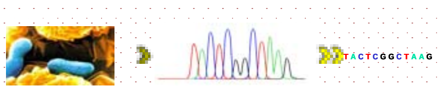


Acid Mist Suppression in EW Plant

Digital Inspection of EW Cathodes

R&D
Biomining

BioSigma **Alliance Copper**

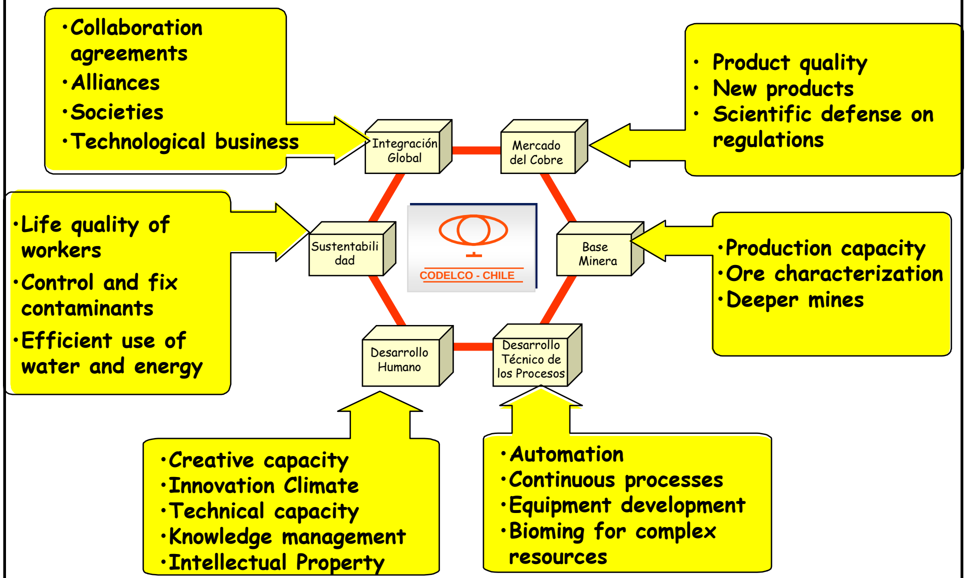


- **Biotechnology for low grade ore processing**
- **Industrial and Environmenmtal Microbiology**
- **Genomic & proteomic of leaching microorganism**

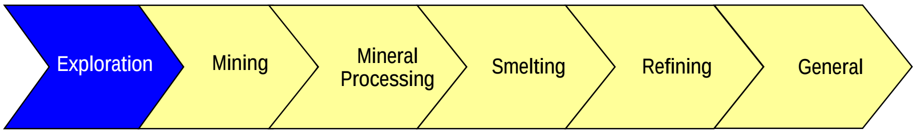
Develop, exploit and commercialize, bioleaching technology to process copper concentrate in agitated tanks.

Opportunities and Challenges in medium Term

Opportunities and Challenges in medium Term

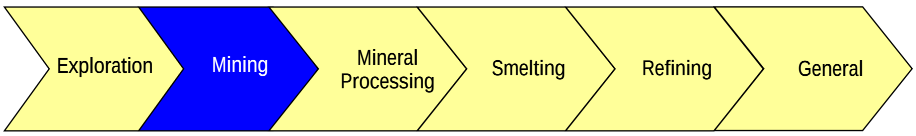


Future Technological Challenges



- Exploration Technologies
- Ore Characterization
- Integrated Models
- On line Information
- Sub Oceanic Exploration

Future Technological Challenges



- Continuous Mining in Open Pit
- Selective material handling
- Remote Operation
- Rapid Development
- Logistic & Organization in Deep Mining
- In situ Leaching
- Virtual and on line control

Future Technological Challenges

Exploration → Mining → **Mineral Processing** → Fundición → Refinación → General

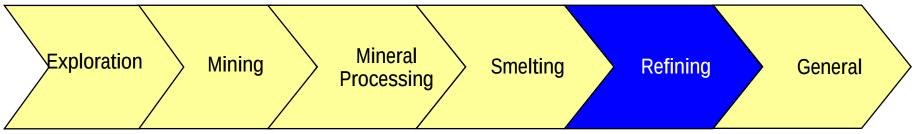
- Energy efficiency in Conminution
- Sub products recovery
- Process reaction on ore quality
- Environmental Sustainability
- Biotechnology of Sulfur Minerals

Future Technological Challenges

Exploration → Mining → Mineral Processing → **Smelting** → Refining → General

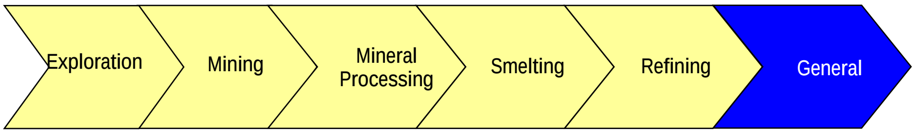
- Environmental sustainability
- Process Reaction on Concentrate quality
- Continuous Process
- On line Process Control

Future Technological Challenges



- Product quality
- Energy efficiency
- Higher metal production rate
- Environmental sustainability of residual contaminant waste
- Sub products recovery

Future Technological Challenges



- Copper recycling technologies
- Submarine Mining
- Nanotechnology development for mining application
- Matching both Technological and Human Development
- Tecnologías de Información
- Sustentabilidad Ambiental de la Minería

Technological development: Balancing risk and reward

Let's assume challenges while controlling risk