Asia-Pacific
Economic Cooperation

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

21, 22, 23 October 2004
Santiago Chile

APEC Energy Working Group

May 2009

Note: This publication includes speakers' presentations which may have terms that do not conform to the APEC Style Manual and Nomenclature. Please visit http://www.apec.org/apec/about_apec/policies_and_procedures.html for the APEC style guide.

Reproduced Electronically in May 2009

EWG 04/2004

APEC Secretariat
35 Heng Mui Keng Terrace Singapore 119616
Tel: (65) 6891 9600 Fax: (65) 6891 9690
Email: info@apec.org Website: www.apec.org

APEC#209-RE-04.3

INTERNATIONAL WORKSHOP “IMPROVING ENERGY EFFICIENCY IN THE APEC MINING INDUSTRY”
21, 22, 23 October 2004
Radisson Hotel · Ciudad Empresarial · Av. Santa Clara 354, Santiago Chile

PROGRAM SCHEDULE

DAY 1

	ACTIVITY	
8:00 – 9:20	Registration and document delivery	
9:20 – 9:30	Workshop welcome and General Information	Mr. Tomas Astorga *Chair, GEMEED- APEC*
9:30 – 9:40	Opening remarks	Mr. José María Sulbrandt *Deputy Director* *Instituto de Asuntos Públicos* *Universidad de Chile*
9:40 – 9:50	Opening remarks	Mr. Alfonso Dulanto *Minister of Mining of Chile*
Session 1: Best Practices and case studies on mineral extraction and processing operations		
9:50 – 10:20	Energy consumption on grinding mills	Mr. Ernesto Beas *División El Teniente* *CODELCO Chile*
10:20 – 10:50	Effective Energy Utilization on Japanese Copper Smelters	Mr. Akihiko Akada, *Sumitomo Metal Mining Co., Japan*
10:50 – 11:10	Questions and answers	
11:10 – 11:30	*Coffee break*	
11:30 – 12:00	Experience of the application of an energy efficiency program at the Autlán Molango Mining Facility	Mr. Norberto Zabala, *Compañia Minera Autlán, México.*
12:00 – 12:30	Questions and answers	
12:30 – 14:00	*Lunch*	
14:00 – 14:30	Energy Consumption of the Copper Mining Sector.	Ms. Sarita Pimentel, *Comisión Chilena del Cobre (COCHILCO)*
14:30 – 15:00	Using control for adding value to energy efficiency of mineral processing plants	Prof. André Desbiens *Université Laval, Québec Canadá*
15:00 – 15:20	Questions and answers	
15:20 – 15:50	Coffee break	
15:50 – 17:50	Round Table 1 (general audience)	Views and Proposals into the Environmental Cooperation Subgroup. / Views and Proposals into

		the Expert Group on Minerals and Energy Exploration and Development (APEC delegates only)
17:50 – 18:30	Questions and answers, discussion	

DAY 2

	ACTIVITY	
8:00 – 9:00	Registration and document delivery	
Session 2: New developments on energy efficient mining technologies		
9:00 – 9:40	Keynote speech: "Mining and energy: The energy efficiency rights"	Mr. Fernando Sánchez A. *CEPAL*
9:40 – 10:10	Improving Energy Efficiency in SAG mills ("The influence of shell, grate and pulp lifters on the throughput of SAG mills").	Dr. Sanjeeva Latchireddi, *University of Utah, USA*
10:10 – 10:40	Energy efficiency of batch, continuous and one step copper processes	Mr. Andrzej Warczok, *University of Toronto, Canadá* Mr. Gabriel Riveros, *Departamento Ingeniería de Minas Universidad de Chile*
10:40 – 11:00	Questions and answers	
11:00 – 11:30	*Coffee break*	
11:30 – 12:00	Challenges for copper mining in the XXI century	Mr. Fernando Geister *CODELCO, Chile*
12:00 – 12:30	Questions and answers	
12:30 – 14:00	*Lunch*	
Session 3: Policies for improving mining energy efficiency		
14:00 – 14:30	China's energy policy and energy efficiency policies directed to the industrial sector, with special reference to mining.	Prof. Yanjia Wang, *Universidad Tsinghua, China*
14:30 – 15:00	Energy Efficiency in the mining industry: opportunities and institutional design.	Mr. Pedro Maldonado *Instituto de Asuntos Públicos Universidad de Chile*
15:00 – 15:20	Questions and answers	
15:20 – 15:50	*Coffee break*	
15:50 – 17:50	Round Table 2	
17:50 – 18:30	Questions and answers, discussion	
18:30 – 18:50	Conclusions remarks and closure	
19:30 – 21:00	*Cocktail*	

DAY 3

	ACTIVITY
Optional site visit to a copper mine	
8:00 - 10:30	Travel to El Teniente mine site
11:00 – 13:30	Technical visit to copper grinding mills
13:30 – 15:30	Visit to Sewell copper museum
16:00 – 18:00	Return Travel to Santiago

Asia-Pacific
Economic Cooperation

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

21, 22, 23 October 2004
Santiago Chile

Session 1: Best Practices and Case Studies on Mineral Extraction and Processing Operations

EXPERIENCIAS OPERACIONALES y MANTENCION PLANTA SAG EL TENIENTE

Ernesto Beas Bustos
GERENTE DE PLANTAS

Codelco Chile
División El Teniente
Millán Nº 1020 Rancagua

RESUMEN

El presente artículo contiene un resumen general de la evolución de los parámetros más importantes, tanto de la parte operativa como de mantención, de la planta de molienda SAG de Codelco Chile División El Teniente desde su puesta en marcha a la fecha.

Del análisis de los resultados obtenidos a través del tiempo en la operación del molino SAG se ha podido encontrar explicación a una serie de fenómenos que en él ocurren. A su vez, se muestra algunas de las modificaciones realizadas tanto en la configuración de la planta como en sus equipos, especialmente en el revestimiento del molino SAG, con lo cual se ha logrado grandes avances en la reducción de los tiempos de detención.

En la primera parte de este trabajo se muestran los parámetros operativos de la planta SAG. En la segunda parte, se muestra un estudio de la eficiencia energética relacionada con la adición de finos en la alimentación del molino SAG y, finalmente, se expone las experiencias relacionadas con la mantención.

Experiencias operacionales de la Planta SAG.

Gerencia Plantas División Teniente

La gerencia Plantas de la División el Teniente está ubicada a aproximadamente 50 Km. de la ciudad de Rancagua. Dentro de ésta, y en la parte superior del Concentrador, se localiza la planta SAG.

Diagrama de flujo

El diagrama de flujo de la planta es el siguiente:

- Un Stock-Pile de aprox. 130.000 ton, de las cuales 24.000 ton son carga viva.
- 4 alimentadores de velocidad variable que descargan en sentido longitudinal a la correa que alimenta el molino.
- En una correa de 60" de ancho y aproximadamente 120 mts. entre poleas, va ubicado un pesómetro de cuatro estaciones y un medidor de tamaño de partículas llamado PETRA.
- El molino SAG es de 36 pies de diámetro por 15 de largo, tiene un motor de 15.000 HP y parrillas de 2 1/2" de abertura.
- La descarga es clasificada en un harnero de 20 pies de largo por 8 pies de ancho con parrillas de 3/4".
- El sobre tamaño alimenta 2 chancadoras de 7 pies cabeza corta. Estos descargan un producto de entre 7 a 9 mm. el que se va como carga circulante al molino SAG.
- El bajo tamaño es clasificado en una batería de Hidrociclones del tipo Krebs D-26 compuesta por 8 unidades. Aquí se obtiene el primer producto final.
- La descarga de los ciclones de la batería primaria va a dos molinos de bolas. Estos tienen 28 pies de largo por 18 pies de diámetro con motores de 6.000 HP. Operan en circuito cerrado con sus respectivas baterías.

El producto final de la planta tiene un 18% + 100 M.

Antes de entrar a la canal de pulpa que alimenta la planta de Flotación todo el producto final pasa por una parrilla despiedradora de 8 mm de abertura que tiene como función retener cualquier piedra de tamaño inadecuado que eventualmente aparecen debido a sobrecarga de los ciclones.

Evaluación de alternativas

Durante una primera etapa se efectuaron una serie de pruebas con el objeto de determinar la mejor alternativa de operación de nuestro módulo SAG. Es así entonces que entre octubre y diciembre del año 91 se probaron varias configuraciones entre las que se destacan:

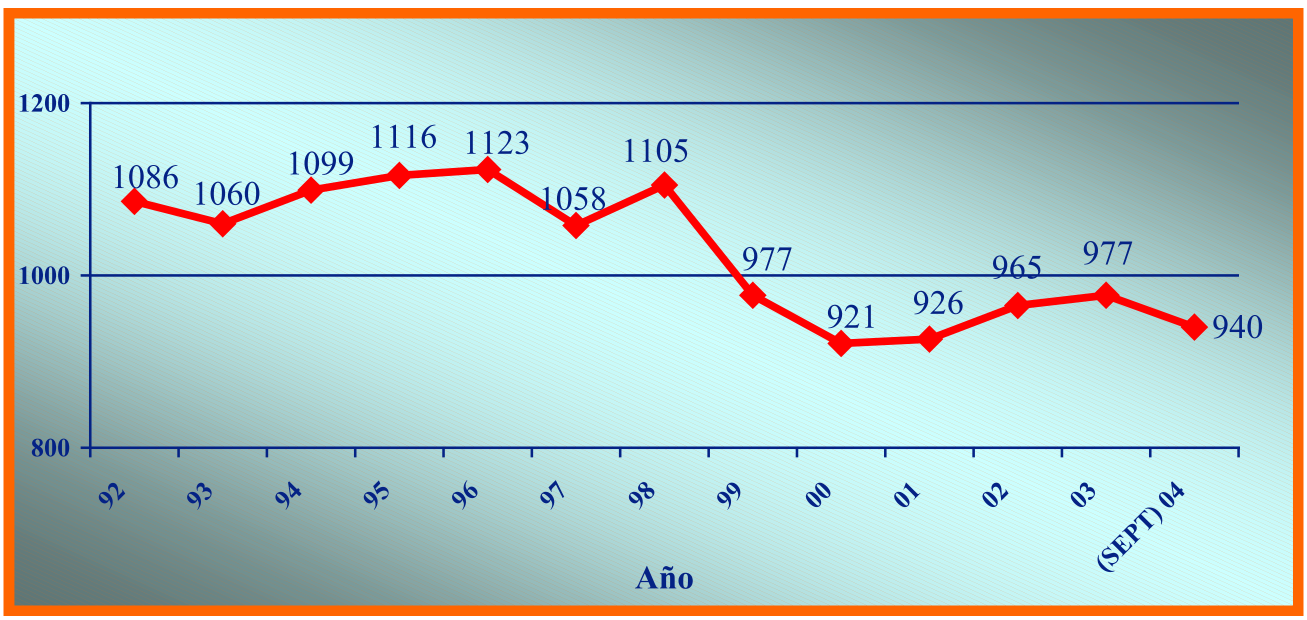
- Full autógeno: Molino SAG, 1 chancador y un molino de bolas.
- Semiautógeno con 4 a 5% de nivel de llenado de bolas (de 5") con el mismo equipo y finalmente
- Semiautógeno con 10.5% de nivel de llenado de bolas y mas e12ø molino de bolas.

Resultados

Los resultados obtenidos se muestran en esta tabla. Podemos destacar en ella el bajo rendimiento tenido con full autógeno respecto a semiautógeno con 10.5% de bolas.

	POWER (KW)		KWH/TMS			
LEVEL	SAG M.	BALLS M.	SAG M.	BALLS M.	TMS/HR	F 80 SAG
FULL AUTOG.	7095	3810	19,0	10,3	381	81283
SEMI AUT. 4%	8474	4204	12,3	6,0	700	53065
SEMI AUT.10.5%	10621	4232	8,9	7,4	1193	87871
SEMI AUT.12,3%	10998		11,3	8,0	976	108540

Rendimiento (TMS/HR).
Con la configuración elegida la evolución del tonelaje procesado desde el año 92 a la fecha fue la que se ve en este gráfico.



Se tuvo un continuo aumento hasta el año 96 bajando en el año 97 debido a dos hechos esenciales:

1. Falla del motor de un molino de bolas (Nº 411) el que debe ser reemplazado por uno de 5000 HP
2. Aumento de la granulometría de alimentación al molino SAG.

Con el objetivo de revertir esta situación de bajo rendimiento se creó un equipo multidisciplinario donde se juntaron representantes de toda la cadena del proceso.

Producto de una mejora considerable en las coordinaciones y en la gestión de cada proceso se logró subir nuevamente el rendimiento a niveles normales desde el mes de Mayo del 97 a Septiembre del 98. Pero, debido al cambio del pesómetro existente hasta ese momento por uno de cuatro estaciones de polines, se detectó que el tonelaje procesado estaba alterado en cerca de un 10%. También en esa oportunidad se instaló parrillas con una abertura de 2" en vez de 2 1/2" lo que conjugado con lo anterior produjo desde esa fecha una disminución en el tonelaje procesado en esta planta.

Variación del F-80 SAG

Pero, indudablemente lo que mas ha influido en la baja del rendimiento de nuestra planta ha sido el aumento del tamaño grueso alimentado al molino SAG.

Podemos ver que de 70.000 micrones tenidos hasta el año 96 se fue aumentando hasta 140.000 en el año 2000 para bajar niveles de 109.000 al presente año.

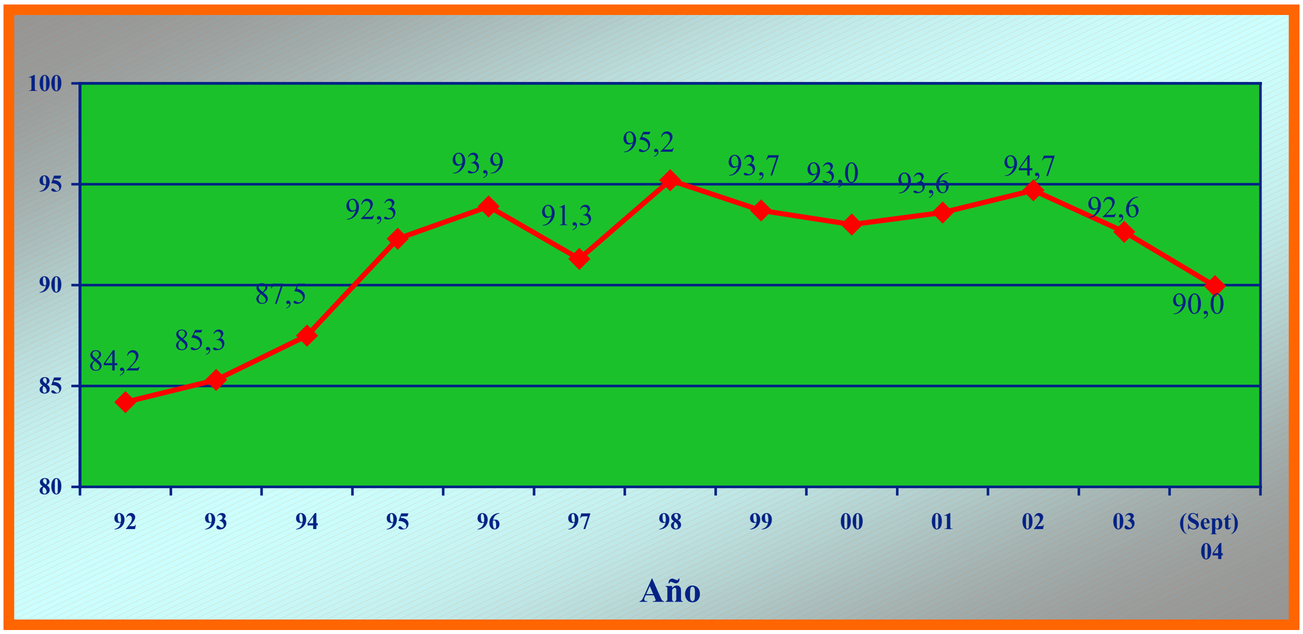
Principales indicadores de gestión operación

Los principales indicadores de gestión que ocupamos son:

- % de utilización
- Costos
- Taza de frecuencia de accidentes
- Productividad

% de utilización

La utilización de nuestra planta ha ido en constante aumento, la baja que experimentó en el año 97 se debió al evento climático mencionado anteriormente (88 hr. de detención) y a un problema en la fabricación de los pulp lifters cambiados en esa oportunidad, lo que produjo una demora de 55 hr sobre lo programado.
La baja experimentada en el año 2000 se debió a que por primera vez se efectuó la mantención mayor del motor del molino SAG la que incluía el desplazamiento del estator del motor.

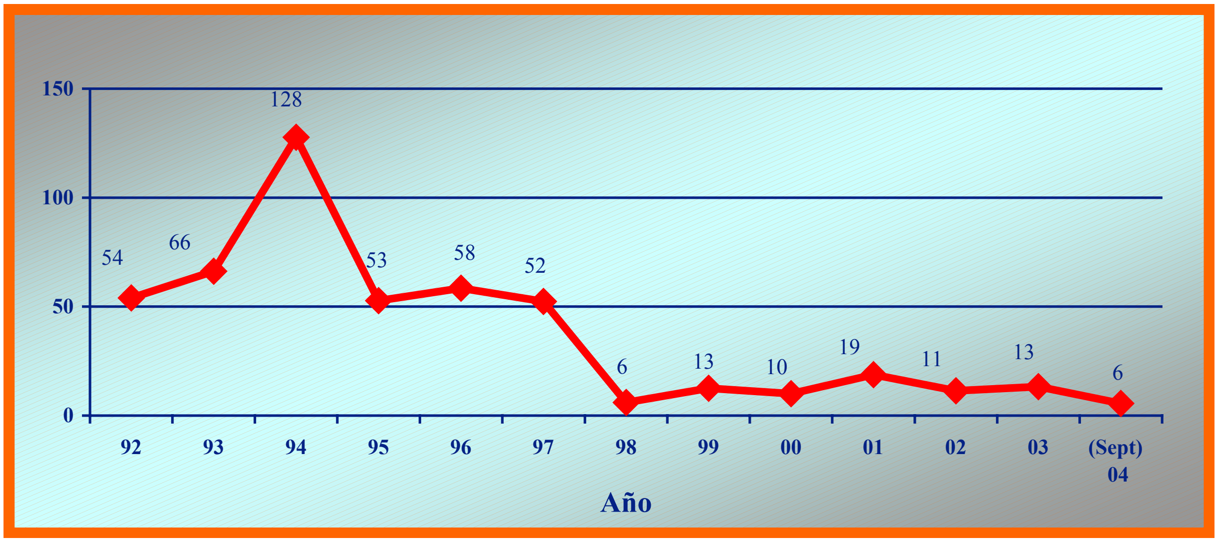


Razones de la mejora en la utilización

- Modificación chutes de traspaso por diseño inapropiado
- Modificación chute de alimentación SAG
- Modificación de diseño de correas de traspaso
- Modificación de diseño de piolas de parada de emergencia

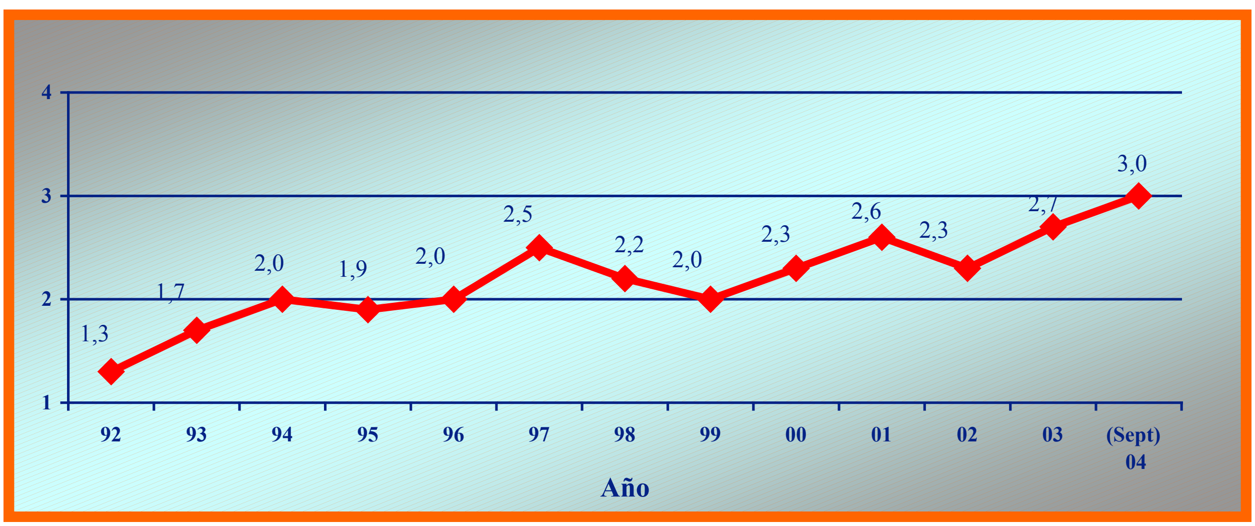
Detención planta por atollos de chutes de traspaso y/o correas y piolas de seguridad

Las horas de detención por atollos y piolas de seguridad bajaron desde 143 hr en el peor año (94) a cerca de 62 hr el año 95. El año 97 se efectúa una nueva mejora esta vez en el chute de alimentación lo que nos ha llevado en el año 2000 a solo 12 hr. de detención.



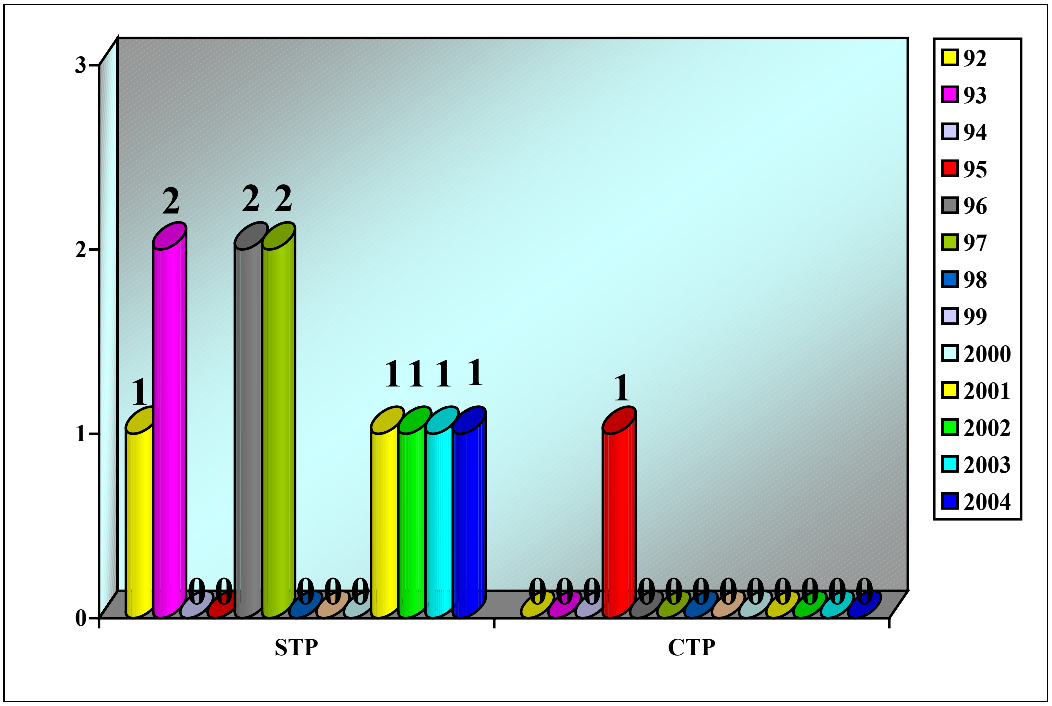
Costos planta SAG (US$/TMS Molida)

Respecto a los costos tenemos que este fluctúa entre 2 y 3 dólares por tonelada molida dependiendo de las perturbaciones que aparezcan y que influyen principalmente sobre el tonelaje procesado.



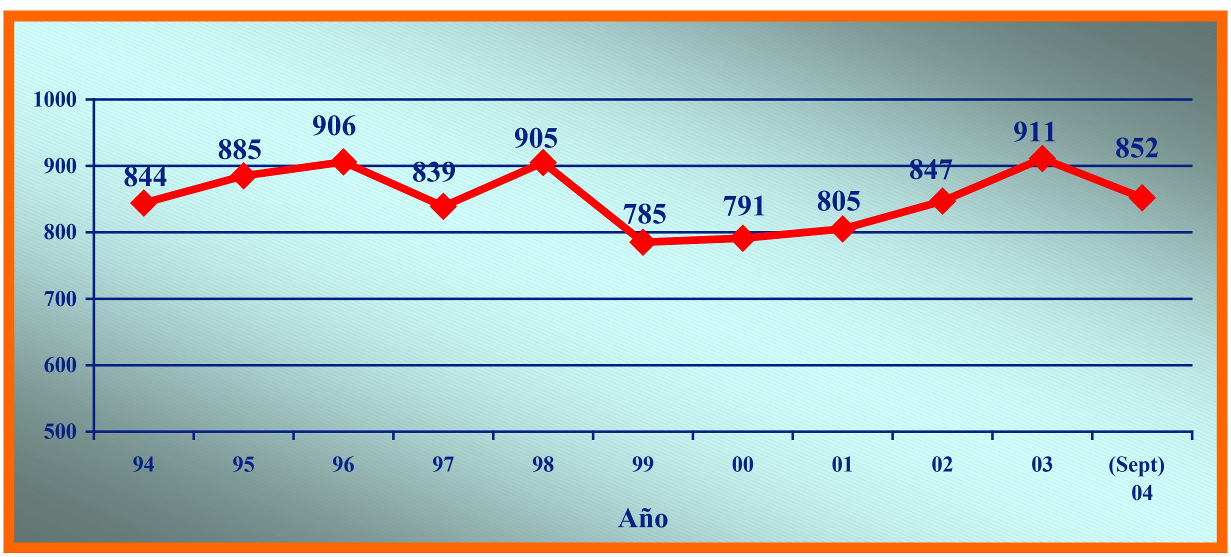
Nº de accidentes por año

En cuanto a los accidentes ocurridos en los años 13 que llevamos corriendo solo hemos tenido 1 accidente con tiempo perdido (marzo 1995).



Productividad (TMS/Hombre inscrito)

La productividad ha bajado notoriamente, influida por la baja de tonelaje tenida los últimos años.



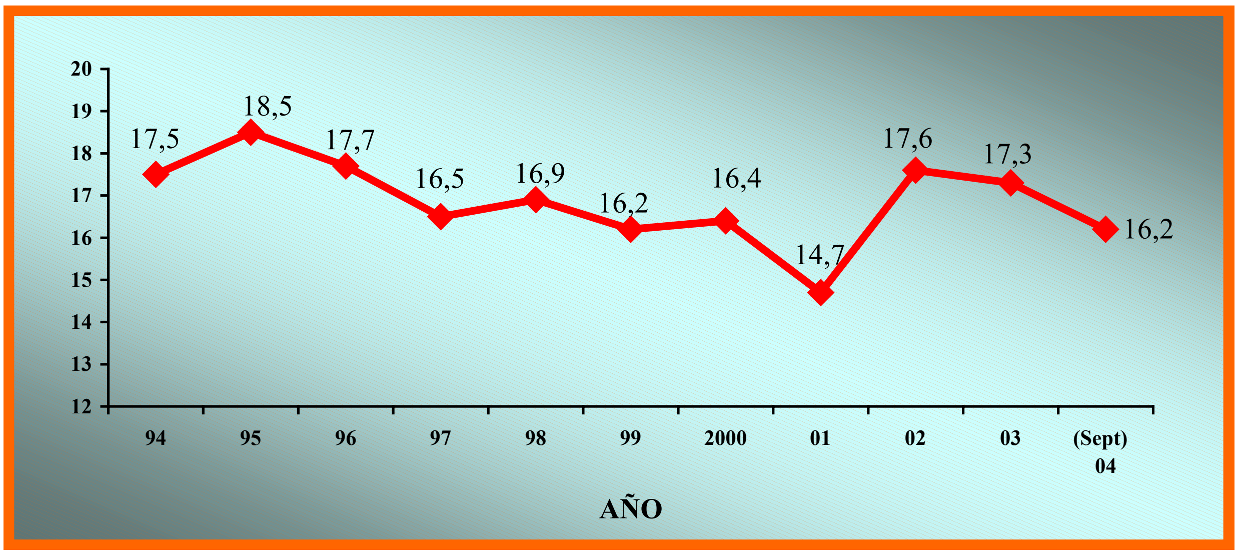
Parámetros de operación

Los parámetros de operación más importantes de nuestro proceso son:

- El porcentaje de +100 M
- El consumo de bolas
- El consumo de energía

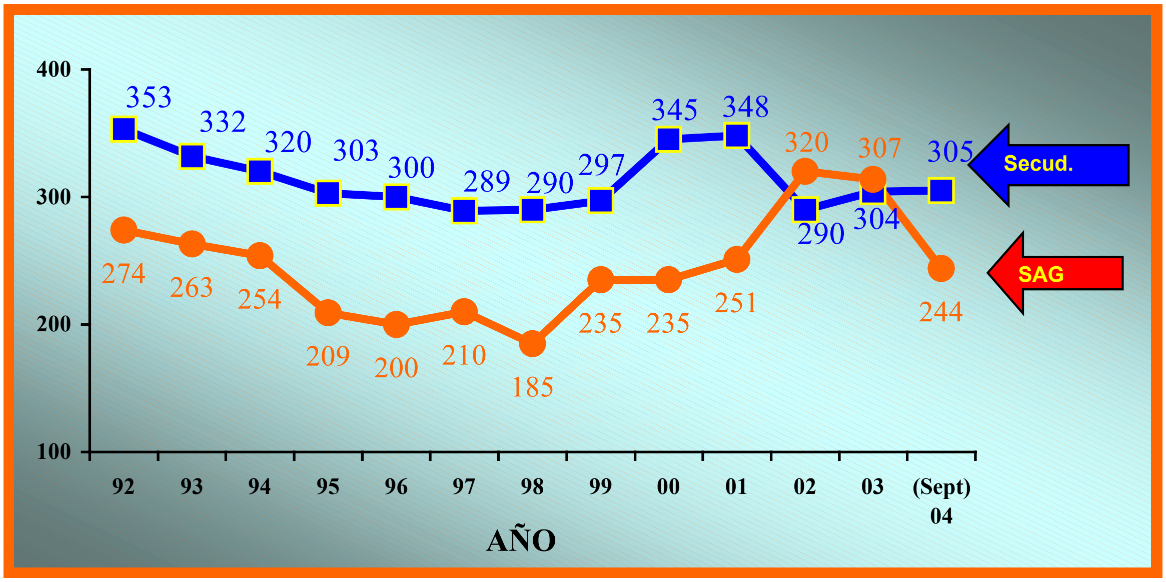
% de +100 M

El % +100 M ha ido bajando producto de algunas mejoras realizadas especialmente en el área de la clasificación, pero la tendencia a la baja de los valores de los últimos años están influenciadas por el bajo tonelaje procesado.



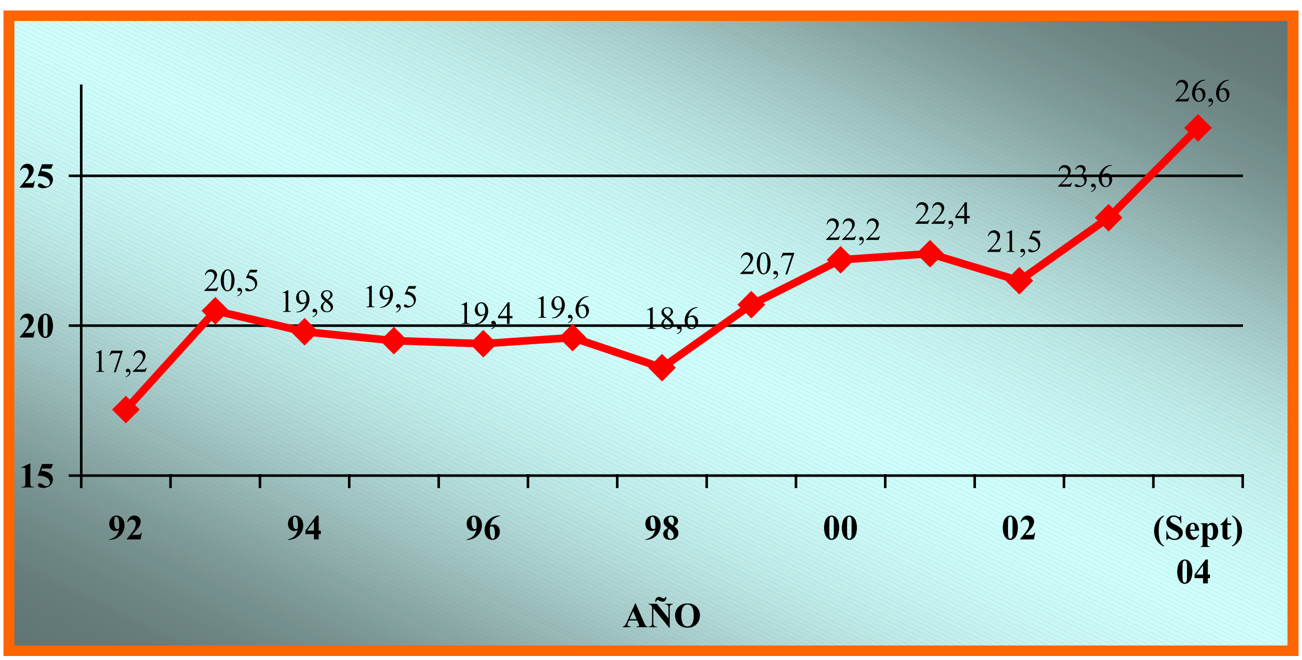
Consumo de bolas

El consumo de bolas para el SAG ha variado según se muestra en la gráfica teniéndose como promedio 245 gr/ton para le molino SAG y 314 gr/ton para los molinos secundarios. En el molino SAG se experimenta una baja en el año 2004 debido posiblemente al cambio de bola 5" por la bola de 6".



Consumo de energía planta

El consumo especifico de energía de la planta permaneció casi estable en aprox. 19,5 kWhr/ton entre los años 1993 al 1997,pero se ha incrementado hasta 26,6 kWhr/ton en los últimos años influido principalmente por la mayor presencia de mineral grueso.

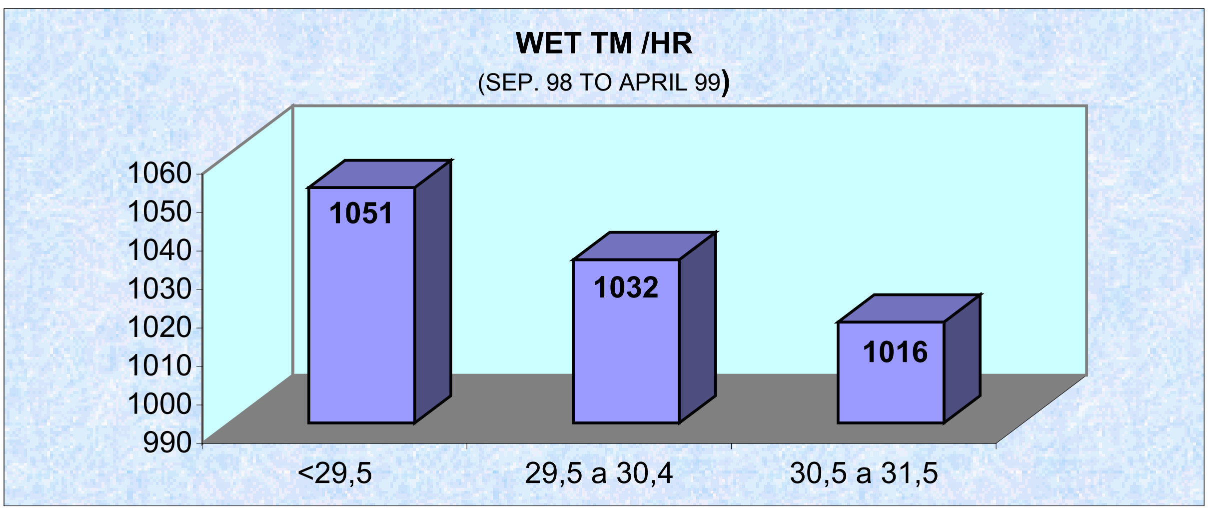


Estrategia operacional

La estrategia ocupada para operar esta planta se fundamenta en dos principios básicos: Procesar el máximo tonelaje para lograr el mejor producto final (máximo 18% + 100 M). Esto se logra al operar con un nivel de llenado de 25 a 28 %, al máximo de velocidad, 10.3 RPM. Variando el %de sólido de alimentación al molino según sea la granulometría que esté entrando al molino y ocupando permanentemente el control experto Súper- SAG

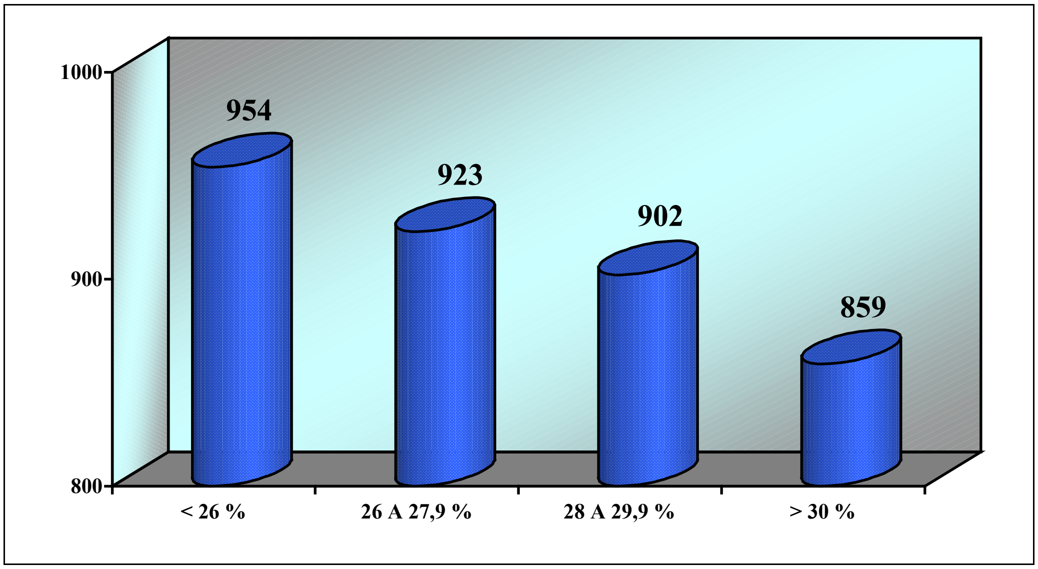
Rendimiento v/s nivel de llenado

Analizando los resultados obtenidos en el período comprendido entre Septiembre del año 98 a Abril del 99 se observa claramente el mayor rendimiento obtenido cuando se operó con niveles inferiores a 29. 5%, produciéndose una diferencia de 31 t/hr respecto a operar con un nivel de sobre 30.5%. Esta diferencia de tonelaje equivale, en el mes, a casi un día de operación.



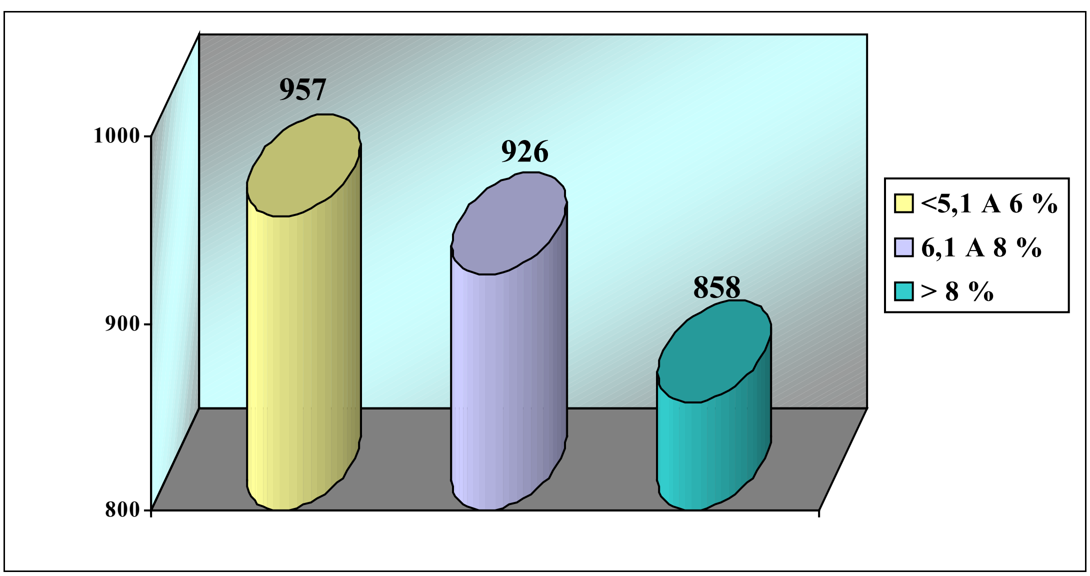
Rendimiento v/s nivel de llenado

Lo mismo sucede al examinar los resultados del período Enero - Octubre del año 2000 donde, producto de una menor cantidad de mineral fino, se hace más elocuente esta diferencia incluso operando con niveles más bajos que en el período anterior. En este caso la diferencia es de 87 t/h



Rendimiento v/s % de mineral grueso (se considera grueso los tamaños sobre 6")

Sin lugar a dudas la variable granulometría es la que más influye sobre el rendimiento de un molino SAG. En el gráfico que se muestra podemos ver los rendimientos obtenidos en el período Enero - Octubre del año 2000, referidos al % de gruesos (partículas de tamaño > 6") presente en la alimentación. Se ve claramente que en la medida que aumenta el % de fracción gruesa disminuye el tonelaje procesado por hr. Cuando se tiene menos que 6% de grueso se logra 957 t/h y cuando este % aumenta tan sólo en 2% baja el rendimiento a 858 t/h. Lo que equivale a un 10% de menor producción.



¿Como revertir situación de bajo rendimiento?

- Cambiando diámetro de bola usada en el molino SAG
- Modificando granulometría de alimentación planta SAG, mediante proceso de prechancado

Fecha de puesta en marcha

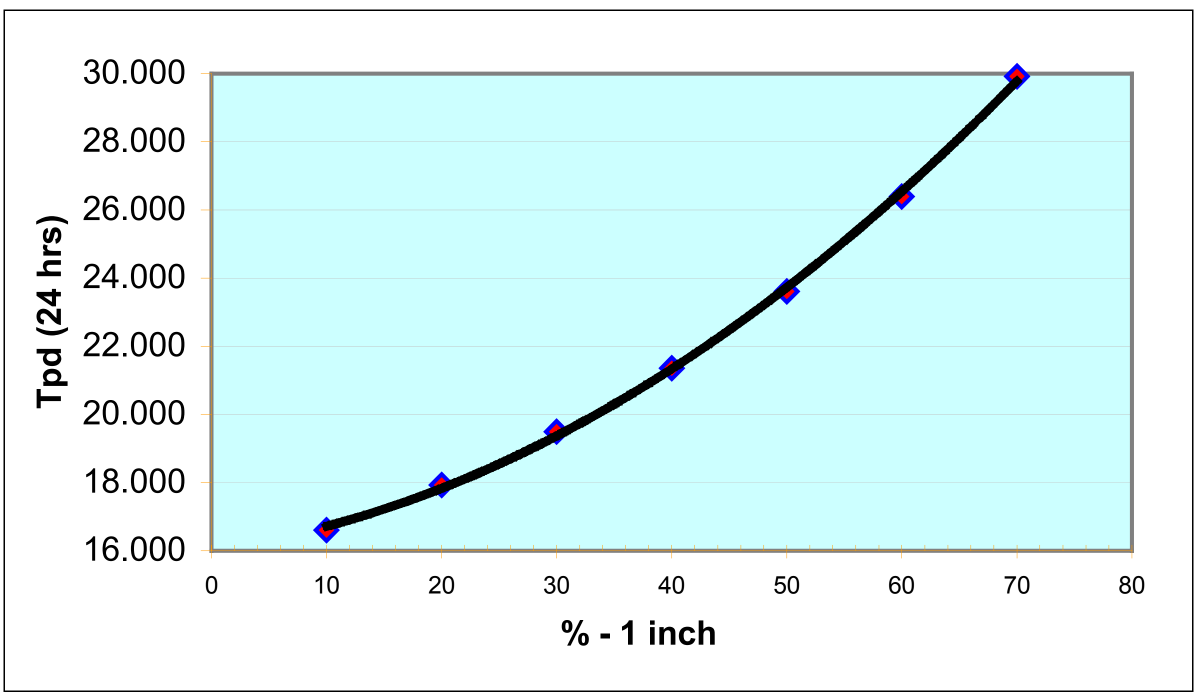
- Cambiando diámetro de bola usada en el molino SAG año 2004
- Proceso de prechancado año 2006

ESTUDIO DEL EFECTO DEL % DE FINO EN EL PROCESAMIENTO DE PLANTA SAG

Efecto del fino en el procesamiento SAG

En la dirección de modificar la granulometría de alimentación se realizó un estudio que ratifica lo observado en la práctica, en el sentido de que los mejores rendimientos (MTR/HR) y menor Consumo Específico de Energía se logran cuando en el mineral alimentado al molino SAG viene con una mayor presencia de finos.

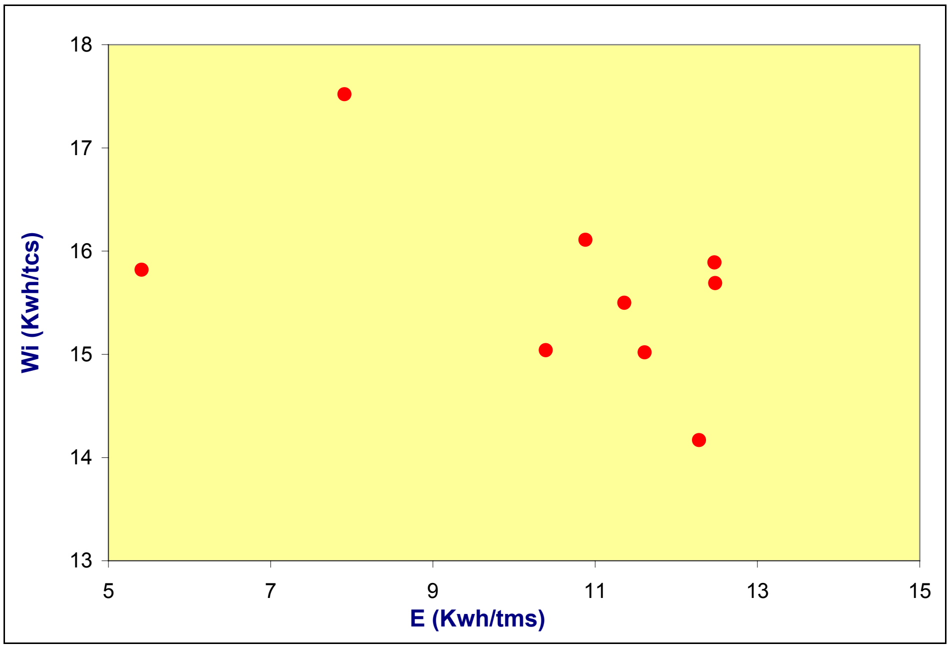
Concordante con lo anterior tomando el % de fino (partículas de mineral < 1 ") presentes en la alimentación al molino SAG se puede ver que, para aprox. 46% de fino, se logra procesar 23508 t/d, con 51 % se procesa 24150 t/d y con sobre 54% se llega a 26600 t/d



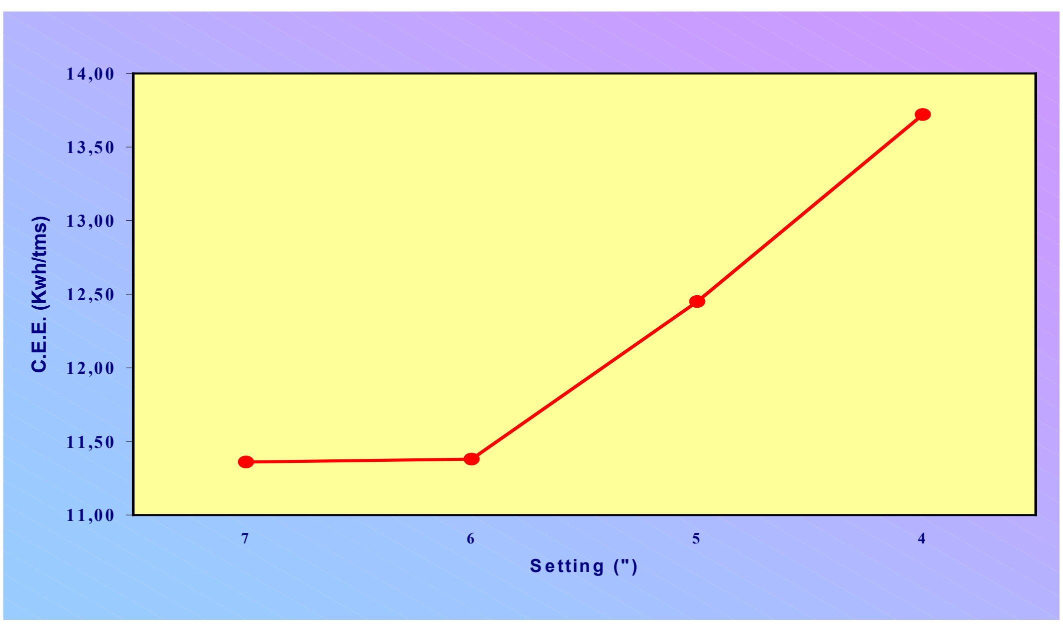
SECTORES ESTUDIADOS EN PRUEBA PILOTOS MOLIENDA SAG

Sector	Litología	C.E.E. (KWH/TMS)
Quebrada Tte.	Andesita Secundaria	5.63
Sub-6	Andesita Primaria	12.97
Esmeralda	Andesita Primaria-Brechas	11.03
Isla Martillo	Diorita Primaria	12.50

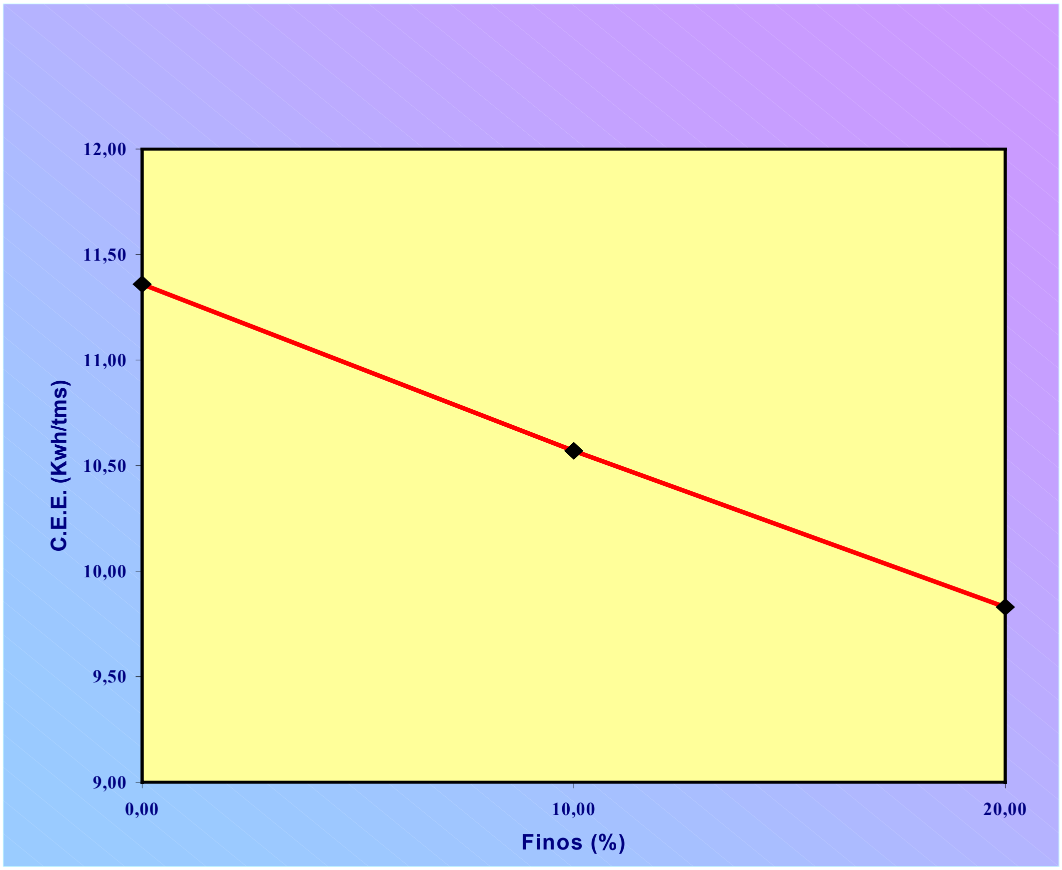
Relación C.E.E. SAG v/s Wi Bolas Bond



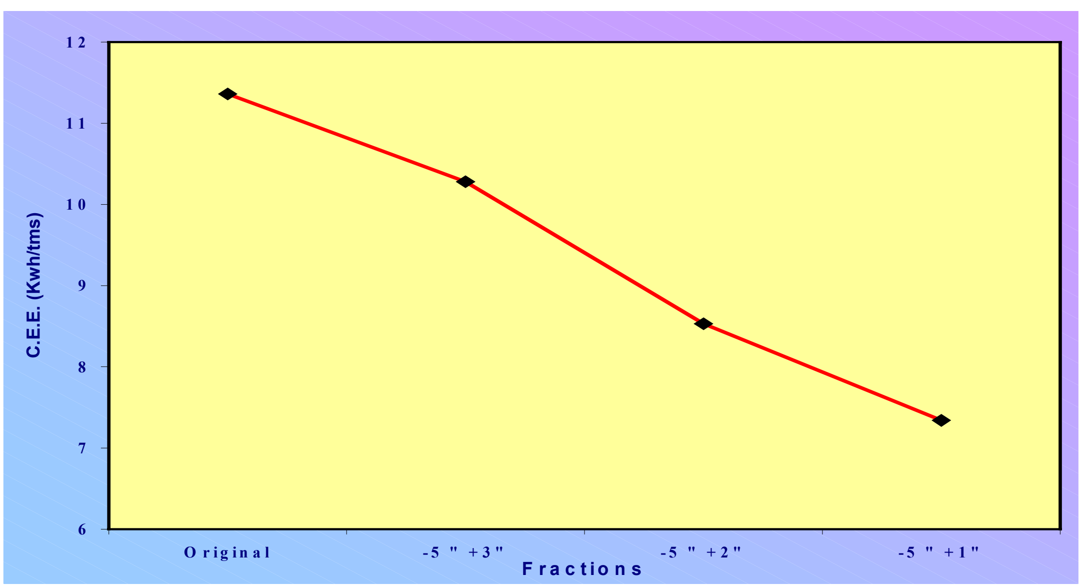
Variaciones del C.E.E SAG en función del setting del chancador primario



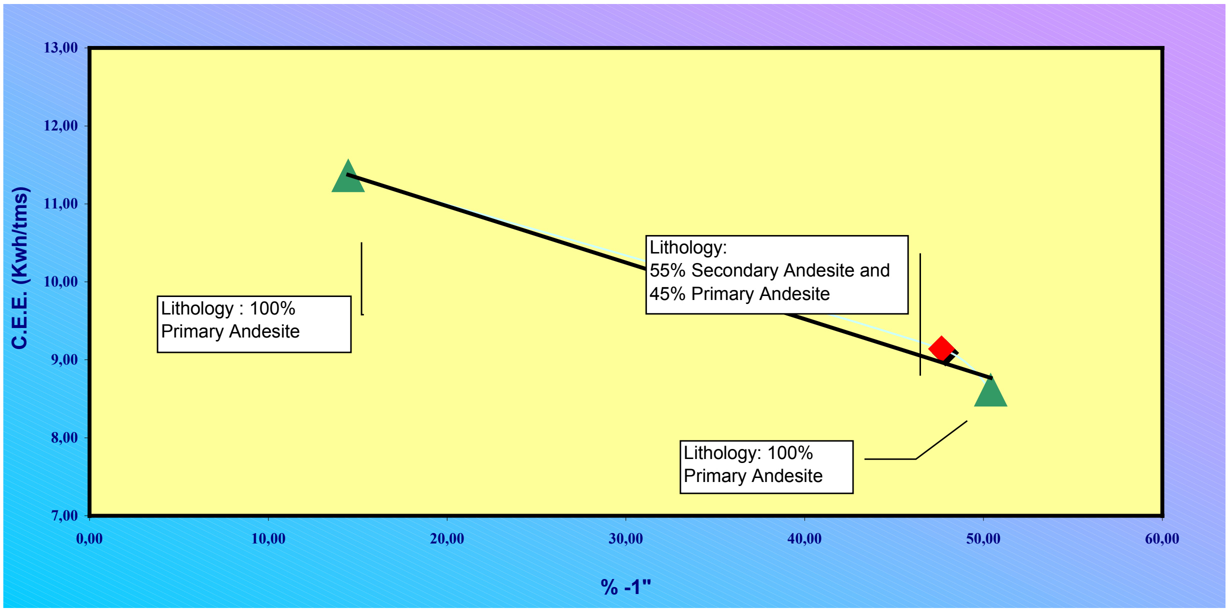
Variaciones del C.E.E SAG en función de la adición de finos



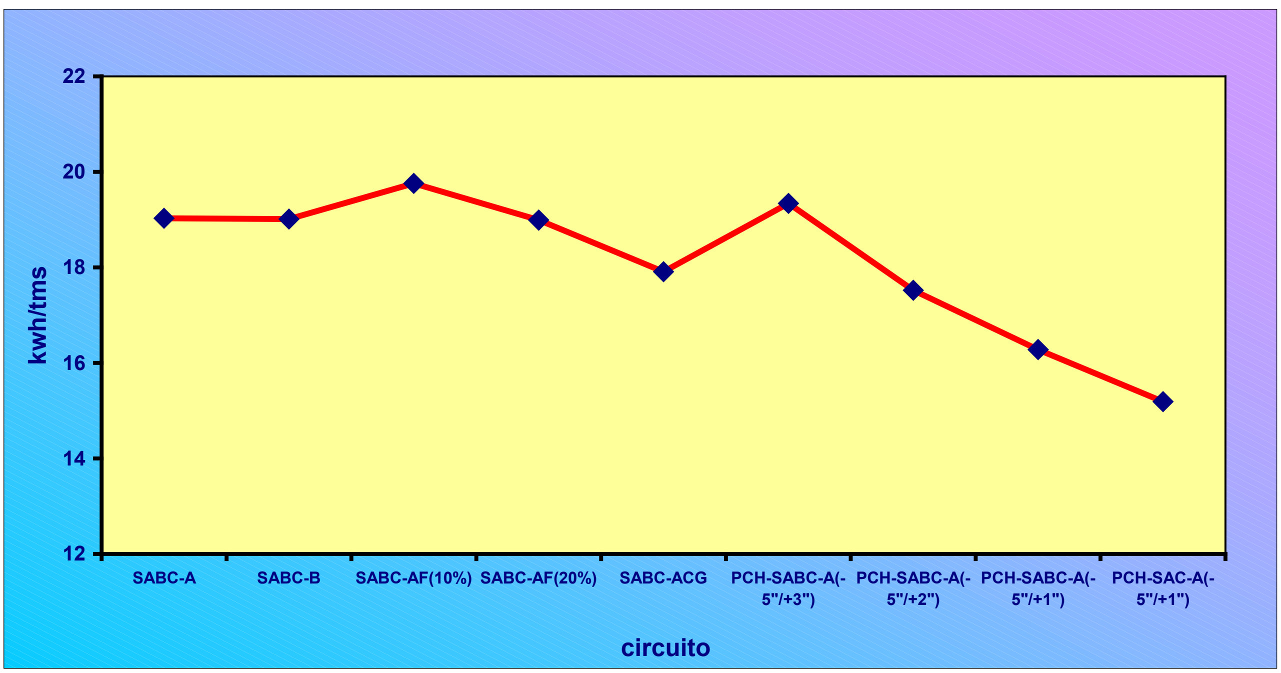
Variaciones del C.E.E SAG en función de la fracción intermedia chancada



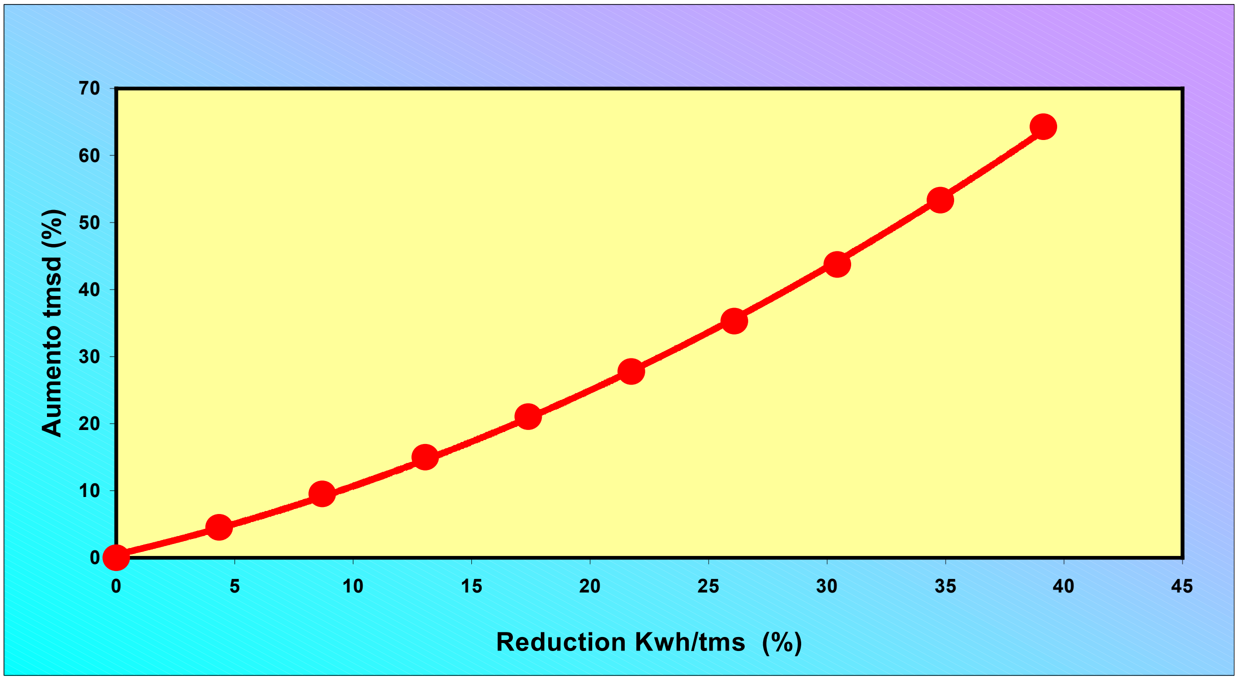
Variaciones del C.E.E SAG en función del perfil granulométrico y tipo de mezcla de mineral



Consumo específico de energía en circuitos alternativos para un producto de 20 %+100



Relación de disminución de e (%) v/s aumento de tonelaje (%)



Conclusiones

El perfil granulométrico de alimentación a la etapa de molienda SAG, es la variable de mayor incidencia en el rendimiento energético y metalúrgico del proceso.

El incremento porcentual de material fino (fracción -1") en la distribución granulométrica de alimentación, minimiza considerablemente el consumo especifico de energía en el molino SAG, aumentando significativamente su tasa de procesamiento dependiendo del criterio utilizado, para incrementar la presencia de finos en la granulometría de alimentación SAG. Es posible, para una misma mezcla litológica, disminuir el consumo especifico de energía entre 11% y un 35%.

De todos los criterios estudiados para la modificación del perfil granulométrico original, el más atractivo resulta ser, el que considera una etapa de pre-chancado de la fracción intermedia -6" /I +1".

Para mezclas litológicas de diferentes características de moliendabilidad SAG, es posible equiparar los consumos específicos de energía, y en consecuencia sus tasas de procesamiento, al procesar idénticas distribuciones granulométricas en la alimentación al molino SAG. En este caso particular, el Wi de bolas de Bond, usualmente utilizado en la etapa SAG para fundamentar mayores o menores durezas de los minerales procesados, no presenta ninguna correlación con el consumo específico de energía en esta etapa de molienda, por lo cual su utilización debe ser descartada con fines de dimensionamiento y calculo de tasas de procesamiento.

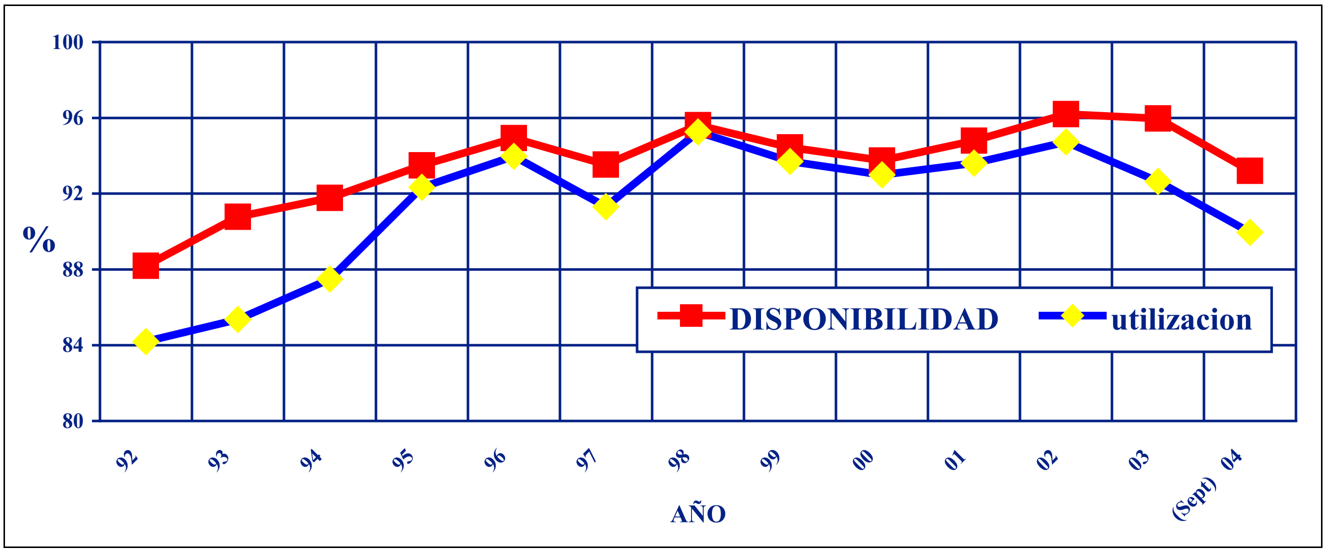
A la luz de los resultados obtenidos en el presente estudio, se hace imprescindible considerar en el diseño de pruebas piloto de molienda SAG, explorar el efecto de la variación del perfil granulométrico, además de las variables tradicionalmente estudiadas como son: velocidad critica del molino, abertura de tromell, numero de rock-port abiertos, configuración de circuitos, nivel de llenado de bolas, etc.

EXPERIENCIAS DE MANTENCIÓN

Disponibilidad planta SAG

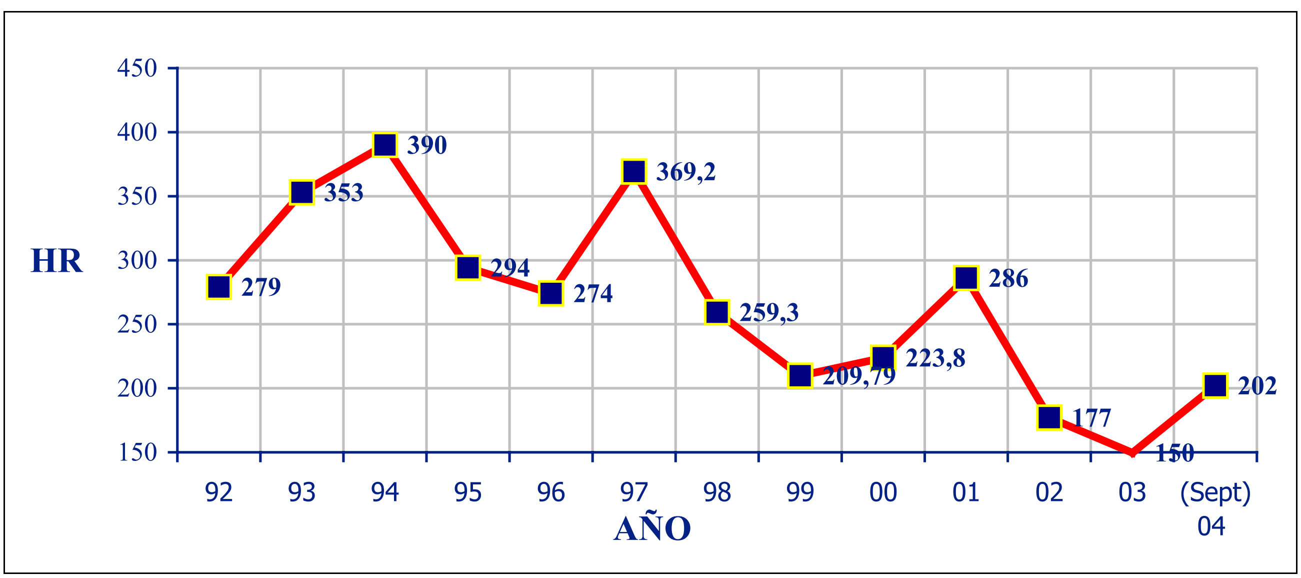
La disponibilidad de la planta SAG Teniente ha ido aumentando hasta alcanzar un 96.2 % el año 2002. La baja experimentada en el año 2004 se debe a la quebradura de lainas en el anillo nº 3 de la tapa de descarga producto de falla en la fabricación.

Debido a una buena gestión operativa, se ha logrado llevar la utilización a valores muy cercanos a la disponibilidad. La baja experimentada en los años 2003 se debe principalmente a interferencias con el proyecto ACB y en el año 2004 a la falta de mineral (debido a atrasos en el ACT) y por falta de agua en los meses de invierno por aluviones en bocatomas.



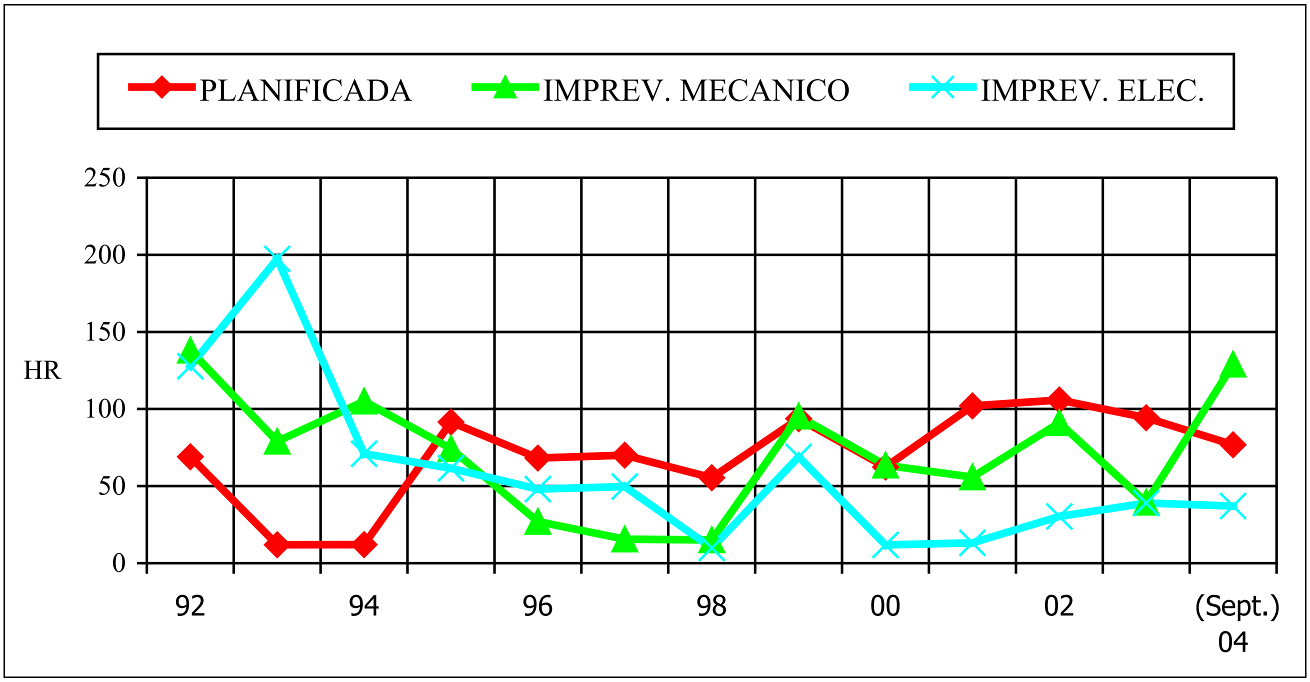
Mantención planificada para cambio de revestimientos

Salvo el aumento experimentado en el año 1997 por el problema de fabricación de los pulp filters, los tiempos ocupados en el cambio de revestimiento han ido bajando paulatinamente.



Mantenciones planta SAG

El aumento de las horas de mantención imprevista observado en el año 2004 se debió a una serie de detenciones provocadas por quiebre de lainas del anillo Nº 3 de la etapa de descarga por falla en la fabricación de éstas.

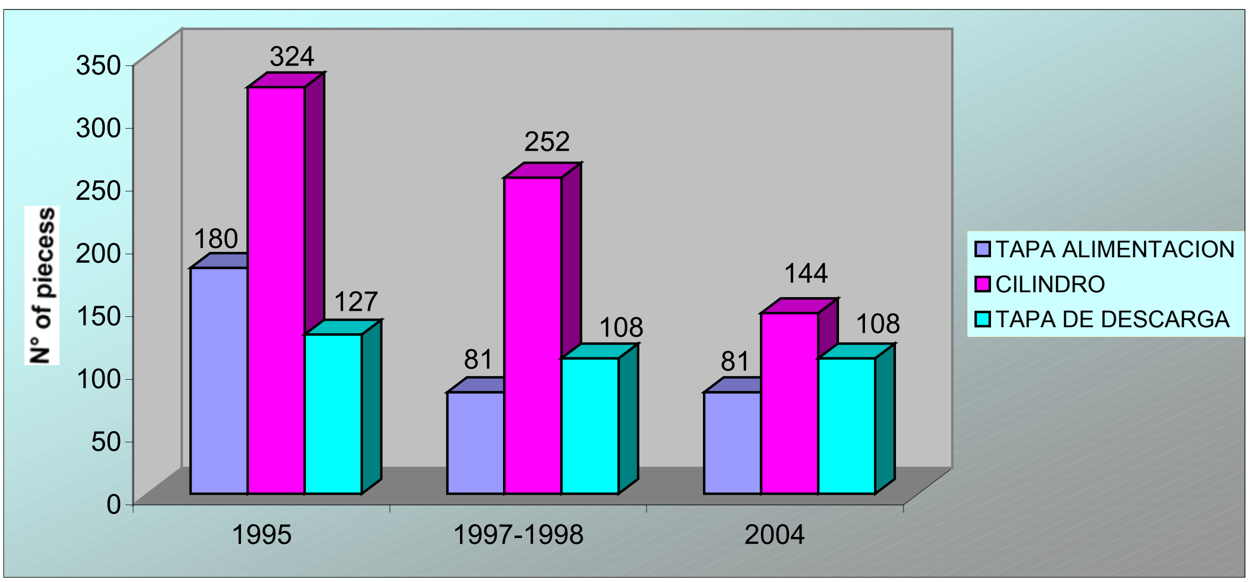


Razones de la mejora de la disponibilidad

- Por intervención en Molinos
  - Racionalización de revestimientos
    - Cambio de perfiles de desgaste
    - Cambio diseño anillo 1 tapa descarga acero a goma
    - Cambio diseño anillo 1 tapa alimentación, acero a goma
    - Eliminación de un anillo tapa alimentación
    - Eliminación de un anillo lifters tapa alimentación
    - Eliminación cono descarga
    - Eliminación de un anillo de lifters en el cilindro
    - Disminución de 18 a 9 lainas anillo 2 tapa descarga
    - Disminución de 18 a 9 pulp lifters anillo 2 descarga
    - Estandarización de pernos
    - Cambio de slot parrillas de descarga SAG
    - Eliminación de lifters en anillo Nº 1 en tapa alimentación y descarga
    - Eliminación de filas de lifters en cilindro de 72 a 36
    - Eliminación de un anillo de placas en el cilindro (de 3 a 2)
    - Aumento en un 20% red de evacuación pulp-lifters anillo 1
    - Se aumenta hasta 30 mm espesor goma de recubrimiento pulp- lifters

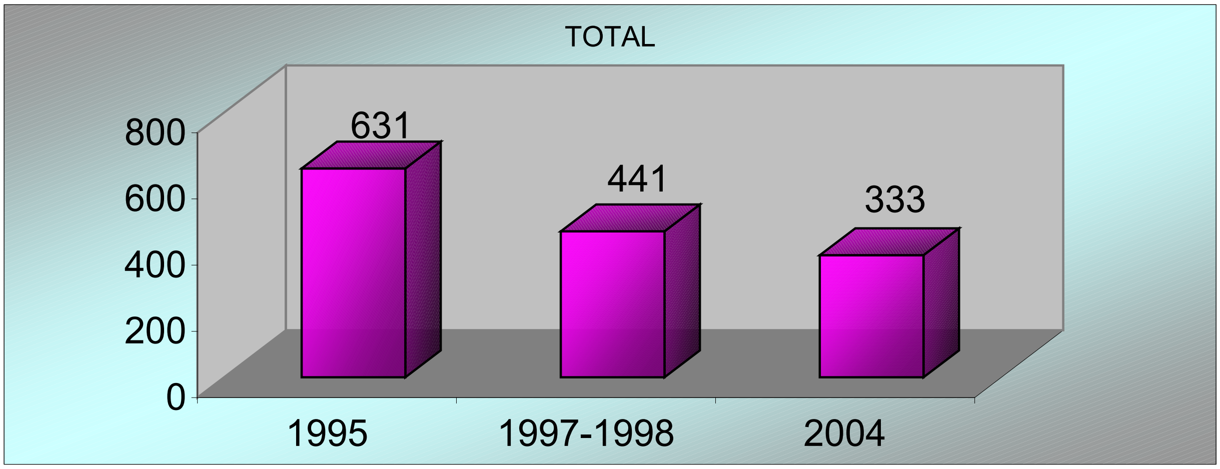
- Traspaso pulp lifters importados a nacionales
- Cambio diseño trommel
- Instalación monorriel alimentador lainas SAG
- Compra de simulador de lainas (estadio)
- Por intervención en Planta
    - Implementation de harnero stand by
    - Instalación de segundo chancador de pebles
    - Instalación de compuertas hidráulicas cambio harneros
    - Cambio válvulas pinch por cuchilla
    - Estandarización y modificación cañerías transporte pulpa
    - Cambio diseño harnero, bombas, chutes, correas, etc.
    - Estrategias de control de la planta
    - Comunicación expedita Operación - Mantención
    - Planificación detallada de detenciones planta
    - Cambio sistema resortes harnero
    - Estandarización de válvulas 20" y bifurcaciones

Racionalización revestimiento molino SAG



Disminución de elementos

Debido a las modificaciones que hemos realizado en lo referente al revestimiento, el Nº de piezas ha disminuido de 631 en el año 1998 a 441 en la actualidad. A futuro pensamos llegar a 33 unidades.



Planificación de la mantención

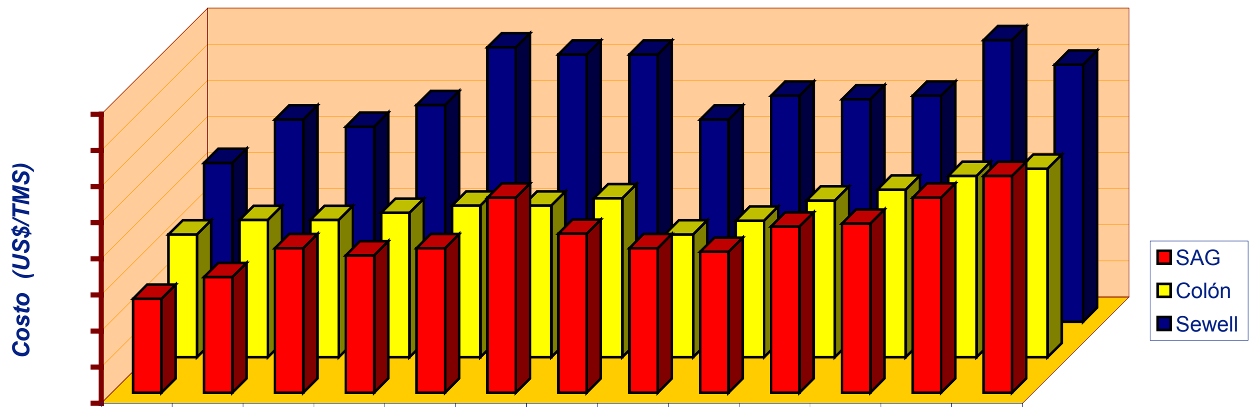
- Planificación en la planta
- Carta gantt antes de cada mantención
- Programas anuales de cambio de revestimientos
- Sistema de control de perdidas
- Control de equipos principales en planta
- Trabajos envergadura externalizados
- Utilización de contratos marcos
- Consignaciones y convenios de repuestos
- Archivo electrónico de planos
- Estandarización de repuestos
- Uso del sap

Planes de desarrollo

- Eliminar la mitad de las filas de los lifters del cilindro
- Eliminar un anillo de lainas de la tapa de descarga
- Modernización del control eléctrico del molino
- Prechancado
- Pebles en circuito abierto con el PDT
- Harnero doble deck
- Consignación de repuestos
- Desarrollo del personal
- Especificaciones comunes repuestos e insumos
- Establecer alianzas estratégicas con proveedores
- Planes futuros considerando impacto ambiental

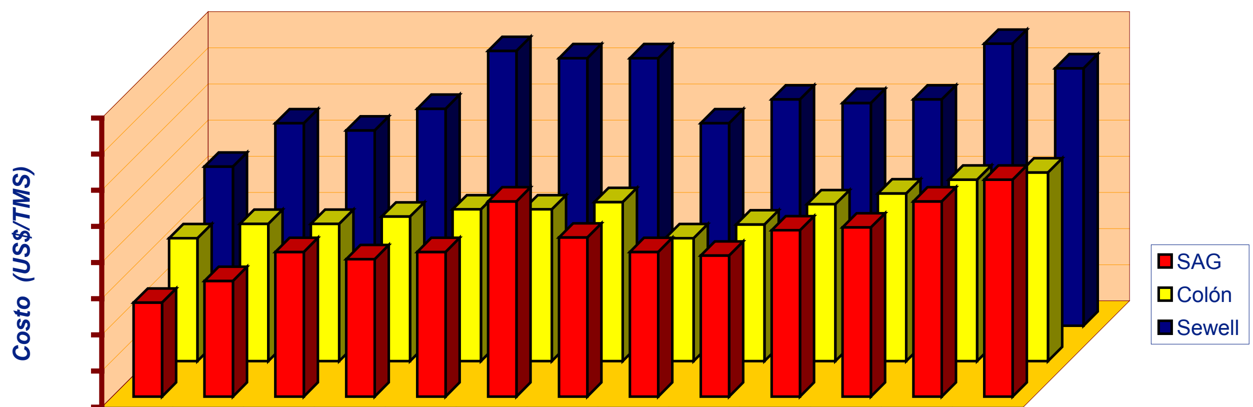
Resultados globales de la Gerencia por sistemas de reducción de tamaño
(Chancado Secundario- Terciario y Molienda)

Costos



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004 (Sep)
SAG	1,3	1,6	2,0	1,9	2,0	2,7	2,2	2,0	2,0	2,3	2,3	2,7	3,0
Colón	1,7	1,9	1,9	2,0	2,1	2,1	2,2	1,7	1,9	2,2	2,3	2,5	2,6
Sewell	2,2	2,8	2,7	3,0	3,8	3,7	3,7	2,8	3,1	3,1	3,1	3,9	3,6

Consumos de energía



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004 (Sep)
SAG	1,3	1,6	2,0	1,9	2,0	2,7	2,2	2,0	2,0	2,3	2,3	2,7	3,0
Colón	1,7	1,9	1,9	2,0	2,1	2,1	2,2	1,7	1,9	2,2	2,3	2,5	2,6
Sewell	2,2	2,8	2,7	3,0	3,8	3,7	3,7	2,8	3,1	3,1	3,1	3,9	3,6

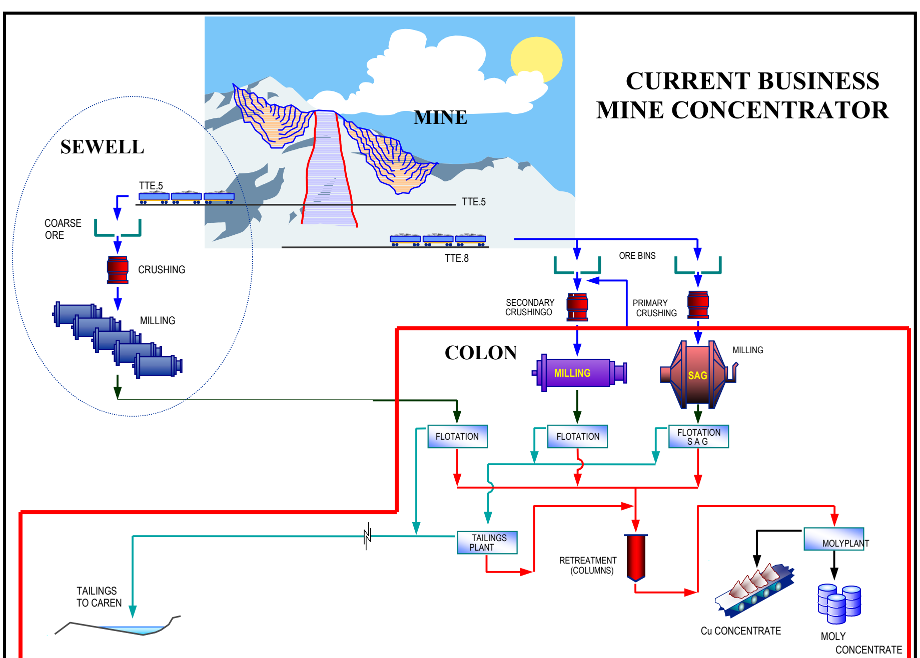
OPERATING AND MAINTENANCE TENIENTE SAG MILL Nº 1.

October 2004

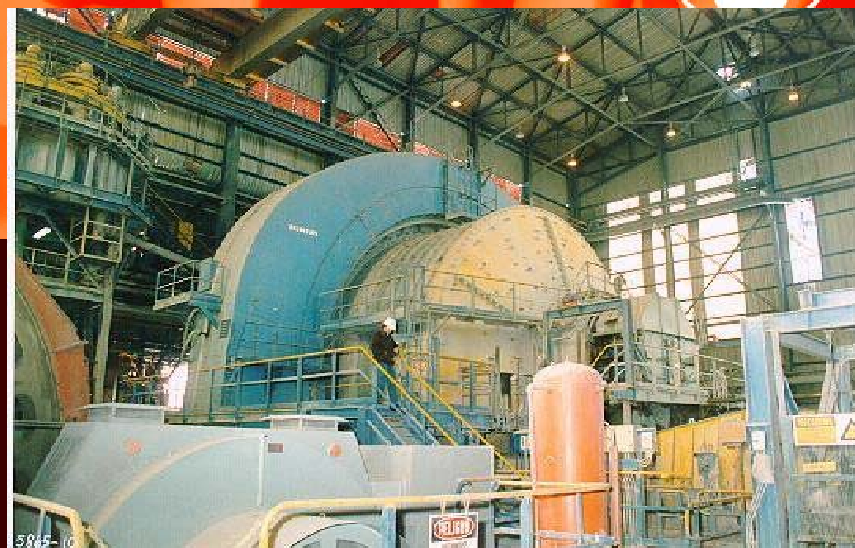
PLANT MANAGEMENT

SAG UNIT

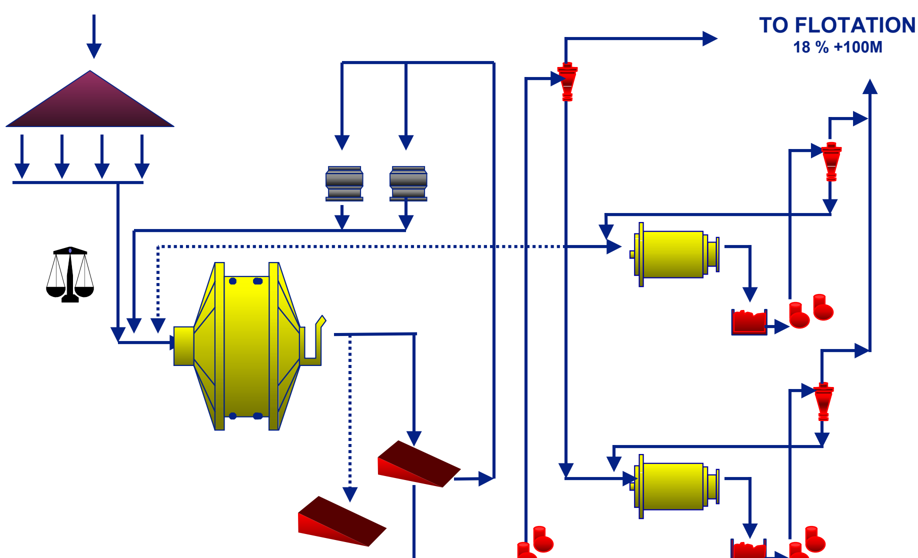

18 11 2003


CURRENT BUSINESS
MINE CONCENTRATOR
MINE
SEWELL
TTE.5
COARSE ORE
CRUSHING
MILLING
TTE.5
TTE.8
ORE BINS
SECONDARY CRUSHINGO
PRIMARY CRUSHING
COLON
MILLING
SAG
MILLING
FLOTATION
FLOTATION
FLOTATION S A G
TAILINGS PLANT
RETREATMENT (COLUMNS)
MOLYPLANT
TAILINGS TO CAREN
Cu CONCENTRATE
MOLY CONCENTRATE

TENIENTE GRINDING SAG PLANT.



FLOW CHART



OPERATING

EXPERIENCES

SAG MODULE, PROCESING RATE

$$TP = P \times U \times 24 / E$$

where :

TP = **Processing rate (tmsd)**

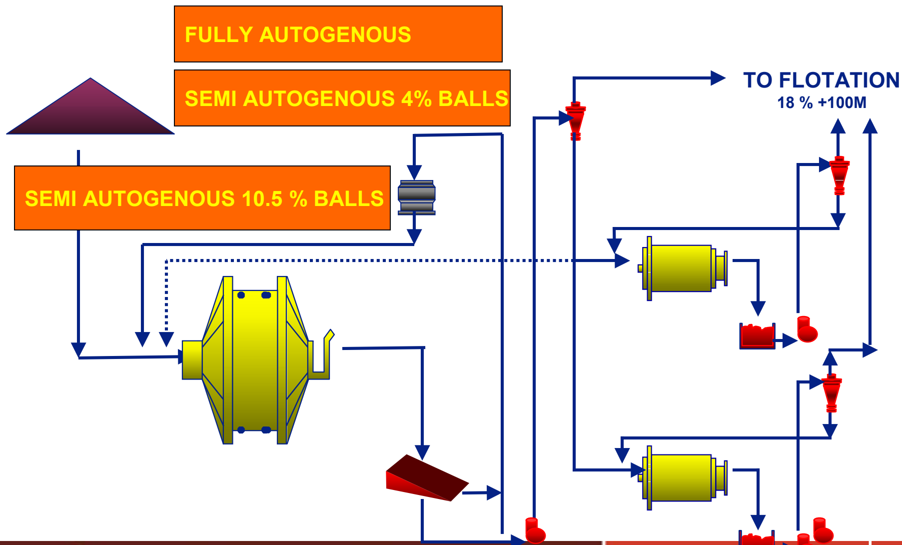
P = **Power Draw (Kw)**

U = **Utilization SAG mill (%/1)**

E = **Energy specific consumption (Kwh/tms)**

ALTERNATIVES EVALUATION

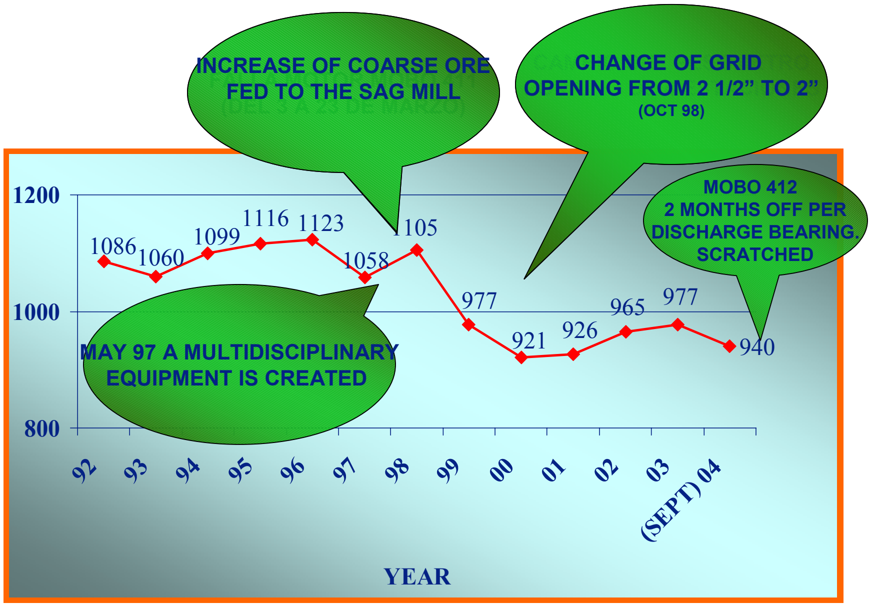
(AUGUST 15 TO DECEMBER 30, 91)



RESULTS

	POWER (KW)		KWH/TMS			
LEVEL	SAG M.	BALLS M.	SAG M.	BALLS M.	TMS/HR	F 80 SAG
FULL AUTOG.	7095	3810	19,0	10,3	381	81283
SEMI AUT. 4%	8474	4204	12,3	6,0	700	53065
SEMI AUT.10.5%	10621	4232	8,9	7,4	1193	87871
SEMI AUT.12,3%	10998		11,3	8,0	976	108540

RATE (TMS/HR)



SAG F-80 VARIATION

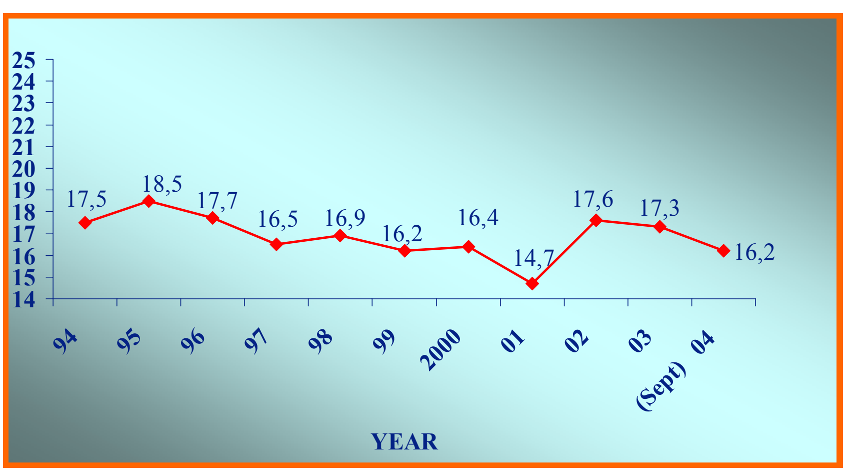
OPERATING PARAMETERS

% OF + 100 MESHES

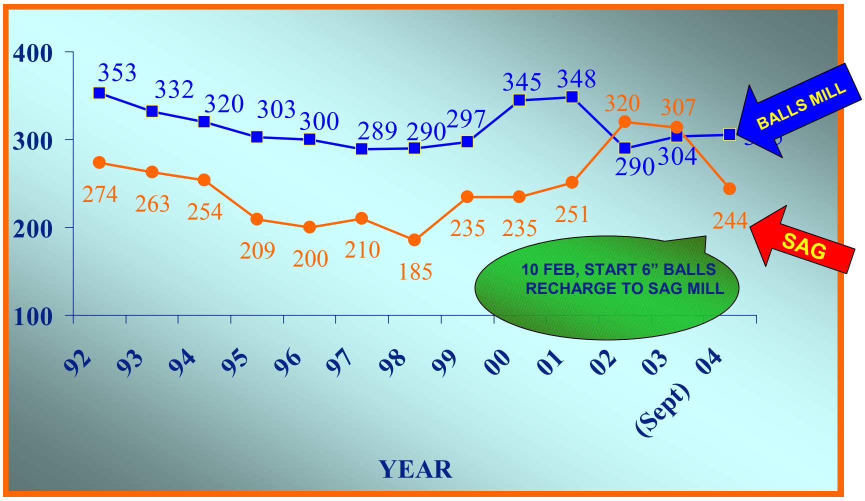
BALLS CONSUMPTION
SAG MILL
BALLS MILL

POWER CONSUMPTION

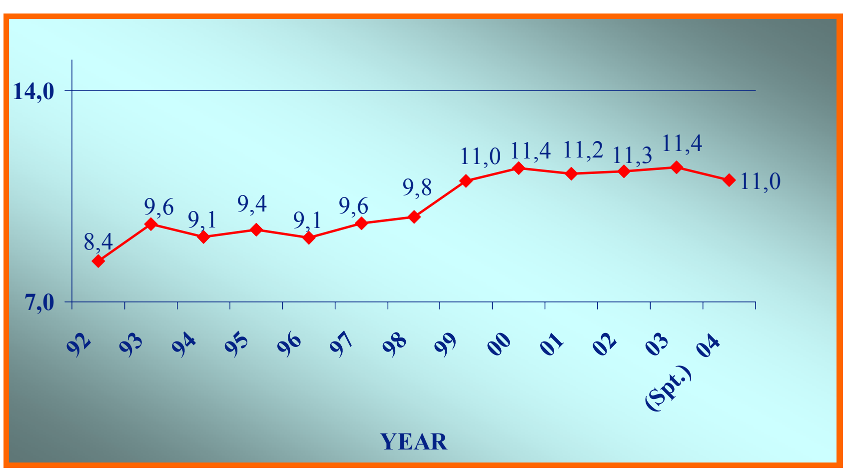
+ 100 MESHES (%)



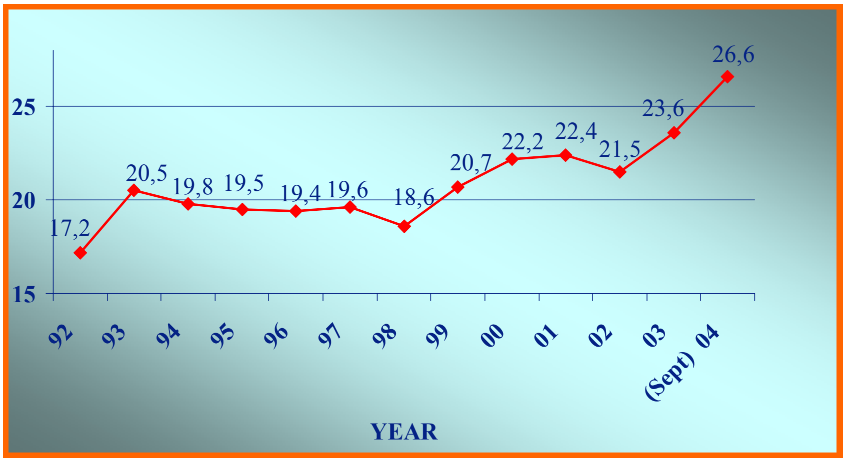
BALLS CONSUMPTION
GR/TON



POWER CONSUMPTION
(KWH/TMS)



PLANTA POWER CONSUMPTION (KWH/TMS)



Wi (kWh/Tcs)

OPERATION MANAGEMENT
MAIN INDICATORS

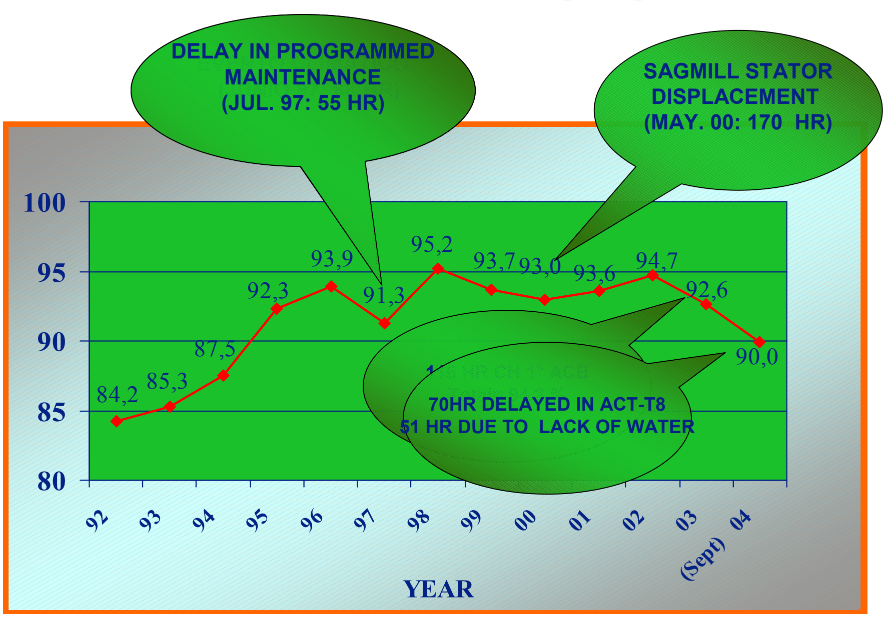
UTILIZATION PERCENTAGE

COSTS

ACCIDENTS FREQUENCY RATE

PRODUCTIVITY

UTILIZATION (%)



UTILIZACION IMPROVEMENT CAUSES

MODIFICATION OF TRANSFER CHUTES DUE TO NON SUITABLE DESIGN (Discharge area is increased)

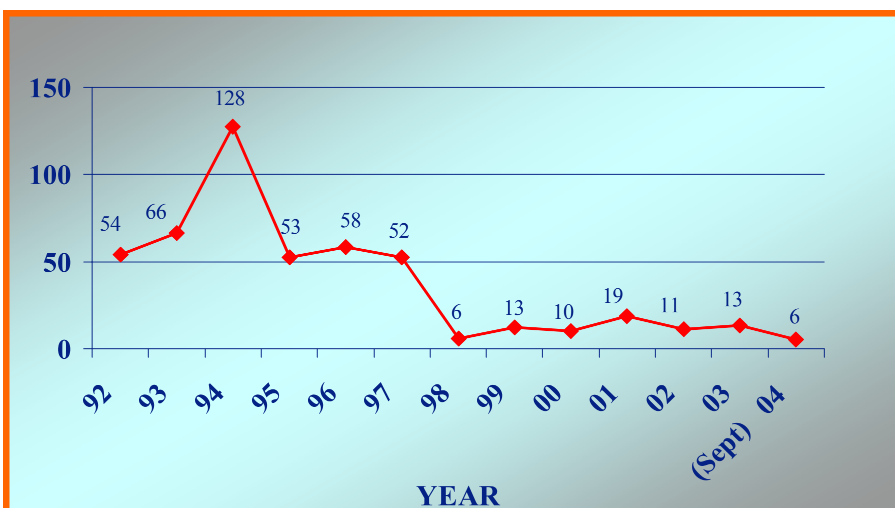
MODIFICATION OF SAG FEEDING CHUTE (Transfer area is increased)

MODIFICATION OF TRANSFER BELTS DESIGN(Grater power motors and higher capacity belt conveyors)

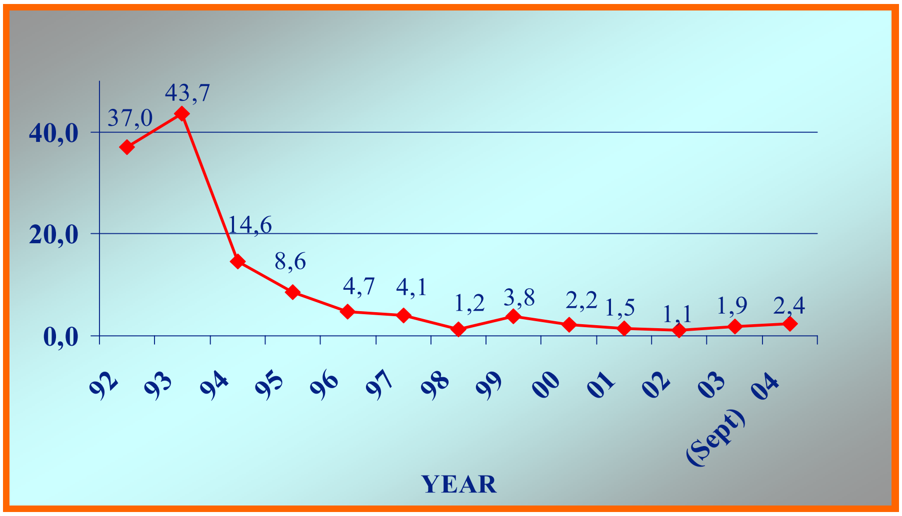
DESIGN MODIFICATION OF EMERGENCY CABLE STOP SYSTEM

(Defenses over cable are installed, to avoid the stop action of falling stones)

PLANT SHUT DOWN HOURS DUE TO TRANSFER CHUTES AND BELTS OBSTRUCTIONS

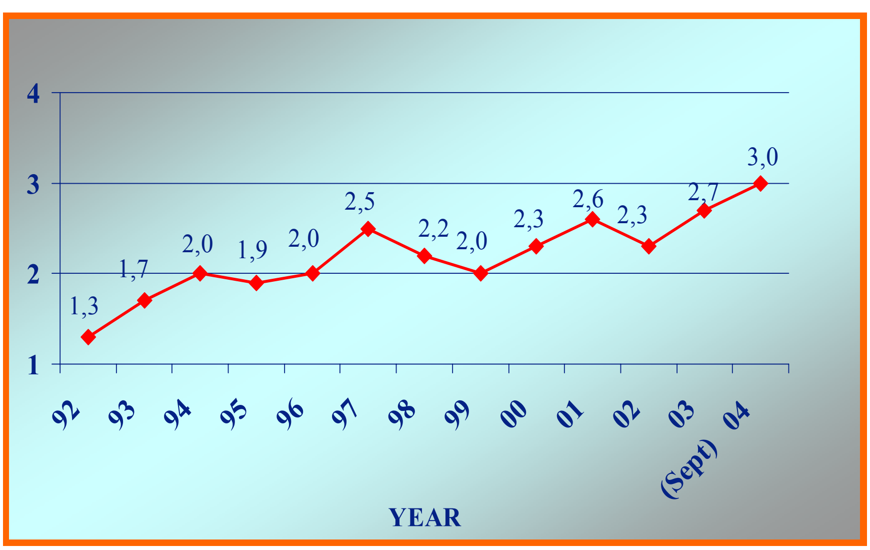


PLANT SHUT DOWN HOURS DUE TO SAFETY CABLES OPERATION

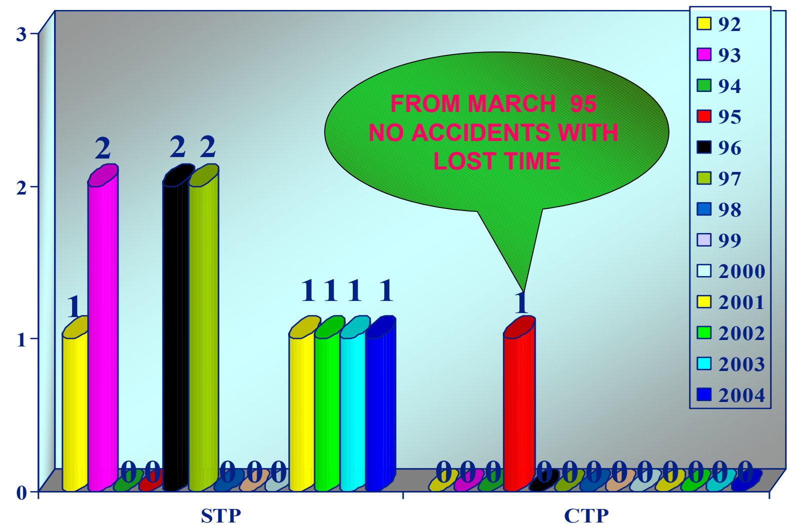


SAG PLANT COSTS

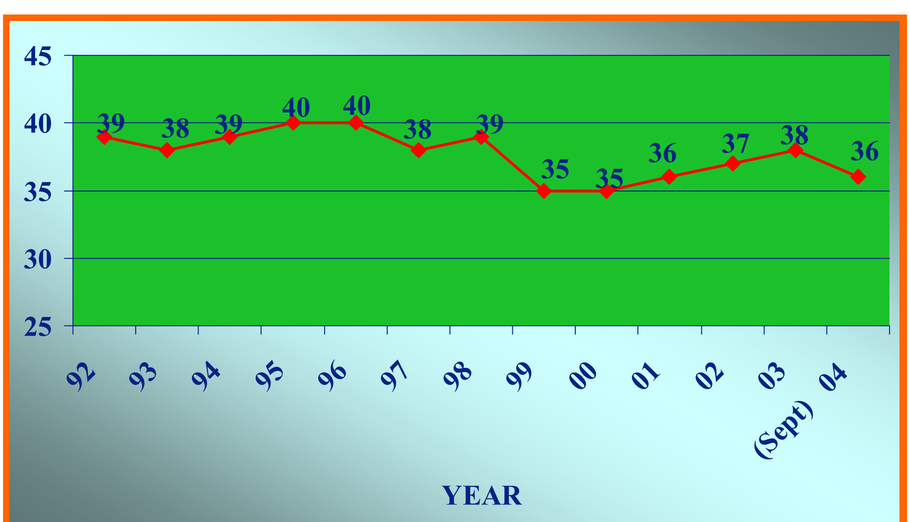
(US$/MTS MILLED)



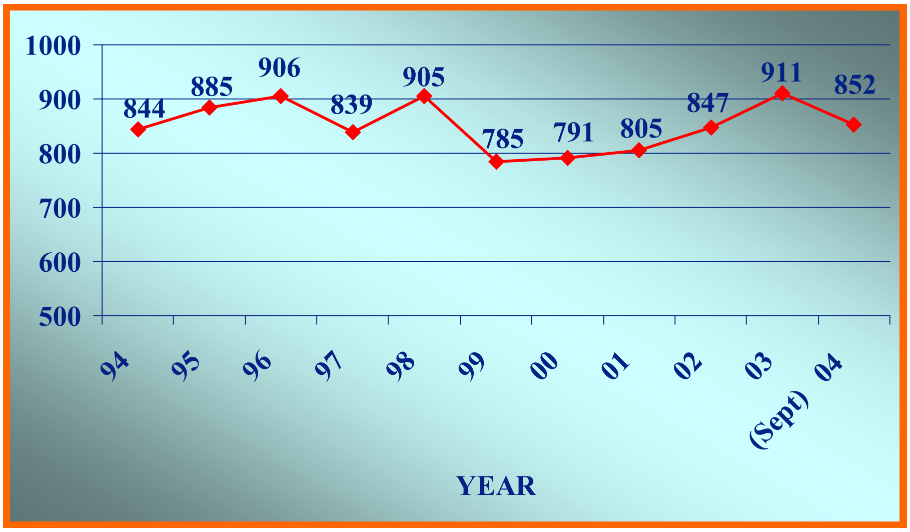
ACCIDENTS PER YEAR



PRODUCTIVITY
(MTSHR/H REGISTERED)



PRODUCTIVITY
(MTS DAY/H REGISTERED)



OPERATION STRATEGY

MAXIMUM TONNAGE TREATMENT

MILL OPERATION FILLING LEVEL (26 TO 30% FILLING)

MAXIMUM SPEED (10.3 RPM)

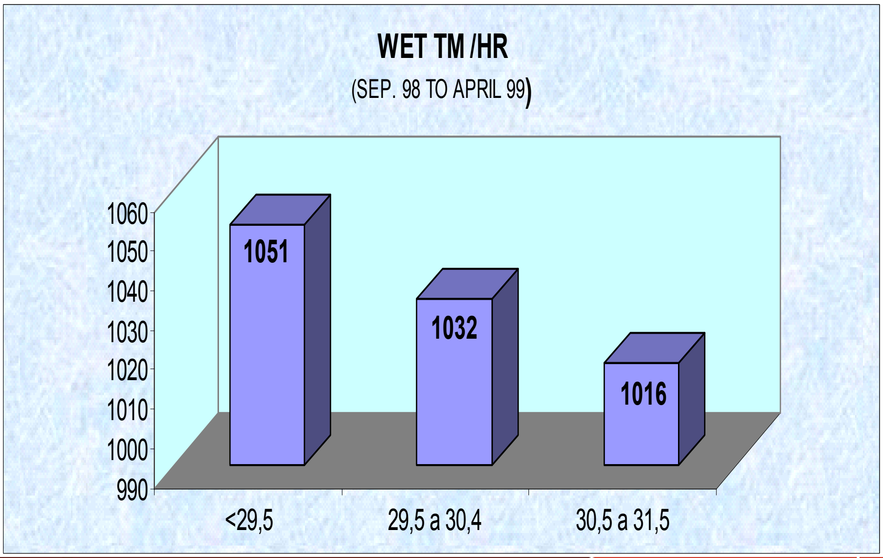
WITH FEED SOLIDS % AS LOW AS ALLOWED BY RECIRCULATION

USING THE “SUPERSAG” EXPERT CONTROL SYSTEM

IMPROVED FINAL PRODUCT

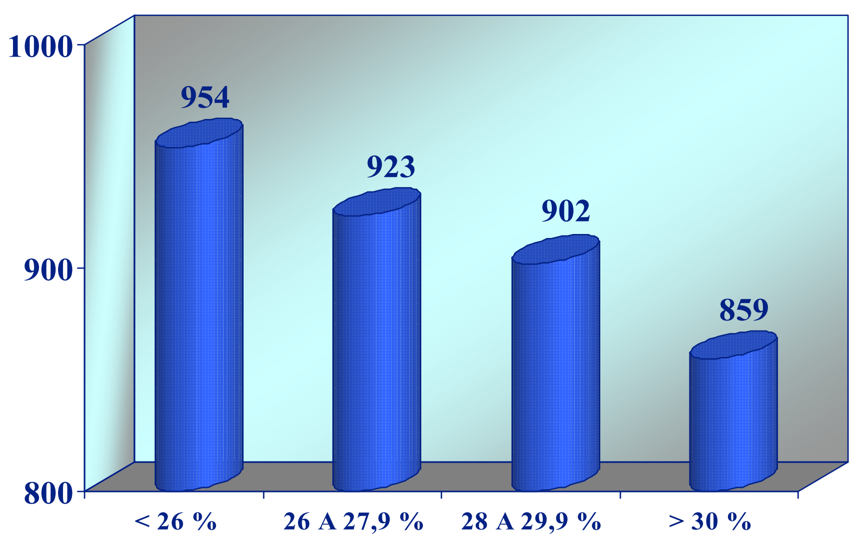
P 80 147 MICRONS

EFFICIENCY V/S FILLING LEVEL



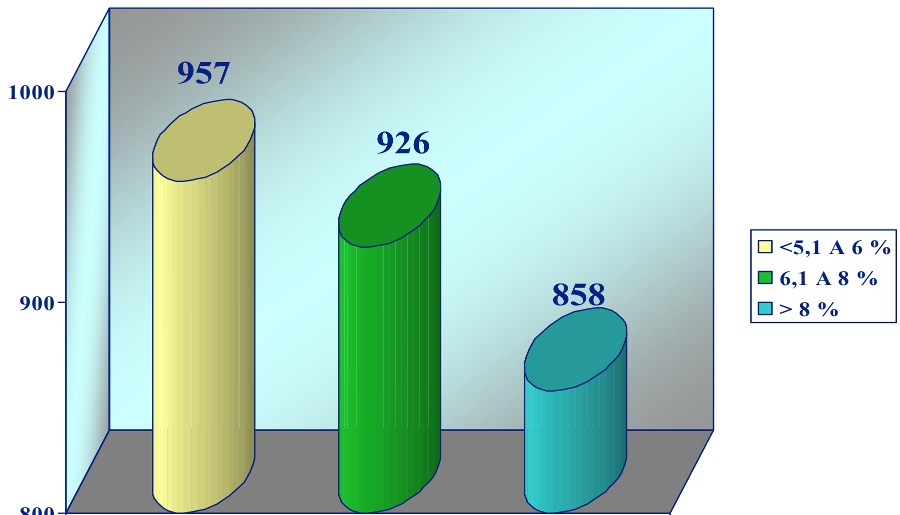
EFFICIENCY V/S FILLING LEVEL

(JANUARY TO OCTOBER 2000)



EFFICIENCY V/S COARSE %

(JANUARY TO OCTOBER 2000)



¿HOW TO REVERT A LOW EFFICIENCY SITUATION?

- **CHANGING THE BALL DIAMETER**

  RECHARGING 6" BALLS

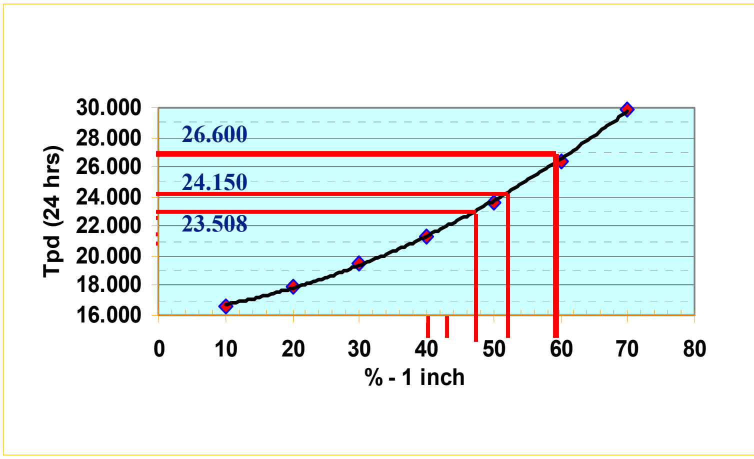
  IMPLEMENTATION DATES YEAR 2.004

- **FEED SIZE DISTRIBUTION MODIFICATION**

  PRE-CRUSHING PROCESS

  IMPLEMENTATION DATES YEAR 2.006

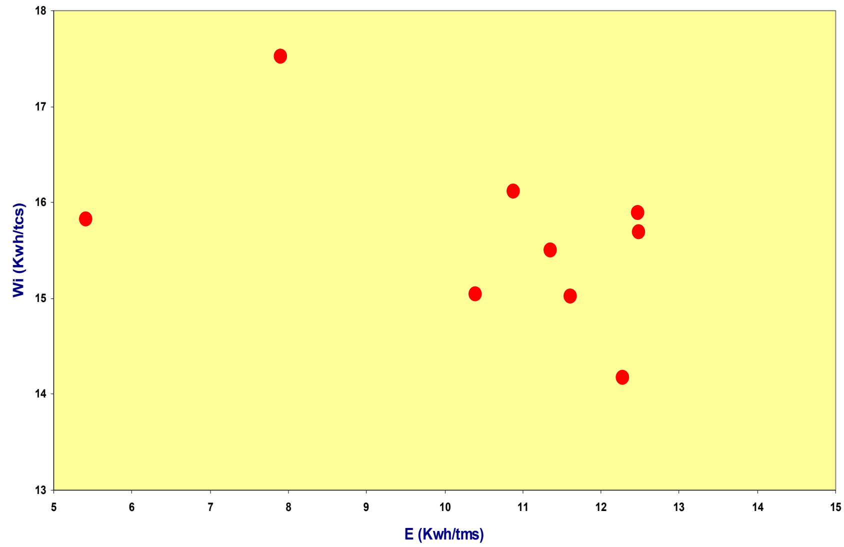
FINE % EFFECT ON SAG PLANT PROCESSING ANALYSIS



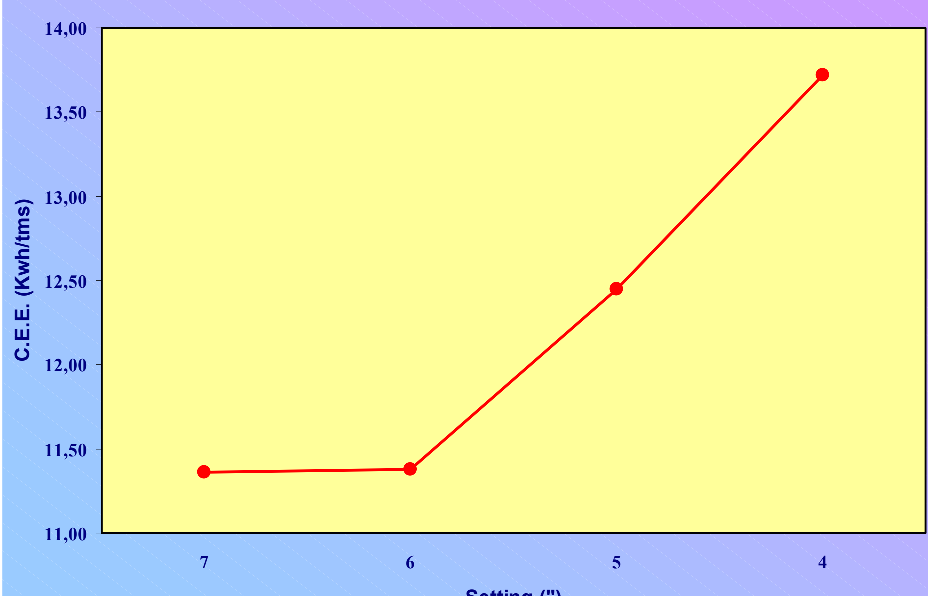
MINE SECTORS STUDIED IN SAG GRINDING PILOT TESTS

SECTOR	LITHOLOGY	C.E.E (KWH/TMS)
QUEBRADA TENIENTE	SECONDARTY ANDESITE	5,63
SUB-6	PRIMARY ANDESIT	12,97
ESMERALDA	PRIMARY ANDESITES-BREACHES	11,03
ISLA MARTILLO	PRIMARY DIORITE	12,50

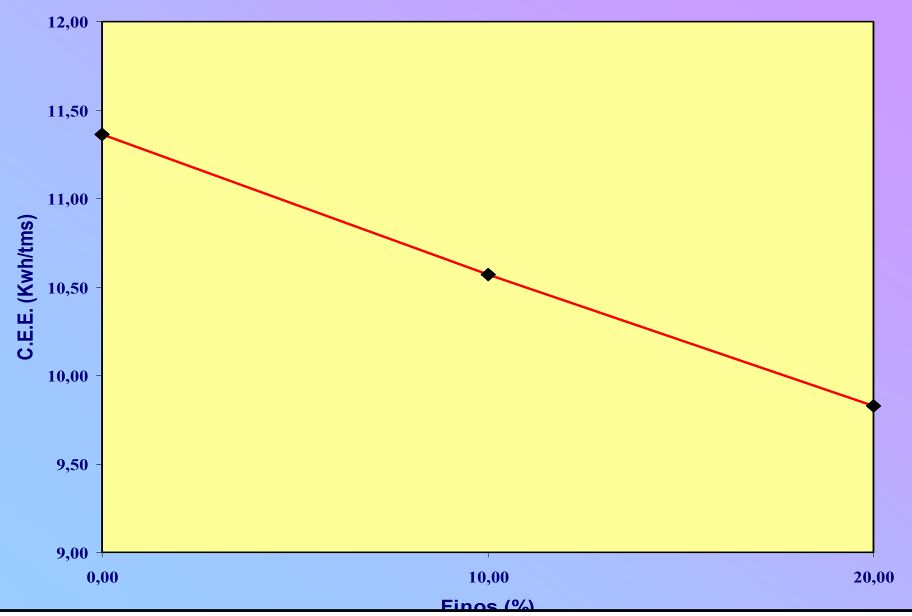
RELATION S.E.C. SAG V/S BOND BALL Wi



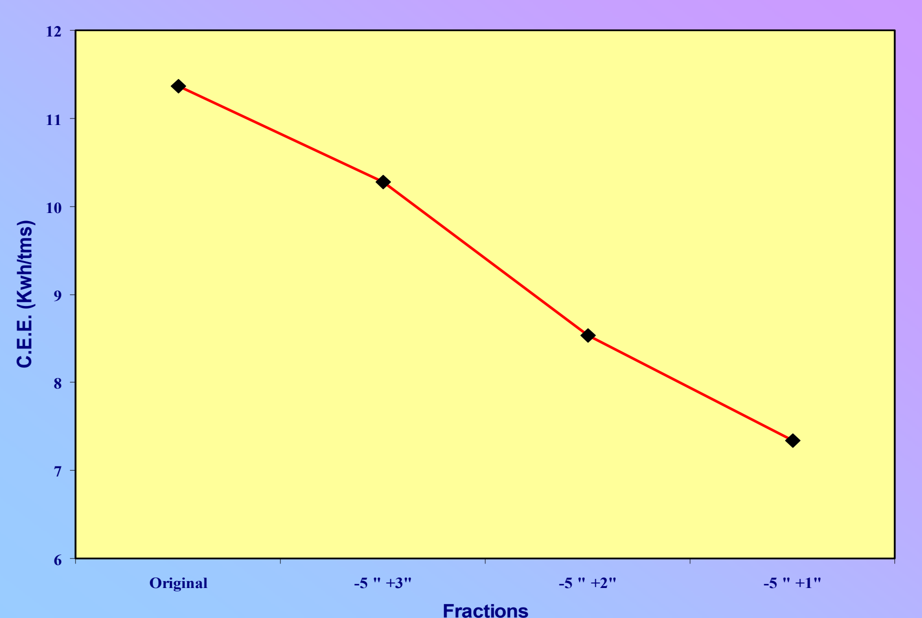
SAG S.E.C. (C.E.E) VARIATION RELATED TO PRIMARY CRUSHER SETTING

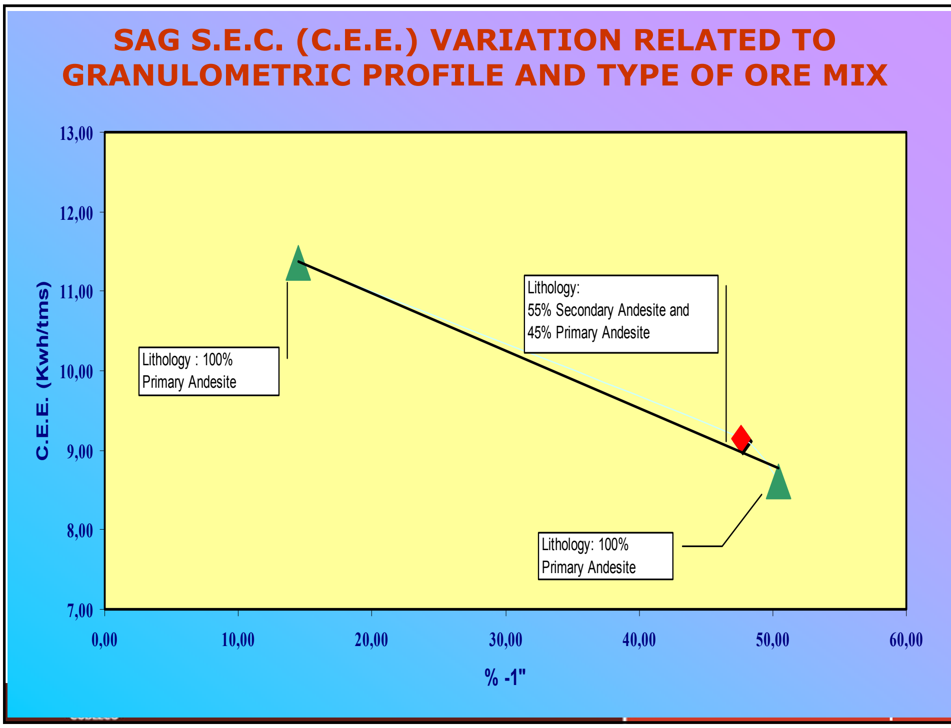


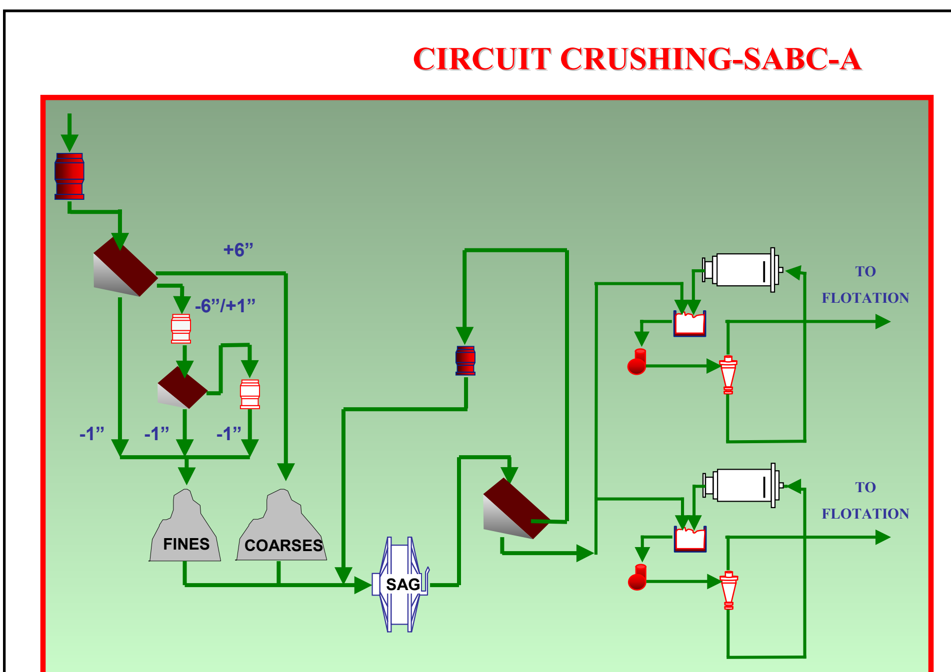
SAG S.E.C. (C.E.E) VARIATION RELATED TO FINES ADDITION



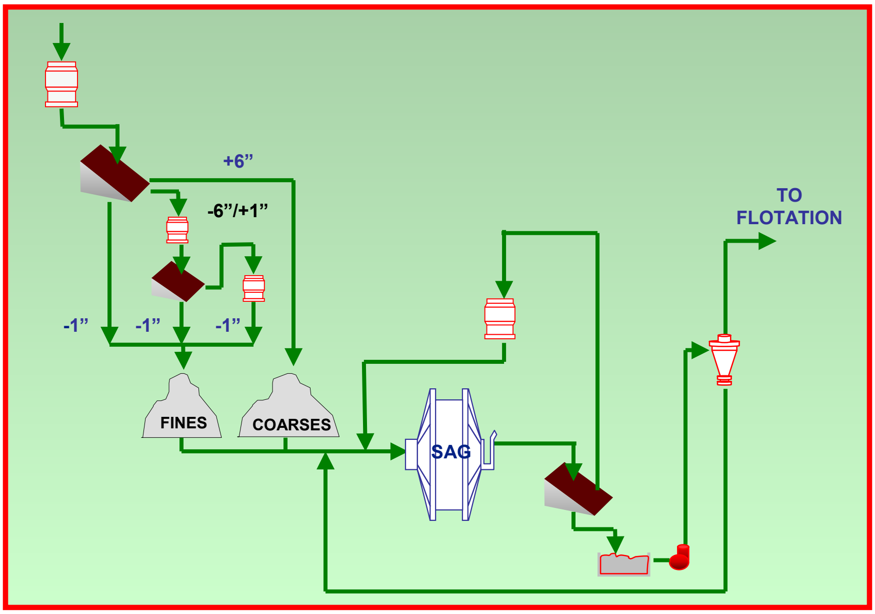
SAG S.E.C. (C.E.E.) VARIATION RELATED TO CRUSHED INTERMEDIATE FRACTION



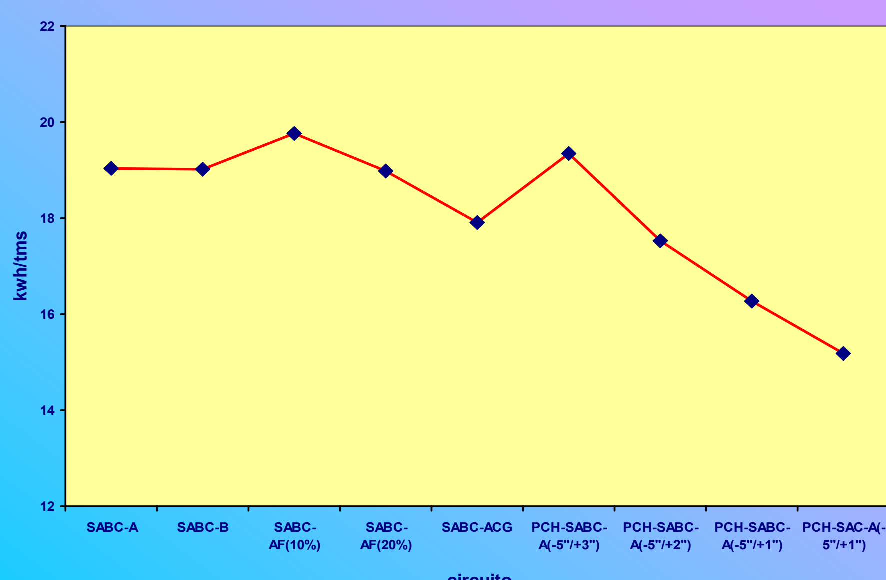

SAG S.E.C. (C.E.E.) VARIATION RELATED TO GRANULOMETRIC PROFILE AND TYPE OF ORE MIX
C.E.E. (Kwh/tms)
13,00
12,00
11,00
10,00
9,00
8,00
7,00
0,00
10,00
20,00
30,00
40,00
50,00
60,00
% -1"
Lithology : 100% Primary Andesite
Lithology: 55% Secondary Andesite and 45% Primary Andesite
Lithology: 100% Primary Andesite


CIRCUIT CRUSHING-SABC-A
+6”
-6”/+1”
-1”
-1”
-1”
FINES
COARSES
SAG
TO FLOTATION
TO FLOTATION

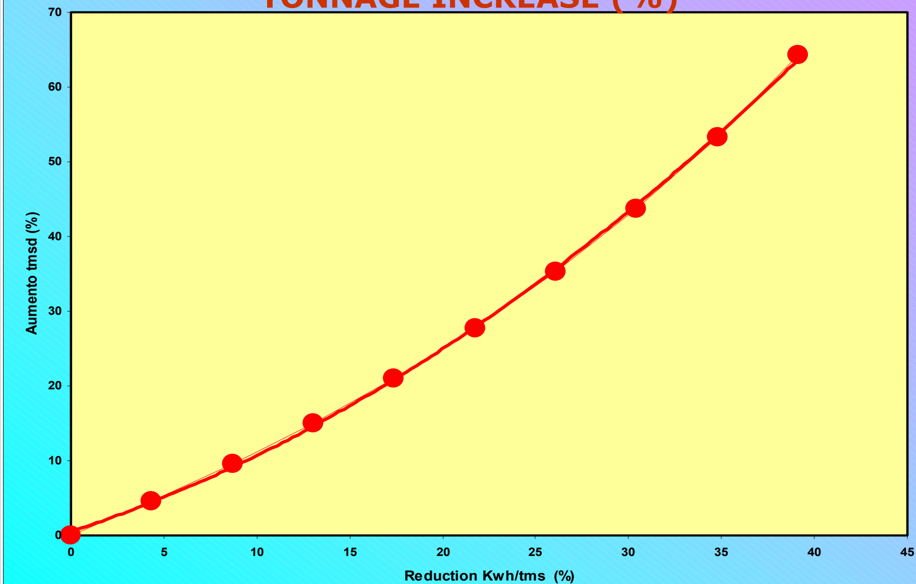
CIRCUIT CRUSHING-SAC-A



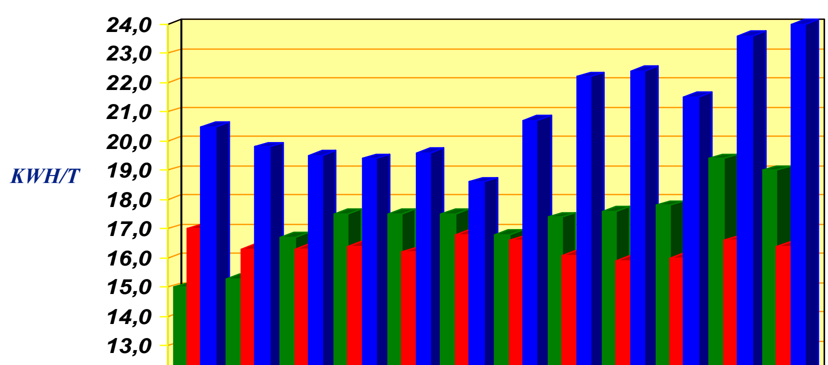
SPECIFIC POWER CONSUMPTION IN ALTERNATIVE CIRCUITS FOR A PRODUCT OF 20%+100M



DECREASE RATIO OF E (%)
V/S
TONNAGE INCREASE (%)

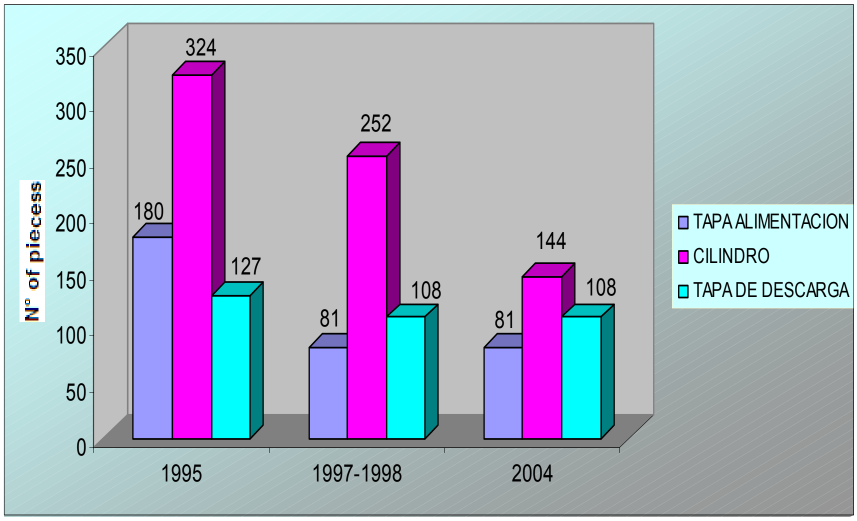


POWER CONSUMPTION
MILLING AND CRUSHING

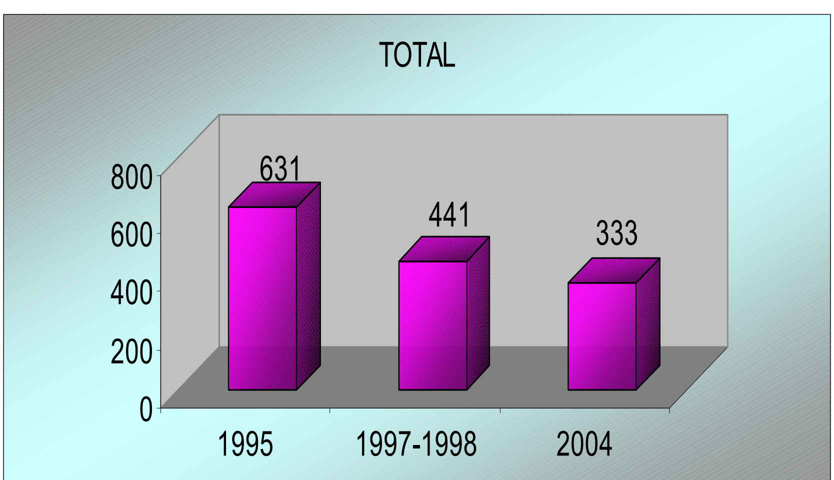


	93	94	95	96	97	98	99	00	01	02	03	04 Sep
Sewell	15	15,3	16,7	17,5	17,5	17,5	16,8	17,4	17,6	17,8	19,4	19,0
Colón	17	16,3	16,3	16,4	16,2	16,8	16,6	16,1	15,9	16	16,6	16,4
SAG	20,5	19,8	19,5	19,4	19,6	18,6	20,7	22,2	22,4	21,5	23,6	26,6

SAG MILL LININGS RATIONALIZATION



ELEMENTS QUANTITY REDUCTION



CONCLUSIONS

THE SAG MILL FEED SIZE DISTRIBUTION IS THE MOST IMPORTANT VARIABLE ON THE ENERGETIC AND METALLURGIC PROCESS EFFICIENCY.

THE PERCENTUAL INCREASE OF FINE MATERIAL (FRACTION -1”) ON THE FEED SIZE DISTRIBUTION, CONSIDERABLY REDUCES THE SAG MILL SPECIFIC ENERGY CONSUMPTION, AND SIGNIFICANTLY INCREASING ITS PROCESSING RATE.

DEPENDING ON THE CRITERION USED TO INCREASE THE PRESENCE OF FINES IN THE SAG FEED SIZE DISTRIBUTION FOR A LITHOLOGIC MIX, IT IS POSSIBLE TO DECREASE THE SPECIFIC POWER CONSUMPTION BETWEEN 11% AND 35%.

FROM ALL THE CRITERIA ANALYZED FOR THE MODIFICATION OF THE ORIGINAL FEED SIZE DISTRIBUTION, THE MOST ATTRACTIVE IS THE ONE THAT CONSIDERS A PRE CRUSHING STAGE OF THE INTERMEDIATE FRACTION -6” / +1”.

CONCLUSIONS

FOR LITHOLOGIC MIXES OF DIFFERENT SAG GRINDING COMPETENCIES, IT IS POSSIBLE TO EQUALIZE THE SPECIFIC ENERGY CONSUMPTIONS, AND CONSEQUENTLY THEIR PROCESSING RATES, WHEN PROCESSING IDENTICAL SAG FEED GRANULOMETRIC DISTRIBUTIONS.

IN THIS SPECIFC CASE, THE BOND BALL Wi, USUALLY USED IN THE SAG STAGE TO ESTABLISH GREATER OR LOWER HARDENESS OF THE PROCESSED ORES, NO MEANS ANY CORRELATION WITH DE SPECIFIC POWER CONSUMPTION IN THIS GRINDING STAGE. FOR THIS REASON ITS UTILIZACION MUST NOT BE CONSIDERED WITH DIMENSIONING PURPOSES AND CALCULATION OF PROCESSING RATES.

IN RELATION WITH THE RESULTS OBTAINED IN THE CURRENT STUDY, WHEN DESIGNING THE SAG MILLING PILOT TESTS, IT IS IMPERATIVE TO CONSIDER THE REVISION OF THE EFFECT OF THE GRANULOMETRIC PROFILE VARIATION, BESIDES THE TRADITIONALLY STUDIED VARIABLES AS THEY ARE: CRITICAL SPEED OF THE MILL, TROMEL OPENING, NUMBER OF ROCK-PORTS OPEN, CIRCUTS CONFIGURATION, BALLS FILLING LEVEL, ETC.

SUMMARY

- THE CHANCES FOR OPTIMIZING THE USE OF THE POTENCIES INSTALLED AND, THEREFORE THE TONNAGES PROCESSED ARE:
  - IN THE EVENT THAT CONVENTIONAL AND SAG MILLING CIRCUITS EXISTS AT A PLANT , IF LACK OF ORE OCCURS, THE SAG PLANTS PROCESS MUST BE MAXIMIZED AS PRIORITY, BY STOPPING, IF NECESSARY, PROCESSING STEPS IN CONVENTIONAL CIRCUITS.
  - SPECIFIC POWER CONSUMPTION OF THE ORE MIX CAN BE VARIED BY CHANGING THE FEEDING GRANULOMETRY TO THE PLANTS, EITHER ADDING FINES OR BY PRE-CRUSHING THE COARSE MATERIAL LESS COMPETENT WITH THE SAG MILLING.
  - OPTIMIZING THE UTILIZACION OF THE PLANT. BY IMPROVING THE MATERIALS QUALITY, ADVANCED DESIGN OF PARTS AND PIECES AND BY REDUCING THE NUMBER OF LINING PIECES, LIFTERS AND PULP LIFTERS, SO AS TO MINIMIZE THE MAINTENANCE HOURS.
  - OPTIMUM OPERATION PARAMETERS MUST BE DETERMINED, SUCH AS FILLING LEVEL, BALLS LEVEL, MILL SPEED, PERCENTAJES OF SOLIDS, ETC., WICH MUST BE INCORPORATED TO EXPERT SYSTEMS.

$$TP\ (tmsd) = P\ (Kw) \times U\ (\%/1) \times 24\ /\ E\ (Kw/tms)$$

END OF PRESENTATION

EFFECTIVE ENERGY UTILIZAYION ON JAPANESE COPPER SMELTERS

AKADA AKIHIKO
SUMITOMO METAL MINING Co. Ltd., Japan

1. Transition of Copper Production in Japan

Figure I shows production and consumption of copper in Japan during the last 5 decades (1). In the 1950's the both production and consumption were still 200,000 tonnes or less. At that time, the blast furnaces, the reverberatory furnaces and the electric furnaces with a small capacity, that were mainly located nearby the copper mines inland, were used for copper smelting. In the 1960's to 1970's the smelters increased their production to balance the rapid increase of domestic demand in the use of the imported copper concentrate because the price of domestic concentrate, that was exploited from the deeper face and processed from the lower grade ore than before, became much more expensive than the concentrate from abroad.

In 1965 the coastal smelter and refinery complex was built by Onahama Smelting and Refining Co. Ltd. to gain an advantage over treatment of the imported concentrate. This smelter was equipped with two reverberatory furnaces that were the one of the largest reverberatory furnace in the world at that time and its original capacity was 72,000 tonnes of copper/year. And then, from 1967 to 1973, the rush of constructing the coastal smelter and refinery complexes that adopted the Outokumpu flash furnaces as smelting furnace and the shut down of the conventional furnaces occurred in Japan. And then, commercial operation of Mitsubishi's continuous furnace started in 1973.

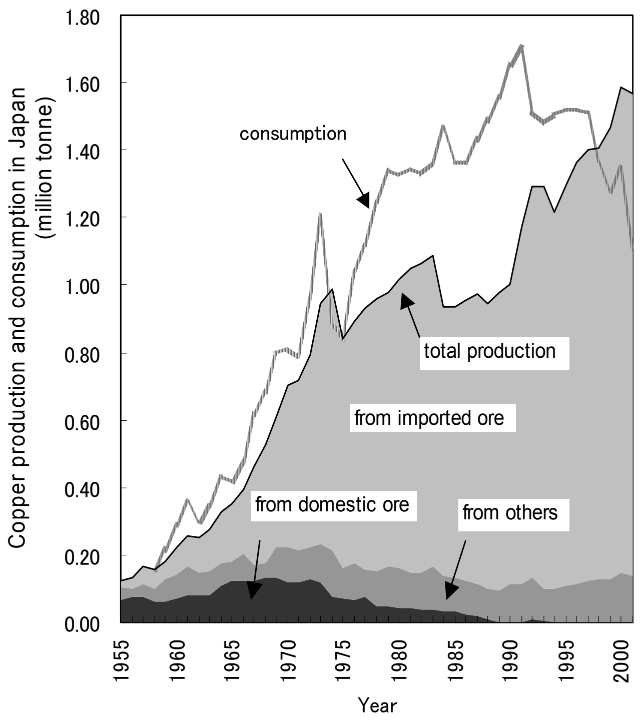


Figure I - Copper Production and Consumption in Japan

On the other hand, in 1970's the energy crises shook the world twice. In Japan, the oil price and the electricity price soared 10-folds and 4-folds, respectively. In order to break through these tougher conditions, Japanese Copper industry tried to reduce the energy cost and to increase production, and survived successfully. Table I shows the copper production of 6 smelters in Japan in 2002.

Table I - Copper Smelters of Japan (2)

COMPANY NAME	Sumitomo Metal Mining Co. Ltd.	Nippon Mining and Metals Co. Ltd.	Onahama Smelting and Refining Co. Ltd	Hibi Kyodo Smelting Co. Ltd	Dowa Mining Co. Ltd	Mitsubishi Materials Corp.
PLANT NAME	Toyo	Saganoseki	Onahama	Tamano Smelter	Kosaka	Naoshima
Annual Production	260,000	472,650	221,000	283,660	65,000	222,000
Type of Smelting Furnace	Flash	Flash	reverberatory	Flash with electrodes	Flash	MMC Continuous
Number of units	1	1	2	1	1	1

2. World Trend in the Copper Industry

2.1. Production and Demand in the World

As can be seen from the forecast of world copper production shown in Figure II, copper production will increase by 1.5 million tonnes during the period from 2003 to 2005 (3). As production from the SX-EW process will not increase, smelter and refinery production are expected to increase.

Figure III shows the predicted world copper demand. The 2002 copper demand of about 15 million tonnes will increase 21 million tonnes by 2010 (4). Nearly half of this 6 million tonnes increase is anticipated due to growth in the Asia/Oceania region.

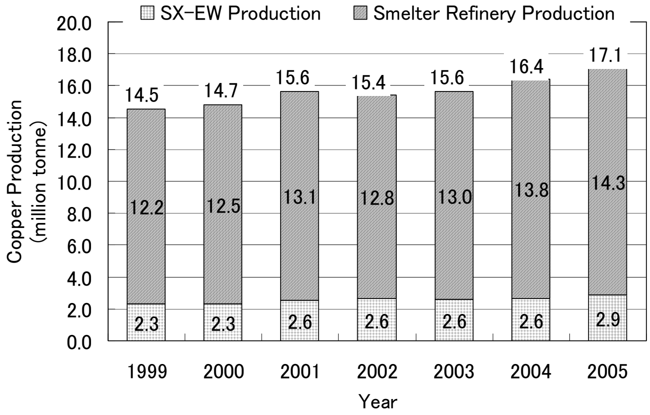


Figure II - Forecast of World Copper Production

2.2. World Trend in Copper Smelters

Table II compares the energy requirements for seven smelting processes, including the energy equivalents of materials consumed by each process (5). Although there is no data for Teniente and Isasmelt because this assessment was done in 1980, the energy requirement for these two processes is estimated as almost the same as the one for Mitsubishi furnace. In addition, It is said that there are no difference in the energy requirements between for the flash smelting and for the bath smelting nowadays.

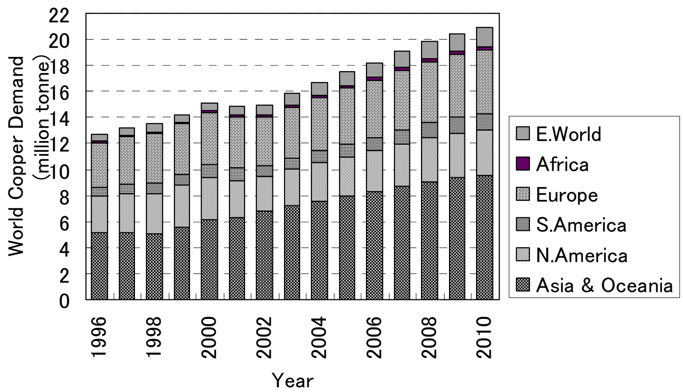


Figure III - Predicted World Copper Demand

Types of smelting furnaces operating around the world are the Outokumpu flash furnace, reverberatory furnace, Teniente Converter, Isasmelt, Mitsubishi furnace, INCO flash furnace, Noranda reactor and the shaft furnace. Figure IV shows world copper production classified by smelting process. Outokumpu flash furnaces produce about half of the total copper production in the world, and are thus the main stream of the copper smelting processes (3).

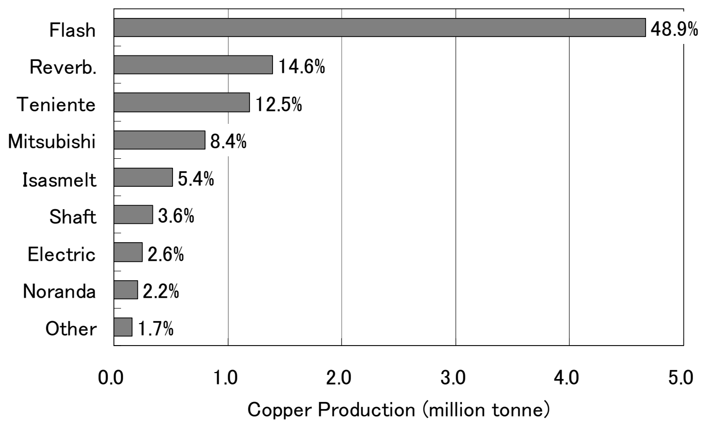


Figure IV - World Copper Production Classified by Smelting Process

Table II - Energy Requirements for Pyrometallurgical Process

	Reverberatory wet charge	Reverberatory dry charge	Electric furnace	INCO flash	Outokumpu flash	Noranda reactor	Mitsubishi reactor
Materials handling	0.77	0.77		0.77	0.60	0.83	0.70
Dry or roast		0.70	2.82	1.96	1.30	0.84	1.36
Smelting							
Fuel	26.39	15.30			0.84	3.92	6.82
Electricity	0.68	0.68	20.08	0.05		1.33	1.67
Surplus steam	-10.55	-4.59			-3.62	-1.92	-8.44
Converting							
Electricity	1.72	1.33	3.08	0.99	0.68	0.39	1.50
Fuel	0.57	0.34	3.78			0.09	0.26
Slag Cleaning					1.57	1.38	1.42
Gas handling							
Hot gas	4.25	2.99	0.82	0.62	0.44	0.73	0.91
Cold gas	0.26	0.42	2.33	0.33	0.22		0.34
Fugitive emissions	3.77	3.77		3.77	3.77	3.77	0.94
Acid plant	2.39	4.08	5.00	3.37	4.07	3.27	4.30
Water	0.11	0.11		0.11	0.11		0.11
Electrorefining	6.14	6.14	5.38	6.14	6.14	6.14	6.14
Materials:							
Miscellaneous					0.04	0.69	0.66
Oxygen				3.72	3.21	3.34	1.36
Electrodes			0.91				0.17
Fluxes	0.04	0.03	0.13	0.02	0.01	0.02	0.06
Water	0.08	0.08		0.08	0.08		0.08
Anode furnace	0.50	0.50	0.54	0.50	0.50	0.50	0.50
Total	37.12	32.63	44.86	22.43	19.96	25.33	20.86

3. Energy Utilization on Japanese Copper Smelters

In 1996, *Nippon Keidanren*, one of the three major economic organization of Japan, decided upon the independence action plan from the viewpoint of the both energy conservation and prevention of CO_2 emission prior to the Kyoto Protocol. The target of this action plan for the non-ferrous metal industry is the reduction of unit energy consumption by 12% in year 2020 compared with 1990. Table III shows the progress until 2001 and predicted ones (6). Although the information below is disclosed as one category for four kind of non-ferrous metals, it is clear that the copper smelters in Japan keep progress in reducing unit energy consumption successfully as copper production takes about 70% of non-ferrous metal production in Japan.

Table III - Energy Consumption of Non-ferrous Metal Industry in Japan

	Fiscal Year 1990	1998	1999	2000	2001	2005(predicted)	2010(predicted)
Cu,Zn,Pb and Ni production(1000 tonne)	2,005	2,153	2,266	2,383	2,320	2,543	2,778
compared with 1990		7%	13%	19%	16%	27%	39%
Energy consumption (TJ)	54.6	53.9	54.6	54.0	53.1	56.5	66.8
compared with 1990		-1%	0%	-1%	-3%	3%	22%
Unit energy consumption (GJ/tonne)	27.2	25.0	24.1	22.7	22.9	22.2	24.0
compared with 1990		-8%	-12%	-17%	-16%	-18%	-12%

The measures of effective energy utilization that have been adopted in the copper smelters in Japan for the last five years are itemized below. There are two main trends for effective energy utilization. One is energy saving and the other is utilizing exhaust energy and spent materials.

1) Energy Saving

- Employment of high efficiency motors
- Reduction of free air infiltration
- Employment of power factor corrected
  a. Oxygen plant b. Power receiving end
- Increasing of blower efficiency
- Increasing of pump efficiency
- Control of damper openness
- Employment of low pressure drop gas line
  a. Catalyst b. Duct arrangement
- Maintenance of oil burner
- Decreasing of resistance in electrolysis circuit
- Less idling operation
  a. Pump b. Coal mill c. Fan d. Furnace
- Employment of lower temperature operation

2) Utilization of exhaust energy and spent materials

- Increasing of heat recovering efficiency
  a. Employment of high heat conductivity material for condenser tube
  b. Employment of boiler instead of SO_3 cooler
  c. Periodic maintenance of condenser tube
- Automobile Shredder Residue for fuel
- Spent Tire for fuel
- Spent Oil for fuel
- Employment of steam dryer using exhaust steam

4. Examples of Energy Utilization at Toyo Smelter

4.1. The Outline of Toyo Smelter and its Expansion Project

The Sumitomo Toyo Smelter commenced its operation in 1971 with a smelting capacity of 850 tpd (tonnes per day) of copper concentrate. The present capacity has reached almost 2,700 tpd of copper concentrate and the projected capacity will reach 3,950 tpd.

The flow sheet of the Toyo Smelter is shown in Figure V and historic data recording the amounts of copper production and projected production at the Toyo Smelter are shown in Figure VI.

The Toyo smelter is carrying out an expansion project to increase its annual electrolytic copper production capacity from 270,000 tpa to 450,000 tpa by 2007 at the latest. The completion of the expansion project will be done the next year under the following policy guidelines:

A. Reduce production costs by increasing smelter capacity.
B. Save on capital costs by utilizing existing capacity.
C. Minimize operation risks resulting from expansion.
D. Strengthen environmental management.

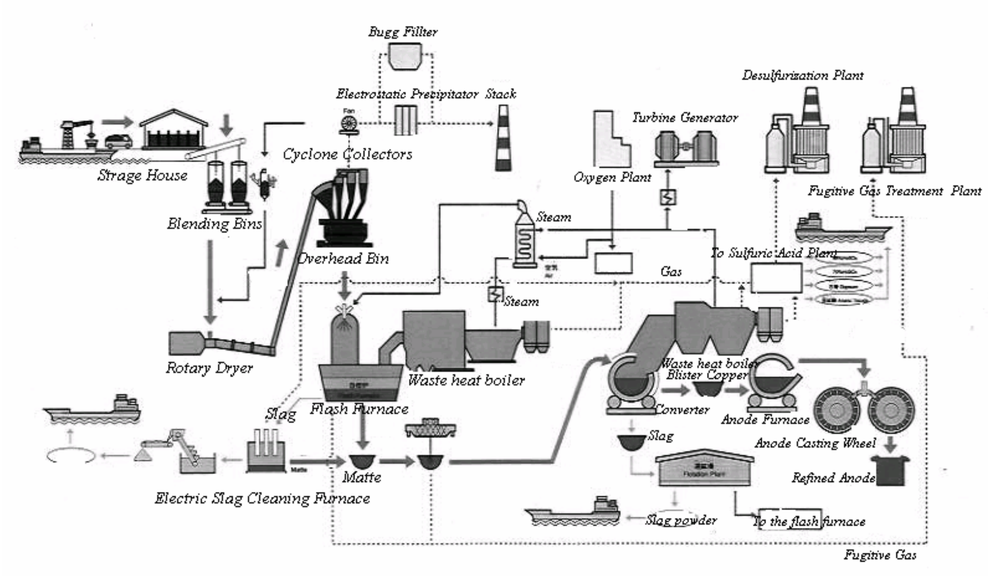


Figure V - Schematic Flow Sheet of the Toyo Smelter

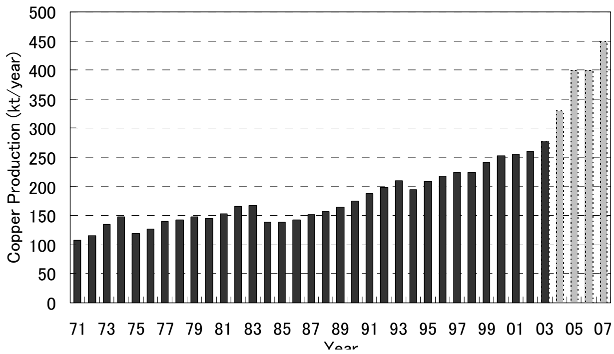


Figure VI - Projected Copper Production

4.2. Fuel Reduction in the Flash Furnace

The Toyo flash furnace was originally equipped four concentrate burners and its dust generation ratio had been around 9% since commencement. When oxygen enrichment to the flash furnace was introduced in 1982 in order to increase the production and to decrease the fuel consumption, dust generation ratio jumped up to 12-14% and fuel consumption increased to compensate the heat for dust decomposition.

In order to reduce dust generation, the Toyo smelter set about developing a

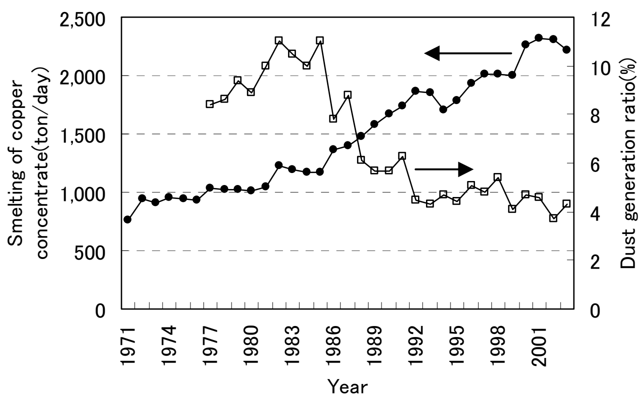


Figure VII - Smelting Rate of Concentrate and Dust Generation Ratio better performance concentrate burner which is still on progress even now. Our strategy for the development of a better performance concentrate burner was worked out based on the two-particles model obtained by an extensive research work of the Sumitomo Metal Mining Niihama Research Laboratory.

The concentrate burner was changed to the single type in 1996 and now the Toyo flash furnace equips the original single concentrate burner called the Sumitomo type concentrate burner.

Table IV shows the heat balance of the flash furnace. Compared to 2003 with 1985, heat input by fossil fuel in 2003 is reduced by 43% of 1985's, or unit heat input by fossil fuel per tonne of concentrate is reduced by 21.5%. In 2007 at the copper production rate of 450,000 tpa, unit heat input by fossil fuel per tonne of concentrate is expected to be reduced by only 3% of 1985's.

Table IV – Heat Balance of Flash Furnace

	Year 1985		2003		2007(plan)	
OPERATING CONDITION						
concentrate charge (ton/hour)	44.5		90		164.6	
dust generation ratio(%)	11.8		5.1		4.0	
O_2 enrichment in Reaction Air	32.1		49.5		72.1	
matte grade	56.0		63.5		65.0	
HEAT INPUT and PRODUCTION (GJ/hour)	(GJ/hour)	(%)				
heat of matte and SO_2 production	80.0	51	172.9	84	382.5	99
heat for decomposition of dust	-24.1	-15	-22.0	-11	-32.8	-9
sensible heat of ore	2.5	2	5.1	2	10.1	3
sensible heat of reaction air	17.1	11	15.0	7	8.7	2
oil and pulverized coal	81.1	52	35.3	17	17.1	4
heat input total	156.7	100	206.4	100	385.5	100
HEAT OUTPUT(GJ/hour)						
sensible heat of matte and slag	45.9	29	103.2	50	209.5	54
sensible heat of gas	73.1	47	65.4	32	117.4	30
sensible heat of dust	7.5	5	7.4	4	15.9	4
heat losses	24.7	16	25.0	12	33.1	9
others	5.5	3	5.3	3	9.7	3
heat output total	156.7	100	206.4	100	385.6	100

4.3. Electric Power Reduction in the Acid Plant

Figure VIII shows the flow of the acid plant at the present. The upper part in this figure is the new gas cleaning system, the middle is the old converting and absorbing line, and the bottom is the newly added converting and absorbing line as a part of the expansion project.

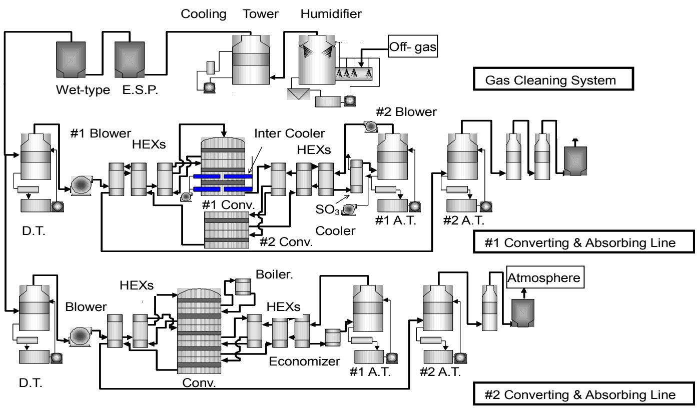


Figure VIII - Schematic Flow Sheet of the Acid Plant

Figure IX shows the changes of the index of electric power consumption per tonne of sulfuric acid produced as compared to the figure in 1985 of 100.

There are two drastic falls of electric power consumption, one was done during 1985 and 1990, and the other has being done for the past four years.

Although the original capacity of the sulfuric acid plant that was consist of the demolished gas cleaning system replaced by the new gas cleaning system drawn in Figure VIII and the old converting and absorbing line was only 850 tpd of sulfuric acid and/or 167 kNm3/h of off gas treated, the capacity of this system was increased to 2,300 tpd and/or 175 kNm3 in accordance with the increase of the smelting capacity by the improvements below.

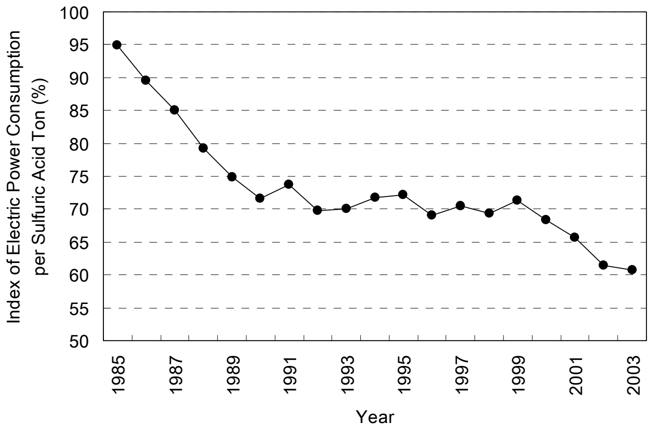


Figure IX – Electric Power Consumption in the Acid Plant

- ✓ Increase absorbing efficiency of No.1 absorber.
  Decrease the inside acid temperature and the outlet acid concentration of the absorber.

- ✓ Increase oxidation rate of converter.
  Increase O_2/ SO_2 ratio of the process gas.
  Increase catalyst temperature in the converter.

As the increase of the treated off gas volume is very small, the electric power consumption for SO_2 blower that is the biggest power consuming equipment almost does not change. On the other hand, the acid production increased almost 2.7 times, so the unit electric power consumption decreased drastically. Moreover, four measures of improvement in order to save the electric power were done shown in table V. As a result, the almost 30% of electric power reduction was achieved during this period

Table V – Measures for Electric Power Saving

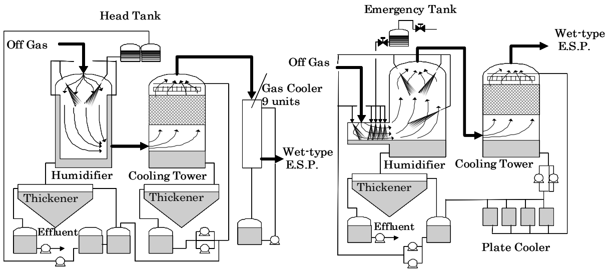
Measures	Enforcement matter	Reduction of electricity MWH/y	Enforcement period
1. Scaling up of SO_2 blower inlet damper	For the purpose of decreasing the specific regular pressure drop at damper 1)No.1 SO_2 blower φ1.16m → 1.60m 2)No.2 SO_2 blower φ1.35m → 2.00m	780	1988
2. SO_2 blower power saving operation	For the purpose of automatic draft control on gas pressure fluctuation at the inlet of acid plant which is mainly attributed to CF operation, the damper opening of the SO_2 blower inlet was improved from 60% to 100% by developing a pressure fluctuation monitoring with online process computer and feed forward system.	1180	1988
3. Gas cooler bypass ducting installation	Though shell & tube type gas cooler is used to control temperature of inlet gas at the drying tower, a bypass duct(φ 2.5m) was installed at the gas cooler, since surplus on gas cooling capacity resulted from the elevation of the SO2 strength. Its operation is done by the optimum opening bypass damper visualized on the picture of a process computer.	410	1987
3. Pressure drop decrease at the converting system	1)Renewal of catalyst to a ring catalyst(Ring catalyst occupies 60% of the whole one) 2)A bypass line modification of A to C heat exchanger.	2,300	1989 to 1992
	Total	4,670	

The reduction of electric power consumption for the last four years was mainly achieved by the implementation of the new gas cleaning system, new converting and absorbing line with high performances.

Figure X shows the old gas cleaning system and the new gas cleaning system. The difference of the pressure loss between the old and new gas cleaning system is shown in this Figure.

In addition, the new converting and absorbing system has several features below:

- SO_2 blower with the current source Inverter can follow the rapid increase and decrease of off-gas volume
- Vanadium pentoxide catalyst with the ring-shape that has lower pressure loss
- High efficiency acid distributors and mist eliminators in the absorption tower
- High efficiency desulfurization tower for flue gas
- DCS control system
- etc.



	Humidifier	Cooling Tower	Gas Cooler	Wet type E.S.P.	total
New System	306	420	-	1,390	2,116
Old System	480	510	549	1,882	3,421
differnce	-174	-90	-549	-492	-1,305

Figure X - Old Gas Cleaning System(left), New System(right), and Pressure Losses(kPa as unit)

Figure XI shows the comparison of the consumption of the electric power of the old and new line. Unit power consumption for the blower on new converting and absorbing line is smaller than the one for the old line by about 25%. When the both line are operated at the same gas volume, total unit power consumption for SO2 blowers is decreased by 13%.

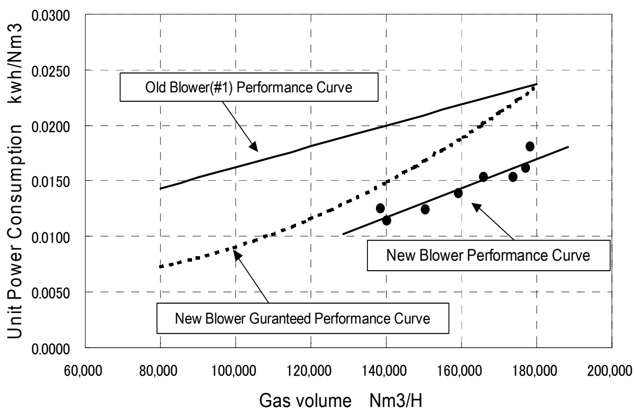


Figure XI - Unit Power Consumption of SO_2 Blowers

Furthermore, various efforts to save the electric power were executed during this period:

- Suspension of No.1 SO_3 cooler fan; 2,010 MWH/Y saving
- Suspension of booster pump for cooling water; 1,120 MWH/Y saving
- Optimization of fugitive gas fan operation; 2,500 MWH/Y saving
- etc.

4.4. Recovery and Utilization of Exhausted Energy and Reinforcement of Cogeneration System

On completion of the expansion project, the improvements for recovery and utilization of exhausted energy and cogeneration system are executed below:

- Installation of a boiler to converter in acid plant

  As the conversion of SO_2 to SO_3 is an exothermic oxidation reaction, there is considerable excess heat generated in the converter. In the old line, this excess heat, 6.7GJ/hour, is removed from the process gas to atmosphere by use of intercooler and SO_3 cooler. In the new acid line, an economizer instead of SO_3 cooler and a boiler instead of intercooler were installed. This boiler system generates steam of 12 T/hour and this steam is send to the powerhouse to generate the electricity.

- Installation of a rotary steam dryer

  The existing equipment for drying raw material is a flash dryer. In order to correspond to the amount of raw material needed for the increase of flash furnace capacity, a rotary steam dryer was added. As this dryer uses steam generated in the plant, there is no need of oil and/or coal consumed. As a result, energy consumption for drying 240 t/hour raw material by two dryers is expected to be reduced by 26% compared with energy consumption for drying 115 t/hour by the existing dryer.

- Installation of a new turbine generator

  At the production rate of 450,000 tpa, steam generated at the plant will increase to 90 t/hour compared to 68 t/hour at the production rate of 270,000 tpa. As the rated output of the existing turbine generator is 8,700 kW, excess steam of 36 t/hour will be dumped without generation. In order to avoid the waste of this steam, a new generator, the rated output 10,200 kW, was installed. By the use of two turbine generators, 10,000 kW at norm. and 18,000 kW at a peak condition will be generated at the production rate of 450,000 tpa. Figure XII shows the cogeneration system at the Toyo Smelter.

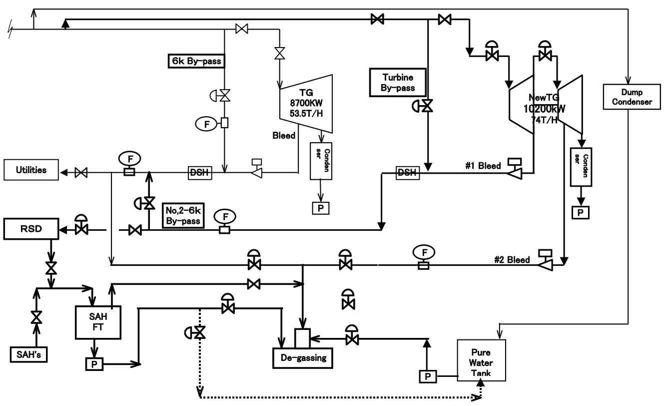


Figure XII - Cogeneration System

4.5. Overall Energy Consumption at Toyo Smelter and Refinery

Figure XIII shows the Index of energy consumption rate per tonne of treated concentrate as compared to the figure in 1985 of 100. Hence, the energy means the total energy consumed at the entire Toyo Smelter and Refinery including the tank house. The unit energy consumption was reduced by 40% or more for the last two decades. And it is expected that the

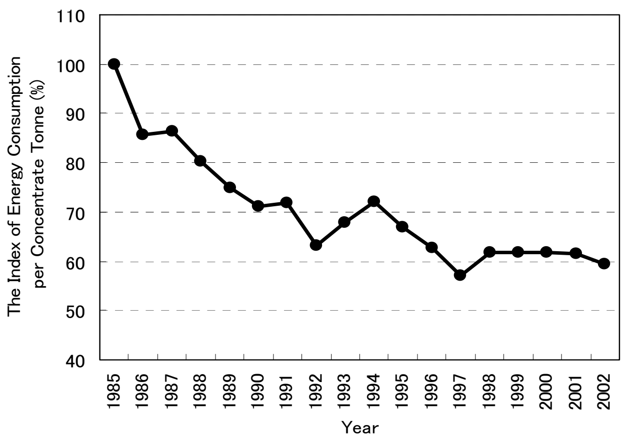


Figure XIII – Energy Consumption rate at Toyo further energy reduction should be done in accordance with the increase of the copper production.

SUMMARY

Copper production in Japan was 1.54 Million ton in 2003, that is the 3rd in the world subsequently to Chile and China. In order to reduce the production cost and to maintain the competitiveness in the world copper business, copper smelters of Japan have been fully using the measures of the both energy saving and utilization of exhaust energy and spent materials.

As an example, the measure at the Toyo Smelter was described. The Toyo Smelter and Refinery is carrying out an expansion project to increase copper production capacity by 1.7 times in order to meet future copper demand growth in the Asia region now. The unit energy consumption at the Toyo Smelter was reduced by 40% or more for the last two decades and further reduction is expected after the completion of its expansion project.

REFERENCES

1. "Yearbook of Minerals and Non-ferrous Metals Statistics", compiled by Ministry of Economy, Trade and Industry, Japan.

2. V.Ramachandran, Carlos Diaz, et al, "Primary Copper Production – a Survey of Operating World Copper Smelters", Copper Cobre,2003, Vol. IV, Book 1, 3-106.

3. Y.Ojima, "Future of Copper Converting Process", Yazawa International Symposium (Metallurgical and Materials Processing: Principles and Technologies), F.Kongoli, K.Itagaki, C.Yamauchi and H.Y.Sohn, etc., TMS, Warrendale, PA, USA, 2003, Vol.2,255-264.

4. Copper Metal Service, Brook Hunt, 2003.

5. C.H.Pitt and M.E.Wadsworth, "An Assesment of Energy Requirement and New Copper Processes", report prepared for the US Department of Energy, contract No. EM-78-S-07-1743, December 1980.

6. Report by Ministry of Economy, Trade and Industry, Japan, 31st January 2003. ;
www.meti.go.jp/report/downloadfiles/g30131c055j.pdf

Effective Energy Utilization on Japanese Copper Smelters

Oct. 21 2004
Akihiko Akada

SUMITOMO METAL MINING CO., LTD.

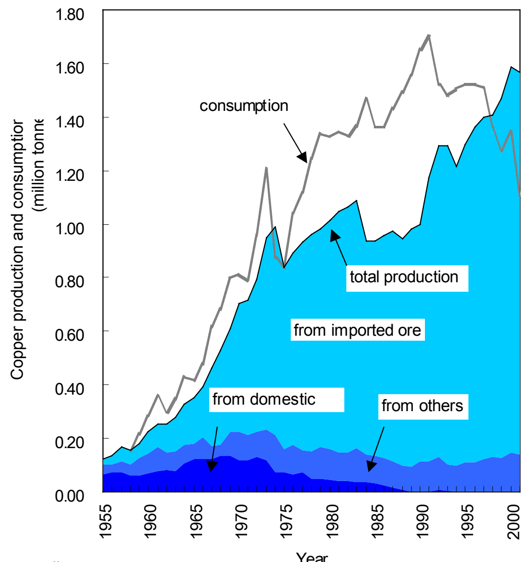
Position of the Japanese Copper Smelters

Comperison of the World Copper Smelters, 2001
(from Mineria Chilena, May, 2003)

	Japan	Chile	W.Europe	China	India	Average
Operating ratio (%)	92	90	93	86	92	83
Cu recovery (%)	98	97	98	97	97	97
SO2 recovery (%)	99	89	99	83	83	84
Productivity (tonne/100 personnel)	97	32	89	15	16	20
Labor cost, unit (US$/h)	31.9	10.6	20.7	1.5	0.8	13.1
Electricity price (¢ /kWh)	6.1	3.2	3.7	4.3	6.7	3.9
Production rate of the world (%)	13	13	9	8	3	100

SUMITOMO METAL MINING CO., LTD.

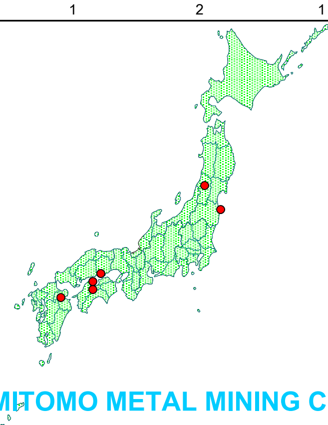
Historical Copper Production and Consumption in Japan



SUMITOMO METAL MINING CO., LTD.

Existing Six Copper Smelters in Japan

Company Name	Sumitomo Metal Mining Co. Ltd.	Nippon Mining and Metals Co. Ltd.	Onahama Smelting and Refining Co. Ltd	Hibi Kyodo Smelting Co. Ltd	Dowa Mining Co. Ltd	Mitsubishi Materials Corp.
Plant Name	Toyo	Saganoseki	Onahama	Tamano Smelter	Kosaka	Naoshima
Annual Production	260,000	472,650	221,000	283,660	65,000	222,000
Type of Smelting Furnace	Flash	Flash	Reverberatory	Flash with electrodes	Flash	MMC Continuous
Number of units	1	1	2	1	1	1



SUMITOMO METAL MINING CO., LTD.

Measures of effective Energy Utilization

1) Energy Saving

Employment of high efficiency motors
Reduction of infiltration air
Employment of power factor corrected
- a. Oxygen plant b. Power receiving end

Increasing of blower efficiency
Increasing of pump efficiency
Control of damper openness
Employment of low pressure drop gas line
- a. Catalyst b. Duct arrangement

Maintenance of oil burner
Decreasing of resistance in electrolysis circuit
Less idling operation
- a. Pump b. Coal mill c. Fan d. Furnace

Employment of lower temperature operation

2) Utilization of exhaust energy and spent materials

Increasing of heat recovering efficiency
- a. Employment of high heat conductivity material for condenser tube
- b. Employment of boiler instead of SO_3 cooler
- c. Periodic maintenance of condenser tube

Automobile Shredder Residue for fuel
Spent Tire for fuel
Spent Oil for fuel
Employment of steam dryer using exhaust steam

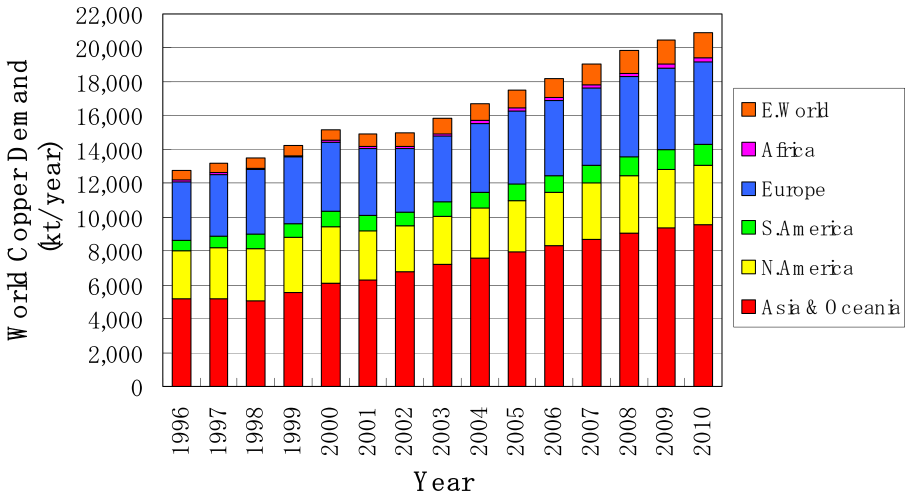
Action Plan of Energy Conservation

	Fiscal Year 1990	1998	1999	2000	2001	2005(predicted)	2010(predicted)
Cu,Zn,Pb and Ni production(1000 tonne	2,005	2,153	2,266	2,383	2,320	2,543	2,778
compared with 1990		7%	13%	19%	16%	27%	39%
Energy consumption (TJ)	54.6	53.9	54.6	54.0	53.1	56.5	66.8
compared with 1990		-1%	0%	-1%	-3%	3%	22%
Unit energy consumption (GJ/tonne)	27.2	25.0	24.1	22.7	22.9	22.2	24.0
compared with 1990		-8%	-12%	-17%	-16%	-18%	-12%

SUMITOMO METAL MINING CO., LTD.

Predicted World Copper Demand

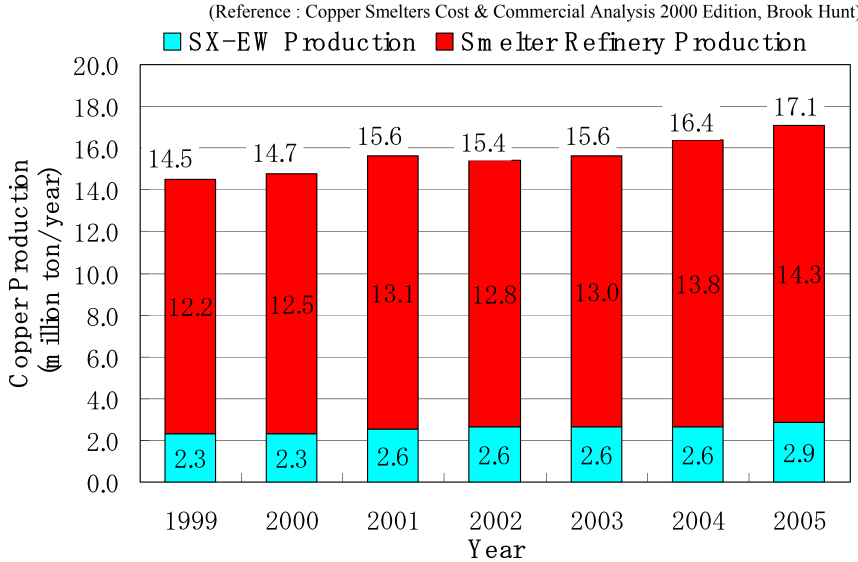
(Reference : Copper Metal Service, Brook Hunt, 2003)



SUMITOMO METAL MINING CO., LTD.

Prospects for World Copper Production

(Reference : Copper Smelters Cost & Commercial Analysis 2000 Edition, Brook Hunt)



SUMITOMO METAL MINING CO., LTD.

Energy Requirement of Various Processes

Energy Requirement of Pyrometallurgical Processes(GJ/ton)

	Reverberatory wet charge	Reverberatory dry charge	Electric furnace	INCO flash	Outokumpu flash	Noranda reactor	Mitsubishi reactor
Materials handling	0.77	0.77		0.77	0.60	0.83	0.70
Dry or roast		0.70	2.82	1.96	1.30	0.84	1.36
Smelting							
Fuel	26.39	15.30			0.84	3.92	6.82
Electricity	0.68	0.68	20.08	0.05		1.33	1.67
Surplus steam	-10.55	-4.59			-3.62	-1.92	-8.44
Converting							
Electricity	1.72	1.33	3.08	0.99	0.68	0.39	1.50
Fuel	0.57	0.34	3.78			0.09	0.26
Slag Cleaning					1.57	1.38	1.42
Gas handling							
Hot gas	4.25	2.99	0.82	0.62	0.44	0.73	0.91
Cold gas	0.26	0.42	2.33	0.33	0.22		0.34
Fugitive emissions	3.77	3.77		3.77	3.77	3.77	0.94
Acid plant	2.39	4.08	5.00	3.37	4.07	3.27	4.30
Water	0.11	0.11		0.11	0.11		0.11
Electrorefining	6.14	6.14	5.38	6.14	6.14	6.14	6.14
Materials:							
Miscellaneous					0.04	0.69	0.66
Oxygen				3.72	3.21	3.34	1.36
Electrodes			0.91				0.17
Fluxes	0.04	0.03	0.13	0.02	0.01	0.02	0.06
Water	0.08	0.08		0.08	0.08		0.08
Anode furnace	0.50	0.50	0.54	0.50	0.50	0.50	0.50
Total	37.12	32.63	44.86	22.43	19.96	25.33	20.86

SUMITOMO METAL MINING CO., LTD.

Features of Smelting Processes (1) Flash

Furnace Type	Productivity $T/m^2 \cdot D$	Furnace Charge	Matte Grade %	Characteristics
1.Flash smelting				
Outokumpu	8 ~ 11	dry conc.	55 - 65	environment-friendly process high flexibility for operation high potentiality for expansion high dust generation
Inco	12	dry conc.	45	pure oxygen smelting autogenous operation low dust generation restriction on MG (low MG)

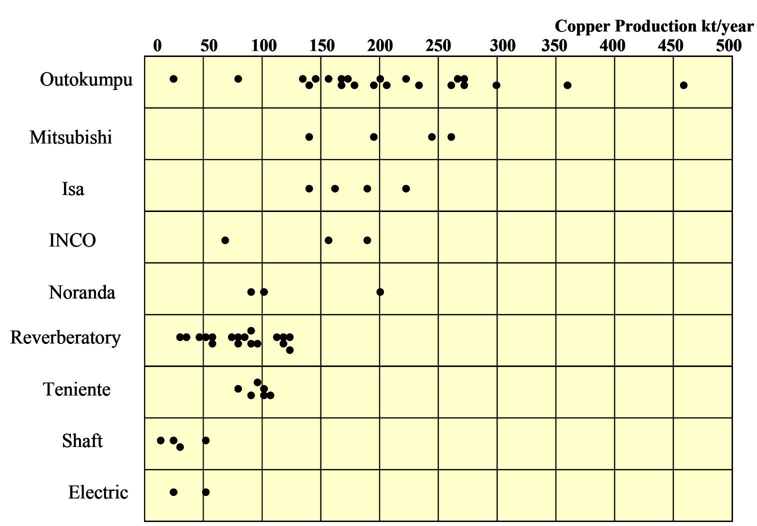
SUMITOMO METAL MINING CO., LTD.

Features of Smelting Processes (2) Bath

Furnace Type	Productivity $T/m^2 \cdot D$	Furnace Charge	Matte Grade %	Characteristics
2.Bath smelting				
Noranda	15	green conc.	65 - 75	high flexibility for row materials high MG (white metal) short brick life of tuyere
Mitsubishi	21	dry conc.	55 - 70	continuous process short brick life high energy cost due to pressurized air
Teniente	12	green conc.	70 - 75	high flexibility for row materials short brick life of tuyere
Oxy-Fuel reverb.	5	green conc.	40 - 45	low MG and productivity
Vanyukov	80	green conc.	45 - 70	form smelting high productivity low dust generation
Isa smelt	65	conc. pellet	55	compact furnace using a submerge low dust generation due to conc. pellet short brick life

SUMITOMO METAL MINING CO., LTD.

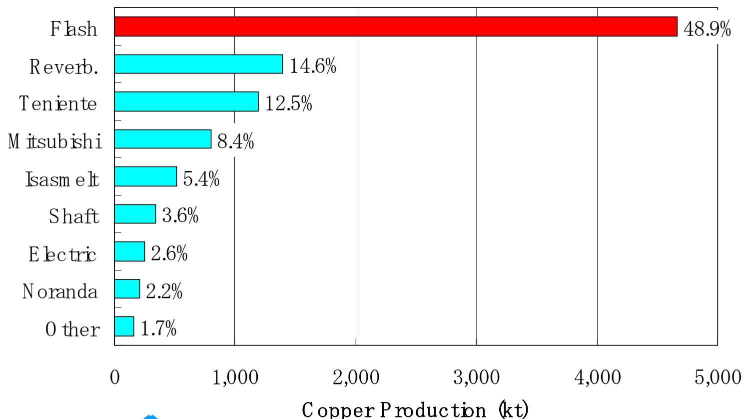
Productivity of individual smelting furnace



World Smelting Furnaces

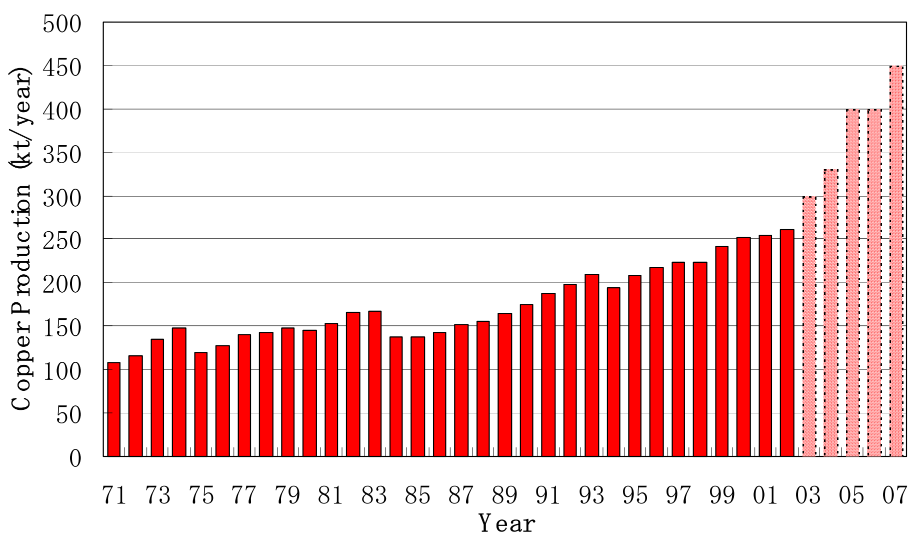
(Reference : Copper Smelters Cost & Commercial Analysis 2000 Edition, Brook Hunt)

	O/K FF	Reverb.	Teniente	Isa	Mitsubishi	INCO FF	Noranda	Shaft	**Sum**
Asia and Oceania	13	2	0	5	3	0	2	1	**26**
S. America	3	6	8	0	0	0	0	0	**17**
Europe	5	1	0	0	0	0	0	2	**8**
N. America	2	3	1	1	1	4	1	1	**14**
Sum	**23**	**12**	**9**	**6**	**4**	**4**	**3**	**4**	**65**



SUMITOMO METAL MINING CO., LTD.

Planed Copper Production of Toyo Smelter



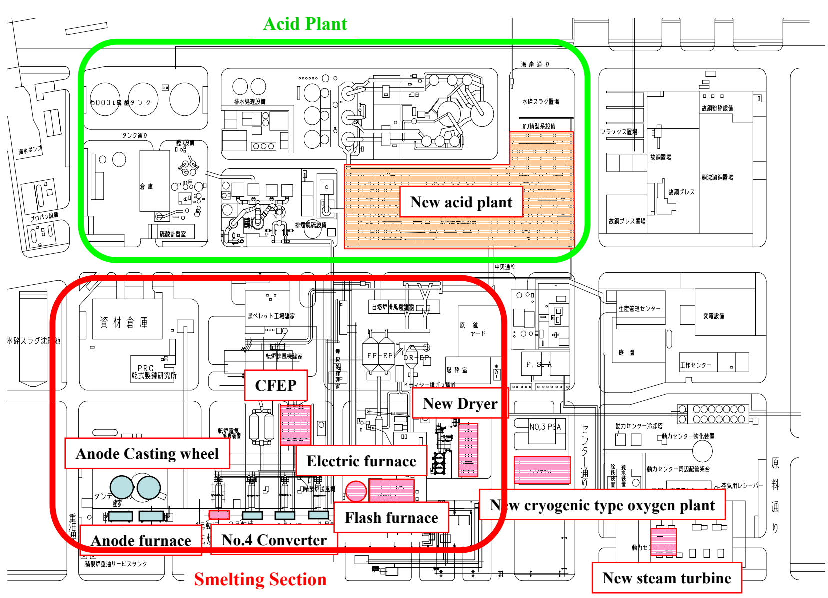
SUMITOMO METAL MINING CO., LTD.

Expansion Policy of the Toyo Smelter

A. Reduce production costs by increasing smelter capacity
B. Save on capital costs by utilizing existing facilities
C. Minimize operation risks resulting from expansion
D. ~~Strengthen environmental management~~

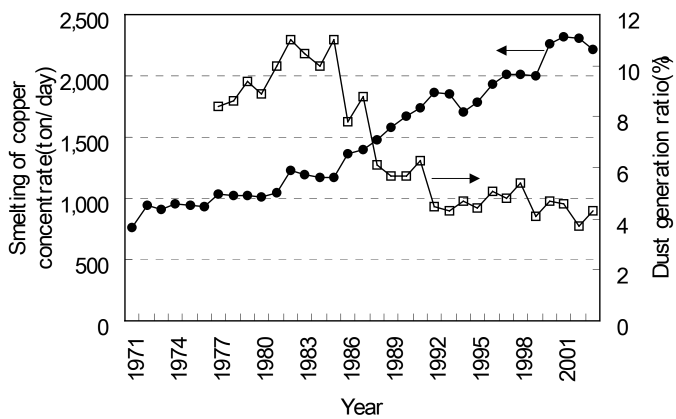
SUMITOMO METAL MINING CO., LTD.

Layout of the Smelting Area



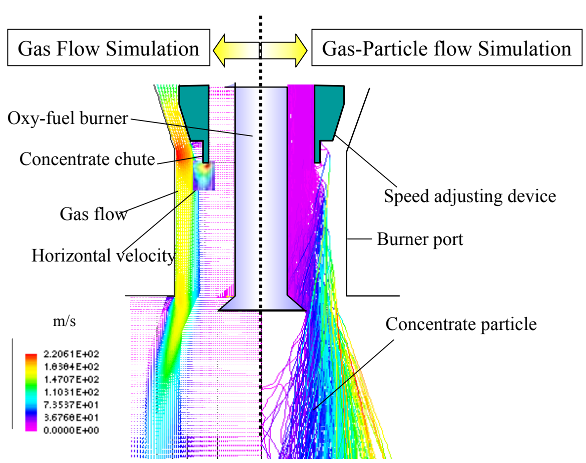
SUMITOMO METAL MINING CO., LTD.

Dust Generation Ratio in Toyo Flash Furnace



SUMITOMO METAL MINING CO., LTD.

Example of gas and gas-particle simulation model Concentrate Burner



SUMITOMO METAL MINING CO., LTD.

Fuel Reduction in Sumitomo Flash Furnace

	Year 1985		2003		2007(plan)	
OPERATING CONDITION						
concentrate charge (ton/hour)	44.5		90		164.6	
dust generation ratio(%)	11.8		5.1		4.0	
O_2 enrichment in Reaction Air	32.1		49.5		72.1	
matte grade	56.0		63.5		65.0	
HEAT INPUT and PRODUCTION (GJ/hour)	(GJ/hour)	(%)				
heat of matte and SO_2 production	80.0	51	172.9	84	382.5	99
heat for decomposition of dust	-24.1	-15	-22.0	-11	-32.8	-9
sensible heat of ore	2.5	2	5.1	2	10.1	3
sensible heat of reaction air	17.1	11	15.0	7	8.7	2
oil and pulverized coal	81.1	52	35.3	17	17.1	4
heat input total	156.7	100	206.4	100	385.5	100
HEAT OUTPUT(GJ/hour)						
sensible heat of matte and slag	45.9	29	103.2	50	209.5	54
sensible heat of gas	73.1	47	65.4	32	117.4	30
sensible heat of dust	7.5	5	7.4	4	15.9	4
heat losses	24.7	16	25.0	12	33.1	9
others	5.5	3	5.3	3	9.7	3
heat output total	156.7	100	206.4	100	385.6	100

SUMITOMO METAL MINING CO., LTD.

Installation of Rotary Steam Dryer

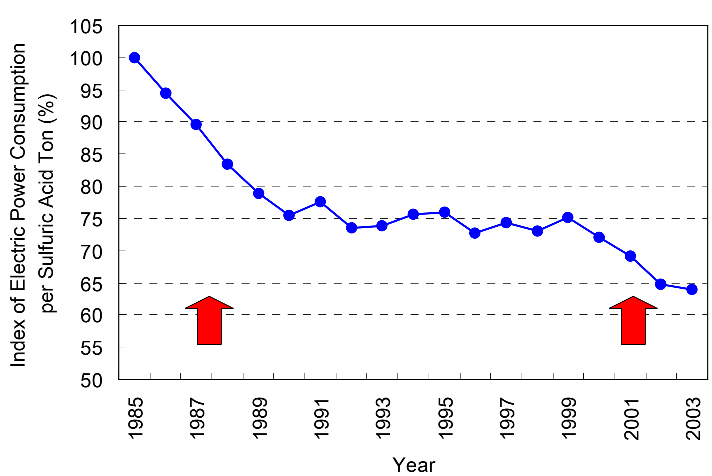
SUMITOMO METAL MINING CO., LTD.

Reduction of Fuel and SOx Emission at 450 KT/Y

	unit	Present	450,000T/Y
Feed rate of rotary dryer	WT/H	120	80
Feed rate of rotary steam dryer	WT/H	−	160
Fossil fuel of dryer (crude petroleum conversion)	L/H	2049 →	1698
SO2 volume	Nm3/H	13.5	10
Exhaust gas volume	Nm3/H	99000	99000
SOx density by fossil fuel	ppm	137	101

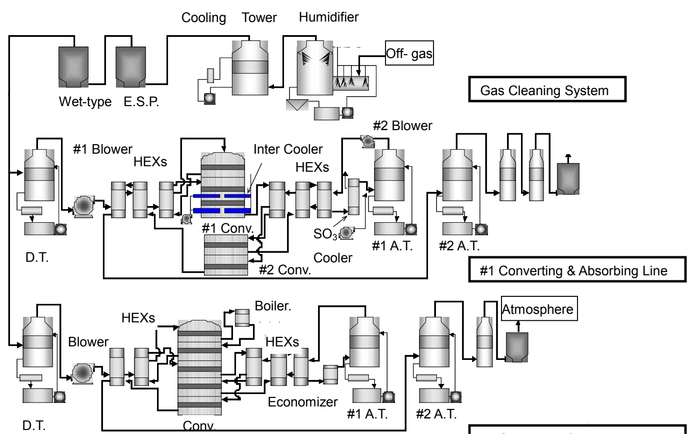
SUMITOMO METAL MINING CO., LTD.

Trend of Unit Energy Consumption at Acid Plant



SUMITOMO METAL MINING CO., LTD.

Schematic Flow of Acid Plant



SUMITOMO METAL MINING CO., LTD.

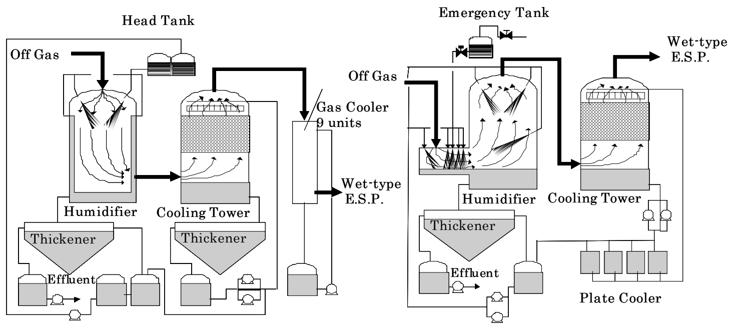
Various Measures for Energy Saving at Acid Plant

Measures	Enforcement matter	Reduction of electricity MWH/y	Enforcement period
1. Scaling up of SO_2 blower inlet damper	For the purpose of decreasing the specific regular pressure drop at damper 1)No.1 SO_2 blower φ1.16m → 1.60m 2)No.2 SO_2 blower φ1.35m → 2.00m	780	1988
2. SO_2 blower power saving operation	For the purpose of automatic draft control on gas pressure fluctuation at the inlet of acid plant which is mainly attributed to CF operation, the damper opening of the SO_2 blower inlet was improved from 60% to 100% by developing a pressure fluctuation monitoring with online process computer and feed forward system.	1180	1988
3. Gas cooler bypass ducting installation	Though shell & tube type gas cooler is used to control temperature of inlet gas at the drying tower, a bypass duct(φ 2.5m) was installed at the gas cooler, since surplus on gas cooling capacity resulted from the elevation of the SO2 strength. Its operation is done by the optimum opening bypass damper visualized on the picture of a process computer.	410	1987
3. Pressure drop decrease at the converting system	1)Renewal of catalyst to a ring catalyst(Ring catalyst occupies 60% of the whole one) 2)A bypass line modification of A to C heat exchanger.	2,300	1989 to 1992
	Total	4,670	

About 7% of total electric consumption at Acid Plant

SUMITOMO METAL MINING CO., LTD.

Gas Cleaning System

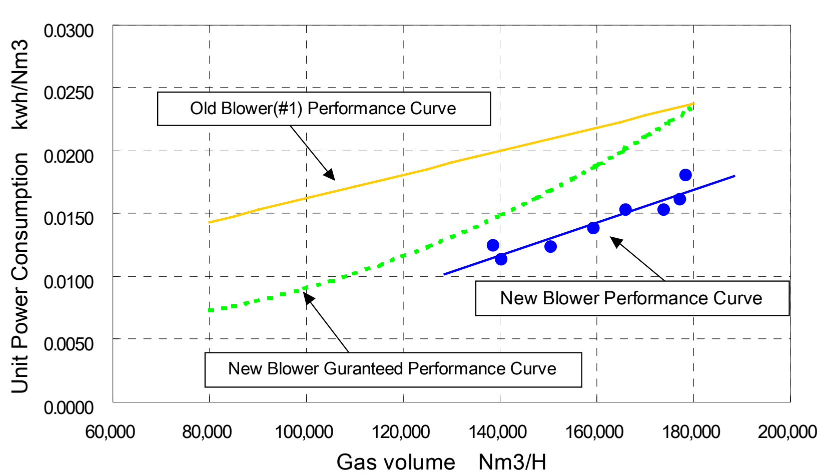


	Humidifier	Cooling Tower	Gas Cooler	Wet type E.S.P.	total
New System	306	420	-	1,390	2,116
Old System	480	510	549	1,882	3,421
differnce	-174	-90	-549	-492	-1,305

Unit: kPa

SUMITOMO METAL MINING CO., LTD.

Unit Power Consumption of SO2 Blower



SUMITOMO METAL MINING CO., LTD.

Introduction of Converter Boiler – (1)

Old line

Inter Cooler Fan : 210kW

New line

Converter Boiler

SUMITOMO METAL MINING CO., LTD.

Introduction of Converter Boiler –(2)

Old line

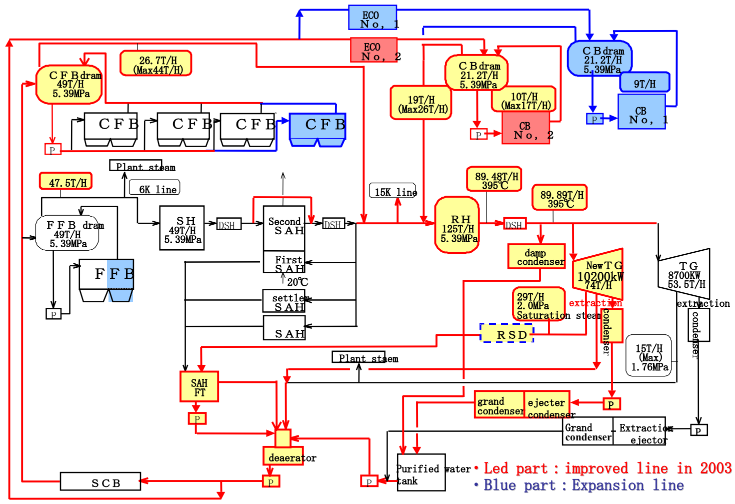
SO3 Cooler Fan : 160+290 kW

New line

Economizer

SUMITOMO METAL MINING CO., LTD.

Boiler Turbine Flow sheet



SUMITOMO METAL MINING CO., LTD.

Boiler & Turbine Generator

No. 1 Steam Turbine

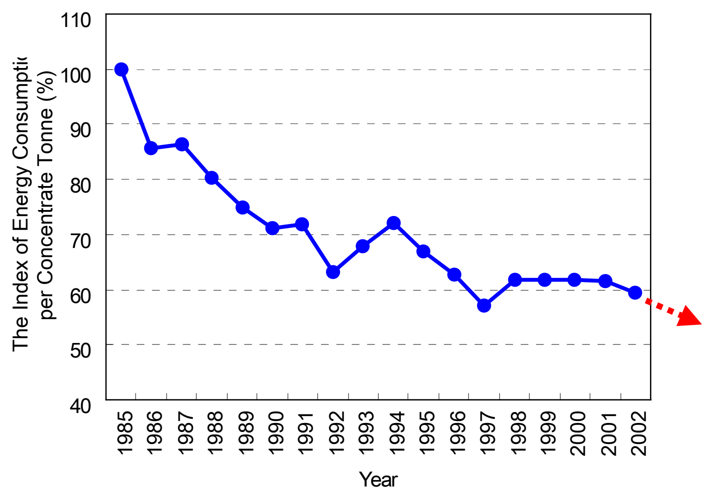
(8,700kW)

No. 2 Steam Turbine

(10,200kW)

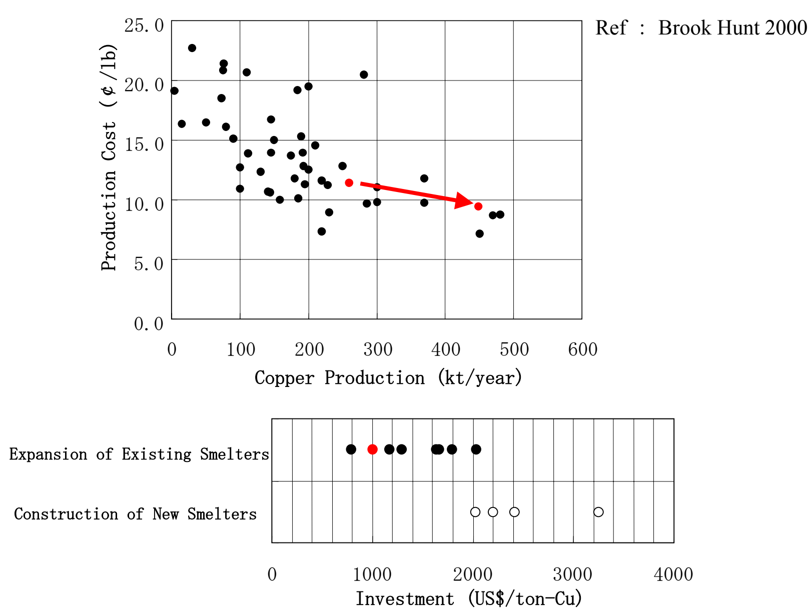
SUMITOMO METAL MINING CO., LTD.

Trend of Unit Energy Consumption at Toyo Smelter



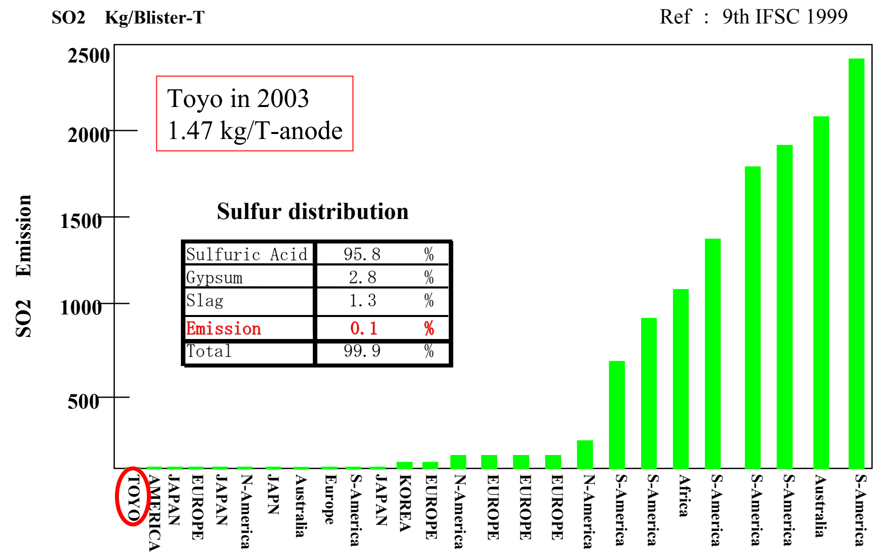
SUMITOMO METAL MINING CO., LTD.

Copper production vs Production Costs



SUMITOMO METAL MINING CO., LTD.

SO2 Emissions per Ton of Anode



Sulfuric Acid	95.8	%
Gypsum	2.8	%
Slag	1.3	%
Emission	0.1	%
Total	99.9	%

SUMITOMO METAL MINING CO., LTD.

Sources of Copper of Japan

Sources of Copper Imports by Mine Configuration

	1970	1975	1980	1985	1990	1995	2000	2001
Independently Developed Mines	40.8	51.3	45.8	40.2	54.4	198.8	557	551.9
Percentage	10.9%	7.4%	5.70%	4.80%	5.80%	18.50%	41.30%	42.90%
Financed Mines	103	345.5	297.9	275.3	312	342.2	446.9	395.8
Percentage	27.5%	49.9%	37.00%	32.60%	33.50%	31.80%	33.20%	30.80%
Other Mines	230.1	295.4	461	530.1	564	534.2	344	337.3
Percentage	61.5%	42.7%	57.30%	62.70%	60.60%	49.70%	25.50%	26.20%
Total	373.9	692.2	804.7	845.6	930.4	1075.2	1347.9	1285

(Unit: equivalent 1000 tonne of Cu)

Note:

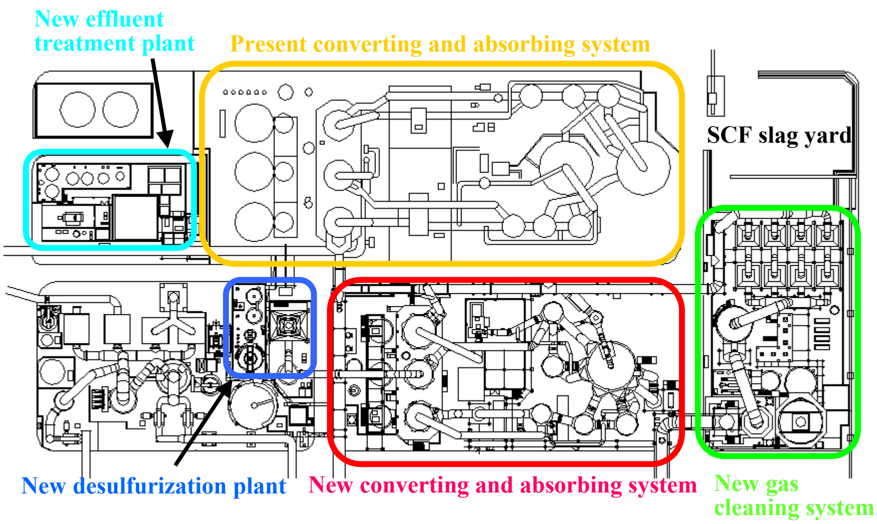
Independently Developed Mines: mines in which a company has been involved from the exploration stages and in which the company has invested; imports procured from mines where there is capital participation and the procuring company is involved in capital participation.

Financed Mines: mines where there has been both financing and capital participation by companies but where the procuring company is not involved in financing or investment.

Other Mines: other than those described above

SUMITOMO METAL MINING CO., LTD.

Layout of New Acid Plant



SUMITOMO METAL MINING CO., LTD.

Ranking of Copper Production in the world

Ref : Brook Hunt 2000

Rank	Smelter	Country	Copper production (t/year)
1	Chuquicamata	Chili	480,000
2	LG Nikko	Korea	452,000
	Toyo after expansion	Japan	450,000
3	Saganoseki	Japan	450,000
4	Caletones	Chili	378,000
5	Norddeutche Affinerie	Germany	370,000
6	Guixi	China	340,000
7	Atlantic Copper	Spain	300,000
8	Souther	Peru	290,000
9	La Caridad	Mexico	285,000
10	Kennecot	U.S.A	265,000
11	Toyo	Japan	260,000
12	Naosh	Japan	235,000
13	Onahama	Japan	228,000
14	Tamano	Japan	225,000
15	Mount Isa	Australia	210,000

SUMITOMO METAL MINING CO., LTD.

Acid Plant Capacity

	#1 (Present Plant)	#2 (New Plant)	Total
Gas Cleaning System			
Inlet Gas Volume (Nm^3/hr)	(165,000)	275,000	275,000
Converter and Absorber			
Inlet SO2 Density (vol %)	13	13	-
SO2 Volume (Nm^3/hr)	22,750	22,100	44,850
Sulfuric Acid Production Capacity(tons/day)	2,000	2,000	4,000

Converter

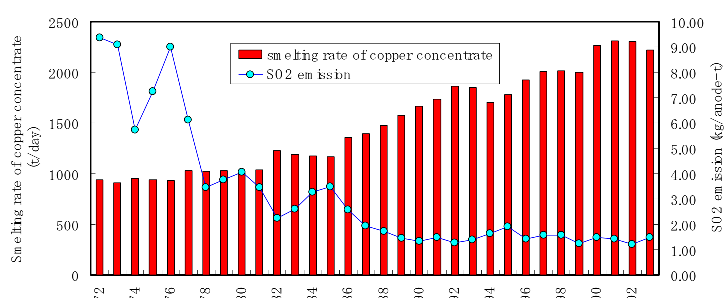
Old line

New line

De-Sulfurization Tower

SUMITOMO METAL MINING CO., LTD.

SO2 emission and smelting rate of copper concentrate

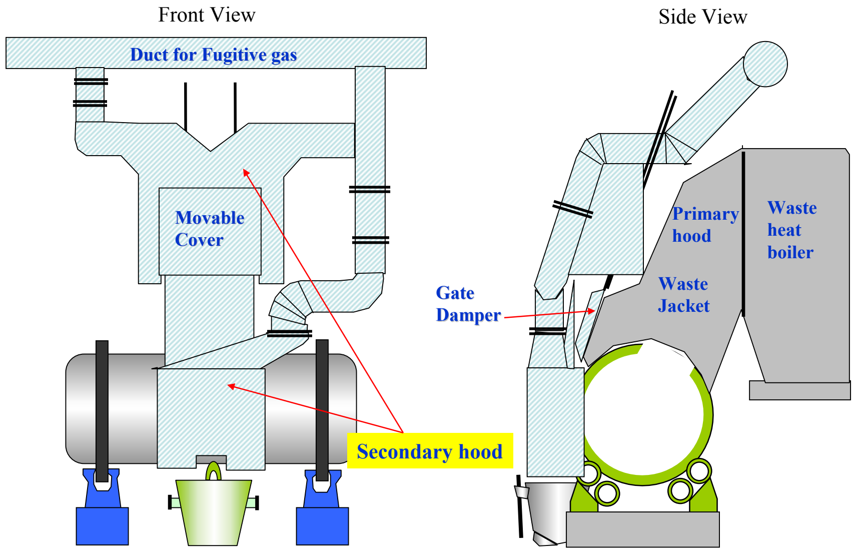


Sulfur distribution

Sulfuric Acid	95.8	%
Gypsum	2.8	%
Slag	1.3	%
Emission	0.1	%
Total	99.9	%

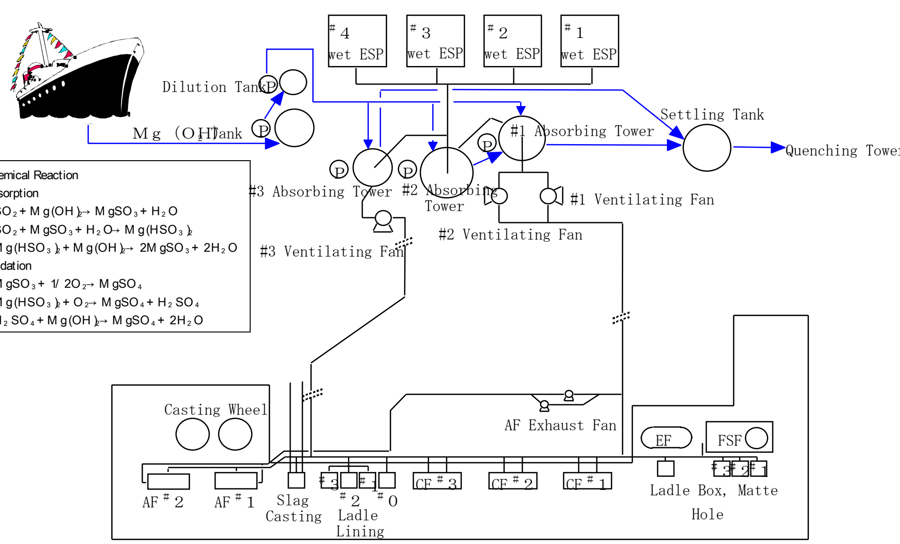
SUMITOMO METAL MINING CO., LTD.

Fugitive gas collecting system



SUMITOMO METAL MINING CO., LTD.

Fugitive Gas Collecting System



SUMITOMO METAL MINING CO., LTD.

Expansion Schedule

	2002	2003	2004	2005	2006	2007
Capacity of copper production (KT/Y)	270	300	330	400	400	450
Dryer		Install New Dryer				
Flash Furnace		Rebuild		Renew Waste Heat Boiler		
Slag Cleaning Furnace		Rebuild				
Converter		2hot-2blowing		3hot-2blowing (No.4CF)		
Anode Furnace				Enlarge Furnace		
Oxygen Plant		Install New Cryogenic Type				
Steam turbine		Install No.2 Steam Turbine				
Acid Plant		Construct New Acid Plant				
Tank house			←	150KT ISA process Start	→	
Precious Metal Plant			Start Au production →			

SUMITOMO METAL MINING CO., LTD.

REMARKS ON THE EXECUTION OF AN ENERGY EFFICIENCY PROGRAMME IN MEXICO MINERA AUTLAN'S MOLANGO MINING UNIT

NORBERTO I. ZAVALA-ARNAUD
Mining Director, Compañía Minera Autlán, S.A. de C.V.

Summary

Efficient use of energy is simply vital for any country since its significant social and economic impact. Protecting non-renewable resources and reducing pollution in both, industrial production processes and energy use, are paramount issues for mankind. However, we should admit that there is another reason for which energy efficiency is critical: the growing cost of energy in the world.

Minera Autlán is the leading manganese ore and ferroalloy producer in Mexico and utilises pyro-metallurgical processes, which make the company a very important natural gas and electricity consumer. These energy sources are relevant cost inputs for manganese and ferroalloys.

Therefore, Minera Autlán is fully committed to getting energy efficiency, especially in the last years. The company is permanently working on identifying potential ways to improving energy efficiency, developing and executing projects in this regard and following up the results. This strategy implies a virtuous circle, which leads us to gradually reduce the energy consumption in our production process. As in any optimisation process, the marginal advantages obtained will indicate the scope and limits of our search.

1. Foreword

Minera Autlán was established in 1953 in a town called Autlán, located in the State of Jalisco, Mexico to exploit a manganese ore deposit. At that time, the type of the ore exploited allowed the company to use a relatively simply industrial process to market the ores. Later on, Minera Autlán began to explore a new manganese ore deposit in the Molango Manganiferous District, located in the State of Hidalgo. This place includes one of the most important manganese ore deposits in the world. Notwithstanding, the physical and chemical characteristics of the new ore required Minera Autlán to develop another technological process.

Then, Minera Autlán commissioned a nodulisation kiln in 1968. This is a horizontal rotary kiln (diameter: 5 m., length: 114 m.), which is used to calcine the natural ores in order to improve their physical and chemical properties. The new ore obtained is called manganese nodules, which are employed as the main raw material to producing ferroalloys in electric furnaces.

Nowadays, most of the manganese nodule output is used for ferroalloy production at Minera Autlán's plants. Our final products, the manganese ferroalloys, are used as essential raw material for steel production in both Mexico and abroad.

My paper today is focused on the several efforts carried out by the Autlán's Molango Mining Unit to improving energy efficiency in our industrial processes. I will comment especially about our achievements of the last years.

As the audience will see in the course of my presentation, the main achievements take place over the last seven years. Such steady and important attainments should have rendered significant fruits on our costs posted in US dollars, however the unexpected highs recorded by world energy prices in the last years have somewhat offset our savings in energy consumption. Our work and effort to improve energy efficiency is currently critical, because we are committed to finding new efficiency opportunities to balance the high energy prices. We are sure that the path followed by Minera

*Compañía Minera Autlán, S.A. de C.V. – Dirección de Minería

Autlán is the right one, since our main competitors are also facing similar pressures caused by energy prices, and our company is successfully working in this regard.

Minera Autlán has primarily worked on two specific targets:

1. Lessening of natural gas consumption per tonne of finished product from the rotary kiln (MCAL/t)
2. Lessening of electricity consumption per tonne of finished product (KWH/t).

As for electricity, I should mention that the Molango Mining Unit has always been self sufficient, since it owns an electricity generating plant. This plant includes five generators (total capacity of 10.75 MW). Our Worthington engines can use natural gas or diesel as fuel. Usually we use natural gas as the main fuel, and use diesel only in specific cases.

It is noteworthy that the most important savings achieved by Minera Autlán in Molango are those related to the thermal efficiency of our rotary kiln process, since the kiln consumes more than 85% of total energy used in this mining unit. However, we also have reduced the electricity consumption of the plant and mine. Thus, the electricity generating plant currently works with only two generators.

So, even though some efforts were focussed on thermal efficiency and others on electric efficiency, all of them imply energy savings. Such savings are directly related to less natural gas consumption in both, the rotary kiln and the electricity generating plant.

2. Development

2.1 Background

Minera Autlán produces manganese nodules (as manganese oxides) from manganese carbonates. The company uses a rotary kiln for this purpose and the main fuel is natural gas, which is at the same time, one of the most important cost inputs for manganese nodules. As everybody knows, world natural gas prices have gradually increased over the last years and therefore; this is now a critical factor when producing manganese nodules.

Since the commissioning of the rotary kiln in 1968, the company has permanently looked for improving opportunities to get the most out of its efforts on thermal efficiency.

On the other hand, our production process requires the use of high energy consuming equipment, such as the rotary kiln, extractor fans, cooling fans, crushers, compressors, etc. But, we have made decisions to reduce the energy consumptions in this regard too.

I will firstly address the measures we have carried out to reduce the natural gas consumption of the rotary kiln, and later on, I will discuss about our efforts to lessen our electricity consumption.

2.2 Lessening of natural gas consumption at the rotary kiln

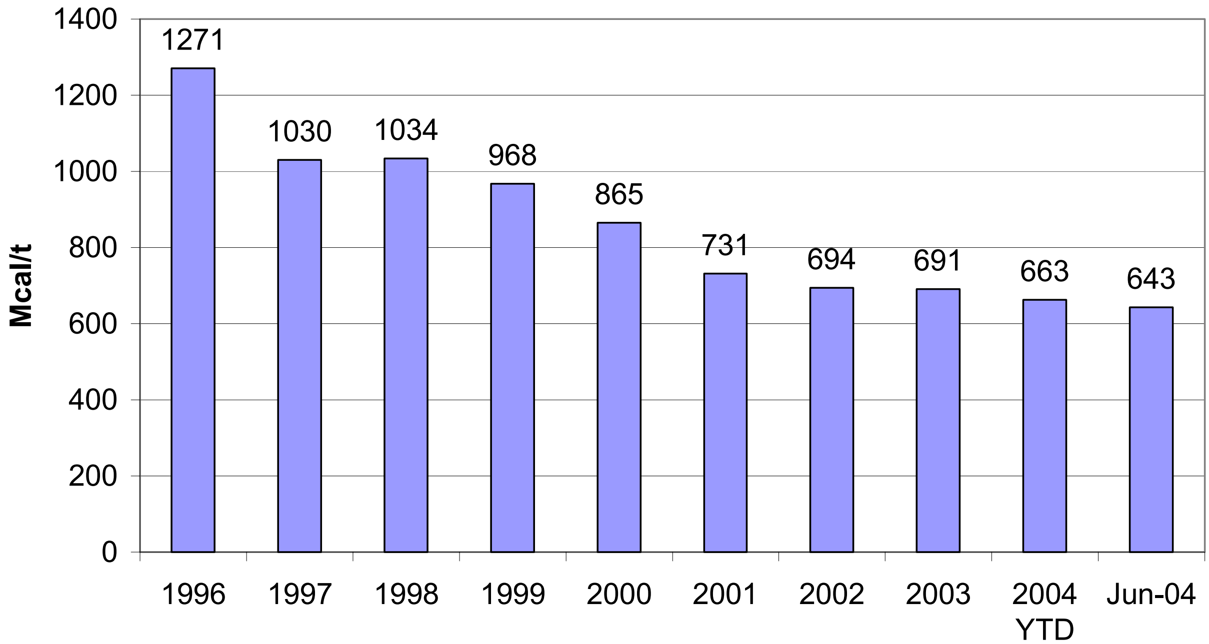
Graph I shows a histogram concerning our natural gas consumption posted in Mcal/t. As it can be seen, we have achieved significant consumption reductions. We could accomplish this goal by working in the most important improving opportunities:

<u>Improving Opportunities</u>

As in most of pyro-metallurgical processes, part of the heat related to the nodulisation of manganese ore, is lost by different ways:

- Throughout conduction, radiation and convection in the kiln structure.
- Through the gases and dust sucked by the shaft fan.
- As sensible heat from manganese nodules.
- Through the re-process of out of size specification manganese nodules.

Graph I: Historical Natural Gas Consumption per Metric Tonne of Output



Moreover, there are other phenomena that take place inside the kiln and that impact on the use of heat:

- Non-standard distribution of heat inside the kiln (because of the suck from the shaft)
- Inefficiency over the heat transmission to the particles feed to the kiln:
    - Due to the size of the particle.
    - Due to the low gas percentage in contact with the ore loading.
- Combustion inefficiency.

<u>Measures applied</u>

Over the time, we have applied several measures to eliminate the inefficiency causes discussed above. I will describe below each cause as well as their effects on the process:

Installation of concrete removers inside the furnace

In order to improve the contact between gases and ores, we set up special devices that we call "refractory concrete removers". These are a kind of small walls and are used to remove or turn over the ore loading as soon as it goes through them. Without these removers, part of the load would remain on the top in contact with gases, while the other part would be in the bottom of the kiln taking advantage of the heat from the refractory concrete. Therefore, other part of the load would be in the middle of the both loads mentioned above and the disadvantage would be a minor temperature. I would like to explain clearly the importance of the concrete removers, using a simply analogy. Please imagine the preparation of a cake; if it is cooked poorly the surface of the cake will be toasted but inside you will find an uncooked cake.

Our concrete removers avoid that the different loading layers remain inert. By contrast, using our removers, the material is mixed and the heat transmission is homogenised throughout all their particles.

Set up of metallic lifters inside the kiln

Taking into account the positive experience in the use of the removers and looking for increasing the contact between the heat derived from the gases and our ores, the company installed three series of 70 metallic lifters in different stages. This measure has been the most important one, since the marginal benefits achieved. We attribute the lifters 50% of the savings we have accomplished since 1972 to date. The lifters we use lift the loading and pour it over the top of the kiln, taking advantage of the heat from gases. Otherwise, this contact would be impossible. Additionally, other improvements we have developed in the course of the years, have allowed us to improve the energy efficiency by 6.51%.

Increase of combustion air temperature

As I have discussed above, a great part of the heat provided to the process is lost in the production of manganese nodules. These nodules get out from the kiln at more than 1,000° C.

Manganese nodules are cooled through a special reciprocating cooler made of four fans. Then, there is a heat interchange between nodules (hot) and air (cold). So, we get nodules at lower temperature with stabilised chemical and metallurgical properties, and on the other hand, hot air at 600-800° C.

This air is used for combustion. The old system only allowed carrying the air to the burners at 180° C. By using our new system installed in 2000, we have air for combustion at 400° C. This system consists of a high-temperature resistance fan and a technically isolated duct system. We should recall that, in the cement production processes, air is used directly from the cooler to the kiln through the same shaft suck. This allows taking advantage of the maximum temperature of air.

However, we cannot do the same in our process because the contact of the cold air with the just made nodules causes an adverse re-oxidation, impacting negatively on the quality of our product. But, we continue to find the way to carry the air to our burners keeping its highest temperature. Meanwhile, the heat recovery we have achieved using our method has contributed with a reduction of 10.66% of total.

Reduction of re-circulation of nodule fines

We call “nodule fines” to the manganese nodules sized less than ¼”. Our ferroalloy plants do not consume this product because it causes operation problems. Therefore, most of this product is re-processed in the kiln, although a minor part is marketed. In order to resize the nodule, we require providing almost 50% of the heat necessary for transforming crude ore into manganese nodules, which is well beyond our aspirations.

By lessening the size of our nodule fines, which are re-processed in the kiln, we got that we re-circulate now 45% of what we re-circulated in the past (7 tonne/hr vs 16 tonne/hr). The company was able to accomplish this goal by testing several kinds of mesh in the screening system of nodules. However, we should admit that the increasing production of -4”+1” vs -1/2” +1/4” nodules played a crucial role in our success. These size improvements are primarily due to better process controls, experience and scientific development.

2.3 Lessening of electric energy consumption

Minera Autlán, as most of other mining companies in the world is a high-electricity consumer. The Molango Mining Unit has always been self sufficient in electricity because it has its own electricity generating plant since the establishment of Molango. As I discussed above, the plant includes five generators (total capacity of 10.75 MW). Our Worthington engines can use natural gas or diesel as fuel. Since 1999, when the Molango’s demand was 5 MW, the company began to implement specific measures to lessen the electricity consumption related to both, the industrial plant and the other areas of Molango. However, the most significant measures were focused on the Treatment Plant, where the unit electricity consumption decreased notably.

Specific Measures

We found that the fans used in the plant represented one of the most important improving opportunities to reduce our electricity consumption.

On the other hand, by looking for lessening natural gas consumption, we also found that we could reduce electricity consumption, replacing certain equipment that allowed us to get both objectives. I will explain each one of our measures.

Table I shows a summary of the results we achieved when applied the three concrete actions in our equipment.

Table I

Equipment	Power (HP)	% Savings	Saved Power (HP)	Measures
VX-2	300	100	300	Hot Air Fan (HAF)
VDQS	150	100	150	Hot Air Fan (HAF)
VDQI	150	100	150	Hot Air Fan (HAF)
VAR	250	80	200	Drive
VE-3	125	30	38	Drive
VE-4	100	70	70	Drive
VTIH	1,000	10	100	Seal
Compressor	250	80	200	Use of a smaller compressor
Total Savings			***1,208***	

Drives

As in most pyro-metallurgical plants, we extensively use induced draft fans (radial and axial flux centrifugal fans). We are aware that these kinds of equipment (related to hydraulic turbo-machines and centrifugal pumps) operate with very specific features. The first one is that the flux is directly proportional with the rotation speed. The second one is that pressure changes with the square of speed. Most importantly, the third one is that power changes with the cube of speed. Usually, the flux of this kind of equipment is regulated through floodgates powered by electromechanical, pneumatic or hydraulic devices. Although this is a simple and cheap way to make such regulation (at least for its initial investment), it may be very expensive in the long run in some cases. This operation cost is especially expensive when the fans work with their floodgates partially closed. In these cases, the energy consumption is great and economically unproductive. We carried out an analysis in order to detect the best fans according to their investment return. So, we began to install drives (solid state speed variators) for each one of the fans. The table above shows the fans where the drives were installed, as well as the result we got.

Hot Air Fan Installation (HAF)

We installed a high-temperature and abrasion resistance fan as part of our plan to reduce the gas consumption. The design of this new fan allowed us to replace four fans. Three of such four fans were used for the combustion air at the burners. The other fan worked as an extractor at the nodule cooler. So, our savings consisted of three fans, which are no longer used and that are exhibited in the table 1 as HAF. This is the most significant actions and represents 50% of the savings achieved by the plant.

Compressed Air Use

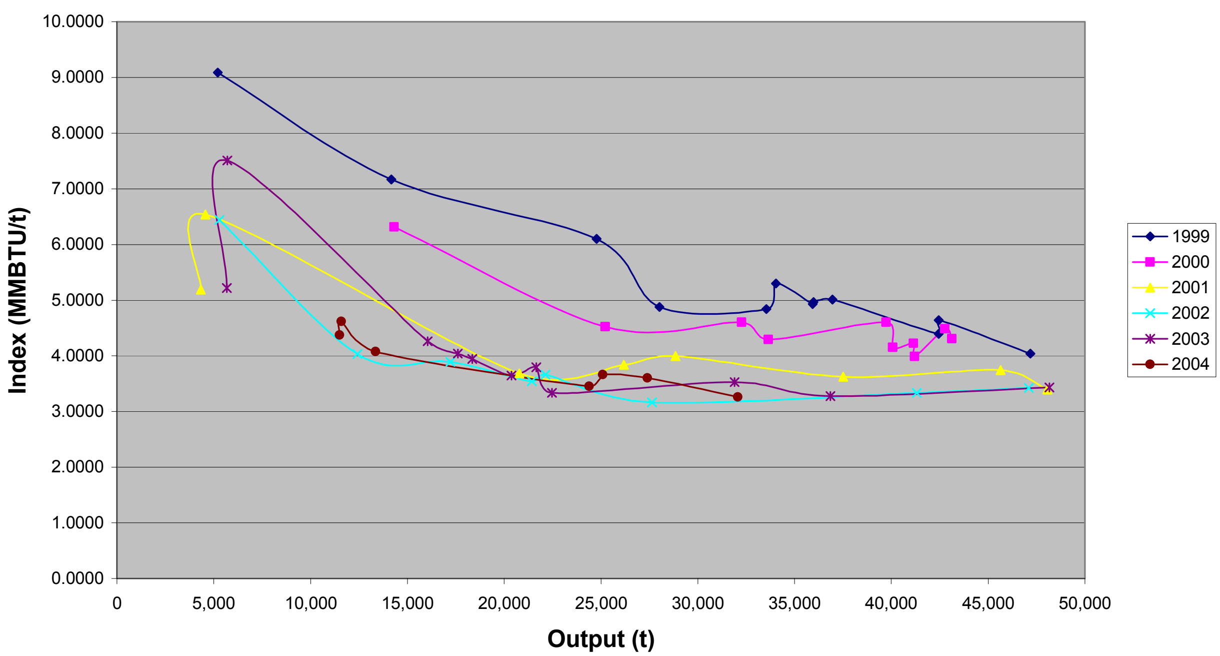
The plant worked with a compressed air system provided by a reciprocating compressor of pistons (250 HP). Taking into account the current operation conditions of the plant, we concluded that we could use just a compressor of 50 HP, by modifying slightly certain equipments. The 250 HP compressor is now only used in special situations, as when major kiln repairs are needed, because we require more flux.

3. Conclusion

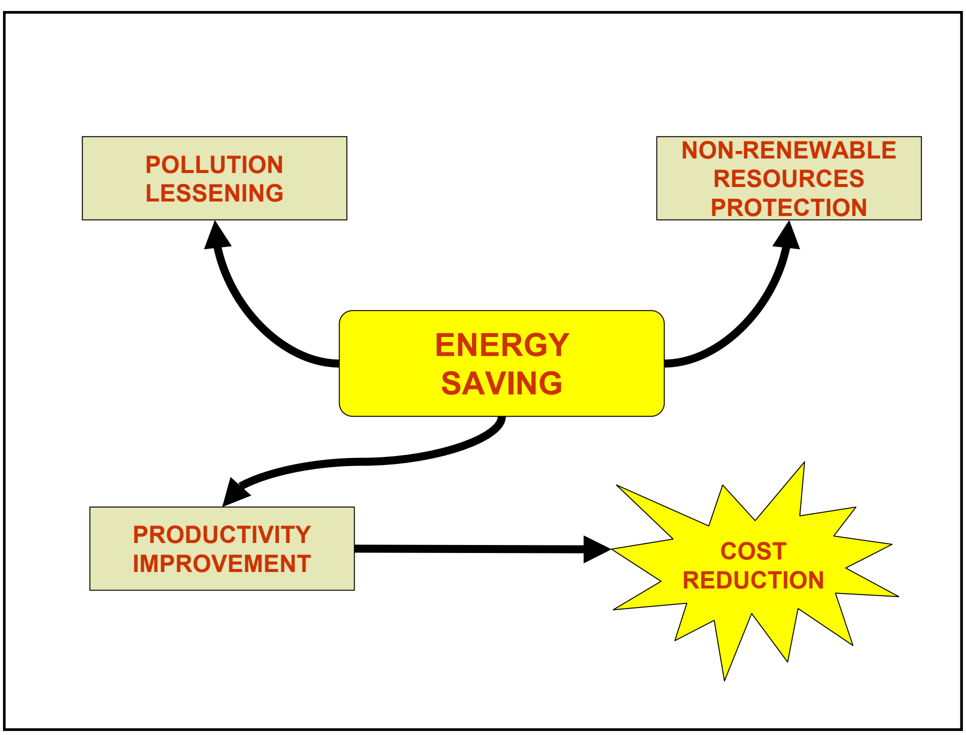
All the measures we have taken have significantly contributed to reduce considerably our energy consumption. Graph II shows the improvement of the Global Energy Index concerning the Molango Mining Unit.

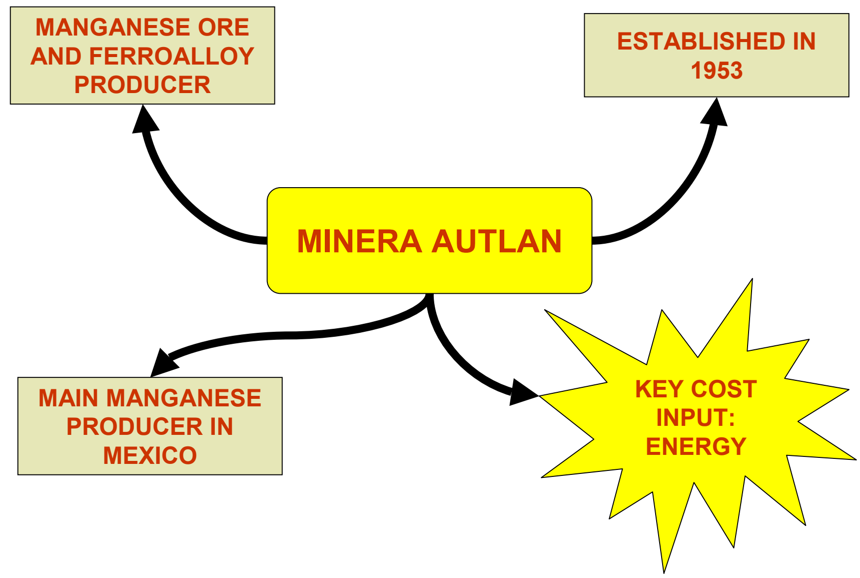
The results we have achieved prompt us to continue to find more ways to increase our energy efficiency. Notwithstanding we require technology investments to continue to progress in this regard in the light of the results of the last two years. Since we are self sufficient in electricity, we do not have access to the support given by local authorities to make more investments in energy affairs. However, we expect some changes in this regard soon so that there is a positive impact on the industry.

Graph II: Global Energy Index

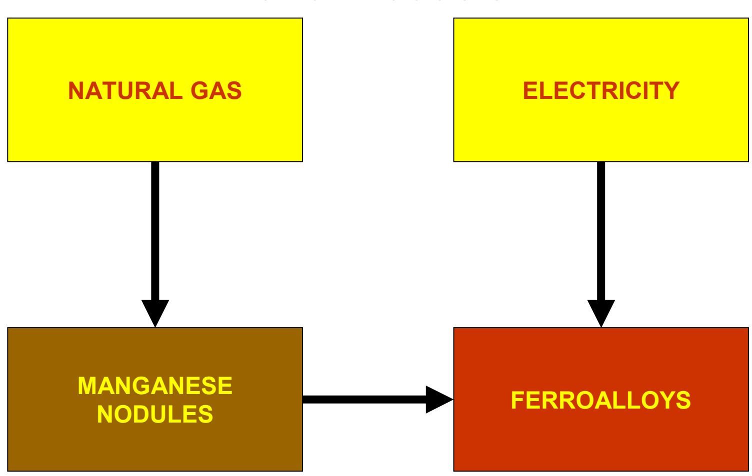


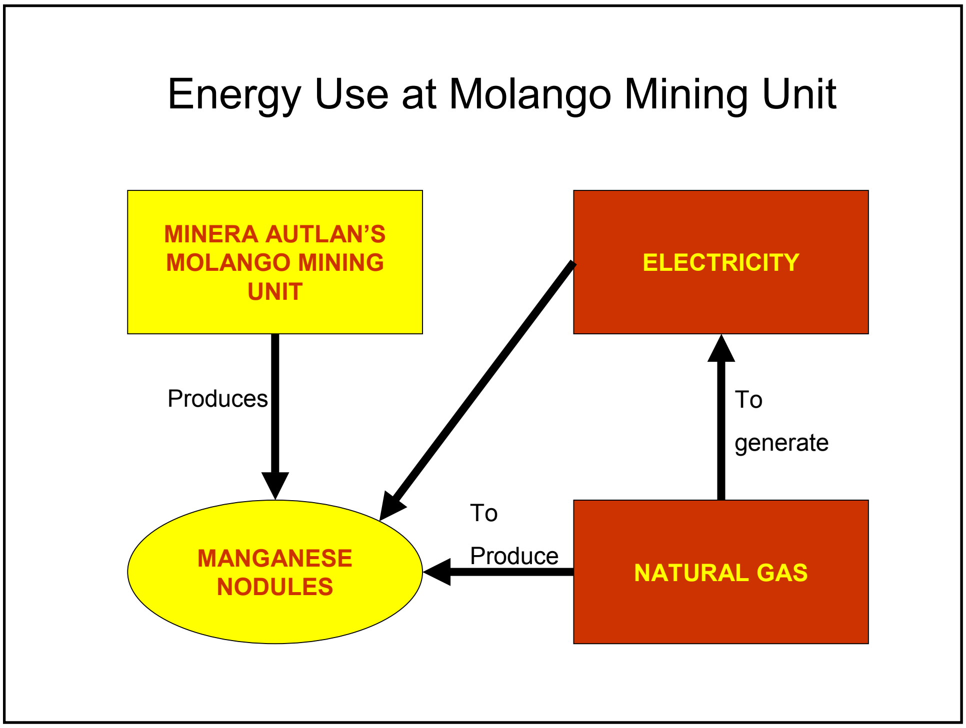

REMARKS ON THE EXECUTION OF AN ENERGY EFFICIENCY PROGRAMME IN MEXICO
MINERA AUTLAN´S MOLANGO MINING UNIT

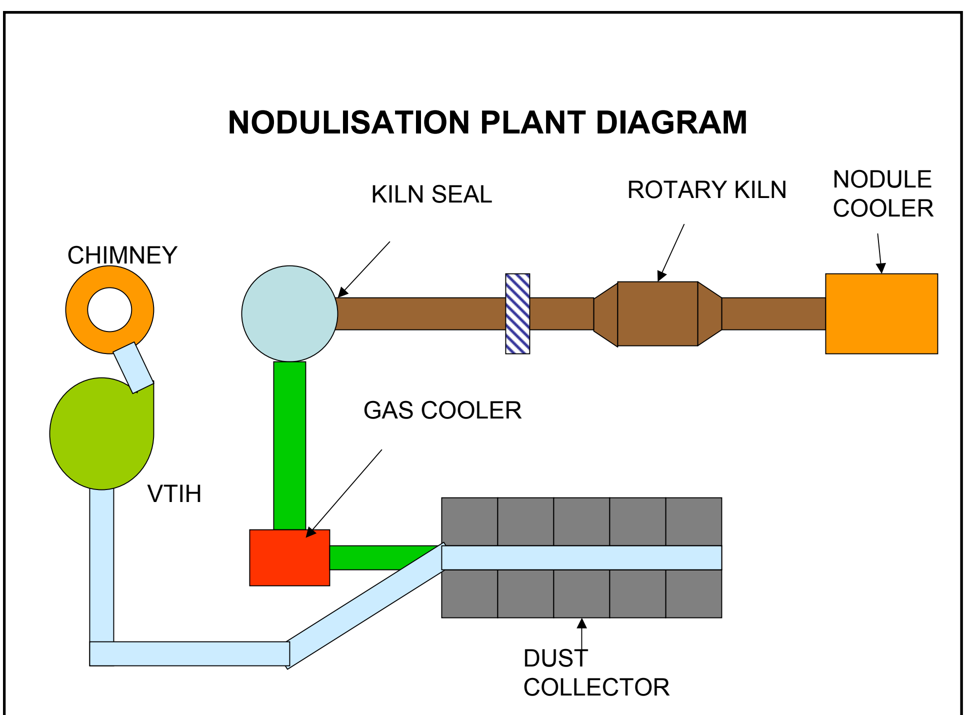

POLLUTION LESSENING
NON-RENEWABLE RESOURCES PROTECTION
ENERGY SAVING
PRODUCTIVITY IMPROVEMENT
COST REDUCTION



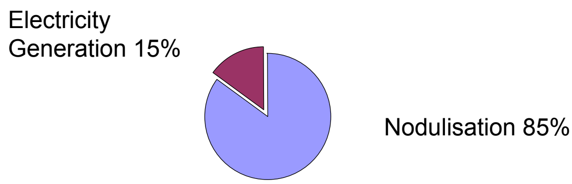
Minera Autlán’s Main Raw Materials and Products



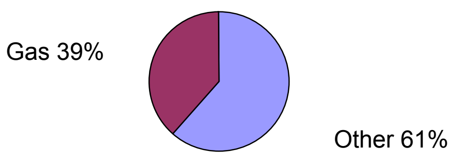

Energy Use at Molango Mining Unit
MINERA AUTLAN'S MOLANGO MINING UNIT
ELECTRICITY
Produces
To generate
To Produce
MANGANESE NODULES
NATURAL GAS


NODULISATION PLANT DIAGRAM
KILN SEAL
ROTARY KILN
NODULE COOLER
CHIMNEY
GAS COOLER
VTIH
DUST COLLECTOR

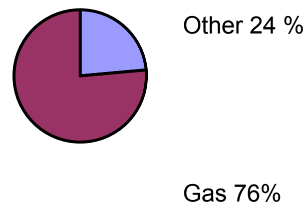
Natural Gas Use at Molango



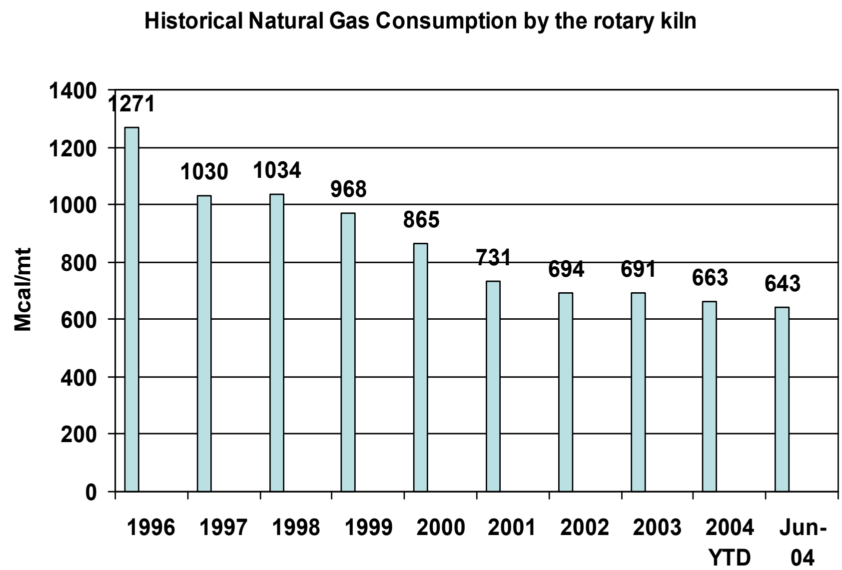
Cost Distribution at Molango Unit



Cost Distribution at the Nodulisation Plant



The current conditions have prompted us to look for savings in our thermal and electric energy consumption in a permanent way

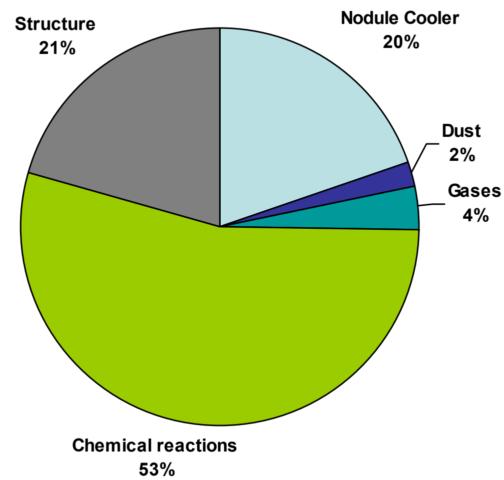


Improving Opportunities

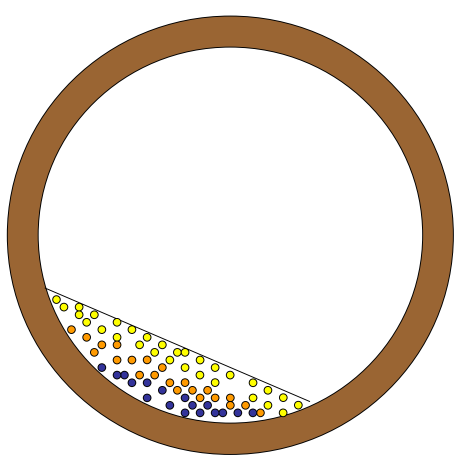
As in most of pyro-metallurgical processes, part of the heat related to the nodulization of manganese ore, is lost by different ways:

•Throughout conduction, radiation and convection in the kiln structure.
•Through the gases and dust sucked by the shaft fan.
•As actual heat from manganese nodules.

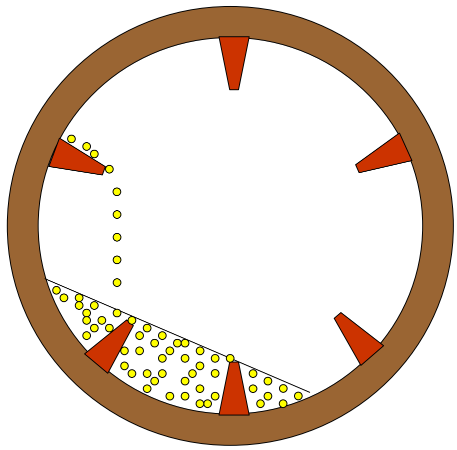
Rotary Kiln Thermal Balance



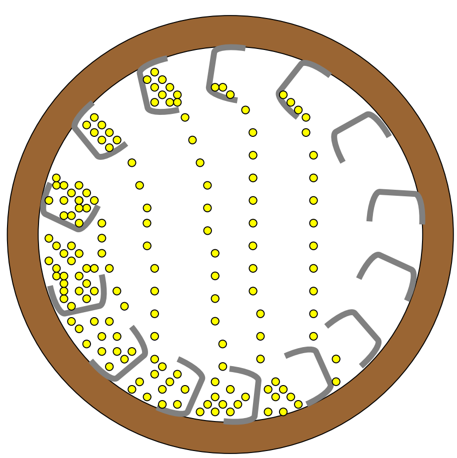
1.- Installation of Concrete Removers inside the Rotary Kiln



Installation of Concrete Removers inside the Rotary Kiln

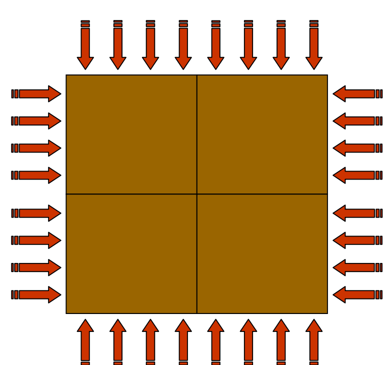


2.- Installation of Metallic Lifters inside the kiln

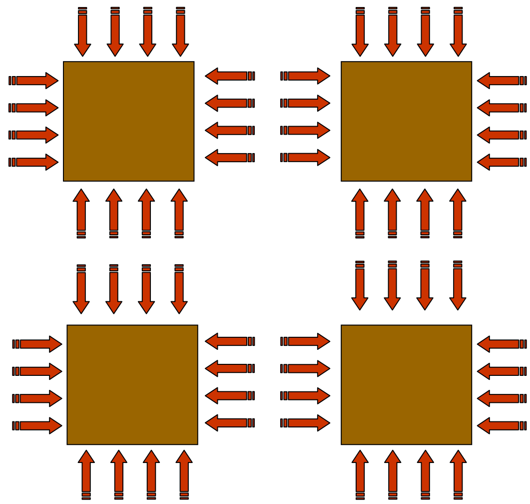


3.- Reduction of the size of the ore feeded to the kiln

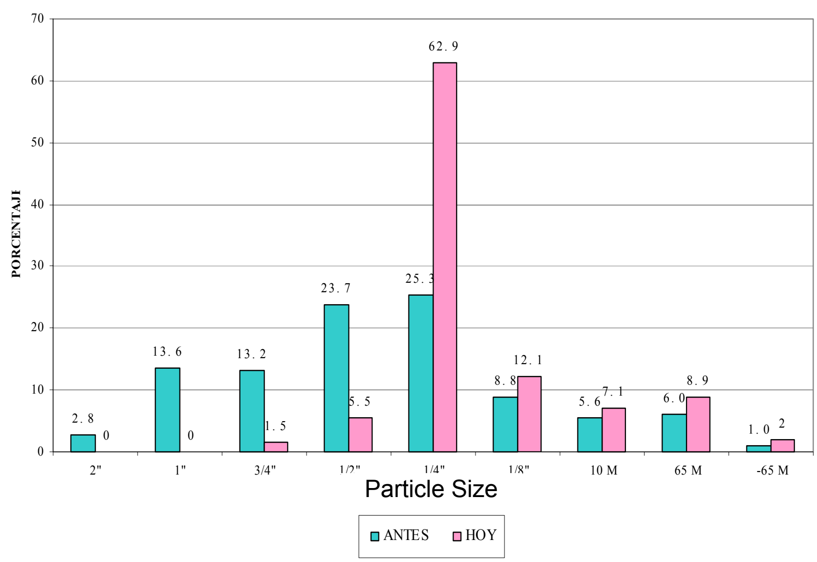
Heat transfer in a large particle (ie. 32 thermal units / surface unit)



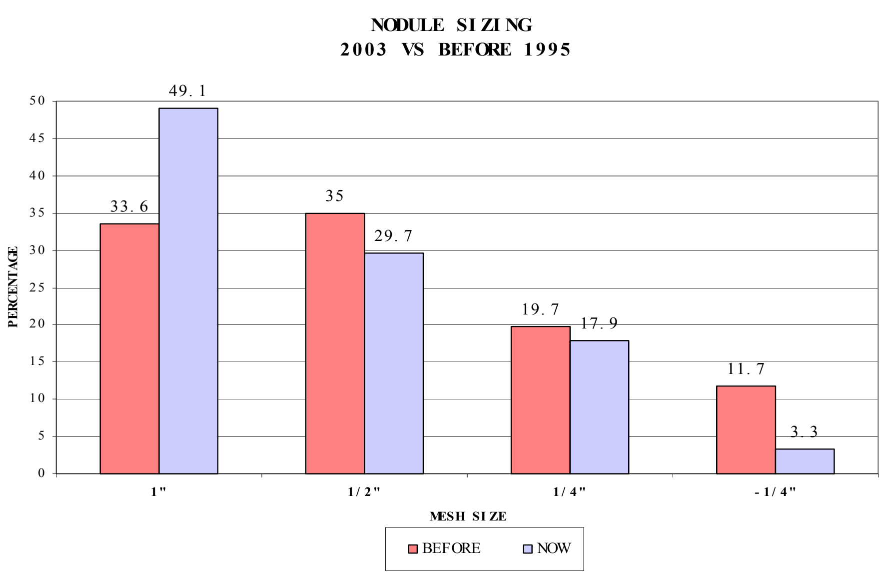
Heat transfer in a small particle (ie. 64 thermal units / surface unit)



Feed Sizing to the kiln 2003 vs Before 1995

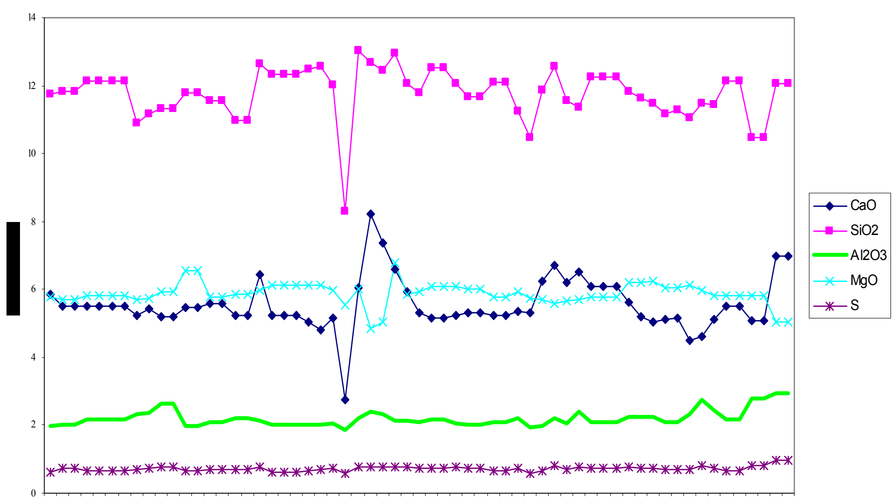


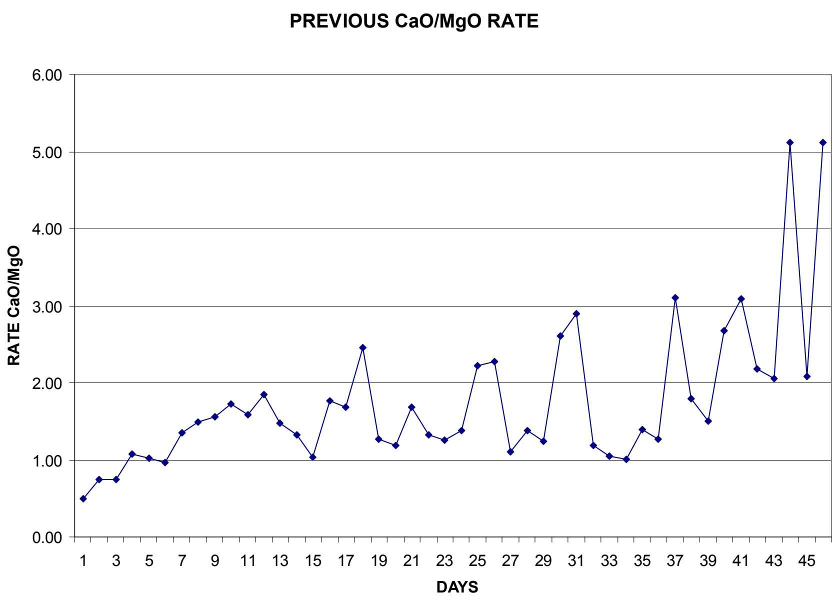
Nodule sizing has also improved. This has allowed us to reduce the re-circulation of manganese nodule fines
inside the kiln, as can be seen in the next slide



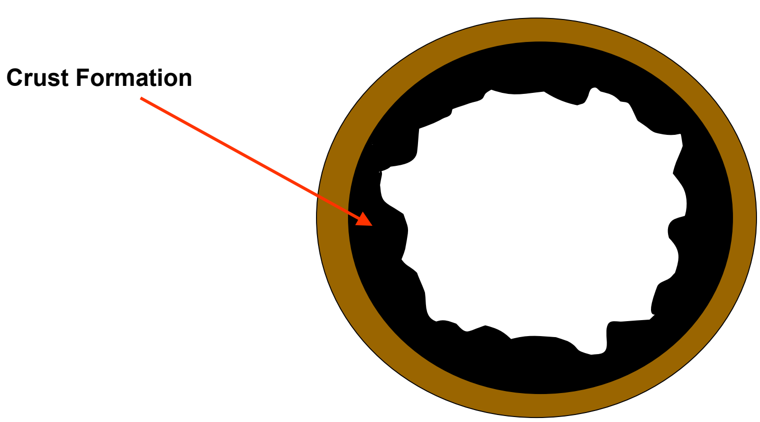
4.- We have also worked to get more stability in the chemical composition of the ore

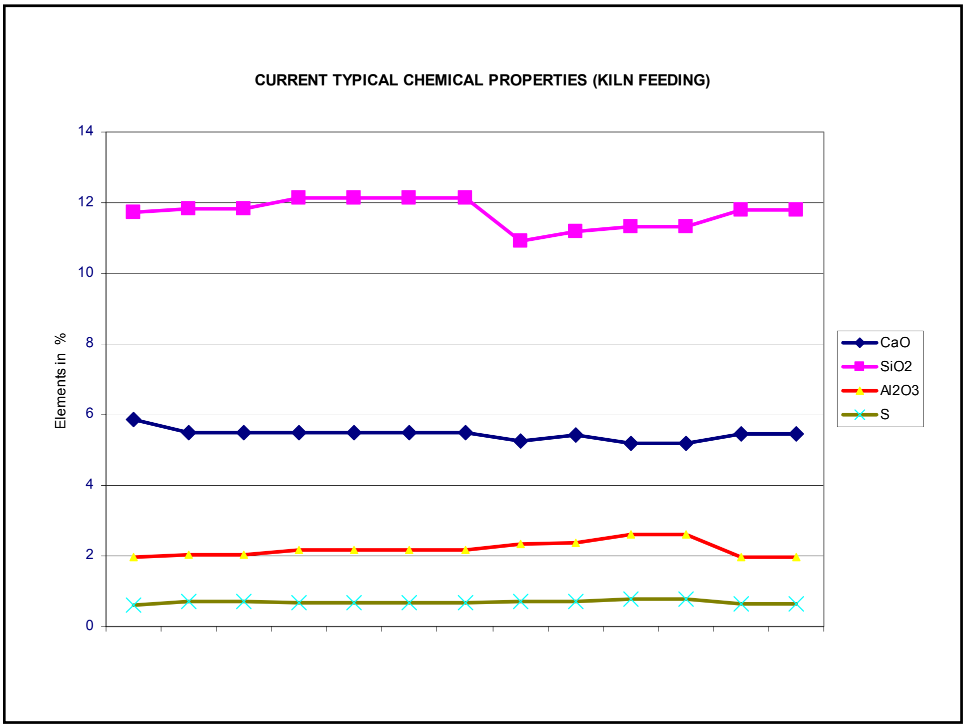
PREVIOUS TYPICAL CHEMICAL PROPERTIES (KILN FEEDING)



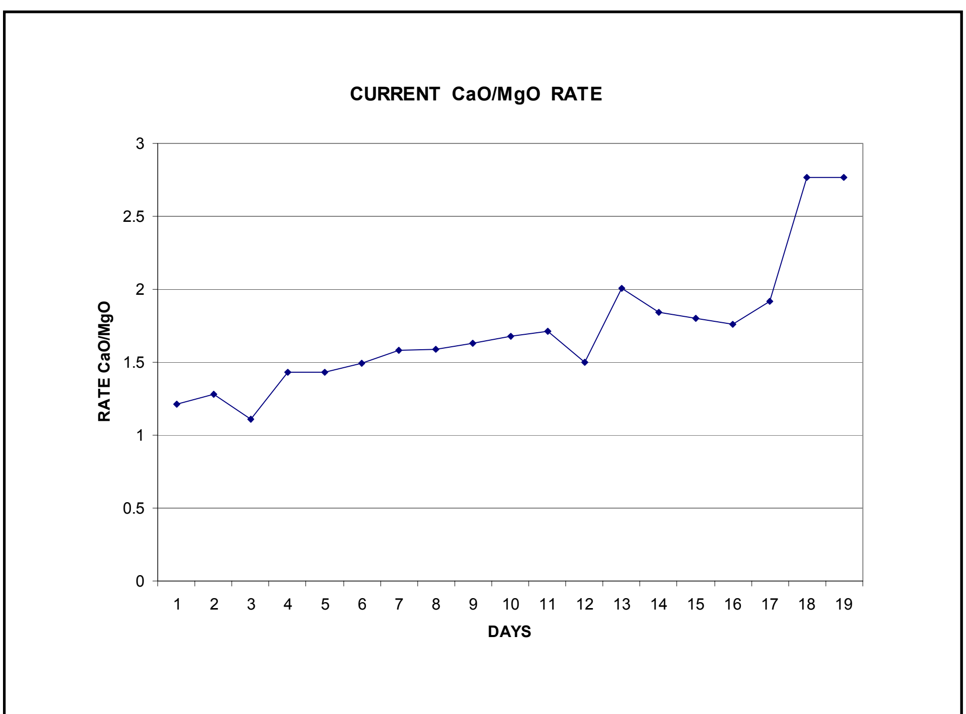


Crust formation inside the kiln because of a lack of chemical control



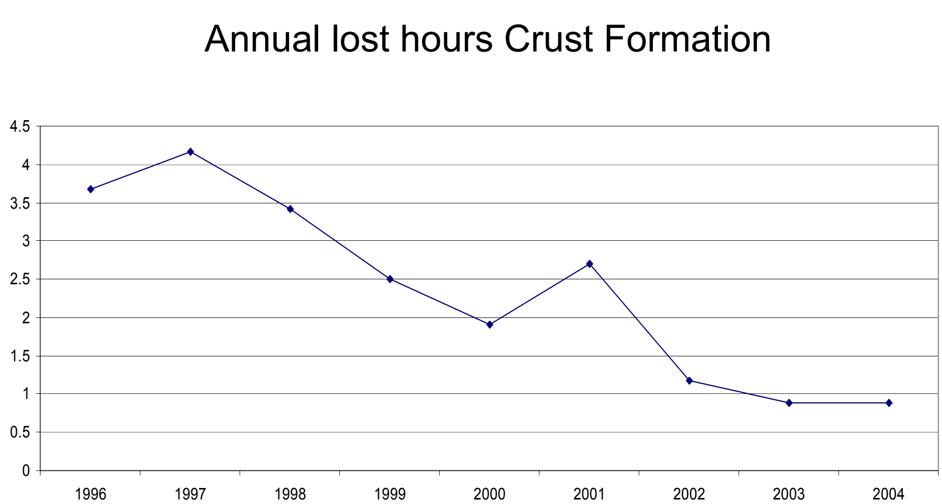


CURRENT TYPICAL CHEMICAL PROPERTIES (KILN FEEDING)
Elements in %
14
12
10
8
6
4
2
0
CaO
SiO2
Al2O3
S



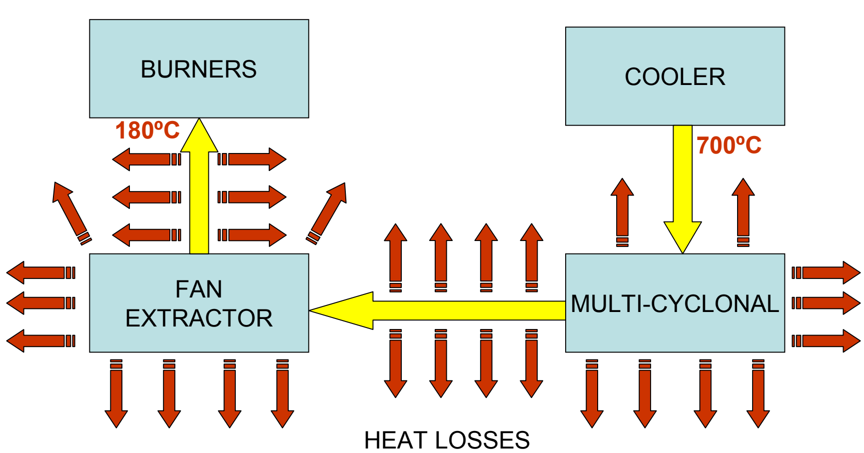
CURRENT CaO/MgO RATE
RATE CaO/MgO
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
DAYS

Thanks to the measures taken, crust formation has reduced, efficiency has increased and gas consumption has decreased

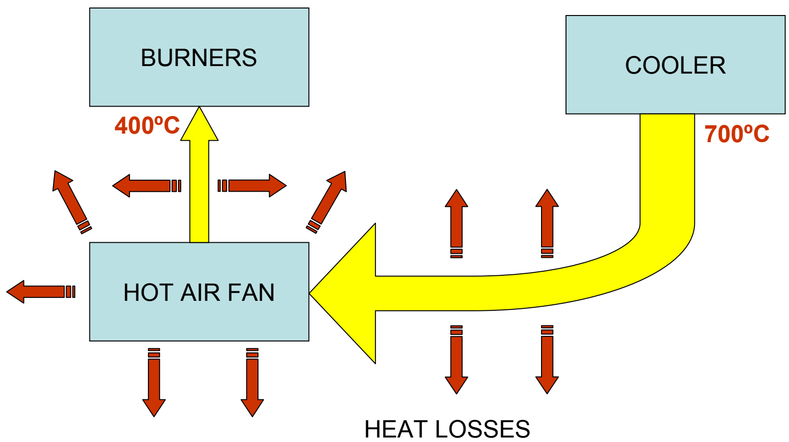


5.- Increase of combustion air temperature

Previous design of hot air recovery system

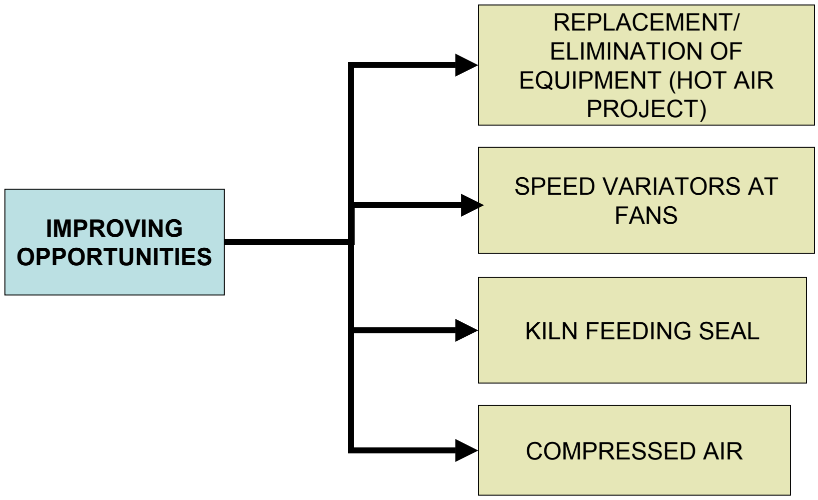


Modified design of hot air recovery system



6.- Lessening of Electricity Consumption

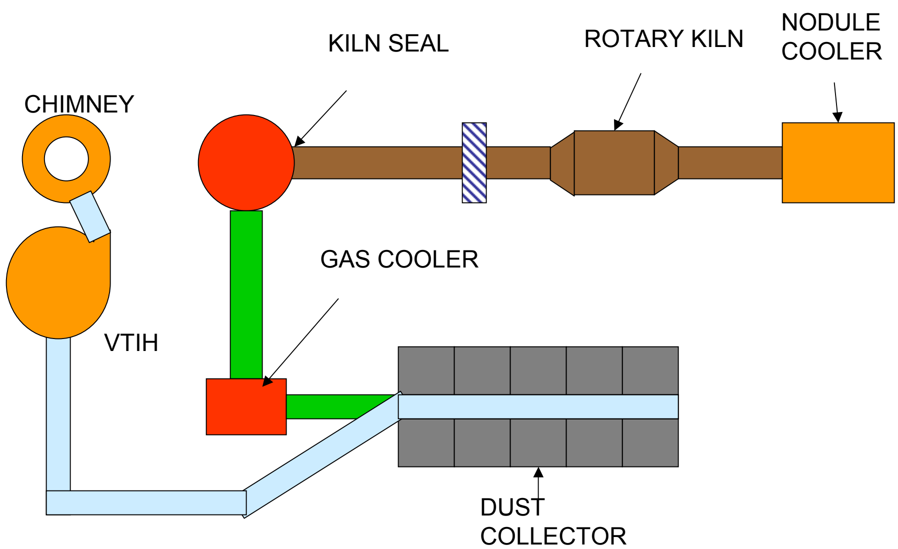
We took advantage of several Improving Opportunities



Feeding Seal

- We modified the design of the kiln feeding seal in order to eliminate false air inflow to the system, and then save gas and electricity

NODULISATION PLANT DIAGRAM



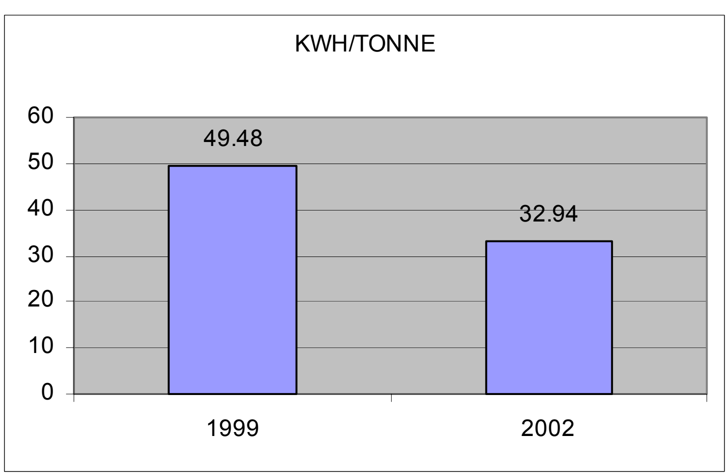
Summary of measures implemented and electricity savings

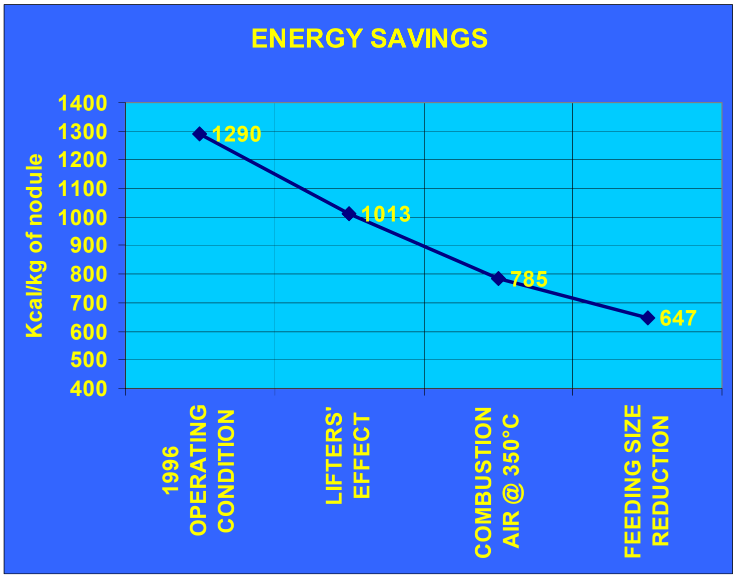
Equipment	Power (HP)	% Savings	Saved Power (HP)	Measures
VX-2	300	100	300	Hot Air Fan (HAF)
VDQS	150	100	150	Hot Air Fan (HAF)
VDQI	150	100	150	Hot Air Fan (HAF)
VAR	250	80	200	Speed Variator
VE-3	125	30	38	Speed Variator
VE-4	100	70	70	Speed Variator
VTIH	1,000	10	100	Seal
Compressor	250	80	200	Use of a smaller compressor
Total Savings			***1,208***	

Electricity savings results

- Previously, we operated an electricity generating plant with 3 generators of 2 MW each one (total nominal capacity: 6 MW)
- Currently, we operate a generator of 2 MW and other one of 2.75 MW. (total capacity: 4.75 MW). Maximum demand is 3.6 MW

Reduction of unit consumption of electricity at the plant





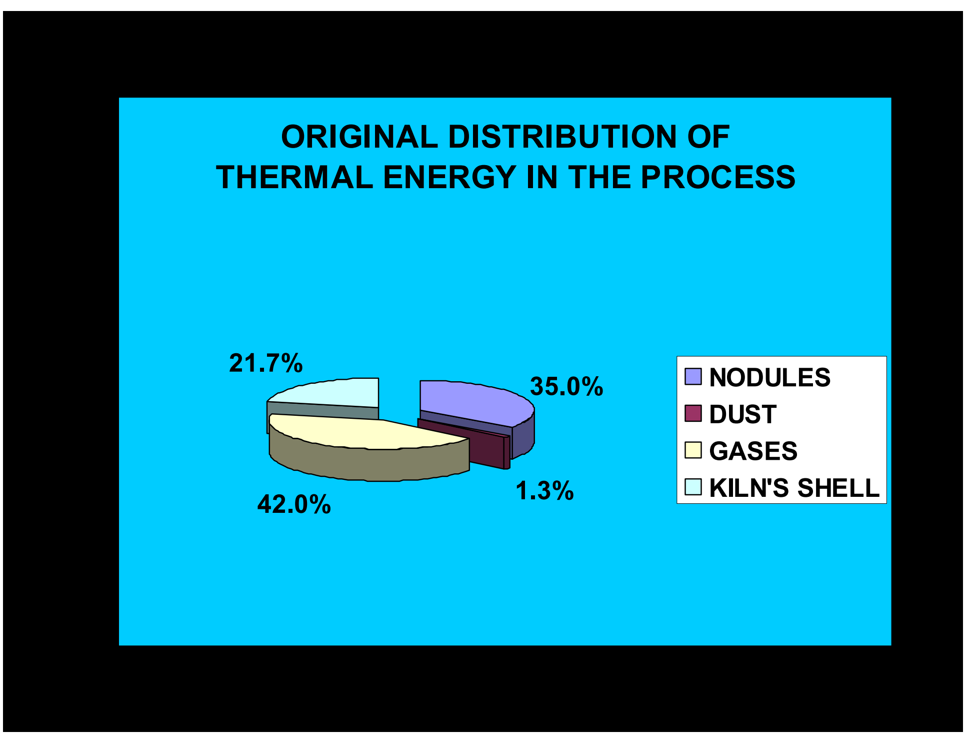
Cost – Benefit Analysis

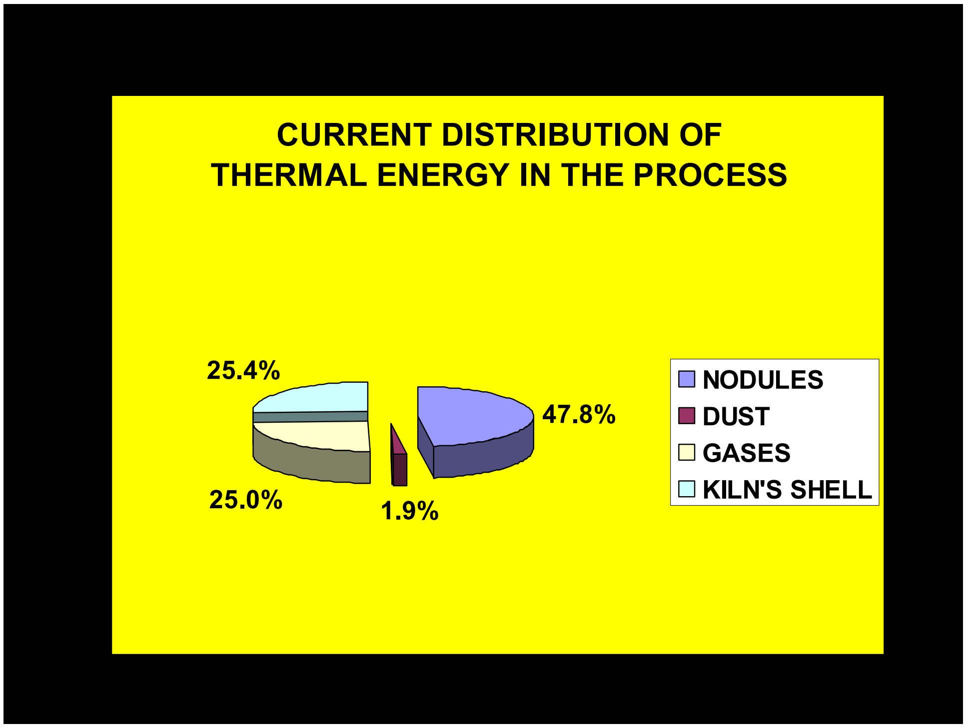
- 1996 – ytd investments concerning energy savings
  - **USD 350,000**

- 1996 – ytd financial savings:
  - **USD 15,210,200**

Conclusion

- All companies are able to look for energy saving opportunities in a lesser or a greater extent.
- This usually implies positive economic, environmental and social impacts.
- It is a paramount duty keeping our interest in looking for new improving opportunities and following up the relevant decisions.




CURRENT DISTRIBUTION OF
THERMAL ENERGY IN THE PROCESS
25.4%
47.8%
25.0%
1.9%
NODULES
DUST
GASES
KILN'S SHELL

ENERGY CONSUMPTION OF THE CHILEAN COPPER MINING SECTOR 1992-2000

PIMENTEL, SARA
International and Environmental Affairs Unit
Chilean Copper Commission
CHILE

ABSTRACT

This paper presents a diagnosis of the Chilean copper mining industry situation in regards of its energy consumptions. At the same time, it is analyzed the form in which the global and unitary consumptions of the different areas of copper processing have evolved within the period that this study covers (1992 – 2000), as well as the key factors in the changes occurred.

The base information used to build the study was given by the copper mining companies in a disaggregated form, released by areas, stages and processes, distinguishing between consumption of electric energy and the different types of fuels.

The results show that while the country's copper production increased 138% in a period of 9 years, the consumption of energy associated to this production only increased 90%.This is also reflected in the reduction of the global unitary coefficients of energy consumption which decrease about 20%, impelled mostly by a reduction in fuels consumption.

The consumption of energy of the copper mining sector in Chile, in the period covered by the study, fluctuates around 8% of the total energy consumed by the country, reaching its maximum value in the year 2000, with a participation of 10%. If it is considered that the contribution of the mining sector to the national GDP in the same period is about 8%, then, it is possible to conclude that the copper mining activity consumes energy proportionally to its contribution to the GDP .

1. INTRODUCTION

In order to fulfill the commitments acquired by the country when ratifying the United Nations' Framework Convention on Climate Change, in 1998 the Chilean Copper Commission actively participated in the elaboration and revision of the chapter corresponding to the copper mining sector of the National Inventory of Green House Gases which was based on the years 1993 and 1994. The inventory was made following the methodology established by the Intergovernmental Panel on Climate Change (IPCC) on the basis of the energy consumptions, fuel and electric energy, of each one of the areas of the copper refining process.

It is within this context that the Chilean Copper Commission decided to carry out a project focused on determining the evolution of the sector's energy consumptions, in the period between the years 1992 and 1998, which it was later complemented with the data obtained for the years 1999 and 2000 by the Efficient Use of Energy Group of the Clean Production Framework Agreement of the Large Scale Mining Sector.

The study's objective was, in one hand, to establish the unitary and global energy consumption coefficients (fuels and electric energy) for each one of the copper processing stages and through them, to analyze the way in which the sector's energy consumption has evolved along the decade, due to changes on technological and commercial product portfolio, and other factors.

2. METHODOLOGY

In order to approach the study, the copper refining process was determined by defining the different areas, stages and processes that generate flows of characteristic materials, whose volume decreases as the product's refining degree improves.

With these definitions we generate a survey and sent it to the main producing and refining companies, covering approximately a 97% of Chile's copper production. The survey was specific and segmented, considering the areas, stages and characteristic processes of each company, according to the knowledge the Chilean Copper Commission has of them.

The survey aimed to obtain data, as disaggregated as possible, in respect to energy consumption (fuels and electric energy), flow of inter-area material, technologies, production in each stage, generation and disposition of residues, among other antecedents.

With the information provided by the companies, the consumption of fuels and electric energy in each one of the copper production areas, in the period considered by the study, the Specific Unitary Coefficients of each fuel consumption (kg, m^3 or tons per metric ton of fine copper produced) were calculated for each one of the mining operations and areas. Then, we calculated a Global Unitary Coefficient of fuel consumption (Megajoule per metric ton of fine copper produced), based on the gross calorific values of each one of them[1]. In the case of electric energy, the corresponding Specific Unitary Coefficient was calculated (KWh and Megajoule per metric ton of fine copper produced).

The unitary values of each mining operation were weighed based on their respective production, to obtain a sectorial average value representative of each production area of the Chilean copper industry.

Afterwards, with the unitary values determinated for each year and area, the total energy consumptions (fuels and electric energy) of the copper mining sector were estimated, based on the data available in COCHILCO, in regard to copper production in each one of the process areas.

3. ENERGY CONSUMPTION IN THE CHILEAN COPPER MINING INDUSTRY

3.1. GLOBAL UNITARY COEFFICIENTS

TABLE I
FUELS CONSUMPTION BY PROCESS AREA

	1992	1993	1994	1995	1996	1997	1998	1999	2000
OPEN PIT (MJ/Tonne of fine copper in mineral)	4,443	4,305	5,111	4,758	4,403	4,139	4,255	3,643	3,985
UNDERGROUND MINE (MJ/ Tonne of fine copper in mineral)	514	532	577	587	525	425	482	550	753
BENEFICIATION (MJ/ Tonne of fine copper in concentrates)	505	393	153	342	259	291	231	218	192

[1] Source: National Energy Balance 1979 – 1998 Chile, from the National Energy Commission.

OXIDES TREATMENT (MJ/Tonne of fine copper in EW cathodes)	**951**	**808**	**966**	**3,099**	**2,977**	**2,457**	**2,406**	**3,650**	**3,597**
SMELTER (MJ/Tonne of fine copper in Blister)	**11,497**	**11,477**	**11,300**	**10,632**	**9,881**	**9,398**	**8,621**	**7,577**	**7,773**
REFINERY (MJ/tonne of fine copper in ER cathodes)	**1,142**	**1,140**	**1,092**	**1,042**	**1,025**	**768**	**800**	**1,033**	**1,011**
SERVICES (MJ/Tonne of total fine copper)	**1,084**	**447**	**350**	**370**	**297**	**321**	**402**	**403**	**427**

MJ: Megajoule
Source: Data processed by the Chilean Copper Commission

TABLE II
ELECTRIC ENERGY CONSUMPTION BY PROCESS AREA

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
OPEN PIT (MJ/Tonne of fine copper in mineral)	**956**	**775**	**781**	**750**	**710**	**581**	**586**	**505**	**452**
UNDERGROUND MINE (MJ/ Tonne of fine copper in mineral)	**1,051**	**1,105**	**1,102**	**1,023**	**972**	**902**	**932**	**1,152**	**1,195**
BENEFICIATION (MJ/ Tonne of fine copper in concentrates)	**5,384**	**5,470**	**5,749**	**5,572**	**5,032**	**5,075**	**5,458**	**5,816**	**6,144**
OXIDES TREATMENT (MJ/Tonne of fine copper in EW cathodes)	**10,210**	**8,990**	**9,647**	**9,921**	**9,878**	**9,512**	**9,588**	**9,842**	**10,096**
SMELTER (MJ/Tonne of fine copper in Blister)	**2,633**	**2,760**	**2,967**	**2,816**	**2,719**	**2,896**	**3,081**	**3,432**	**3,464**
REFINERY (MJ/tonne of fine copper in ER cathodes)	**1,325**	**1,266**	**1,252**	**1,182**	**1,192**	**1,195**	**1,201**	**1,230**	**1,241**
SERVICES (MJ/Tonne of total fine copper)	**566**	**563**	**559**	**536**	**596**	**567**	**630**	**498**	**476**

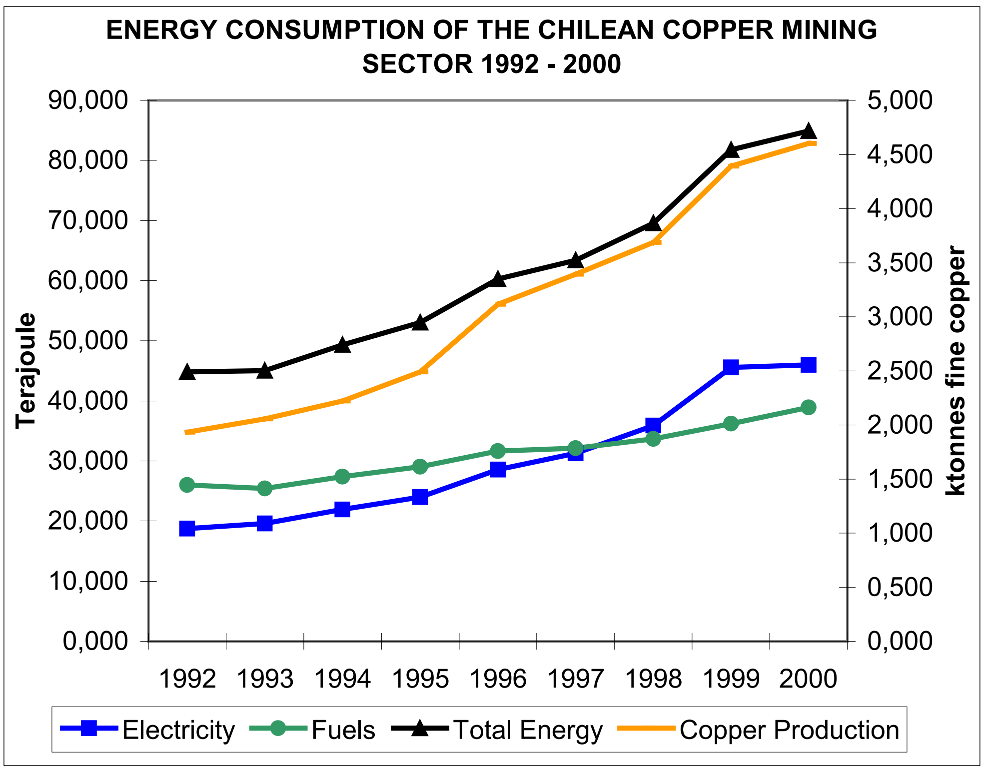
Source: Data processed by the Chilean Copper Commission

3.2. TOTAL ENERGY CONSUMPTION AND GLOBAL UNITARY COEFFICIENTS

Based on these global unitary coefficients of fuels and electric energy consumption determined for each copper processing area and on the intermediate productions considered in each area, an estimation of total energy consumption was made, regarding fuels as well as electric energy, for all the copper mining sector; i.e., including the production of those companies that did not inform energy consumption levels. In addition, an average Unitary Global Coefficient was calculated for Chilean copper mining.

As seen in Figure I, the total energy consumption for the copper mining sector increased 89.5% between the years 1992 and 2000. It may be emphasized that, in the same period, the country's fine copper production increased by 138,1%. The energy consumption as fuel grew by 49.5% during the same period, whereas the electric energy increased by 145,1%.

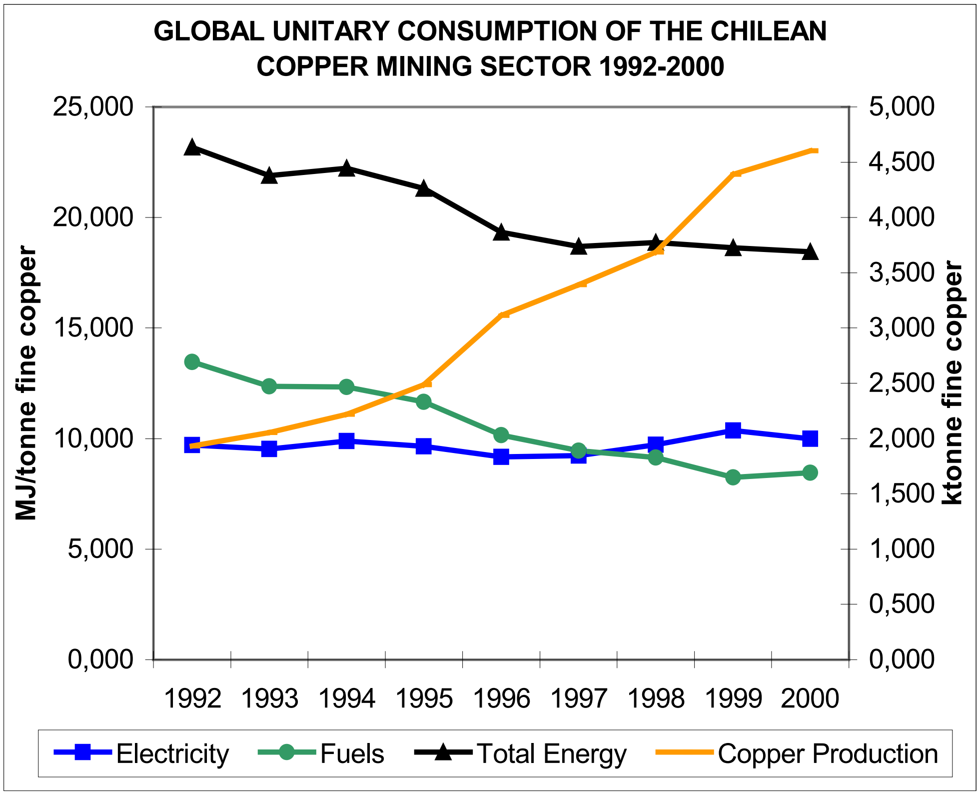
FIGURE I



Source: Data processed by the Chilean Copper Commission

The global unitary coefficients (Figure II) of the sector's total energy consumption experienced a sustained decreasing tendency, with a 20.4% diminution between the years 1992 and 2000, impelled by the decreasing values of fuel consumption's global unitary coefficients, which decreased by 37.2% in the period, while the electric energy coefficients, although show slight fluctuations, stay quite stable, in general.

FIGURE II



Source: Data processed by the Chilean Copper Commission

Previous results are explained basically by changes in the copper production portfolio (EW cathodes, ER cathodes, concentrate, blister) and technological changes, some of which have been impelled by environmental measures.

Since 1994 large scale mining projects of oxides began producing. The fine copper production originated from oxide mining, increased by 913% between 1992 and 2000. In 1992 the production of EW cathodes was only a 7% of Chile's total fine copper production, whereas 30% in the year 2000.

Fine copper originated from sulphide minerals increased its production by an 80%, with a change in the end product portfolio. In 1992, a 66% corresponded to refined products (blister/anodes, fire-refined copper and ER cathodes), which decreases to a 45% in the year 2000.

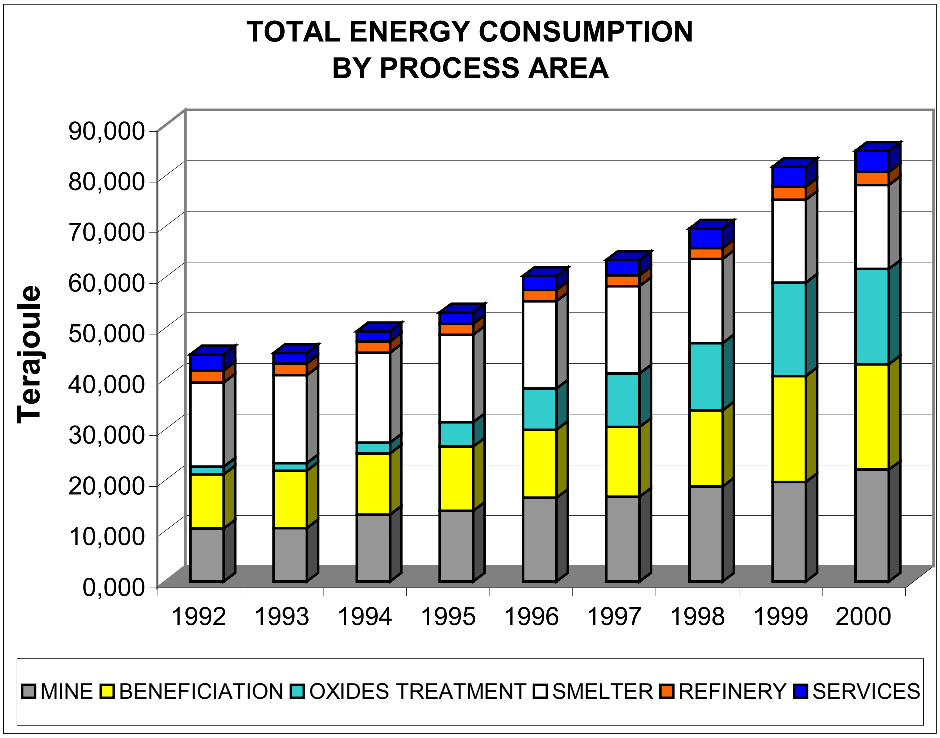
On the other hand, the environmental measures oriented to improve air quality in the surrounding areas of copper smelter facilities and to fulfill the standards, impelled technological and operational changes in copper concentrate smelters. Since 1994, reverberatory furnaces that operated in the country, which were big fuel consumers, have been changed by other smelting units. Currently, smelters operate with Flash furnaces and Teniente converters, which allow an autogenous smelting of concentrates and, therefore, lesser fuel consumption.

Another factor that has also implied lesser fuel consumption is the change of copper concentrate thermal drying to a highly efficient mechanic filtering, which is being implemented in most mining operations.

3.3. CONTRIBUTION OF PROCESS AREAS TO ENERGY CONSUMPTION

As a result of the change in the end product portfolio indicated above, changes have also occurred in regards to relative energy consumption of each stage of the copper production process, which may be seen in the following figures.

FIGURE III



Source: Data processed by the Chilean Copper Commission

The mine and beneficiation plant consume almost half of the total energy consumed by the copper mining sector, a situation that has kept practically unchanged during the study period (47% in 1992 and 50% in the year 2000).

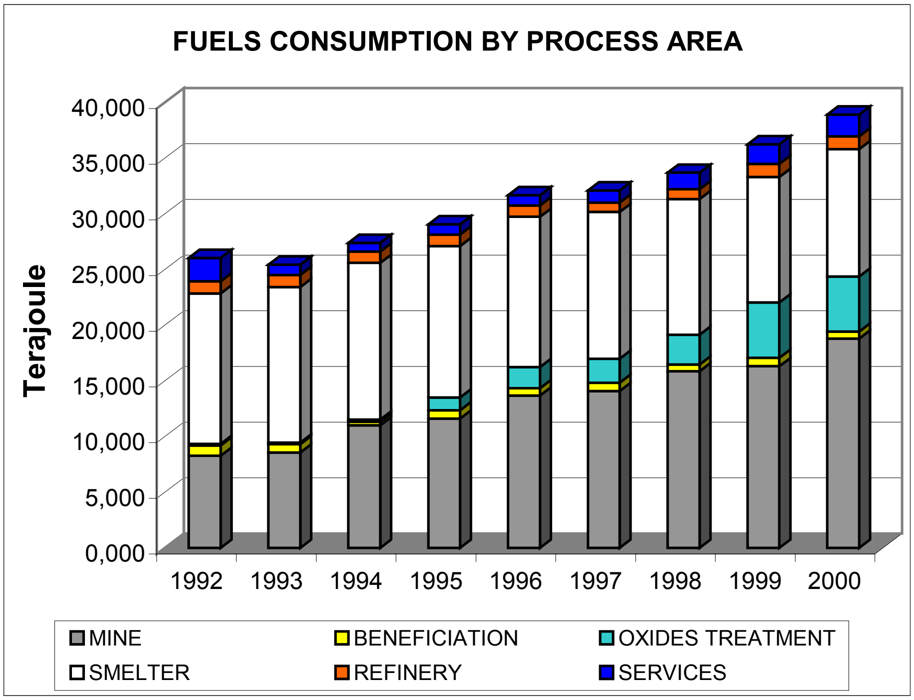
In one hand, the energy consumed by the treatment of oxide minerals (leaching/ solvent extraction/ electrowinning) strongly increases its participation between the years 1992 and 2000, being initially of 3% to reach a value of 22%, due to starting-up of large projects in this area.

On the other hand, smelting process decreases its participation in the sector's total consumption of energy from 37% to 19%, due to technological changes impelled by environmental measures. Participation of the refining area in copper mining's total energy consumption is not relevant and fluctuates between 3% and 5%.

In what refers to fuels consumption per area (Figure IV) in copper mining, mine and smelting account for about 80% of the total fuels consumed by the sector.

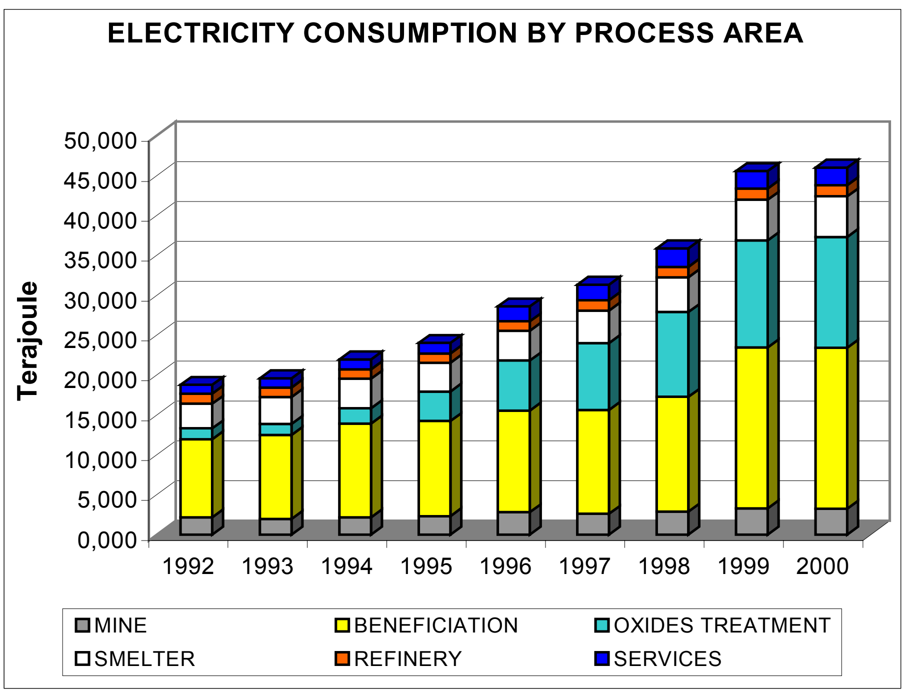
At the beginning of the decade, smelting area consumed more than half of the total amount of fuels consumed by the Chilean copper mining sector (52%); however, its participation decreased through the years due to technological changes in smelters, as explained earlier, and it consumed only 29% of the total fuels in the year 2000.

FIGURE IV



Source: Data processed by the Chilean Copper Commission

FIGURE V



Source: Data processed by the Chilean Copper Commission

In regards to electric energy (Figure V), the minerals beneficiation processing area which at the beginning of the period consumed 52% of the total electric energy used by copper mining sector, decreased its relative participation to a 44%. In this area, electric energy is used mainly in crushing and milling of minerals and the unitary consumption values are a variable that depends on the mineral hardness index, which is characteristic of each mining operation.

The smelting of concentrates, which in the year 1992 was the second area regarding electric energy consumption, with a share of 17%, even when it increases the unitary consumption values, due to the installation of systems to capture and handling gases and sulphuric acid plants, decreases its relative share to an 11% at the end of the period, being displaced by the treatment of copper oxide minerals.

The treatment of copper oxides, which at the beginning of the 90's had a share of 7% in the sector's total electric energy consumption, increased to 30% in the year 2000, due to the explosive increase of copper production from this type of minerals (913% between 1992 and 2000).

The four areas of the copper production process in Chile that consume about 90% of the total energy (both fuels and electricity) consumed by the sector are the following: open pit mines, beneficiation of copper sulphide minerals, treatment of oxide minerals and the smelting of concentrates, including sulphuric acid plants.

The copper mining energy consumption patterns also changed strongly during the decade. In the year 1992, a 58% of the total energy consumed by the sector corresponded to fuels, while in the year 2000, the electric energy accounted for a 54% of the total consumption.

Finally, the copper mining sector's energy consumption in Chile, in the period considered by the study, fluctuates around 8% of the total final energy consumed by the country, reaching a maximum value in the year 2000, with a 10% share. Considering that the mining sector's contribution to the national GDP in the same period was also around 8%, then, it is possible to conclude that the copper mining activity consumes energy in proportion to its contribution to the GDP.

Analyzing the final consumption of energy products in the country (that is, in the suitable form for its final use, which means that electricity includes hydro and thermoelectricity), of the total amount of energy consumed, an average of 14% belongs to electric energy and 86% to a variety of fuels. Copper mining sector consumption is significantly more intensive in the use of electric energy than the national average, with a period average of 48% of electric energy consumption and a 52% in fuels, a tendency that accentuates in the last years, reaching 54% of electricity and 46% of fuels of the sector's total energy consumption in the year 2000. Of the total fuels consumed by copper mining industry, more than 90% are Diesel and Fuel Oil, while the share of other fuels (coal, firewood, kerosene, LPG and gasoline) is marginal.

Regarding the share of copper mining in the country's final consumption per energy type in the year 2000, the sector consumed an average of 30% of the total electric energy consumed by the country and only 5% of total fuels.

GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

ENERGY CONSUMPTION COPPER MINING SECTOR IN CHILE 1992 - 2000

Sarita Pimentel

International and Environmental Unit

GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

The present study is a diagnosis of energy consumption, both fuels and electricity, for the copper mining industry in Chile.

It also analyses the evolution of Global Unitary Coefficients in each defined process area, their contribution to the total use of energy and the factors that have been relevant for changes in pattern of consumption.

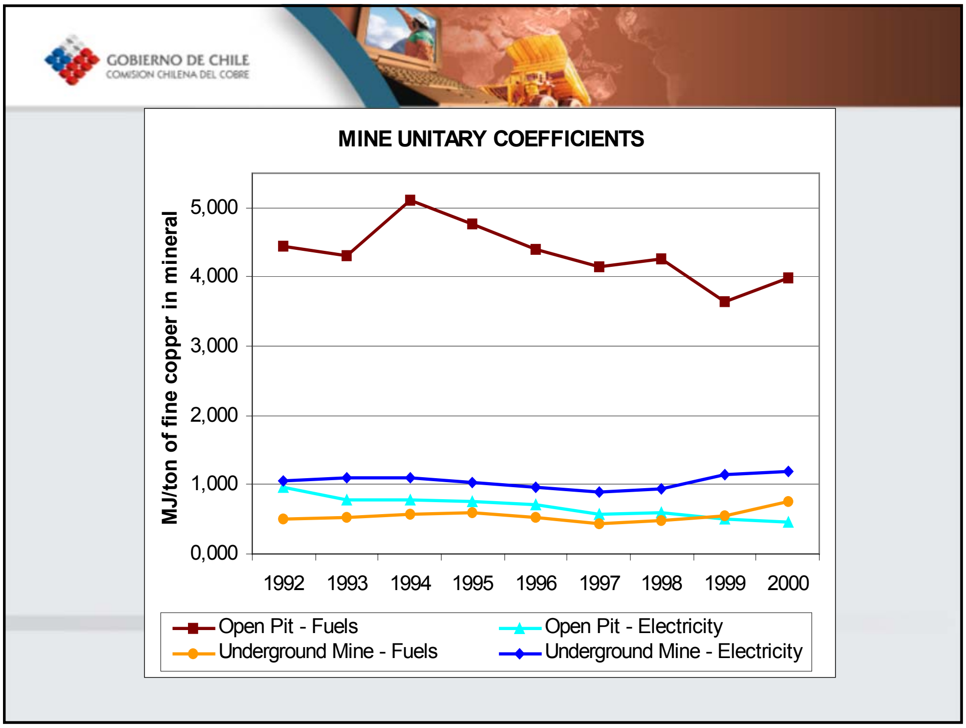
GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

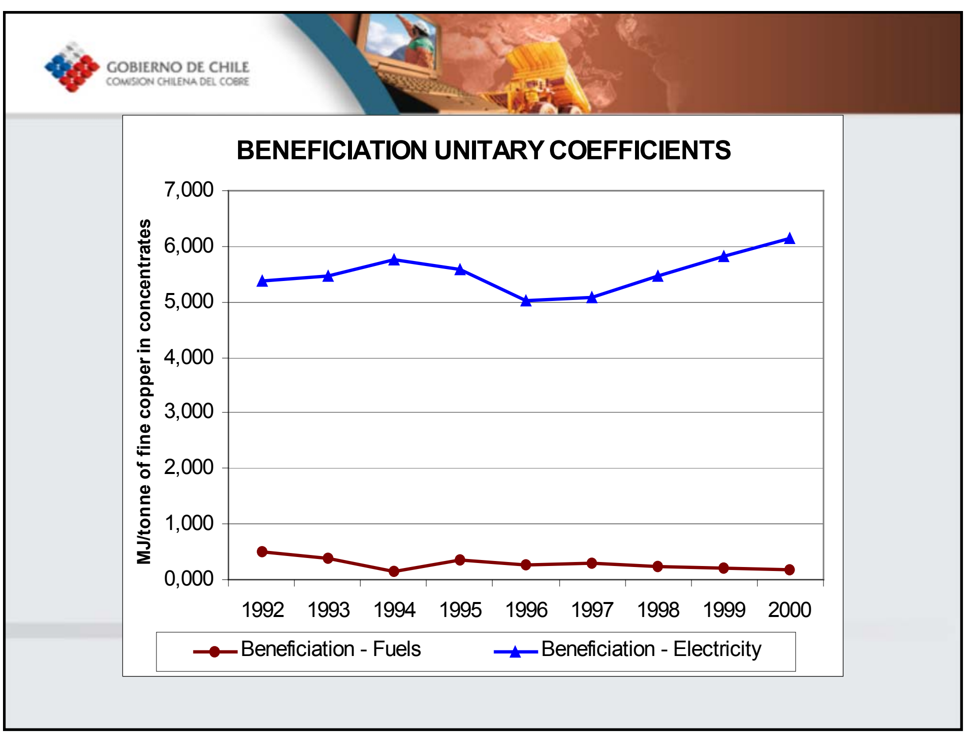
METHODOLOGY

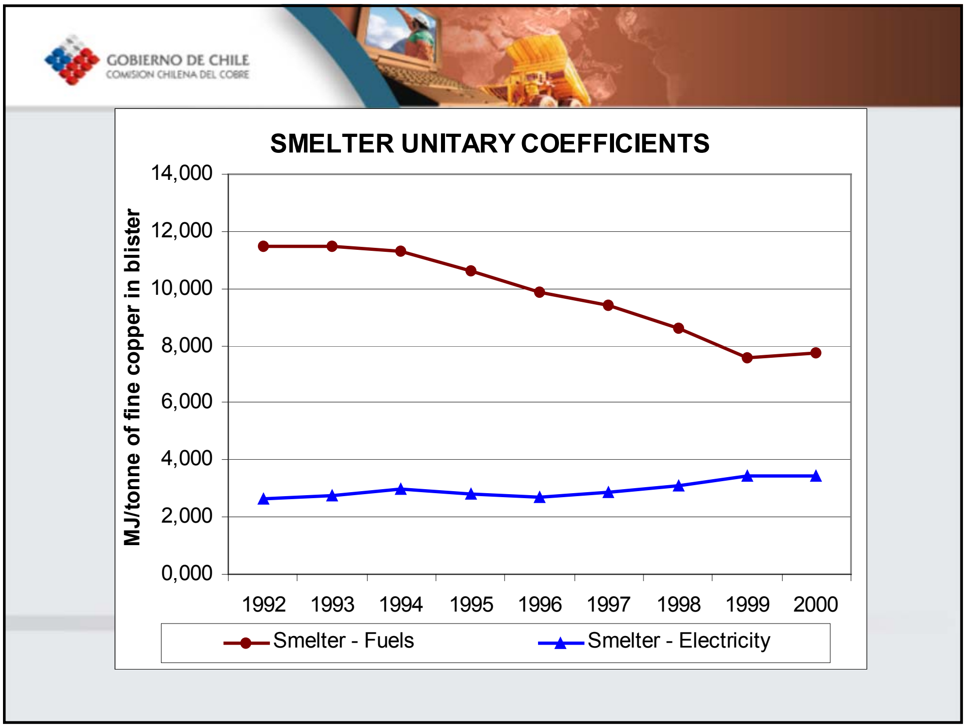
- Definition of copper mining process in areas, stages and unitary processes
- Generation of a survey which was sent to the most important copper producers and refiners, covering around 97% of the chilean copper production
- The survey was specific, considering typical areas, stages and unitary processes of each company.

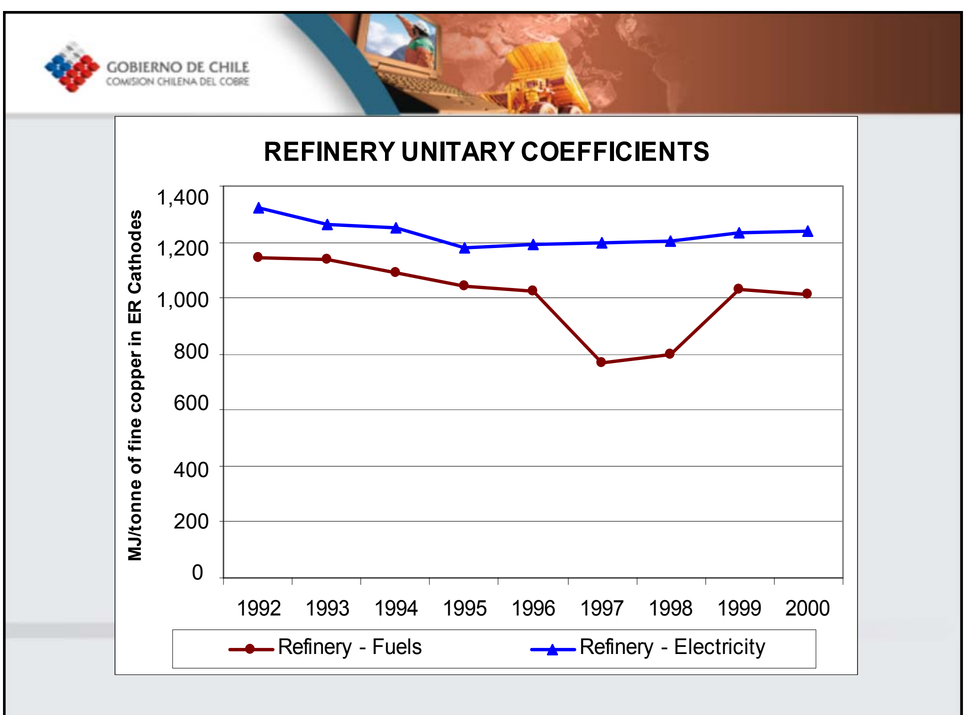
GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

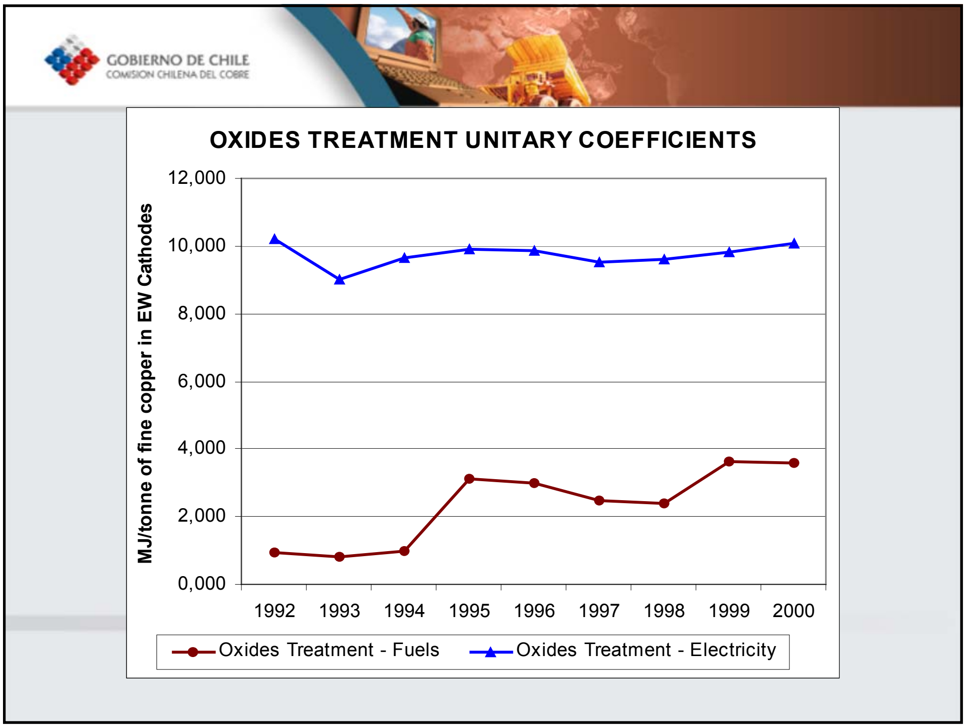
- The objective of the survey was to obtain information, as disaggregated as possible, in respect to energy consumptions, different fuels and electricity, flows of inter-area materials and other data.
- With the data provided by the companies, **Global and Specific Unitary Coefficients** for energy consumption in the mine, beneficiation plant, smelter, refinery, oxide treatment (LX-SX-EW) and services were calculated.
- Unitary consumptions are refered to fine copper content in minerals, concentrates, blister, ER and EW cathodes, as appropriate.

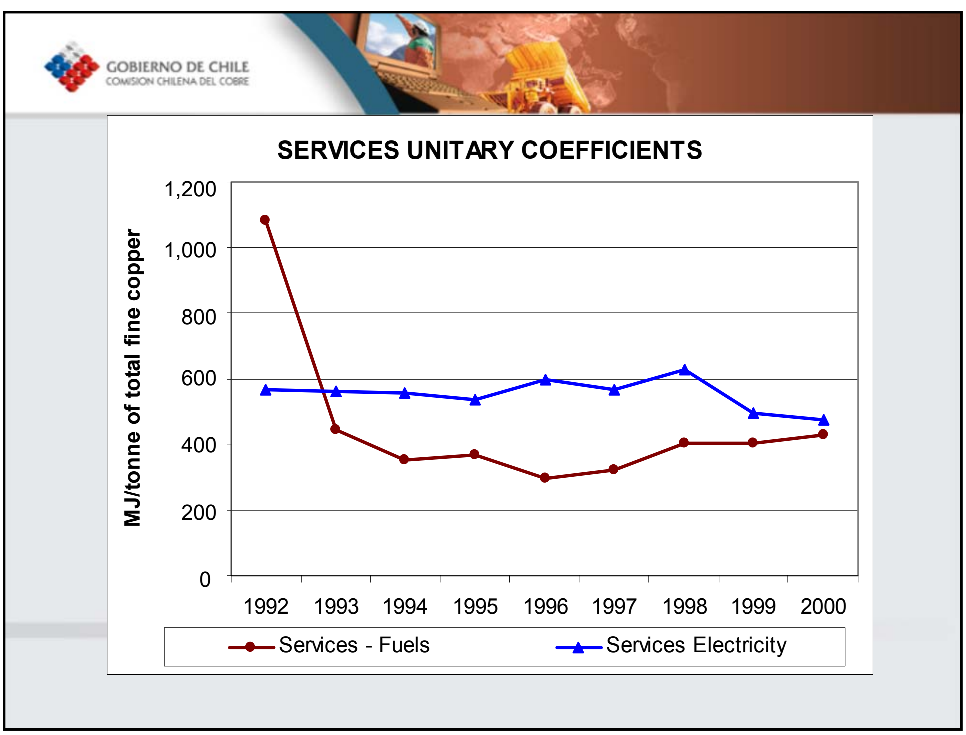

GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE
MINE UNITARY COEFFICIENTS
MJ/ton of fine copper in mineral
5,000
4,000
3,000
2,000
1,000
0,000
1992
1993
1994
1995
1996
1997
1998
1999
2000
Open Pit - Fuels
Open Pit - Electricity
Underground Mine - Fuels
Underground Mine - Electricity


GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE
BENEFICIATION UNITARY COEFFICIENTS
MJ/tonne of fine copper in concentrates
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0,000
1992
1993
1994
1995
1996
1997
1998
1999
2000
Beneficiation - Fuels
Beneficiation - Electricity


GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE
SMELTER UNITARY COEFFICIENTS
MJ/tonne of fine copper in blister
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0,000
1992
1993
1994
1995
1996
1997
1998
1999
2000
Smelter - Fuels
Smelter - Electricity

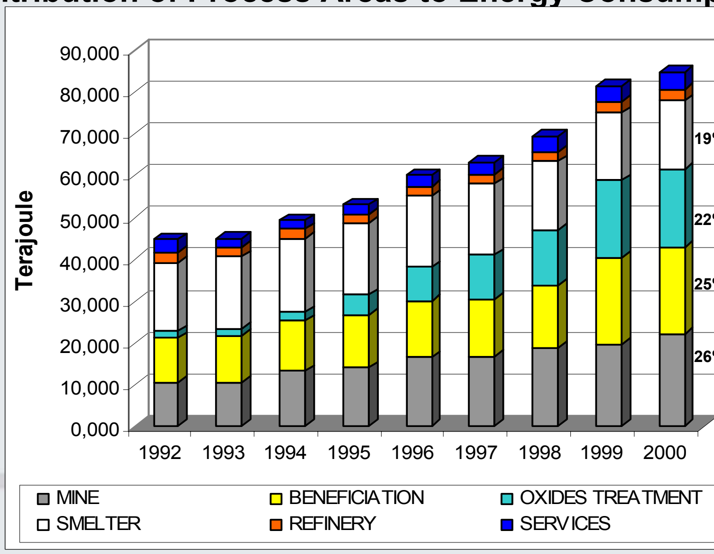

GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE
REFINERY UNITARY COEFFICIENTS
MJ/tonne of fine copper in ER Cathodes
1,400
1,200
1,000
800
600
400
200
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
Refinery - Fuels
Refinery - Electricity


GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE
OXIDES TREATMENT UNITARY COEFFICIENTS
MJ/tonne of fine copper in EW Cathodes
12,000
10,000
8,000
6,000
4,000
2,000
0,000
1992
1993
1994
1995
1996
1997
1998
1999
2000
Oxides Treatment - Fuels
Oxides Treatment - Electricity


GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE
SERVICES UNITARY COEFFICIENTS
MJ/tonne of total fine copper
1,200
1,000
800
600
400
200
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
Services - Fuels
Services Electricity

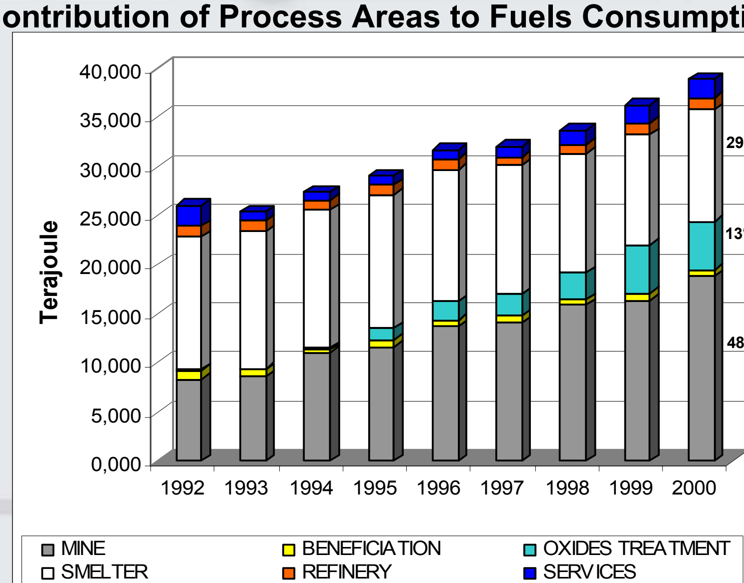
GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

Contribution of Process Areas to Energy Consumption



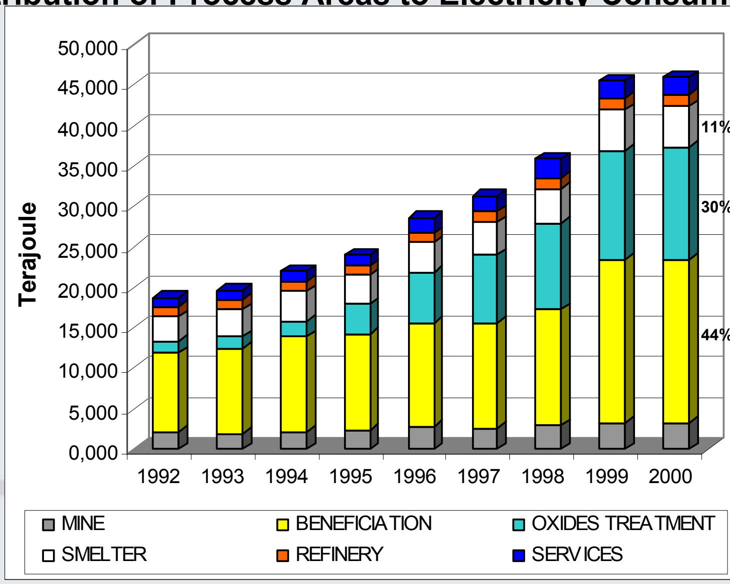
GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

Contribution of Process Areas to Fuels Consumption



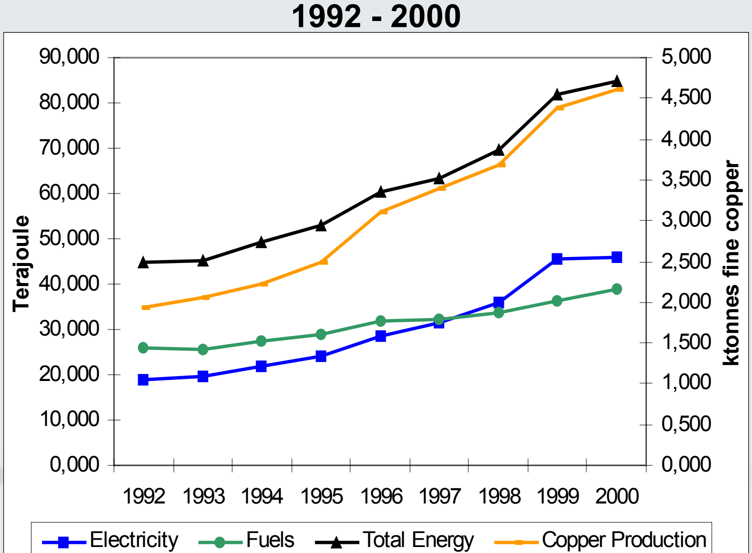
GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

Contribution of Process Areas to Electricity Consumption



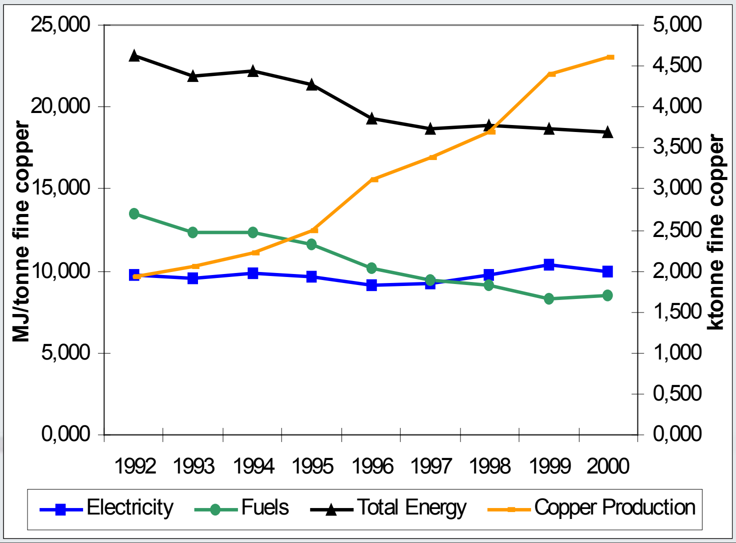
GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

Energy Consumption of Chilean Copper Mining Sector 1992 - 2000

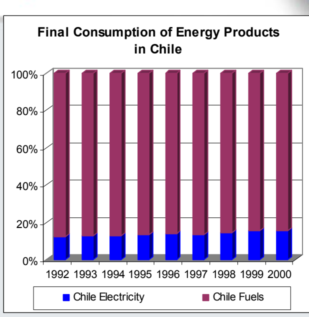


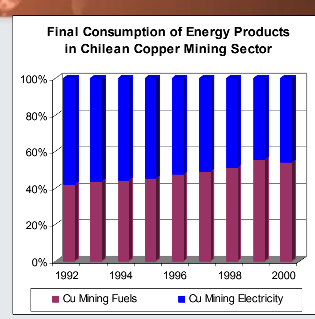
GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

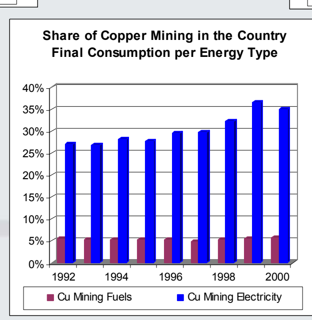
Unitary Consumption of Chilean Copper Mining Sector 1992 - 2000



GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE







GOBIERNO DE CHILE
COMISION CHILENA DEL COBRE

CONCLUSION

Having in mind the results of the study and the areas where energy consumption is most relevant, to improve energy efficiency the chilean copper mining industry may focus its efforts to:

- Fuels consumption in open pit mines and smelters
- Electricity consumption in beneficiation and oxides treatment plants

Using Control for Adding Value to Energy Efficiency of Mineral Processing Plants
Uso del Control Automatico para Aumentar la Eficiencia Energetica de Plantas Mineralurgicas

André Desbiens[1], Eduardo Núñez[1], Rene del Villar[2], Daniel Hodouin[2], Éric Poulin[3]

LOOP (Laboratoire d'observation et d'optimisation des procédés)
[1] Department of Electrical and Computer Engineering
[2] Department of Mining, Metallurgical and Materials Engineering
Université Laval, Pavillon Pouliot, Quebec City, Quebec, Canada G1K 7P4 (desbiens@gel.ulaval.ca)

[3] Breton Banville et ass.
375, Sir-Wilfrid-Laurier, Mont-Saint-Hilaire, Quebec, Canada J3H 6C3

Abstract. Because of globalization and international competition, mineral processing plant managers seek at reducing production costs. These plants are major energy consumers and therefore energy efficiency is becoming an important objective. Other incentives are the energy cost that will probably continue to rise and the environmental and social pressures for reducing energy consumption. Using more energy efficient equipment is a first approach. Better plant operation using on-line data processing, as described in this paper, is another way to improve energy efficiency. On-line data processing consists in using the measurements provided by sensors and the knowledge of the plant behaviour to automatically, continuously and adequately manipulate plant actuators. An ideal on-line data processing is made up of three hierarchic layers: process observation, process control and process optimization. The layers, their interaction and their energetic benefits are described. Some case studies illustrate the energy efficiency improvements provided to mineral processing plants by using on-line data processing techniques.

Resumen. Como resultado de la globalización de mercados y la competencia internacional, las empresas mineras se han visto en la necesidad de reducir sus costos de producción. Estas empresas son grandes consumidoras de energía y por ende la eficiencia energética es para ellas un objetivo crucial. Otros incentivos son el costo creciente de la energía y las presiones ambientales y sociales para reducir el consumo de energía. El uso de equipos más eficientes del punto de vista energético es una alternativa. Una mejor operación de las plantas existentes mediante el tratamiento en-línea de la información disponible, tal como se explica en este artículo, es otra alternativa, a menudo menos onerosa. El tratamiento en-línea de datos consiste en usar las mediciones de instrumentos y el conocimiento del proceso para manipular automática, continua y adecuadamente los distintos accionadores existentes. Idealmente, un tratamiento en-línea de datos está compuesto de tres niveles jerárquicos: observación, control y optimización del proceso. Estos tres niveles, su interacción y sus beneficios energéticos son descritos en este artículo. Algunas experiencias prácticas ilustrando las mejoras energéticas logradas en plantas mineras mediante el uso de técnicas de tratamiento en-línea de datos son asimismo presentadas.

1. Introduction

Nowadays, with globalization and increasingly furious international competition, mineral processing plant managers are constantly seeking at reducing the production costs while increasing the throughput and the product quality. Since these plants are intensive energy consumers, improving their energy efficiency may obviously contribute to reduce the production costs. Furthermore, the energy efficiency challenge becomes unavoidable since the energy cost will more than likely continue to rise and as a result of increasing environmental and social pressures for reducing energy consumption.

To illustrate the existing pressure for energy efficiency, Hydro-Québec (Quebec hydroelectrical producer and distributor) offers financial assistance to large-power customers for new projects designed to reduce specific electricity consumption [1]. Hydro-Québec operates the most extensive transmission system in North America with 32539 km of lines and makes it available to customers inside and outside Quebec. For the Quebec market, Hydro-Québec supplies a heritage pool of up to 165 TWh per year, 93% being hydroelectric. The objective of the first Hydro-Québec program is to save 100 GWh of electricity from 2003 to 2006. The financial assistance budget is Cdn 8.5 M$. The program aims at encouraging customers to present electricity conservation proposals. To be eligible, participants must agree to take measurements before and after the project implementation to show savings achieved. The financial assistance objective is to reduce the payback period to one year. The customer must pay at least 25% of the total costs and the project must be completed within 18 months. Hydro-Québec also offers financial assistance to major customers for an energy consumption analysis at the industrial site or for the demonstration that the first-time implementation in Quebec of a new technology would result in energy savings.

A first approach for the plants to increase their energy efficiency is to use equipment that consumes less energy. This initiative may consist in replacing the existing equipment with more efficient ones or by installing new equipment aiming at reducing the specific energy consumption of existing processes. Improving energy efficiency may also be attained through better plant operation. This can be achieved by making a judicious on-line use of process sensors and large plant operation databases. The next section is devoted to a description of the on-line data processing approach. Section 3 presents some case studies to illustrate the benefits of this energy saving method. The last section concludes the paper.

2. Process observation, control and optimization to improve energy efficiency

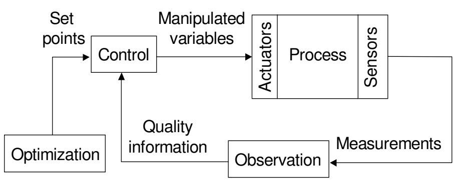


Figure I - On-line data processing

On-line data processing consists in using the measurements provided by plant sensors and the knowledge of the dynamic plant behaviour (evaluated from measurement databases recorded during plant operation) to automatically, continuously and adequately manipulate plant actuators, such as valves and variable speed drives, in order to achieve a specific objective. An ideal on-line data processing, often referred to using the generic name of control, is made up of three hierarchic layers (Figure I): process observation, process control and process optimization.

Process observation aims at getting useful on-line information about the plant behaviour, therefore allowing to "see" the process states and thus detecting operation problems, abnormal performances, etc. The basic equipments needed are reliable sensors. However, using data processing techniques such as fault detection and isolation (FDI) [2], data reconciliation [3] and observers [4], may greatly improve the process "picture". FDI rapidly detect and physically localize problems such as sensor biases and leaks, whose rapid correction will reduce bad consequences on the production. Data reconciliation techniques improve the quality of the noisy measurements by forcing them to be consistent with the knowledge engineers have about the plant, such as mass and energy conservation laws. Observers are soft-sensing algorithms; they infer signals that cannot be measured (not at all or not frequently enough). They generate new measurements that can be used to improve the plant operation. Even if process observation is based on passive techniques, they certainly help engineers improving their vision of the process states and therefore corrective actions such as equipment or operation changes can be taken.

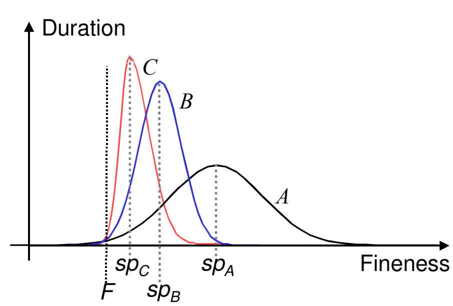


Figure II - Process variability

Once the on-line measurements have been improved by the process observation layer, they may be used to continuously adjust the actuators to provide process control actions [5]. Through feedback and feedforward, process control allows maintaining the measured variables at selected set points despite the presence of disturbances, such as changes in ore properties. A consequence of the process stabilization around a selected operating point is the decrease of process variability, as qualitatively illustrated in Figure II [6]. It compares, for three different control strategies, the time (ordinate) the grinding product fineness is at a given value (abscissa). Control strategy *A* performing poorly, a large dispersion around the set point occurs. Control strategy *B* provides a tighter disturbance rejection and the measurement is more often close to the desired set point. Control *C* would be representative of an advanced control approach that intrinsically takes into account the physical and operational limitations of the process. If the objective is to have the product fineness 95% of the time larger than *F*, a lower set point (sp_C) may be selected for strategy *C* than for strategy *B* (sp_B), whereas *B* set point is lower than *A* set point (sp_A). Since grinding is a very costly operation, decreasing the fineness set point translates in significant energy savings. Furthermore, even if the set points are not changed, better control usually results in a smoother and less costly operation.

The third layer is the process optimization step [7]. It consists in continuously selecting the set points of the control layer to optimize a control objective. The goal could be the minimization of energy consumption (in absolute values, per ton of processed material, per ton of product, etc.). However, the objective is usually related to profit maximization. The profit being obviously dependant on energy consumption, a side effect is often a decrease in the energy costs. Optimization is a very flexible tool that could help in taking into account energy consumption regulations (better energy price if the energy consumption remains below a given threshold, energy price changing depending on the time of the day, etc.). Indeed, one could imagine an optimization strategy that will maximize the profit as long as the energy consumption remains below the threshold.

Process observation, control and optimization are added values for energy savings. Indeed, for several plants, such on-line data processing requires none or very little new equipment. They can also provide many additional benefits such as a better knowledge of the plant, a product quality respecting specifications more often, a throughput increase, an easier-to-operate plant leading to more effective use of personnel, a reduced downtime and a decrease in maintenance costs.

Energy saving estimations are often underestimated because the plant units are usually considered separately. For instance, optimizing a flotation plant does not procure any real energy savings. However the energetic impact on subsequent metal extraction processes and smelting may be considerable. Hence, ideally, plant wise evaluation should be performed.

3. Case studies

Section 3.1 describes a case study where the use of data reconciliation allowed the detection of abnormal operating conditions in a grinding circuit. Even if they are difficult to estimate, the energetic impacts were important. Section 3.2 details the implementation of a grinding control strategy that lead to 9% gain in the specific energy consumption while increasing the tonnage and maintaining the product size distribution. Section 3.3 presents the benefits of using observation, control and optimization to improve the energy efficiency of electric arc furnaces. In particular, the optimization is directly aiming at reducing the energy consumption. Finally, the optimization of an induration furnace is discussed in Section 3.4.

3.1. Case study 1: Observation and control of a grinding circuit

Between 1992 and 1994, LOOP researchers undertook an industrial project aiming at developing and implementing a new control strategy for one of three Kidd Creek's grinding circuits (line B) [8-10]. The control strategy was first evaluated on LOOP's grinding circuit dynamic simulator (DYNAFRAG), which permitted the discrimination between more than a dozen possible control alternatives. The selected control strategy was then configured on the plant DCS in early 1994. At the time of the study, Line "B" processed 150 t/h of ore through an open-loop 3.2 m x 4.9 m rod-mill (Allis Chalmers) followed by a 3.7 m x 5.5 m ball-mill (Allis Chalmers) operating in close-circuit with a cluster of eight 380 mm Krebs hydrocylones. Both mill discharges are mixed in a 12 m^3 non-linear pump-box, where a 12x10 Linatex fixed-speed-drive centrifugal pump withdraws the cyclone feed. The installed instrumentation consisted of a weightometer on the rod mill feed belt, magnetic flowmeters to measure three water additions, a nuclear gamma gauge for cyclone overflow pulp density, and an Outokumpu PSI-200 particle size analyser (which could not be used for control because of operational problems).

The use of DYNAFRAG required previous calibration using industrial data gathered from Kidd Creek concentrator. Three sampling campaigns were conducted. Samples and data were processed to obtain the required unit model parameters (breakage and selection functions for the mills, pulp transport within the mills, cyclone parameters, etc). Data reconciliation revealed some abnormal operating conditions such as extremely high mill circulating load ratios (around 1800%) and very high fines short-circuiting to the cyclone underflow. These observations force the freezing of the project until the company fixed the problems, since there was interest in studying control strategies for a circuit running far from its optimum.

A 1800% circulating load ratio (CLR) implies a cyclone feed flow rate (78% solids) of about 3654 t/h of pulp or 1379 m^3 /h (6000 USGPM). At 500% CLR, the value obtained after circuit adjustments, this flow rate drops to 1154 t/h or 435 m^3 /h (1560 USGPM). A 10x12 Warman pump working at 40 ft head has an efficiency of 65% at 6000 USGPM and 75% at 1500 USGPM (assuming no correction for pulp). These figures lead to a power consumption of 251 HP for the first case and 56 HP for the second case, i.e. a saving of 78%. The high circulating load has another effect on the economy of the process. Assuming 40% ball charge, 40% voids between balls and 120% voids filling by the pulp, a 1800% CLR implies a pulp residence time within the mill of about half a minute, whereas the 500% CLR means about 2 min residence time. In other words a lot more energy was spent in pumping a huge circulating load to achieve very little grinding.

A first control strategy aiming at maximizing the tonnage and regulating the product size distribution was first implemented. However, in November 1994, maximizing tonnage was no longer an issue because the minesite was rate limiting and thus the feed rate and the power target were both lowered by approximately 10%. The instrumentation was also modified at that time (installation of a variable speed drive on the cyclone feed pump, the cyclone vortex and apex were changed). To accommodate these changes the control strategy was also modified (see [8-10] for the details). Because of all these changes, quantifying the energetic and metallurgical improvements is a difficult task. The total costs were around Cdn 0.2 M$ and the revenue improvements were conservatively estimated to Cdn 1 M$/annum.

3.2. Case study 2: Control of a grinding circuit

The following example is the improvement of the grinding circuit control in a Peruvian copper concentrator. The basic grinding circuit is composed of a rod-mill followed by three identical ball-mills in parallel. Each ball mill operates in closed circuit with an hydrocyclone. The crushed ore is dry fed to the rod mill from the fine ore bin via conveyor belt, whose speed is adjusted by a PI controller in accordance with the ore feed rate, measured with a balance underneath the conveyor. The feed rate set point is decided by the operator. Water addition to the rod mill is adjusted by a PI controller to ensure an 80% solids mill operation. The rod-mill discharge is distributed to three parallel ball-mills using a three-way splitter. Ideally, the splitter should guarantee an even distribution among the three ball mills. The pulp distribution among the ball mills is determined by the relative position of two moveable palettes. The operator decides the palettes' position. A bad distribution of the pulp among the ball mills results in an uneven mill operation as detailed later on. Each ball mill discharges to a sump-box where water is added to meet adequate cyclone operation conditions. The water addition is controlled by a PI, whose set point is fixed by the operator. The pulp is drawn from the sump box by a variable-speed centrifugal pump feeding the corresponding cyclone. The pump's speed is adjusted by a PI controller in order to maintain a desired pulp level in the sump-box. The cyclone overflow is the final product of grinding circuit, whereas the underflow stream, hereafter called circulating load, is sent back to the ball mill for further grinding. Water is added to the circulating load to meet percent solid requirements in the mill. This control strategy did not permit to reach the production objectives of the concentrator. A first analysis indicated that the existing control loops looked more at preventing process upsets than meeting the concentrator production objectives, that is increasing tonnage, which was rather manually done by the control room operator.

As previously indicated, an ill operation of the splitter led to an uneven distribution of the rod mill discharge among the three ball mills. This was a common situation either resulting from changes in ore hardness or by the entanglement of small broken rods in splitter passages. In such a case, the mill receiving more feed usually went into overloading conditions, its discharge got coarser, and the hydrocyclone underflow stream became larger, thus raising the pump box level. To keep the level at its set-point, the variable speed pump automatically increased the motor speed, thus increasing the cyclone feed which deteriorates the situation even more, since the coarser cyclone overflow disrupts the flotation circuit operation. In many cases, the only solution was to stop feeding the ill ball mill and to reduce the circuit feed (rod mill feed). A final and usual problem arose from changes in ore hardness. In such a case, the operator had to adjust the rod mill feed as quickly as possible to avoid mill content build-up. Sometimes the field operator realized too late the existence of such a situation, in such a way the only solution was a drastic reduction of the rod mill feed or shutting it off completely (for harder ores). In summary, problems associated to the existing control strategy are mainly related to the lack of adequate sensors, resulting from the age of the concentrator (built in the 50's) and to the uneven distribution of pulp to the three ball mills.

A new control strategy [11] was design and partially implemented (Figure III) aiming at increasing plant throughput and stabilize the mills operation. The following actions were considered:

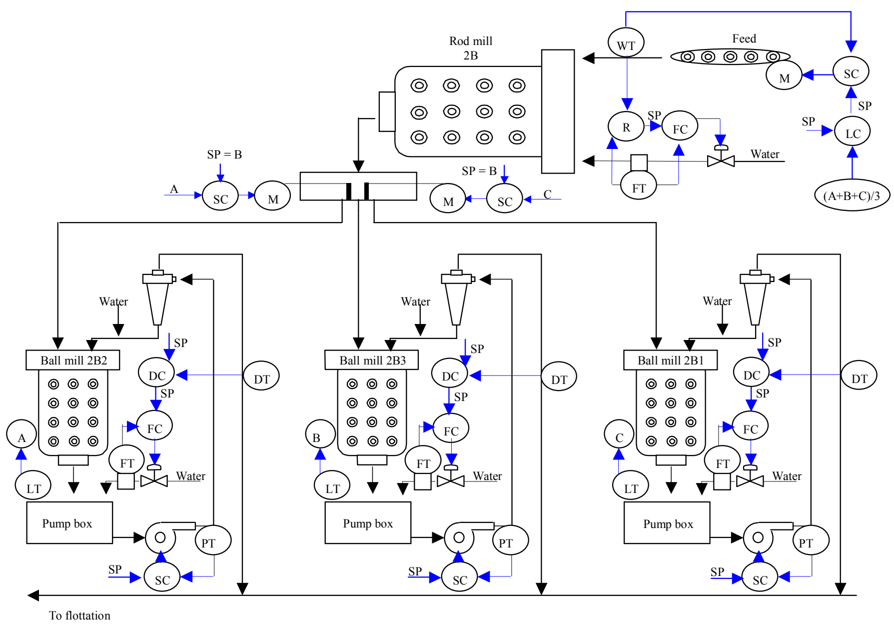


Figure III - New grinding control

- Implementation of a rod-mill percent solids control using a ratio control (instead the original feedback PI); this control accelerates the water addition to the rod-mill based on the amount of ore fed.
- Elimination of the sump-box level control by handling the pump's speed, since it did not produce any concrete benefit except avoiding sump-box overflows.
- Implementation of an automatic control of the rod-mill discharge distribution (splitter); this most important action addresses the heart of the problem. As a result of the previous action, the sump-box level becomes sensible to circulating load fluctuations and rod-mill feed changes and mineral hardness changes. At equilibrium the level of the three sumps should be equal but if one of them is different, the two palettes will automatically move to equalize the three sump levels.
- To maximize the processed tonnage, a control loop was implemented to modify the circuit ore feed rate (conveyor speed) according to the average (three) sump-box level. For instance, if the mineral hardness suddenly decreases, the mills would grind finer and the cyclone will report more material to the overflow, the circulating load would decrease and the average sump-box level would decrease. The control loop would then decide to increase the circuit throughput to take advantage of this softer ore.

The following results were observed after implementation of this new control strategy:

- Much better stability of the circuit operation, particularly of the three ball mills.
- Increased circuit tonnage from 245.7 t/h to 253.6 t/h (2 % to 4% increase).
- An important reduction in energy consumption (1607750 kWh to 1528797 kWh; specific energy from 9.20 kWh/t to 8.42 kW/t; 8% to 10% decrease) despite the increased throughput obtained and a slightly

finer product. Since the concentrator possesses eight similar lines and assuming 362 day of operation per year, the total amount of energy saving would then be 900000 kWh.

- A greater availability of floor operator, since the continued surveillance of the circuit operation was reduced by the implementation of automatic control.

3.3. ***Case study 3: Observation, control and optimization of electric arc furnaces***

Electric arc furnaces consume a large amount of energy in ferroalloy and steel industries. Even if the overall electric metering of these processes is generally adequate from an operational point of view, almost no direct measurement of how the energy is used inside the furnace is made. In that context, the final steps of an optimization procedure are thus difficult to achieve. The arc signature, which corresponds to the voltage-current characteristic at the tip of the electrode, is able to provide on-line information about the internal behavior of the furnace. Observation of that signature is obtained using an electrical model of the furnace and the electrode voltage and current signals. The signature gives the possibility to infer strategic variables regarding the arc such as length, stability, symmetry, dynamic resistance and power dissipation. These variables could be used to observe furnace states, close control loops on non measurable variables or optimize operating practices. Arc signature systems have been tested and installed on different furnace types: submerged arc furnaces (40-55 MVA; 100-150 volts) and long arc furnaces with foamy slag (10-130 MVA; 150-1300 volts). The main objectives of these projects were the optimization of the energy usage and the reduction of the production costs.

In a typical submerged arc furnace application, the implementation of an arc signature system combined with the modification of the control strategies has given the following results:

- The specific consumption (MWh/t) was reduced by 5%.
- The furnace stabilization allowed the increase of operating power and thus the production rate by 25 %.
- The introduction of corrective loads to stabilize the furnace was reduced by 30 %.
- The signature is used to support operation, anticipate and prevent problematic situations.

A pilot campaign on a furnace that produces steel by melting scrap (long arc with foamy slag) has highlighted the following opportunities:

- The reduction of the tap-to-tap time by 8% by the optimization of charging procedures and the improvement of the electrode control. This has a direct impact on the specific consumption and the overall plant production capacity.
- The reduction of foamy slag (coke and oxygen) consumption by 10% by using non measurable variable to control the injection.

3.4. ***Case study 4: Optimization of an induration furnace***

Preparation of iron oxides for iron and steel-making industries requires concentrate agglomeration in pelletizing drums or discs, then sintering of pellets in induration furnaces to give them the required mechanical properties for their handling and transportation to the oxide reduction and iron or steel making site. Induration furnaces are high-energy consumption processes and iron companies have increased recently their efforts to reduce furnace energy consumption [12, 13], while at the same time increasing production levels, and improving product quality control. It is difficult to achieve these goals at the same time because a large number of interacting process variables are involved in the process as shown in Figure IV. Several phenomena occur during the sintering process: pellet drying, heating, hardening and cooling, and coke combustion, magnetite oxidation, and limestone and dolomite calcination. The furnace is divided into seven zones where energy is exchanged between the pellet bed on the traveling grate and the gaz flows: upwards drying (UD), downwards drying (DD), pre-cooking (PC), primary cooking, secondary cooking, primary cooling, and secondary cooling. The main energy sources of the process are the coke added to the pellets, the fuel injected in the burners ($F_{m,PC}$, $F_{m,C1}$ and $F_{m,C2}$) and the electrical power of the five fans (V_1 to V_5) used to force the gas flow within the furnace.

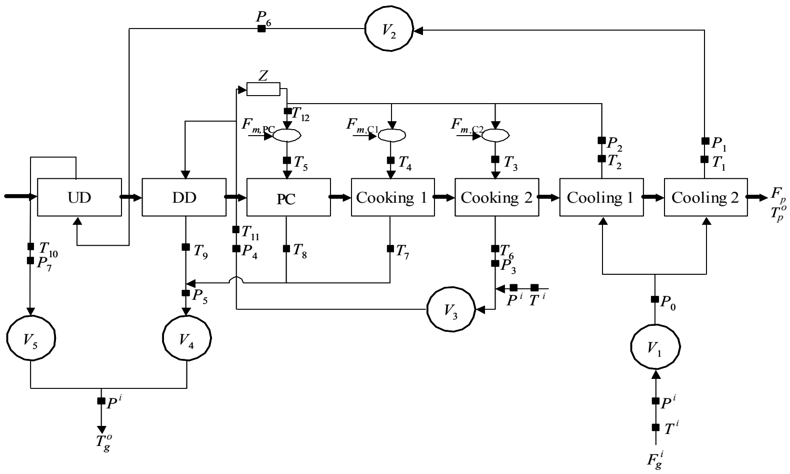


Figure IV - Induration furnace scheme

At the process design level, the energy efficiency is maximized by using counter-current flow of pellets and gas (thick lines in Figure IV indicate pellet flows, while thin lines identify gas streams), thus recycling the energy from the cooling zones to the drying and cooking zones. At the operation level the energy efficiency is managed by selecting optimal operating conditions and by controlling the gas temperatures and pressures (letters T and P respectively in Figure IV). The problem is to optimize a production criterion with respect to 11 manipulated variables (the five fans, the three burner zones, the grate speed, the bed height, and the coke concentration), while keeping process variables in a given sets of constraints imposed by equipment limits, safety rules or quality requirements of the pellet buyer, and coping with the numerous process variables (pellet humidity, size and chemical composition, gas leaks or infiltrations, heat losses…) that disturb the process.

The definition of the operation optimization criterion is critical and must reflect precisely the producer objectives. Usually it is to maximize the net revenue, i.e. the product value minus the production costs. Since energy costs are quite important in the present case, this may lead to a minimization of the total consumed energy, but not necessarily. Another criterion could be to maximize the production rate at constant energy consumption. This would lead to the minimum energy consumption per ton of pellet produced, but not to the minimal total energy consumption. Another option is to maximize the product quality to increase the product value at constant production rate. Obviously this will not be optimal for energy consumption, except if the total energy consumption is constrained at a predefined value. A different point of view could also be to find, at constant production rate and product quality the distribution of consumed energy between the coke addition, the three burner zones and the five fans, which minimized the energy cost. In any case, the optimal conditions will strongly depend upon the selected criterion and the relative cost of electrical power, fuel and coke, factors which may drastically vary from country to country and as a function of the changing world energy market prices.

Table I - Optimization results

Simulation run	1	2	3	4	5	6	7
Production rate	*Max*	*Max*	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*
Fuel consumption	*Nom*	*Nom*	*Opt*	*Nom*	*Nom*	*Min*	*Opt*
Fuel distribution	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*	*Opt*	*Opt*
Pellet quality	*Constr*	*Constr*	*Max*	*Max*	*Max*	*Constr*	*Constr*
Fuel (%) at PC, C1, C2	4, 10, 86	0, 5, 95	0,13, 87	4, 10, 86	0, 5, 95	0, 6, 94	0, 5, 95
Production rate index	107	109	104	101	100	103	110
Total fuel (kg/s)	0.820	0.820	0.858	0.820	0.820	0.674	0.818
Energy index per ton	100.5	101.0	100	100.6	100.7	101.3	100.9
Normalized profits ($)	108	110	103	101	100	105	111

Both the optimization and control levels are difficult to manage because of the high number of manipulated and disturbance variables, and the various criteria and constraints that may be formulated. For such complex processes, simulators are powerful tools for finding guidelines leading to optimal energy efficiency. To illustrate this approach, a simulator of the induration furnace, based on physical and chemical models, has been developed to find optimal operating conditions [14, 15]. Table I presents the results of various simulation strategies. *Max or Min* stands for the criterion that is maximized or minimized, except for run 7 where the net revenue is maximized. *Nom* stands for a variable that is kept at its nominal value, while C*onstr* stands for a variable that is maintained at its low constrained value. Finally O*pt* stands for a variable that is calculated at the criterion optimal value. The results show that the total energy per ton of product does not much vary, while the total fuel consumption can widely vary and, as a consequence, that the furnace tuning should be significantly changed when the fuel price is changing. The results also show that the maximum profit is not necessarily a good criterion to maximize energy efficiency, and that it is important to properly distribute the energy inputs to the process.

4. Conclusion

Observation, control and optimization are on-line data processing techniques that can help in increasing energy efficiency while providing several other benefits. Observation gives the opportunity to "see" the process states. Abnormal operating conditions can then be detected. Signals that cannot be measured otherwise may also be estimated and used to improve the plant control and optimization. The aim of control is to reduce the process variability by a better rejection of disturbances. Related benefits are the possibility of better set point selections and a smoother operation. On-line optimization is a flexible tool that can directly be used to improve energy efficiency of the plant operation. Several plants have already most (if not all) the equipment required for the implementation of on-line data processing. The implementation of such techniques improves the energy efficiency at very reasonable costs. But very importantly, throughout the implementation procedure, the plant personnel will most likely discover problems with some equipment or with the plant operation strategy and they will improve their knowledge about the plant and its operation.

5. References

[1] Hydro-Québec, *Industrial Initiatives Program - Major Customers*, September 2003 (available at http://www.hydroquebec.com/majorcustomers/programmes_economies.html).

[2] Gertler, J., *Fault Detection and Diagnosis in Engineering Systems*, Marcel Dekker, New York, 1998.

[3] Romagoli J.A. and M.C. Sanchez, *Data Processing and Reconciliation for Chemical Process Operations*, Academic Press, 2000.

[4] Kailath, T., A. Sayed and B., *Linear Estimation*, Prentice-Hall, 2000.

[5] Goodwin G.C., S.F. Graebe and M.E. Salgado, *Control System Design*, Prentice Hall, 2001.

[6] Maciejowski J.M., *Predictive Control with Constraints*, Prentice-Hall, 2002.

[7] Edgar, T.F. and D.M. Himmelblau, *Optimization of Chemical Processes*, McGraw-Hill, 2nd ed., 2001.

[8] Flament F., A. Desbiens and R. del Villar, *Distributed Control at the Kidd Creek Grinding Plant. Part I: Control strategy Design*, CIM Bulletin, Vol. 90, No. 1008, pp. 139-144, 1997.

[9] Desbiens A., Flament F. and A. Pomerleau, *Distributed Control at the Kidd Creek Grinding Plant. Part II: Implementation*, CIM Bulletin, Vol. 90, No. 1008, pp. 145-150, 1997.

[10] Ryan L., A. Desbiens and F. Flament, Kidd Creek Mines Automatic Primary Grinding Control, 28th Annual Meeting of the Canadian Mineral Processors, Paper No. 26, 1996.

[11] Núñez E., *Filosofía de control para molienda y clasificación en la planta concentradora de Toquepala y diseño de una estrategia de control utilizando DCS*, Universidad Católica de Santa María, Arequipa, Perú, 2002.

[12] Bernier H. and D. Lebel, *Pellet Quality Improvements at Wabush Mines*, Proc. ICSTI / Iron Making Conf., Toronto, 1998, pp.987-992.

[13] Cross M. and P. Blot, *Optimizing the Operation of Straight-Grate Iron-Ore Pellet Induration Systems using Process Models*, Metallurgical and Materials Transactions, 30B, 1999, pp 803-813.

[14] Kuçukada, K., J. Thibault, J., D. Hodouin, G. Paquet G. and S. Caron, *Modelling of a Pilot Scale Iron Ore Pellet Induration Furnace*, Can. Metallurgical Quarterly, 33, 1994, pp.1-12.

[15] Bébé Ekongolo S., S. Makni, and D. Hodouin, *Global Flow Distribution Simulation for Iron Ore Pellets Induration*, 38th Conf. of Metallurgists, CIM, Quebec, 1999, pp.239-253

Using Control for Adding Value to Energy Efficiency of Mineral Processing Plants

André Desbiens[1], Eduardo Núñez[1], Rene del Villar[2], Daniel Hodouin[2], Éric Poulin[3]

LOOP (Laboratoire d'observation et d'optimisation des procédés)
[1] Department of Electrical and Computer Engineering
[2] Department of Mining, Metallurgical and Materials Engineering
Université Laval, Quebec City, Quebec, Canada

[3] Breton Banville et ass.
Mont-Saint-Hilaire, Quebec, Canada

OUTLINE

- Introduction
  - Energy efficiency and the mineral processing plants
  - Example of pressure for energy effciency
  - Two approaches to increase energy efficiency
- On-line data processing
  - Process observation
  - Process control
  - Process optimization
- Case studies
  - Observation and control of a grinding circuit
  - Control of a grinding circuit
  - Observation, control and optimization of electric arc furnaces
  - Optimization of an induration furnace
- Conclusion

INTRODUCTION - Energy efficiency and the mineral processing plants

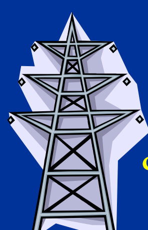
Globalization

International competition

Environmental and social pressure for energy efficiency

Energy efficiency challenge becomes unavoidable.

Energy costs



Intensive energy consumers

Objectives:
- **Reducing production costs**
- **Increasing throughput**
- **Increasing product quality**

INTRODUCTION
Example of pressure for energy effciency

Hydro-Québec:

- Quebec hydroelectrical producer and distributor.
- Most extensive transmission system in North America (32539 km).
- Pool up to 165 TWh/year (93% hydroelectric).
- Offers financial assistance to large-power customers to reduce specific energy consumption.

INTRODUCTION
Example of pressure for energy effciency

First program:

- Objective: to save 100 GWh from 2003 to 2006.
- Financial assistance budget: 8.5 M$.
- Customers must present their proposals.
- They must agree to take measurements before and after to show savings.
- Payback period: 1 year.
- Project completion: 18 months.
- Customers must pay 25% of the total costs.

INTRODUCTION
Example of pressure for energy effciency

Second program:

Financial assistance for

- an energy consumption analysis at the industrial site, or
- the demonstration that the first-time implementation in Quebec of a new technology would result in energy savings.

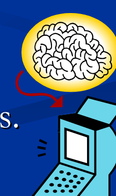
INTRODUCTION - Two approaches to increase energy efficiency

Approach 1:

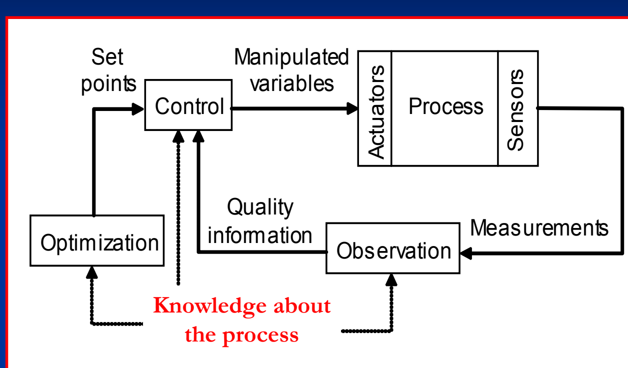
- Replacing existing equipment with more efficient ones.
- Installing new equipment aiming at reducing specific energy consumption of existing processes.

Approach 2:

On-line data processing: judicious on-line use of process sensors and large operation databases.

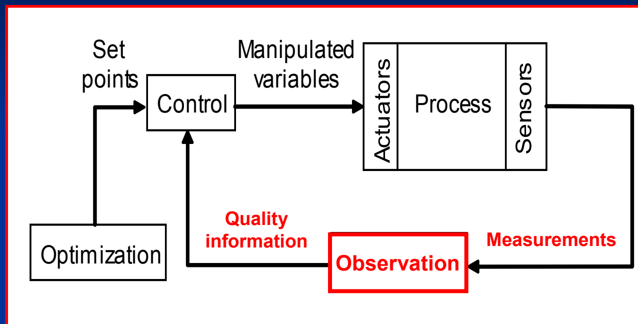


ON-LINE DATA PROCESSING



Measurements + knowledge = Possibility to automatically, continously and adequately manipulate actuators to achieve a specific objective.

ON-LINE DATA PROCESSING
Process observation



- To see the process states, to obtain a better picture of the process.
- To detect operation problems, abnormal performances, etc.

ON-LINE DATA PROCESSING
Process observation

Fault detection and isolation:

- Rapidly detect and physically localize problems such as sensor biaises, leaks, etc.
- Allow rapid corrections reducing bad consequences on the production.

Data reconciliation:

- Improves the quality of noisy measurements.
- Makes them consistent with process knowledge such as mass and energy conservation laws.

ON-LINE DATA PROCESSING
Process observation

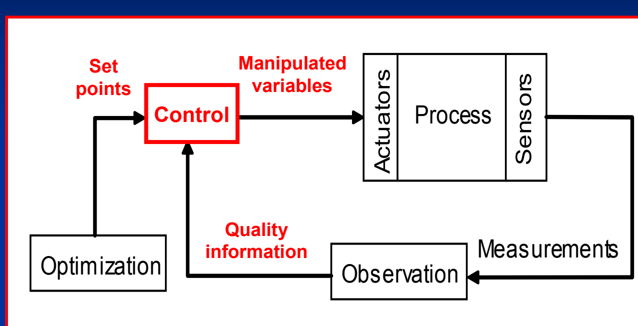
Observers:

- Soft sensor algorithms.
- They infer signals that cannot be measured.
- The availability of these signals can improve the plant operation.

Process observation:

- Even if no automatic actions are taken, a better vision allows engineers to modify equipment or change operation when required.

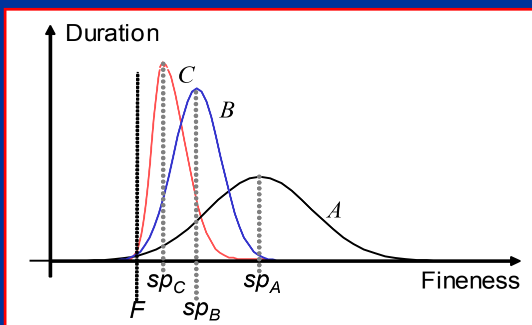
ON-LINE DATA PROCESSING
Process control



- To maintain the measured variables at selected set points by automatically and constinuously manipulating the actuators.
- Makes use of feedback and feedforward.

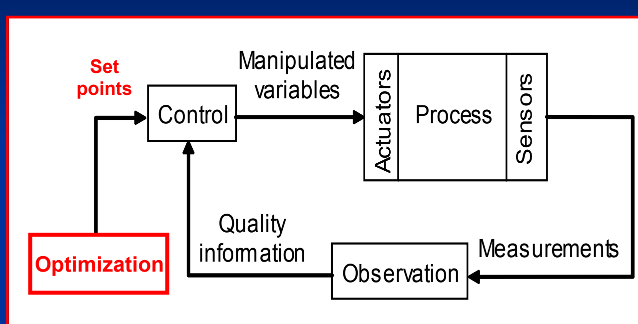
ON-LINE DATA PROCESSING
Process control

- Disturbances (such as changes in the ore properties) must be quickly rejected.
- Provides stabilization around the set points and a decrease of the process variability.



- Smoother operation.
- Less costly operation (even if set points are not changed).

ON-LINE DATA PROCESSING
Process optimization



To automatically select the set points by optimizing a cost function:

- minimization of energy consumption,
- maximizing profits,
- etc.

ON-LINE DATA PROCESSING
Process optimization

Very flexible tool:

- Selection of the cost function.
- Addition of constraints such as taking into account energy consumption regulations.

ON-LINE DATA PROCESSING

- Added values for energy savings.
- For several plants, no or little new equipment needed.
- Several additional benefits:
  - Better knowledge of the plant.
  - Product quality respecting more often the specifications.
  - Throughput increase.
  - Easier-to-operate plant thus more effective use of personnel.
  - Decrease in the maintenance costs.

ON-LINE DATA PROCESSING

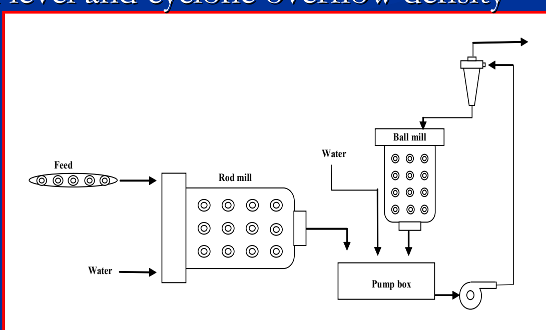
- Energy savings are often underestimated because the plant units are considered separately.
- Example: the optimization of a flotation plant
  - Does not procure any real energy savings.
  - May have important energetic impacts on subsequent processing (meal extraction and smelting).
- Plant wise evaluation should be performed (however, a difficult task).

CASE STUDIES - Observation and control of a grinding circuit

Kidd Creek grinding circuit control:

Objectives (none related to energy):

- Increase plant throughput (not an issue 2 years later).
- Prevent pump box level and cyclone overflow density upsets.
- Stabilize product quality.



CASE STUDIES - Observation and control of a grinding circuit

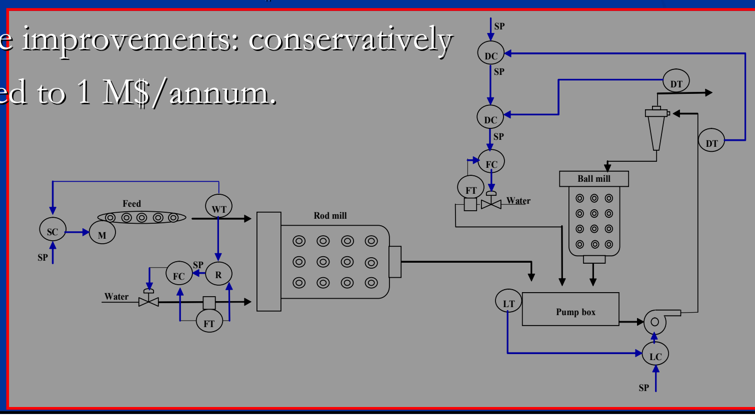
- Design based on a phenomenological simulator (Dynafrag).
- Dynafrag required to be calibrated: 3 sampling campains.
- Data reconciliation revealed some abnormal operating conditions such as extremely high mill circulating load ratios (CLR) (around 1800%).
- 1800% CLR: 3650 t/h of pulp at the cyclone feed (250 HP for pumping)
- 500% CLR: 1154 t/h of pulp at the cyclone feed (55 HP for pumping)

CASE STUDIES - Observation and control of a grinding circuit

- 1800% CLR: a pulp residence time within the mill of about 0.5 minute.
- 500% CLR: 2 min residence time.
- In other words: a lot more energy was spent in pumping a huge circulating load to achieve very little grinding.

CASE STUDIES - Observation and control of a grinding circuit

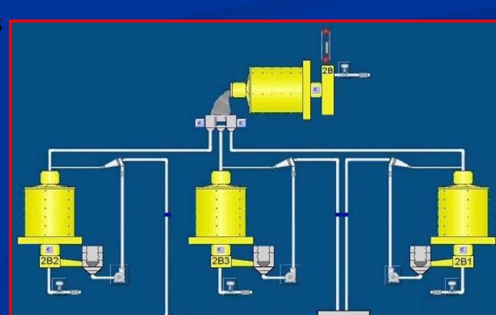
- Because of equipment and objectives changes, difficult to quantify the energetic and metallurgical improvements.
- Total costs: around 0.2 M$.
- Revenue improvements: conservatively estimated to 1 M$/annum.



CASE STUDIES
Control of a grinding circuit

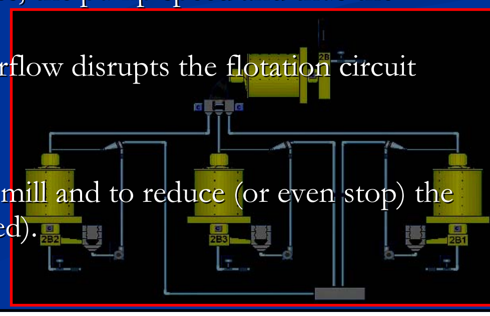
Toquepala grinding circuit control:

- The rod-mill discharge is distributed to 3 parallel ball-mills using a three-way splitter.
- The operator decides the splitter palettes' position.
- Level of 3 sump boxes controlled with variable speed pumps.



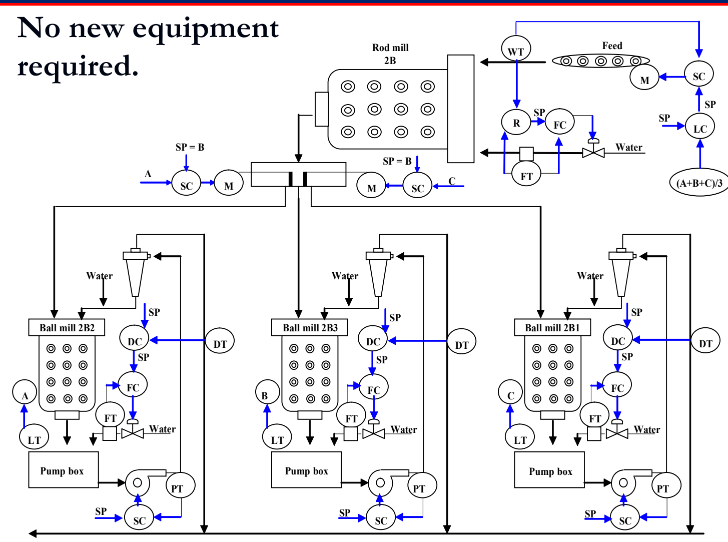
CASE STUDIES
Control of a grinding circuit

- Ore hardness variations or spitter entanglement by small broken rods:
  - the ball mill receiving more feed overloads,
  - the discharge gets coarser and the hydrocyclone underflow stream becomes larger,
  - the sump box level raises, the pump speed and thus the cyclone feed increase ,
  - the coarser cyclone overflow disrupts the flotation circuit operation.
- Solution:
  - Stop feeding the ill ball mill and to reduce (or even stop) the circuit feed (rod mill feed).



CASE STUDIES
Control of a grinding circuit

No new equipment required.



CASE STUDIES
Control of a grinding circuit

Results:

- Better stability of the circuit operation, particularly of the three ball mills.
- Tonnage increase from 245.7 t/h to 253.6 t/h (2 % to 4%).
- Slightly finer product.
- Reduction in
  - monthly energy consumption from 1607750 kWh to 1528797 kWh.
  - specific energy from 9.20 kWh/t to 8.42 kW/t (8% to 10% decrease).
- A greater availability of operators.
- Total gains/year : 4.9 M$
- If applied to the 8 lines of the concentrator: savings would be 8 x 900000 kWh/year.

CASE STUDIES - Observation, control and optimization of electric arc furnaces

Electric arc furnaces:

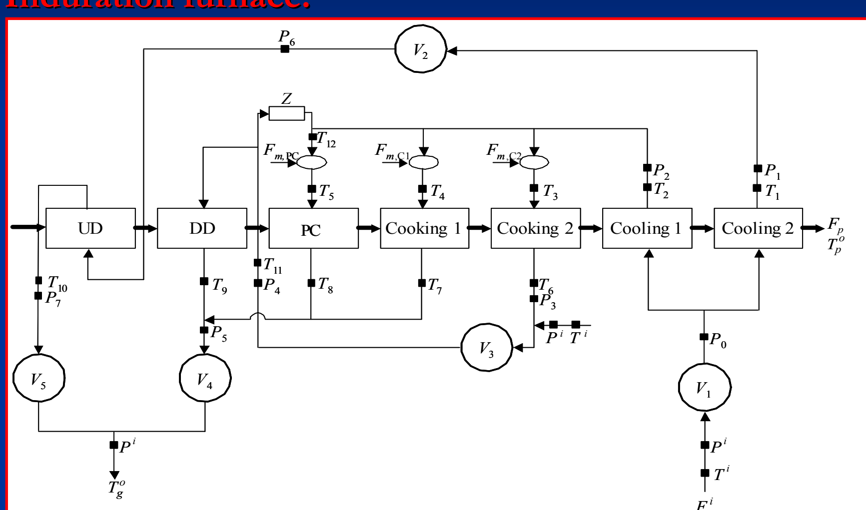
- Consume a large amount of energy in ferroalloy and steel industries.
- No direct measurement of how the energy is used inside the furnace is made.
- On-line information about the internal behavior of the furnace: the arc signature (voltage-current characteristic at the tip of the electrode).
- Observation of the arc signature gives the possibility to infer strategic variables such as length, stability, symmetry, dynamic resistance and power dissipation of the arc.

CASE STUDIES - Observation, control and optimization of electric arc furnaces

- Objectives:
  - Optimization of the energy usage.
  - Reduction of the production costs.
- Arc signature system combined to control have been tested and installed on submerged arc furnaces and long arc furnaces with foamy slag.
- Typical results for submerged arc furnaces:
  - 5 % reduction of the specific consumption (MWh/t).
  - Increase of operating power and thus 25% increase of the production rate.
  - 30% reduction in the amount of corrective loads to stabilize the furnace.
  - The signature is used to support operation, anticipate and prevent problematic situations.

CASE STUDIES
Optimization of an induration furnace

Induration furnace:



CASE STUDIES
Optimization of an induration furnace

Optimization criterion must reflect precisely the producer objectives:

- to maximize the net revenue, i.e. the product value minus the production costs; may lead to a minimization of the total consumed energy, but not necessarily.
- to maximize the production rate at constant energy consumption; leads to the minimum energy consumption per ton of pellet produced, but not to the minimal total energy consumption.
- to maximize the product quality (to increase the product value) at constant production rate; will not be optimal for energy consumption, except if the total energy consumption is constrained at a predefined value.
- to find, at constant production rate and product quality, the distribution of consumed energy between the coke addition, the three burner zones and the five fans, which minimized the energy cost.
- etc.

CASE STUDIES
Optimization of an induration furnace

Simulation run	1	2	3	4	5	6	7
Production rate	*Max*	*Max*	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*
Fuel consumption	*Nom*	*Nom*	*Opt*	*Nom*	*Nom*	*Min*	*Opt*
Fuel distribution	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*	*Opt*	*Opt*
Pellet quality	*Constr*	*Constr*	*Max*	*Max*	*Max*	*Constr*	*Constr*
Fuel (%) at PC, C1, C2	4, 10, 86	0, 5, 95	0,13, 87	4, 10, 86	0, 5, 95	0, 6, 94	0, 5, 95
Production rate index	107	109	104	101	100	103	110
Total fuel (kg/s)	0.820	0.820	0.858	0.820	0.820	0.674	0.818
Energy index per ton	100.5	101.0	100	100.6	100.7	101.3	100.9
Normalized profits ($)	108	110	103	101	100	105	111

- the total energy per ton of product does not much vary
- the total fuel consumption can widely vary
- the maximum profit (run 7) is not necessarily a good criterion to maximize energy efficiency

CONCLUSION

Process observation, control and optimization:

- increase the energy efficiency,
- provide several additional benefits,
- often require no or little new equipment.

Through the implementation, the plant personnel will most likely discover problems with equipment or operation.

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

21, 22, 23 October 2004
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.

---

[1] Peruvian; currently serves as Director of the Natural Resources and Infrastructure Division of the United Nations Economic Commission for Latin America and the Caribbean (ECLAC). His former posts include those of Minister of Energy and Mines of Peru, Deputy to the National Congress and Director of the Latin American and Caribbean Institute for Economic and Social Planning (ILPES) of the United Nations. He has taught at universities in Peru, Brazil, Colombia, Chile, Mexico and Spain.

[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

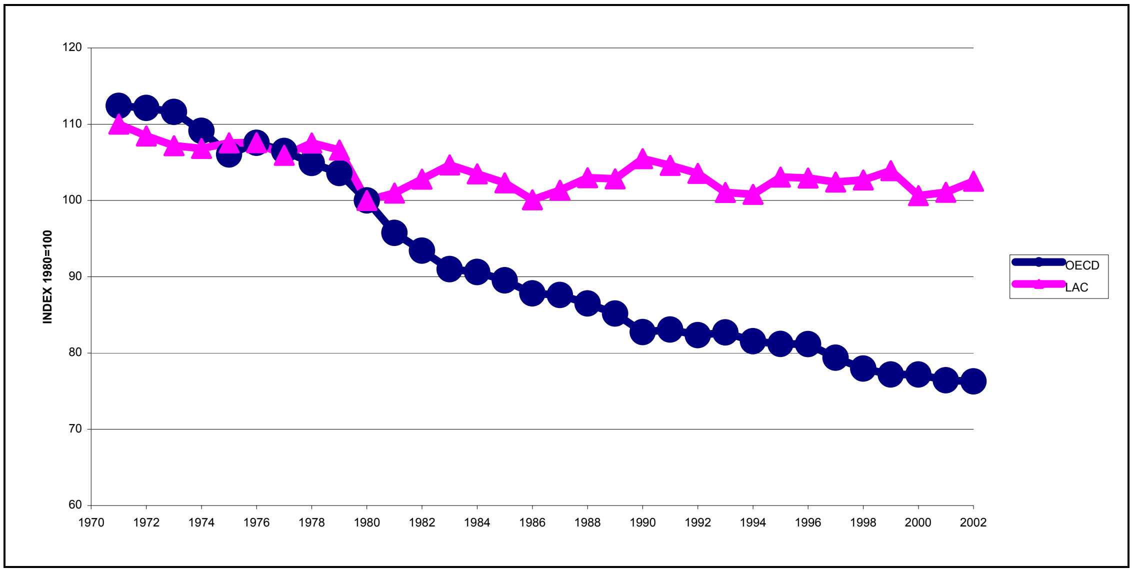
Source: *ECLAC, on the basis of figures from Metallgesellschaft Aktiengesellschaft, "Metal Statistics", and World Bureau of Metal Statistics, "World Metal Statistics".*

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.*

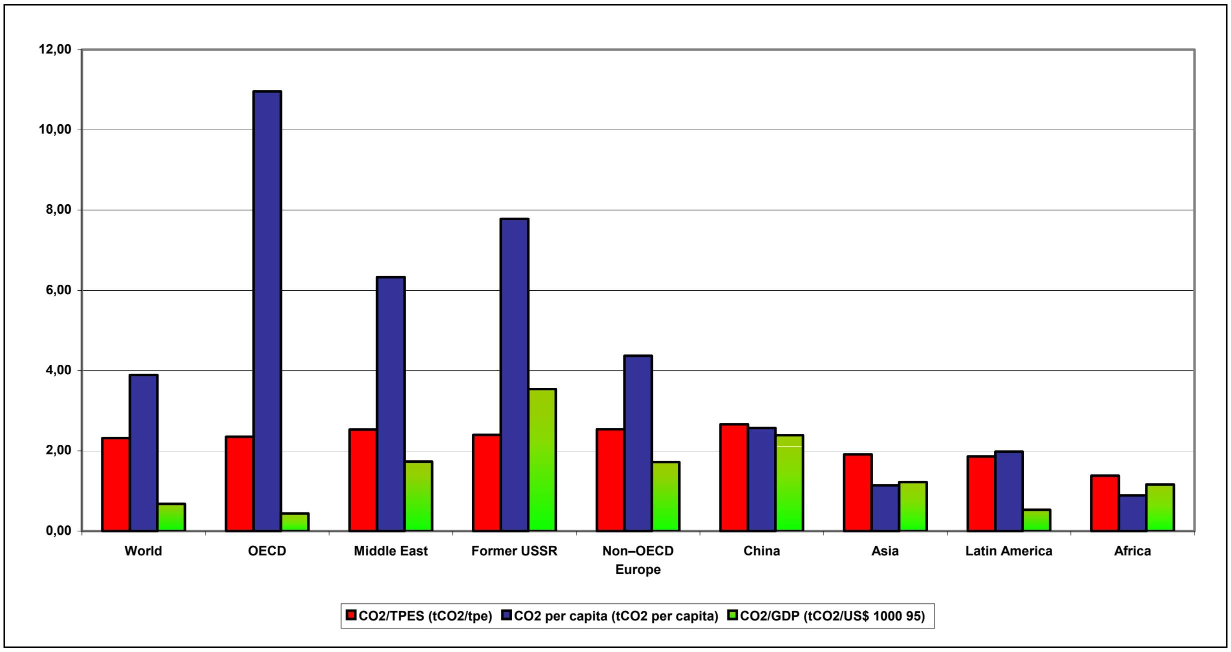
It is this very inequality that determines competitiveness. Productivity differentials generate winners and losers in a capitalist system. In addition, this system grows and accumulates wealth on the basis of what Schumpeter called "creative destruction": technological change destroys and then creates 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



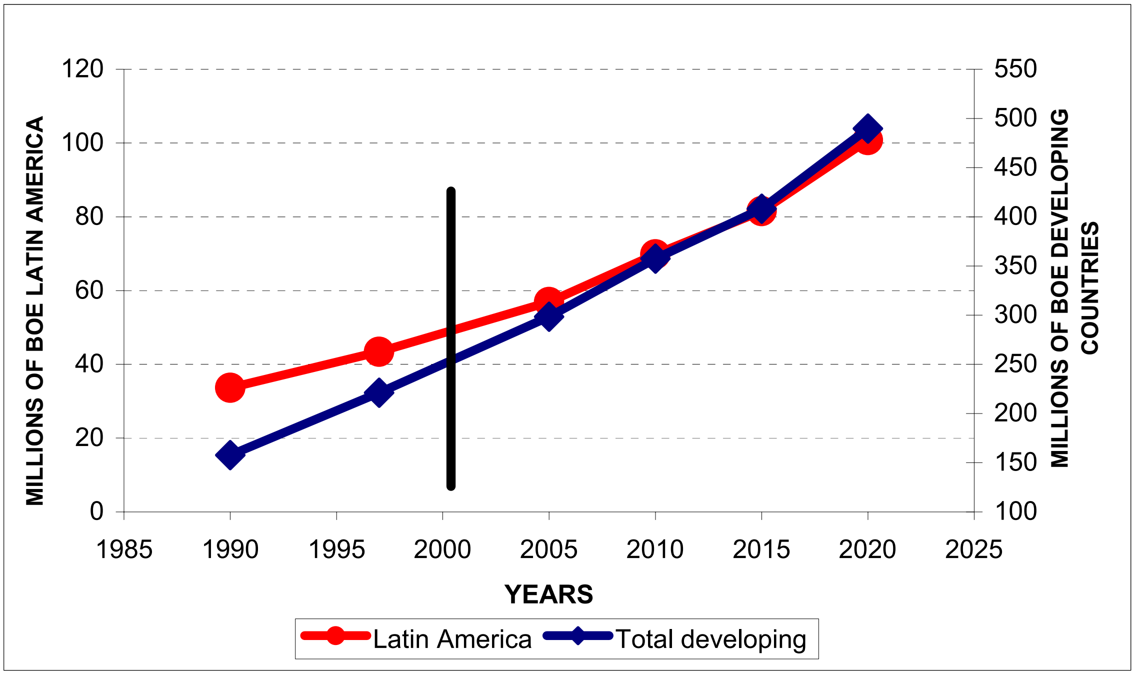
***Source:** ECLAC, on the basis of figures from the International Energy Agency.*

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*



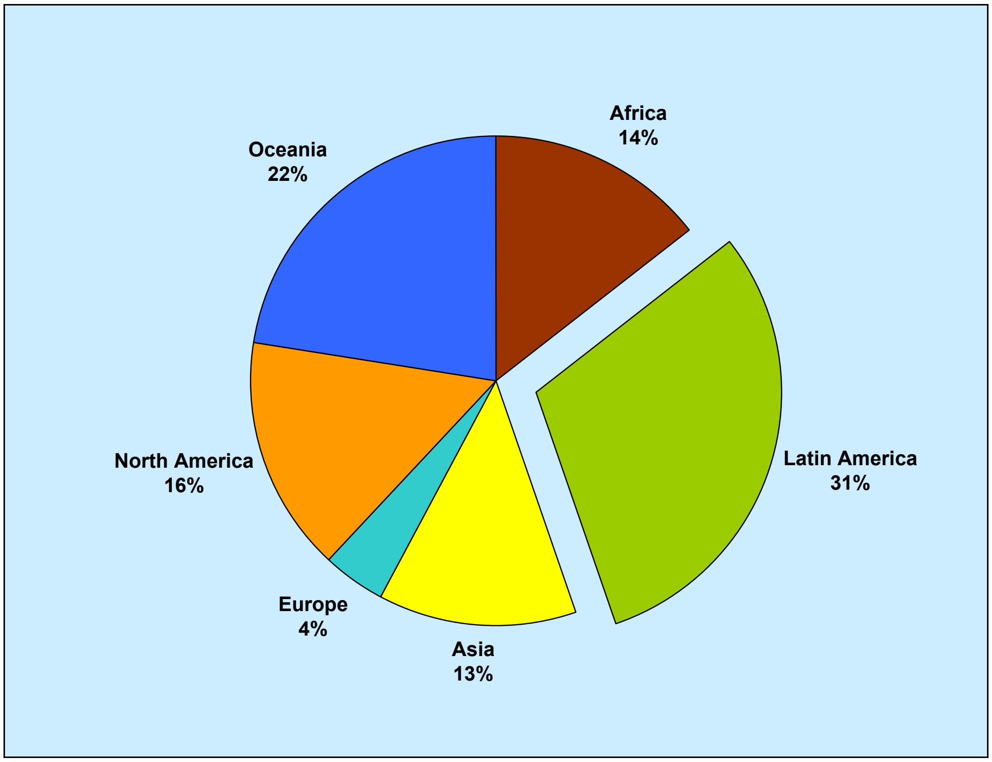
Source*: United States Department of Energy.*

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

FERNANDO SANCHEZ ALBAVERA

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.

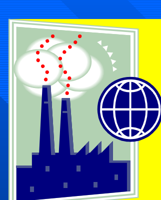
STRUCTURE OF WORLD TRADE OF PRIMARY PRODUCTS

(Thousand of millions of dollars and percentages)

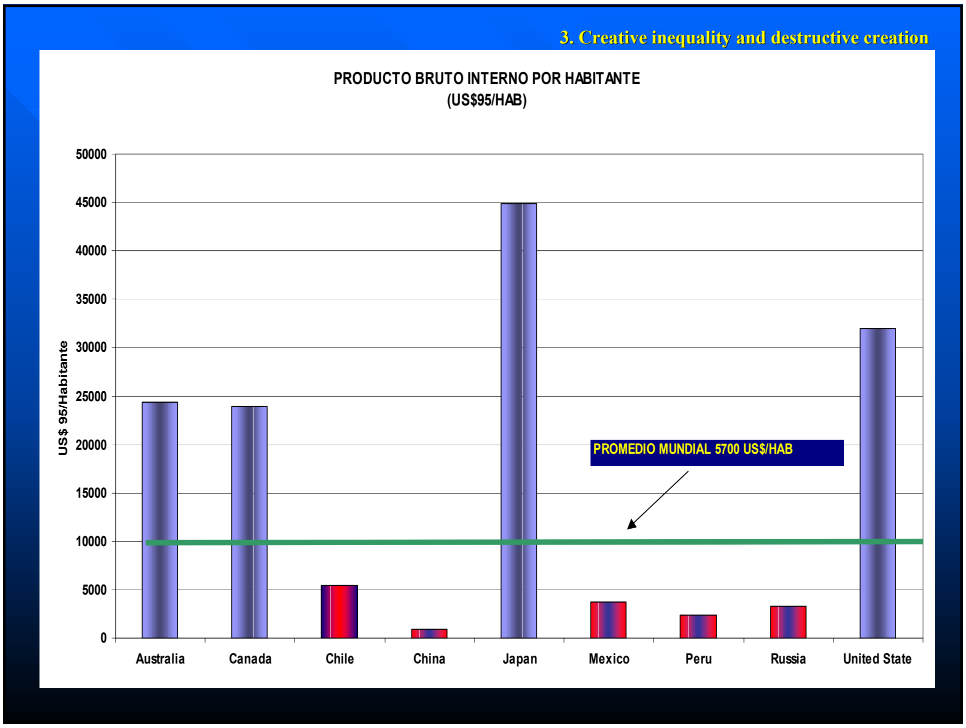
Productos	1980	%	2000	%
Combustibles	481	55	593	45%
Minerales y metales	93	11	190	14%
Materias primas agrícolas	74	9	118	9%
Alimentos	221	25	421	32%
Total	869	100	1322	100%

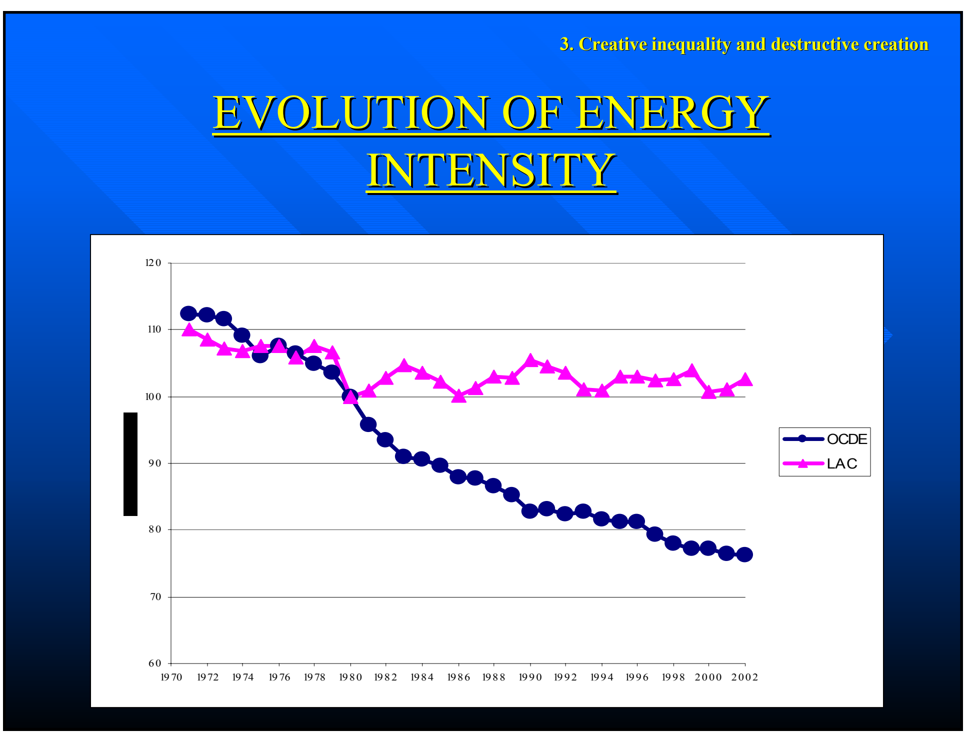
Source: Based on information from *Handbook of Statistics*, UNCTAD, 2002

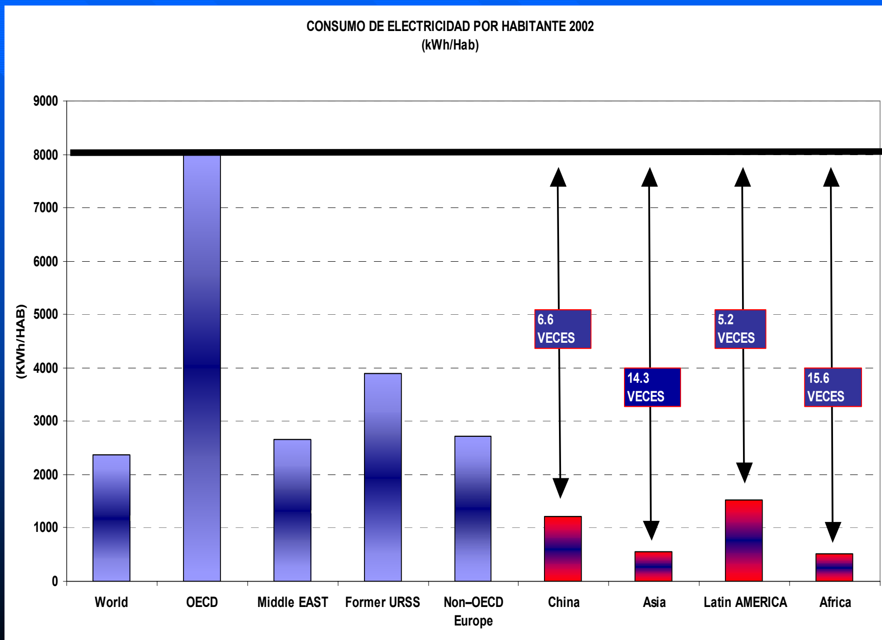
MARKET IS BASED ON UNEQUAL AND DESTRUCTIVE CHANGES

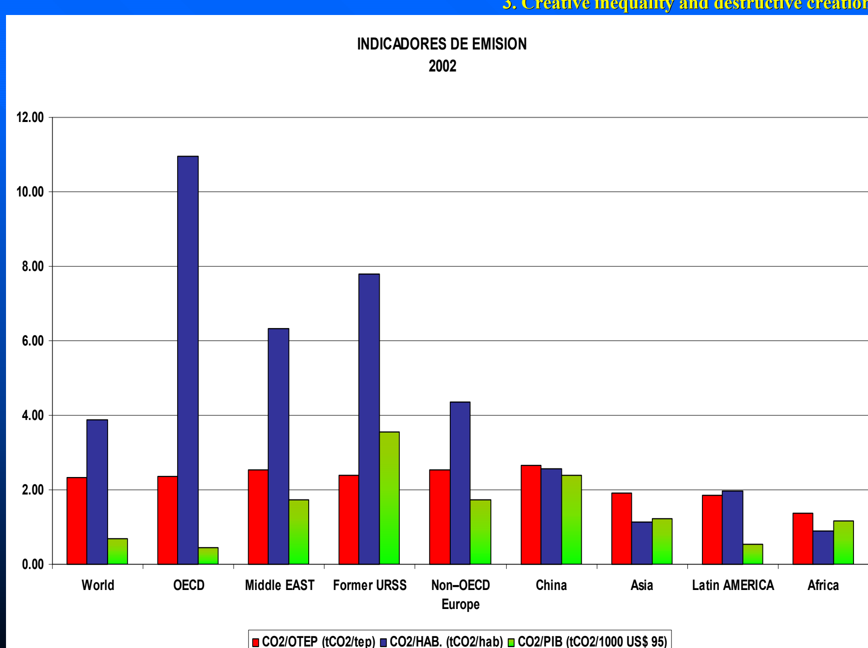


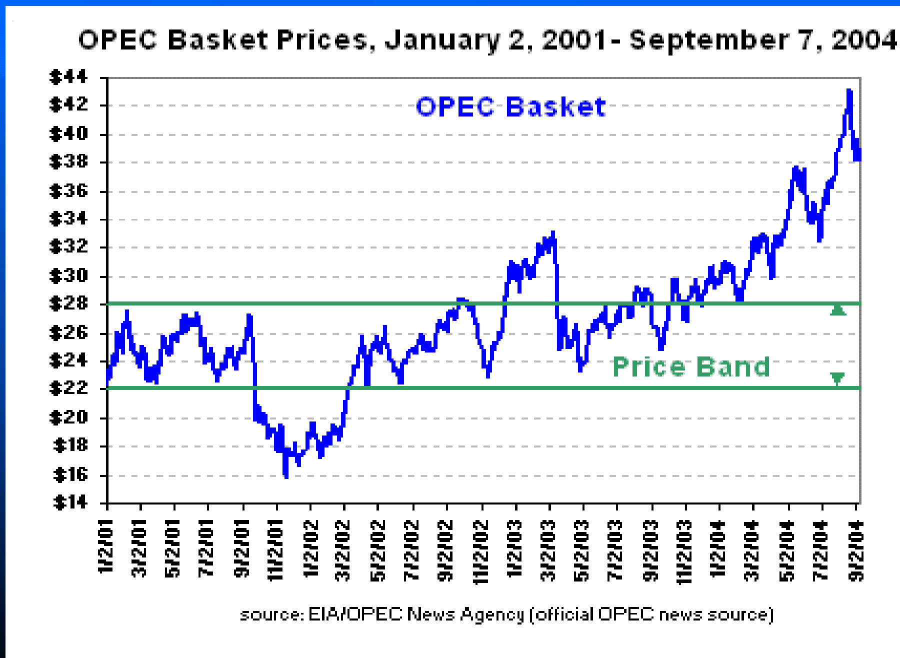
- Natural Resources supply is different and allows economy complementarity.
- Different productivity in the use of factors allows consumers to benefit from the value generated by more efficient tenders
- Energy use shows both the potential productive capacity and its efficiency as well as available life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


3. Creative inequality and destructive creation
PRODUCTO BRUTO INTERNO POR HABITANTE
(US$95/HAB)
US$ 95/Habitante
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
PROMEDIO MUNDIAL 5700 US$/HAB
Australia
Canada
Chile
China
Japan
Mexico
Peru
Russia
United State

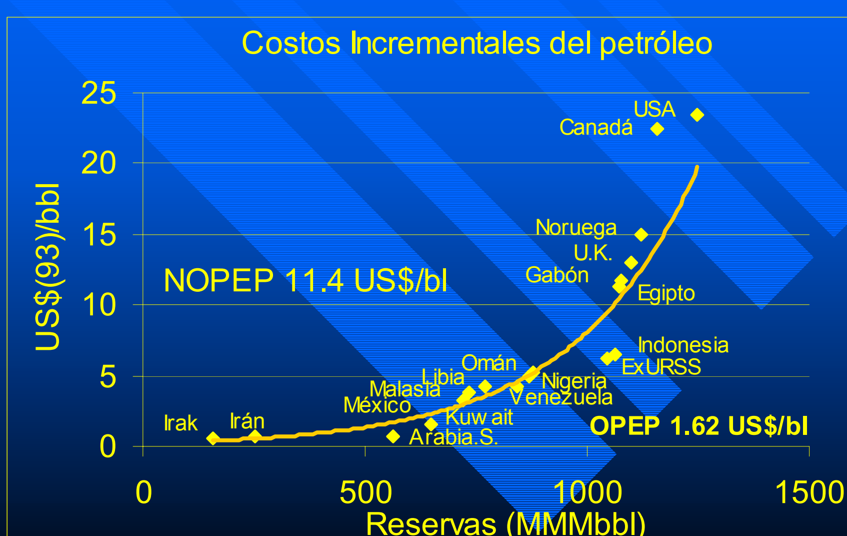

3. Creative inequality and destructive creation
EVOLUTION OF ENERGY INTENSITY
120
110
100
90
80
70
60
1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002
OCDE
LAC

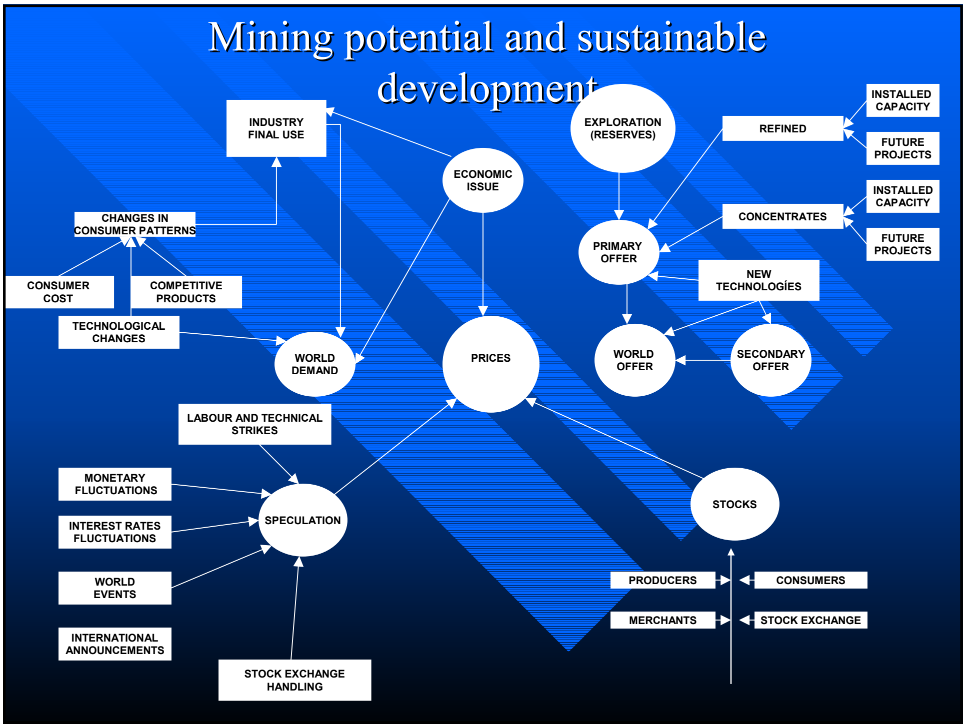

CONSUMO DE ELECTRICIDAD POR HABITANTE 2002
(kWh/Hab)
(KWh/HAB)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
6.6 VECES
14.3 VECES
5.2 VECES
15.6 VECES
World
OECD
Middle EAST
Former URSS
Non-OECD Europe
China
Asia
Latin AMERICA
Africa


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)

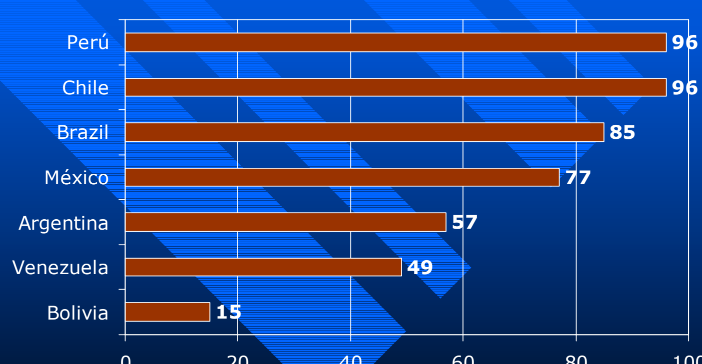


WORLD OIL MARKET



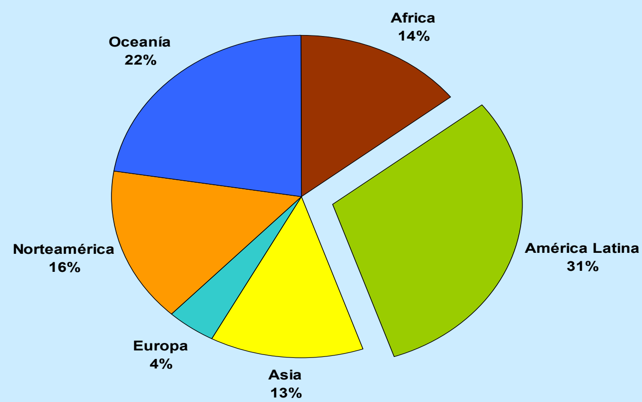


INDEX OF ATTRACTIVE MINING INVESTMENTS



Source: Fraser Institute

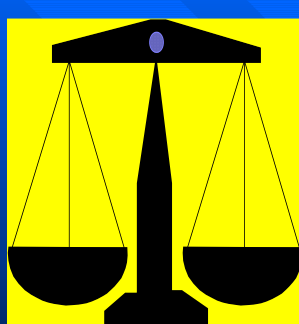
WORLD MINING INVESTMENT: 2002-2007



TOTAL: 76 thousand million dollars

Source: Raw Materials Group, January 2003

SUSTAINABILITY FACTORS

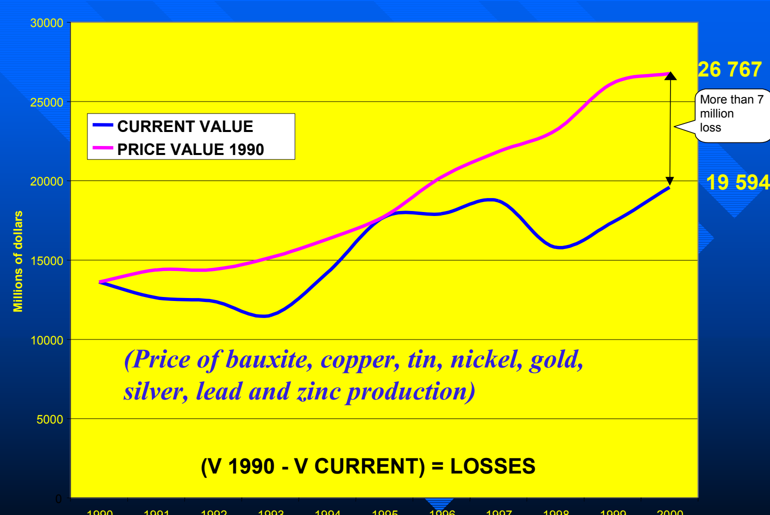


- Financial volatility
- Growth and competitiveness
- Social equity
- Patrimonial integrity
- Consensus

SUSTAINABILITY AND COMPETITIVENESS

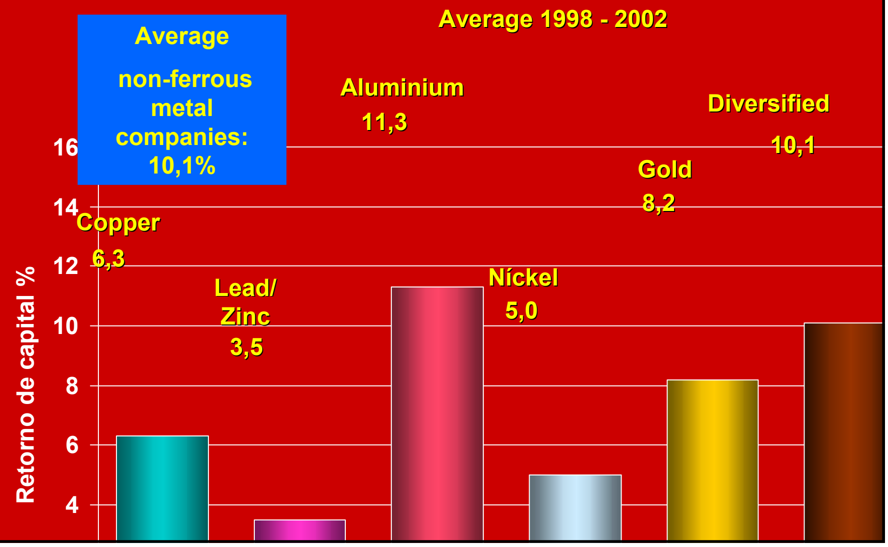
- Mining is an "international price taker".
- Public policies should not affect costs.
- Public policies should stimulate and support reduction of costs (energy auditing, credit lines)

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.

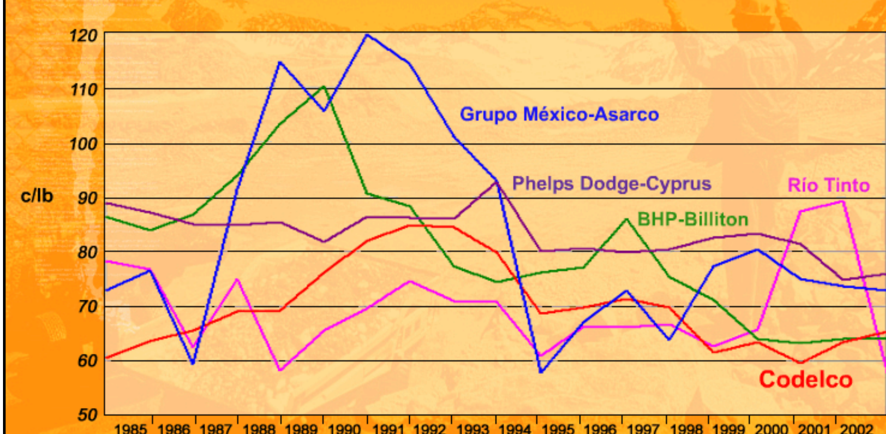
ENERGY INDICATORS OF THE MINING COPPER INDUSTRY OF CHILE

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)

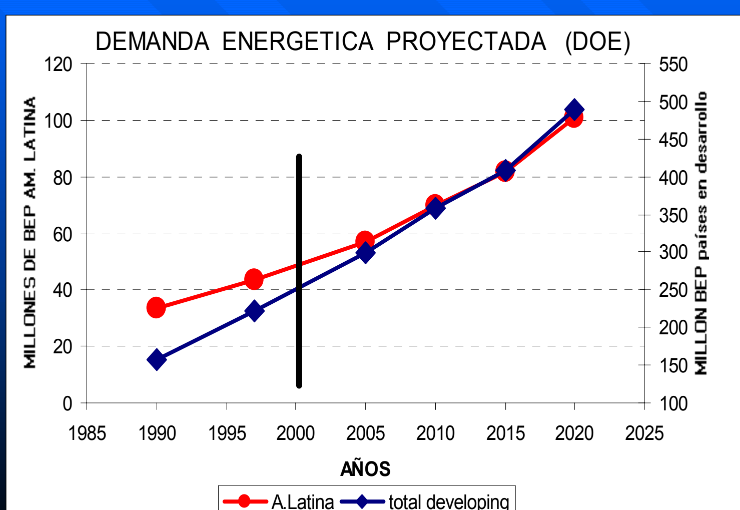


SOCIETY RIGHT TOWARDS ENERGY EFFICIENCY

- 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 ↓



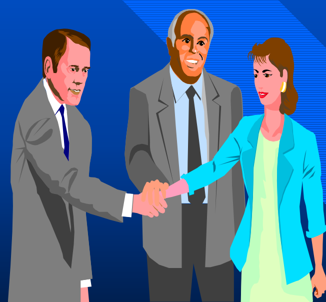
SOCIAL ENTREPRENEURIAL RESPONSIBILITY

- 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

SANJEEVA LATCHIREDDI, Research Associate
RAJ. K. RAJAMANI, Professor
Department of Metallurgical Engineering
The University of Utah
135 S 1460 E, Room 412, Salt Lake City, UT 84112 USA
(sanjeeva@mines.utah.edu and rajamani@mines.utah.edu)

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.

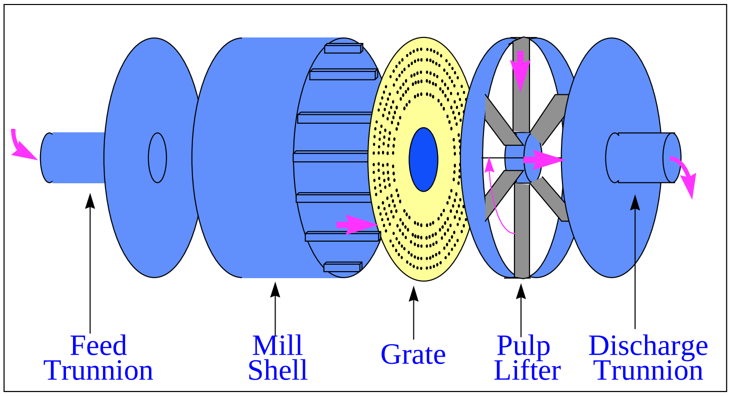


Figure I: Schematic of a typical sag mill.

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.

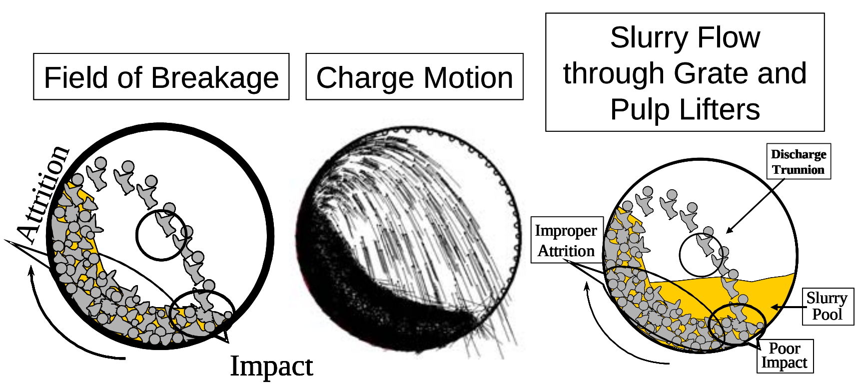


Figure II: Three important factors that affect the energy efficiency of sag mills

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.

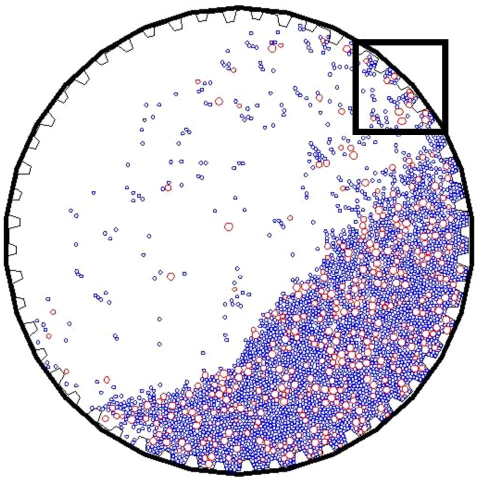
MillSoft can be used affectively to show the effects of different lifter configurations, mill loading, mill speed, and other operating conditions. Unlike single-particle trajectory programs which show only the worse-case condition of a particle path, MillSoft takes into account the entire charge, you 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.

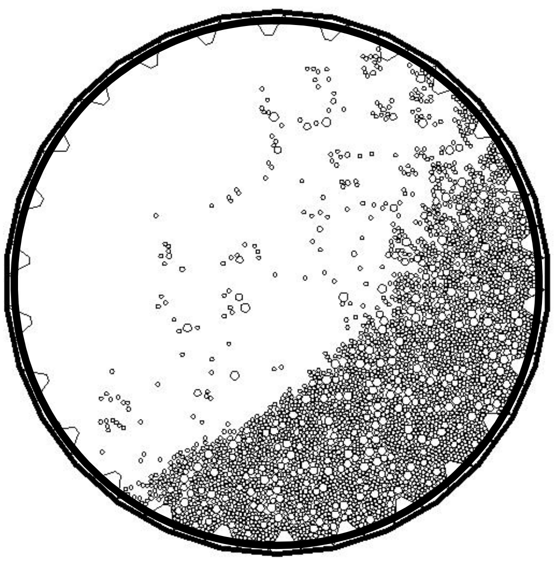


Figure IV: Snap shot of the charge motion with 26 high lifters.

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.

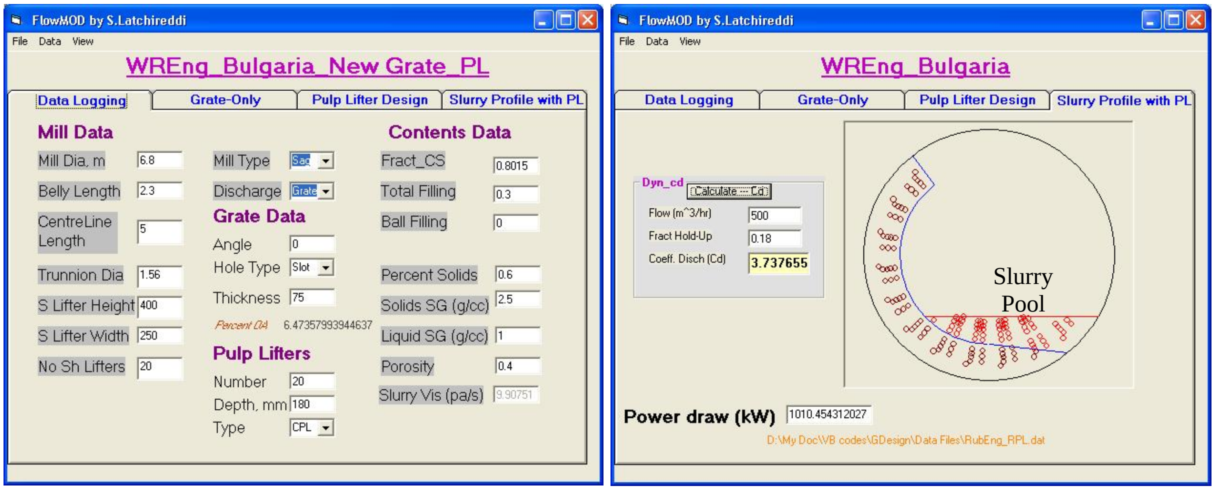
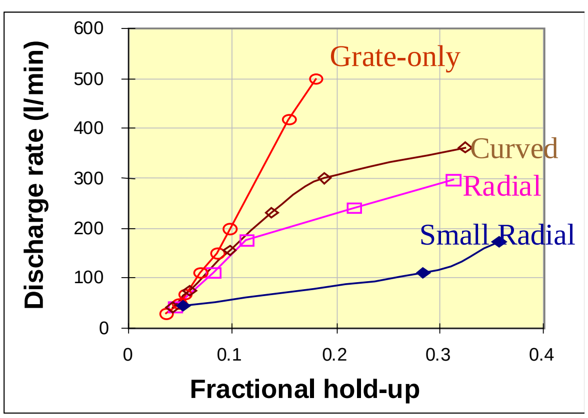


Figure V: FlowMod's a) user interface and b) slurry hold-up and its profile.

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.



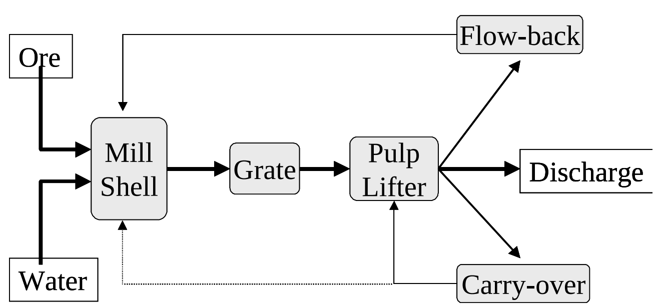


Figure VI: Comparison of flow through pulp lifters. Figure VII: Process of slurry transportation in SAG mill

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.

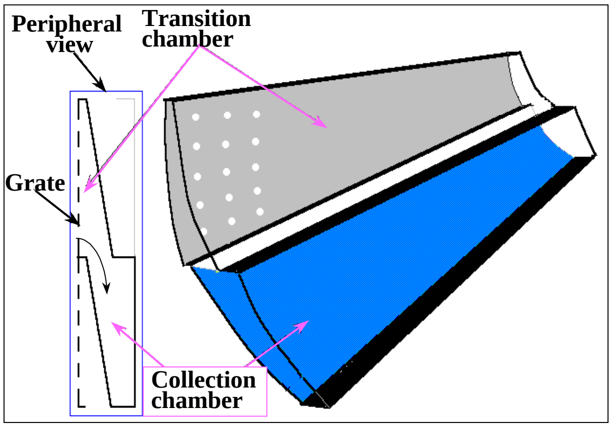


Figure VIII: Schematic of the Twin Chamber Pulp Lifter (TCPL).

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.

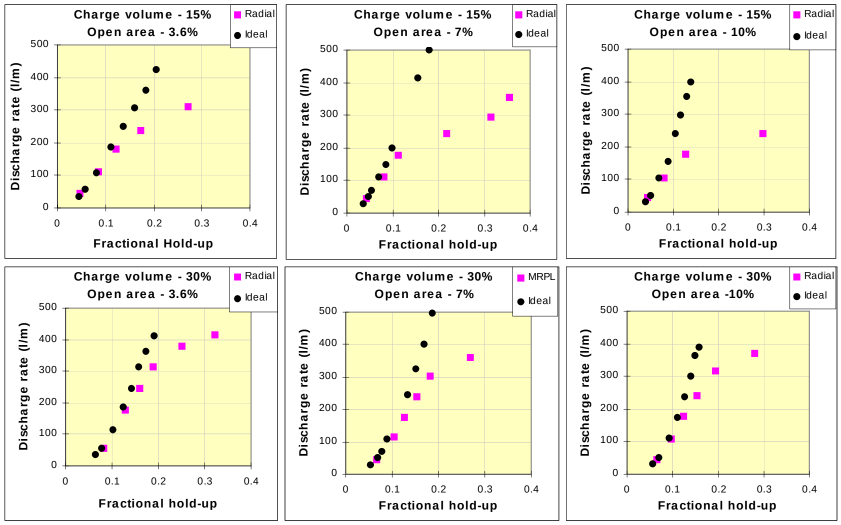


Figure IX: Performance of RPL with variations in charge volume and open area.

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.

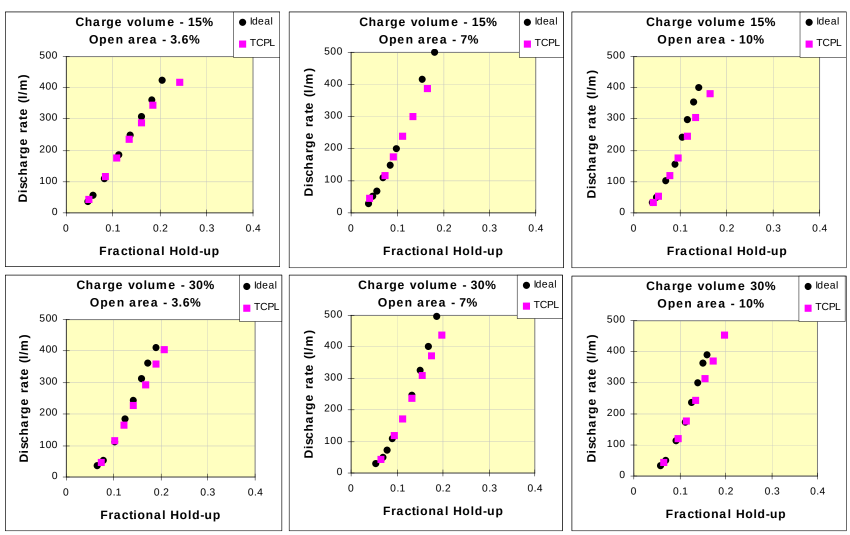


Figure X: Performance of TCPL with variations in charge volume and open area.

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.

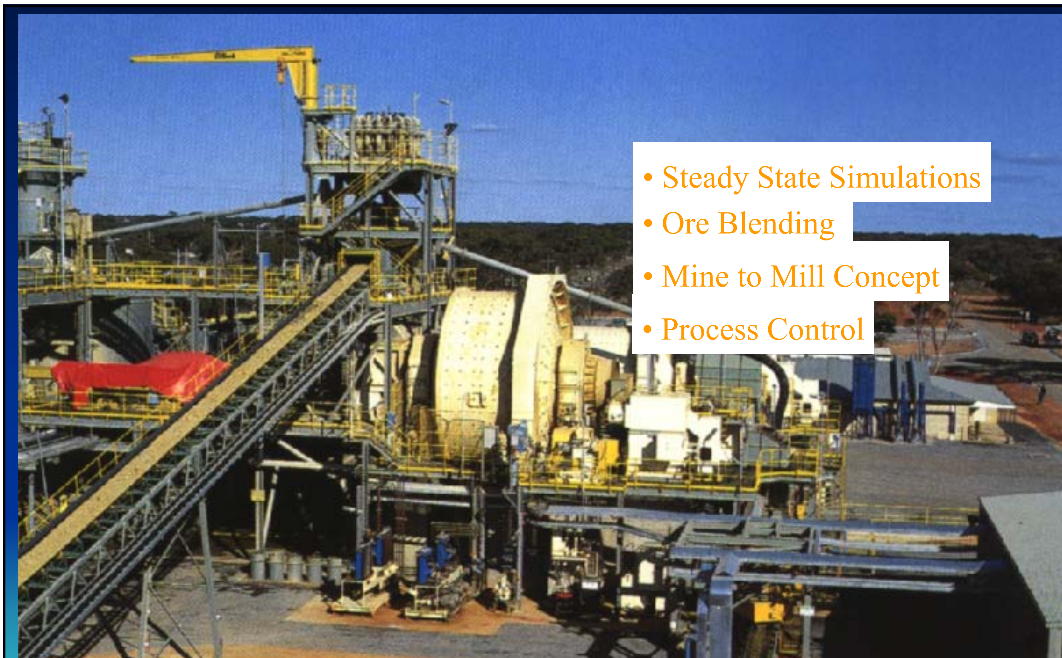
6 ACKNOWLEDGMENTS

The authors are thankful to the Department of Energy for funding the research project (DE-FC26-03NT41786) on “Improving Energy Efficiency via Optimized Charge Motion and Slurry Flow in Plant Scale SAG Mills”

7 REFERENCES

1. Denis, N., Morrell, S., Chapman, B. and Latchireddi, S., 2001. The development and installation of the Twin Chamber Pulp Lifter at Alcoa. Proc. SAG’01, Vancouver, Canada.
2. Moys, M.H., 1986. The effect of grate design on the behavior of grate discharge mills, Int. J. Miner. Process., 18 : 85-105.
3. Austin, L. G., Klimpel, R.R. and Luckie, P.T., 1984. Process engineering of size reduction : ball milling. SME-AIME, New York.
4. Kjos, D. M., 1985. Wet autogenous mills. SME Mineral Processing Handbook N.L.Weiss (Ed) Vol.1, SME, New York, pp. 3c-60 - 3c-75
5. Rowland, C. A. and Kjos, J. M., 1975. Autogenous and semi-autogenous mill selection and design. Australian Mining, September, pp. 21-35
6. Latchireddi, S R., 2002. Modeling the performance of grates and pulp lifters in autogenous and semiautogenous mills. PhD Thesis, University of Queensland, Australia.

7. Latchireddi, S R and Morrell, S, 1997. A new design of pulp lifter for grate discharge mills. Sixth Mill Operators Conference, , Madang, PNG, October : 57-61
8. Latchireddi, S R and Morrell, S, 2003a. Slurry flow in Mills: Grate-only discharge mechanism (part-1). Accepted by Minerals Engineering.
9. Latchireddi, S R and Morrell, S, 2003b. Slurry flow in Mills: Grate-Pulp lifter discharge mechanism (part-2). Accepted by Minerals Engineering.
10. Marcelo Villouta R., 2001. Collahuasi: After two years of operation, SAG 2001, Vancouver, Eds:, Barratt, Allan and Mular :I31-I42.
11. Mark Sherman, 2001. Optimisation of the Alumbrera SAG mills, SAG 2001, Vancouver, Eds:, Barratt, Allan and Mular :I59-I75.
12. R. K. Rajamani, Slurry Transport through the Dynamic Porosity of the Ball Mill," Trans. Indian Inst. of Metals, vol. 50, no. 5, pp. 337-347, October 1997a.
13. R. K. Rajamani, B. K. Mishra and P. Songfack, "The Modeling of Rock and Ball Charge Motion in SAG Mills, in *Comminution Practices,* edited by S. K. Kawatra, Society for Mining, Metallurgy and Exploration, Inc., pp. 195-200, 1997b.
14. R. K. Rajamani and B. K. Mishra, "Dynamics of Ball and Rock Charge in SAG Mills, in *International Autogenous and Semiautogenous Grinding Technology,* edited by A. L. Mular, D. J. Barratt, and D. A. Knight, Vol. 2, pp. 700-712, 1996.
15. B. K. Mishra and R. K. Rajamani, "Simulation of Charge Motion in Ball Mills. Part 1: Experimental Verifications,", International Journal of Mineral Processing, vol. 40, 171–176, 1994a.
16. B. K. Mishra and R. K. Rajamani, "Simulation of Charge Motion in Ball Mills. Part 2: Numerical Simulations,", International Journal of Mineral Processing, vol. 40, 187–197, 1994b.

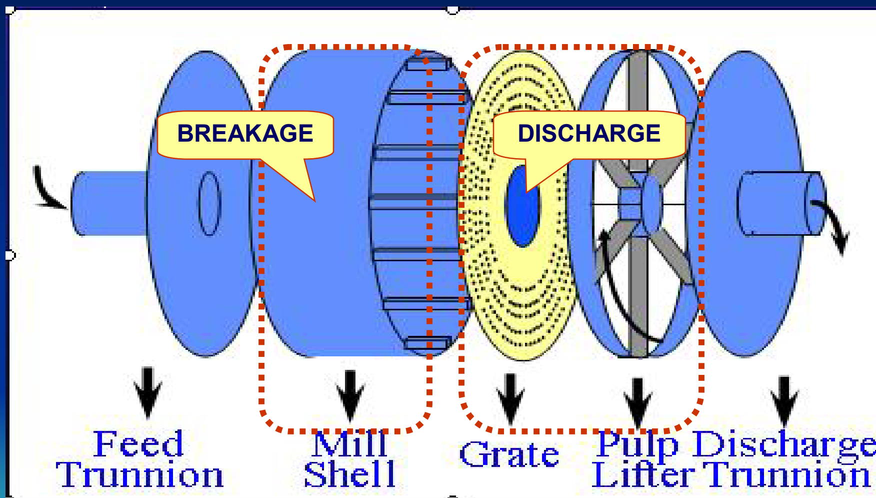


HOW DO WE ENSURE

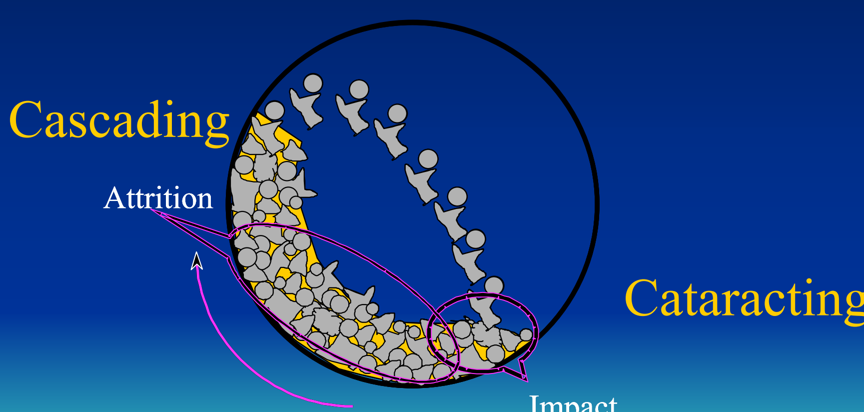
INCREASING ENERGY EFFICIENCY IN SAG MILLS

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

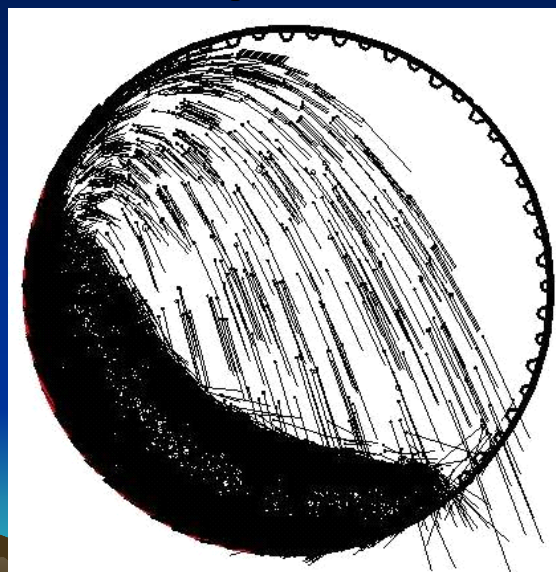
Components of SAG mill



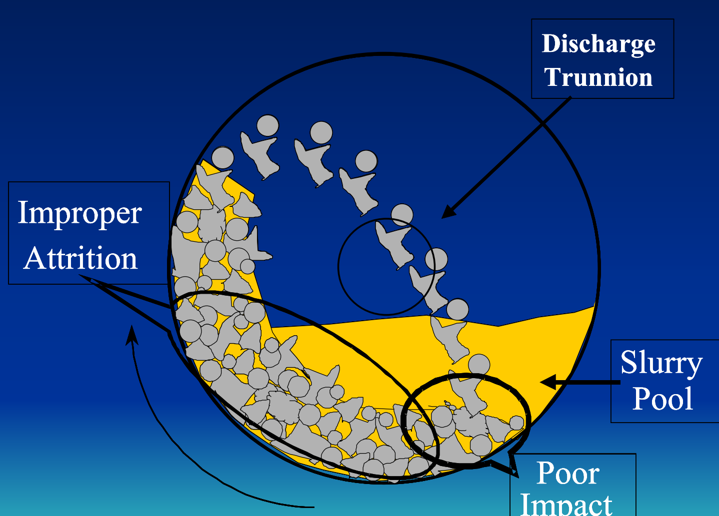
Breakage Process

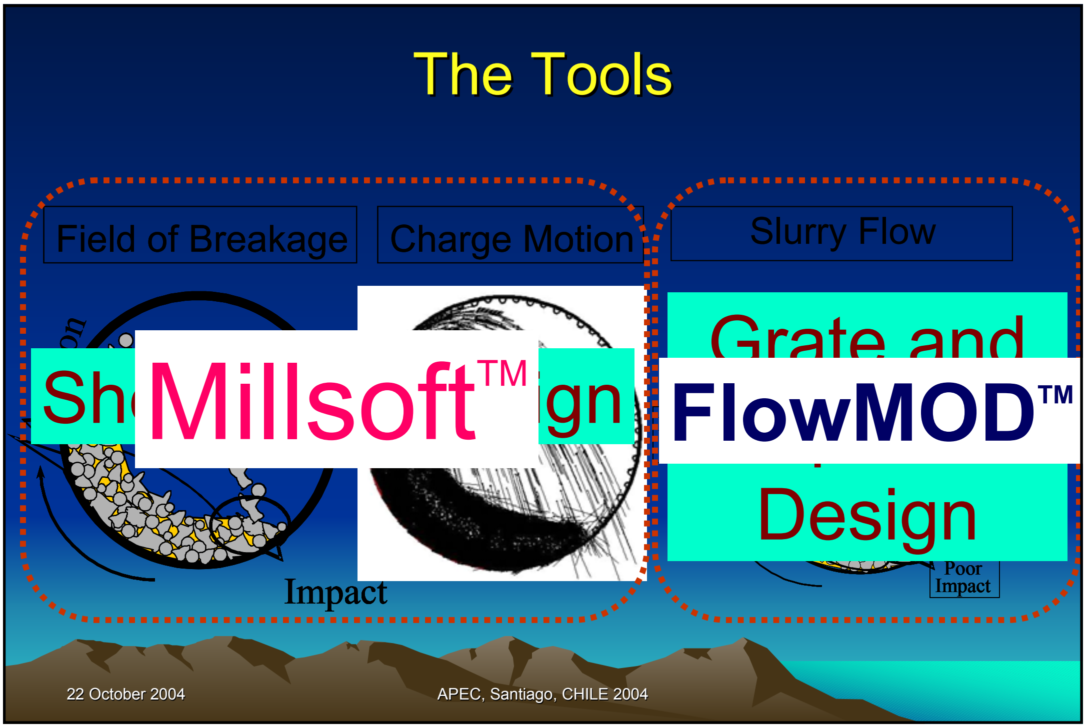


Charge Motion



Slurry Flow

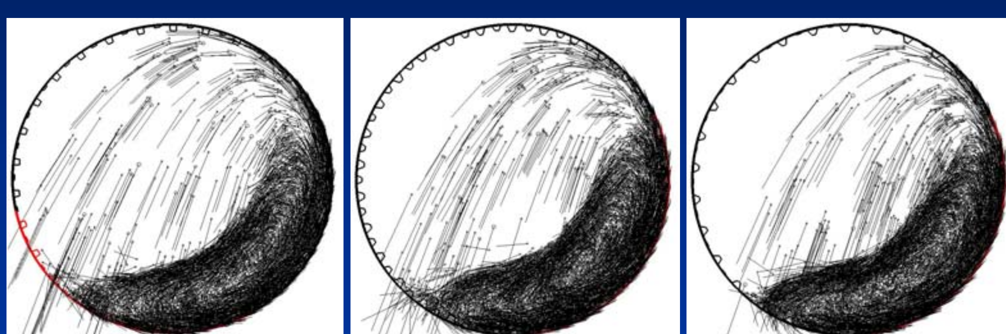



The Tools
Field of Breakage
Charge Motion
Slurry Flow
Millsoft™
FlowMOD™
Grate and
Design
Impact
Poor
Impact
22 October 2004
APEC, Santiago, CHILE 2004


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

Millsoft - parameters

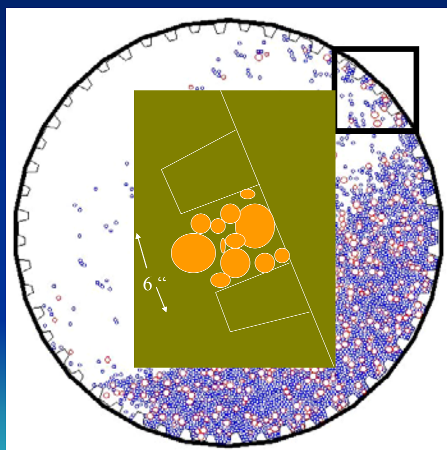
Charge motion



38x24 ft SAG Mill

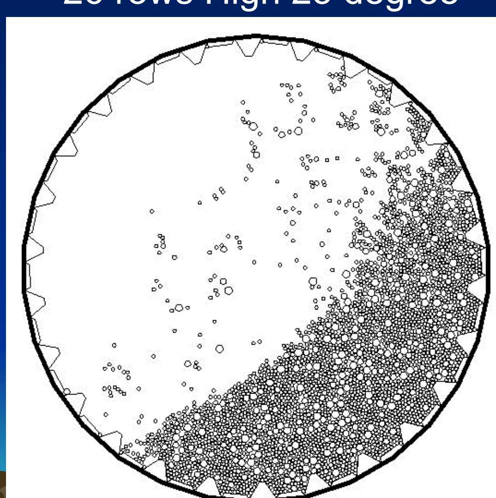
Case study I

52 rows High-Low 17 degree



Case study I (18 Sept 2004)

26 rows High 25 degree

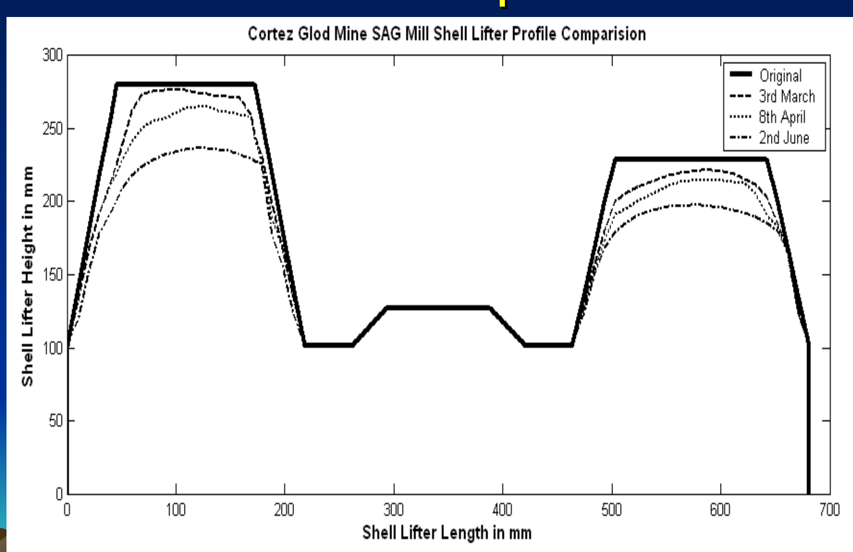


10% less sag power draw.

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



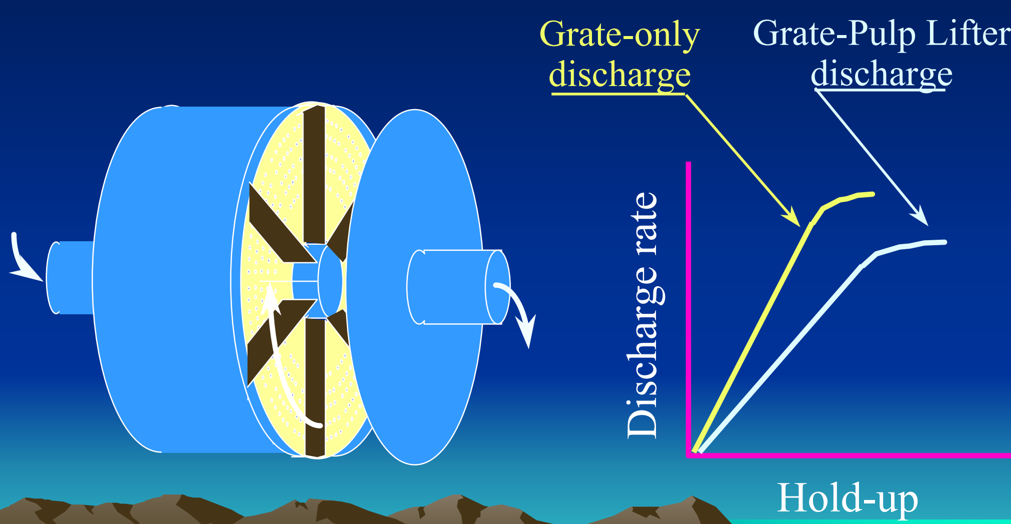
Current Trend

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

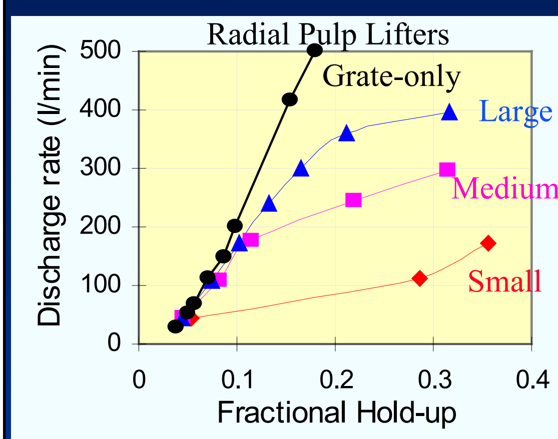
But, what does pulp lifter say?

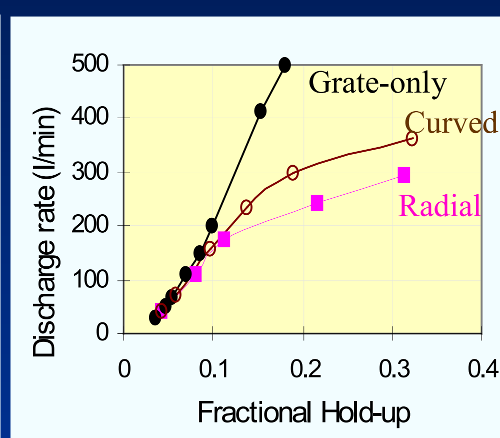
Discharge Grate and Pulp Lifters

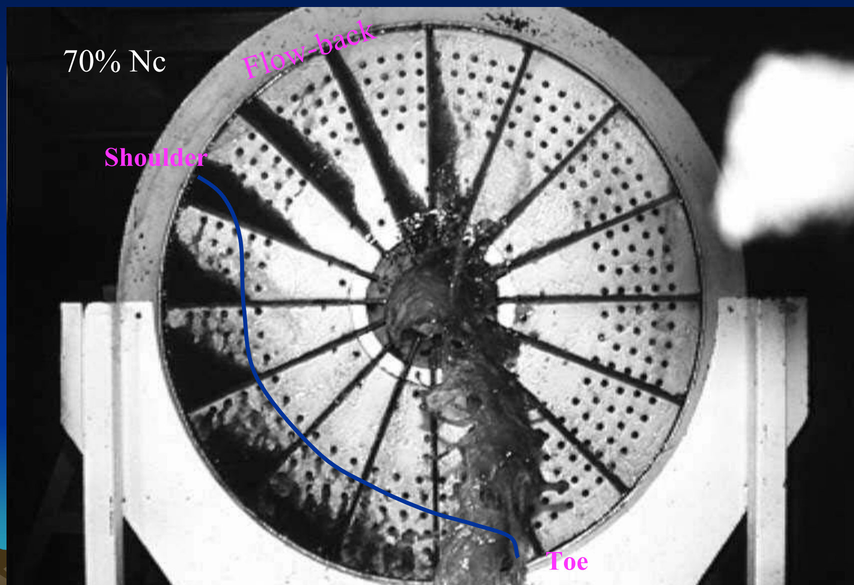
The Concept

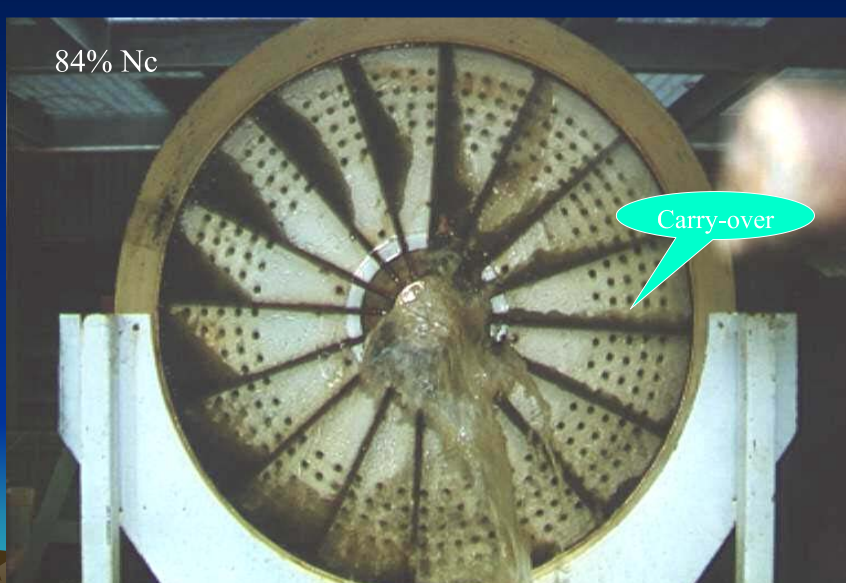


Response of Conventional Designs

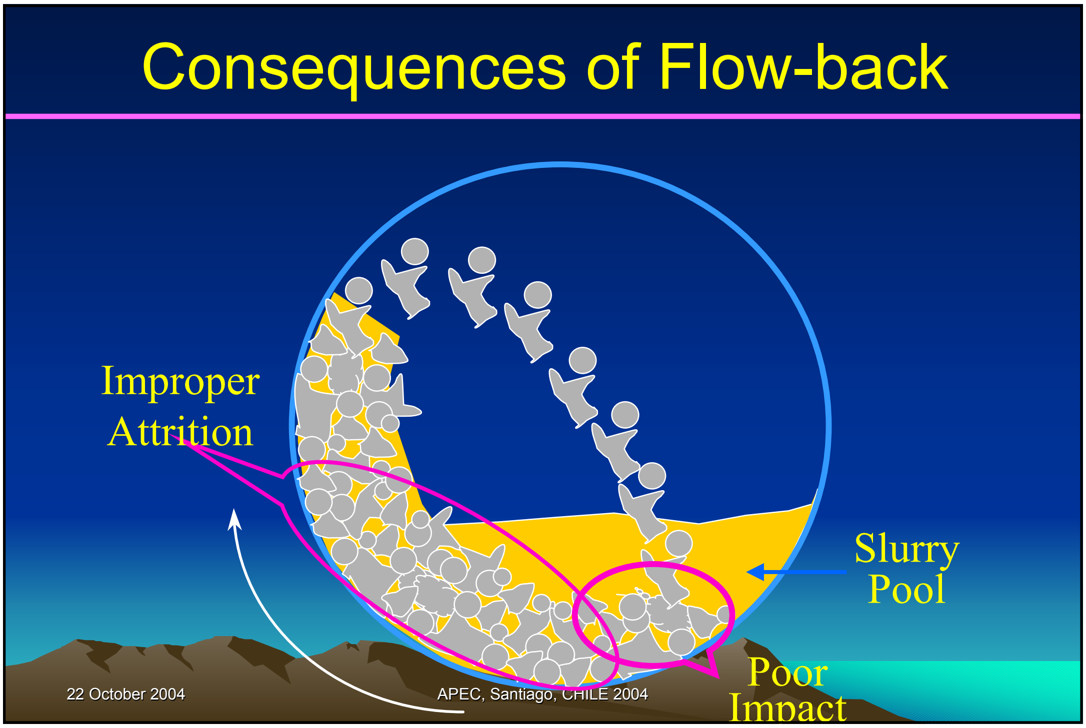




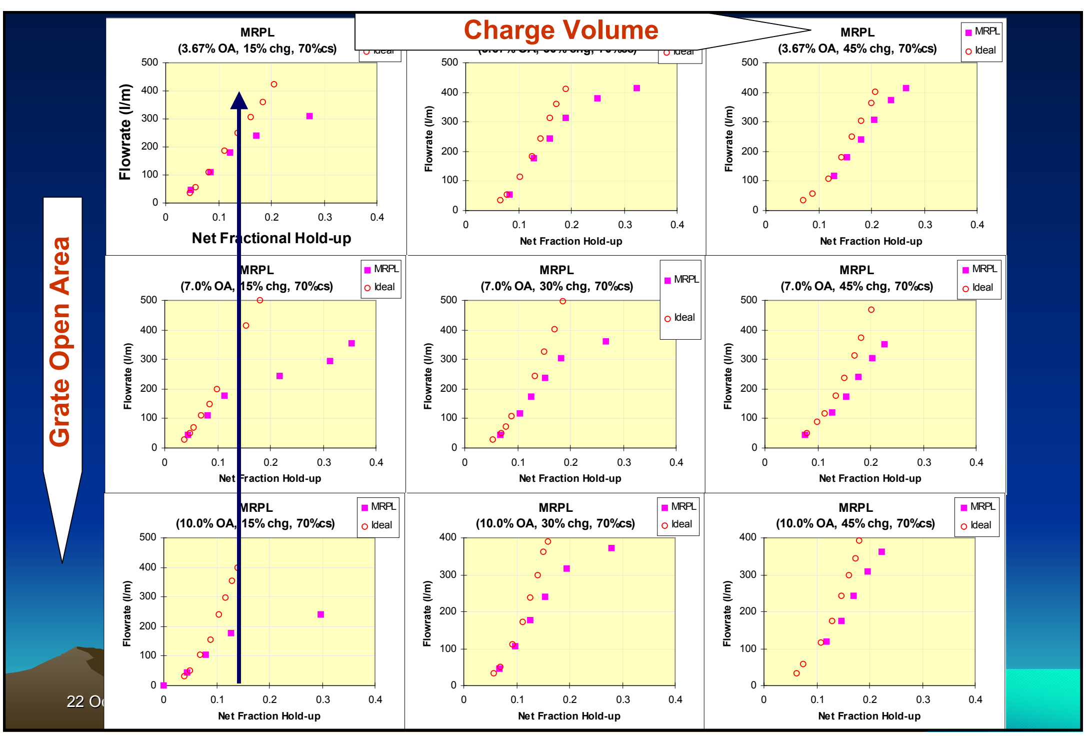




22 October 2004 APEC, Santiago, CHILE 2004



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)
Flowrate (l/m)
Net Fractional Hold-up
MRPL
(3.67% OA, 45% chg, 70%cs)
MRPL
Ideal
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)
Flowrate (l/m)
Net Fraction Hold-up

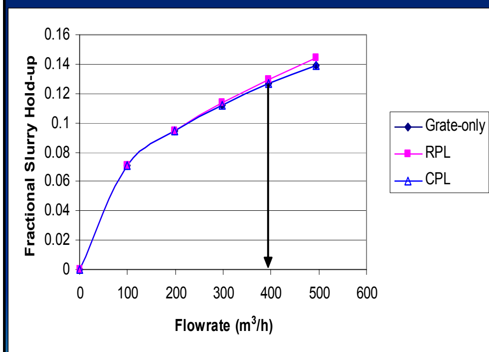
Case Study - 1

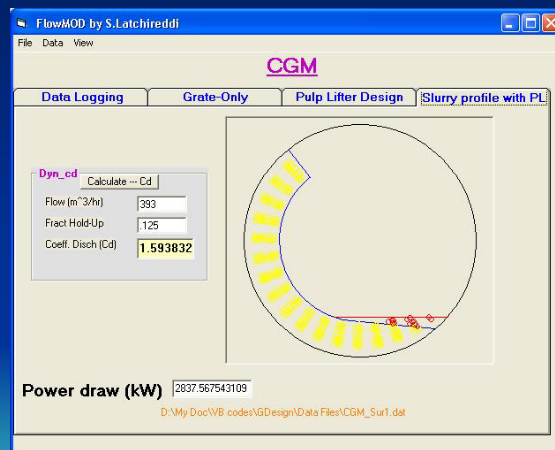
Diameter x Length, ft	26x16
Open area %	6.9
Mill speed, rpm	11.6

Crash stop – Normal ore

22 October 2004 APEC, Santiago, CHILE 2004

Slurry profile – Normal ore

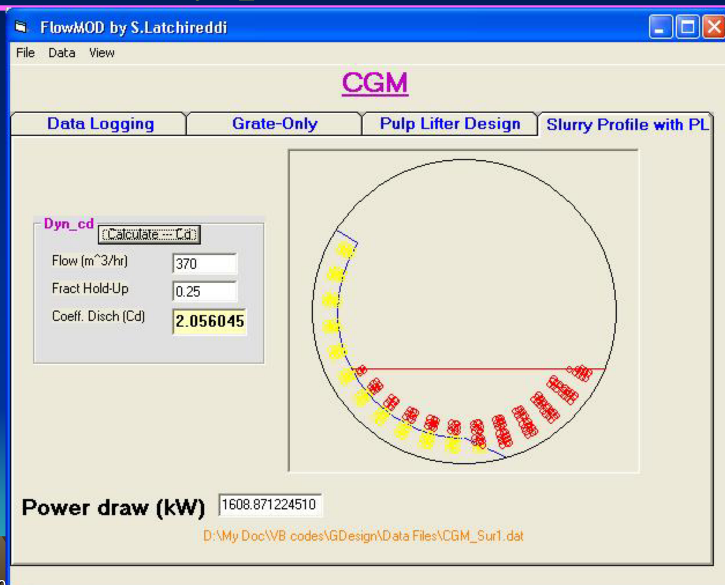




Sandy ore

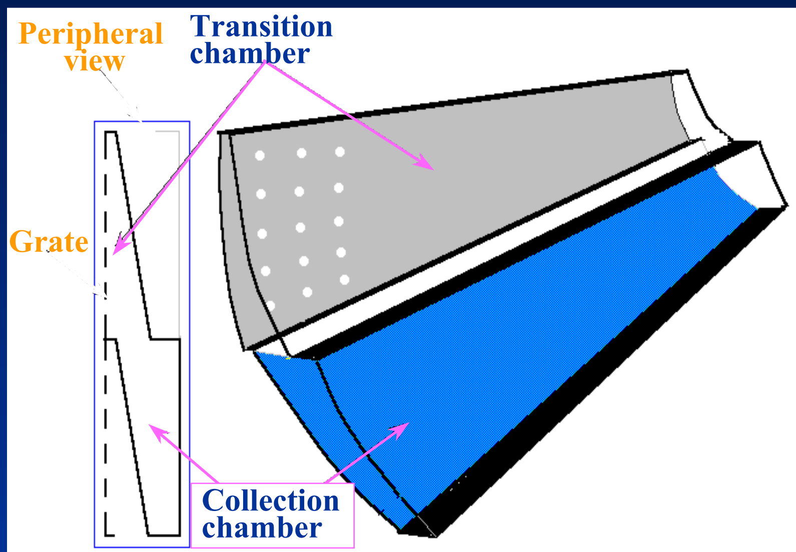
	Normal	Sandy
Bearing Pressure (feed)	460	462
Bearing Pressure (discharge)	482	477
Power (mW)	2800	1530
Sag feed rate, tph	473	423

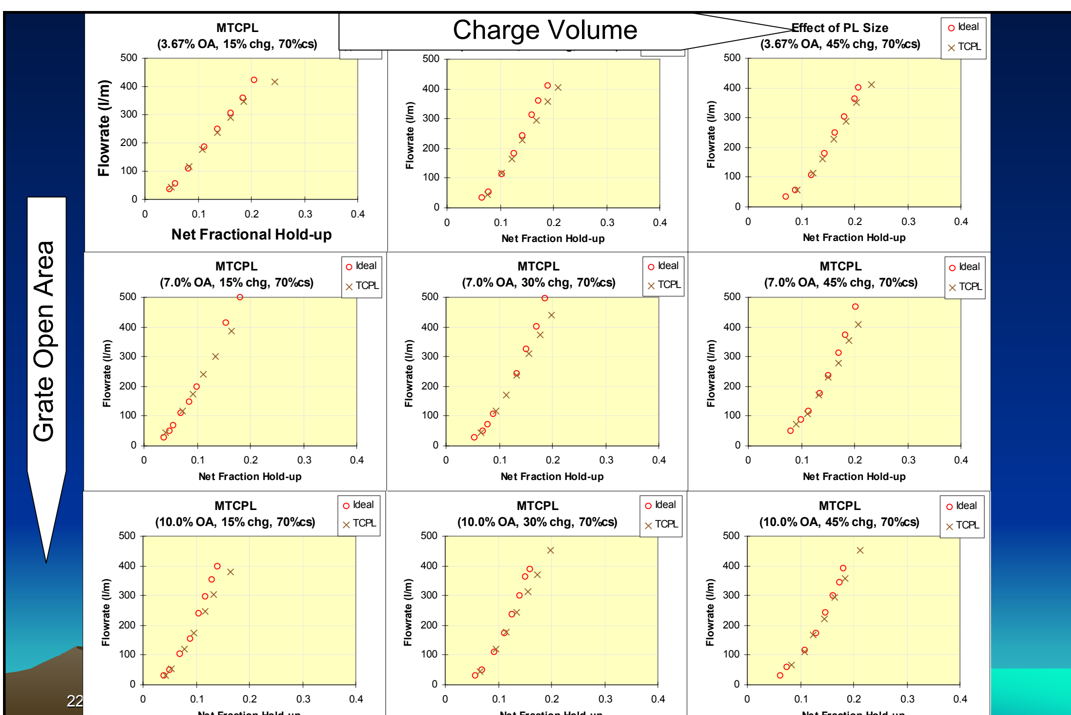
Slurry profile–sandy ore



Ensuring good grinding conditions

Twin Chamber Pulp Lifter



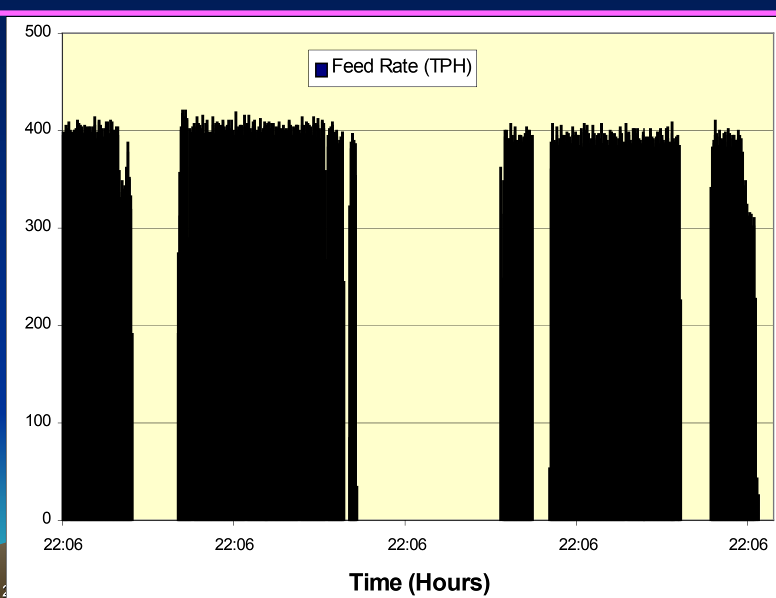


Case Study

Ensuring good grinding conditions

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

Mill Throughput

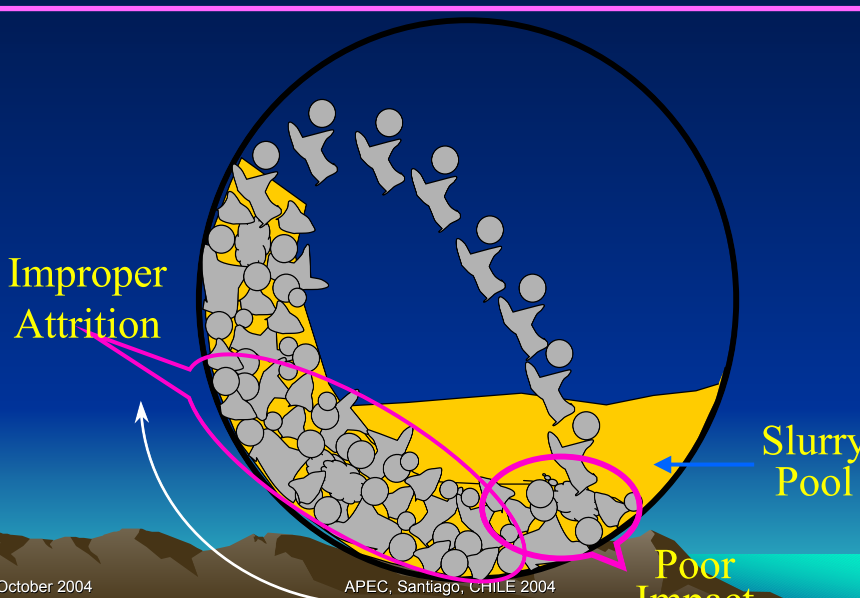


Mill Contents (Pre-installation)

Total Volume -37%

600 mm deep slurry

Mill operation (with RPL)

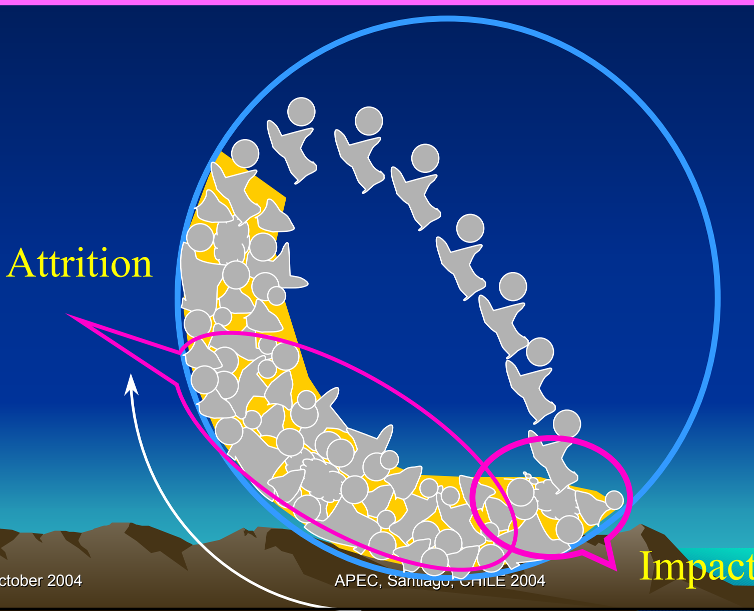


Mill Contents (Post-installation)

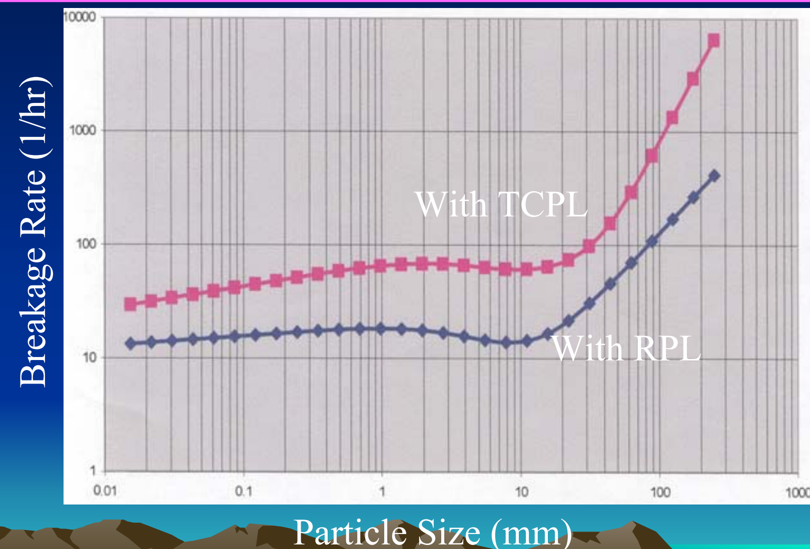
Total Volume -17%

No excess slurry

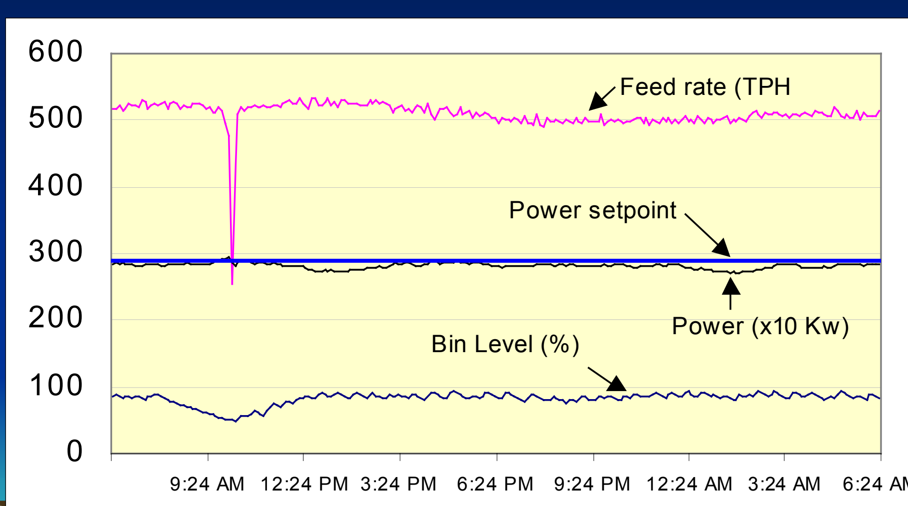
Ideal Grinding with TCPL



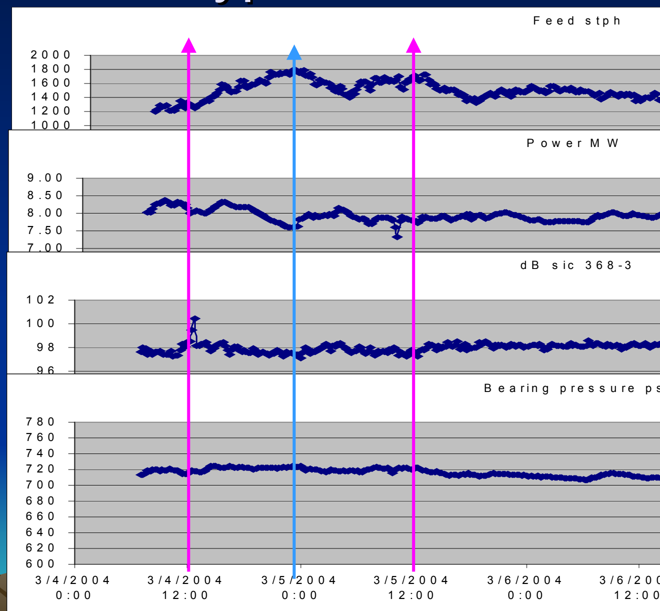
Breakage parameters



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**

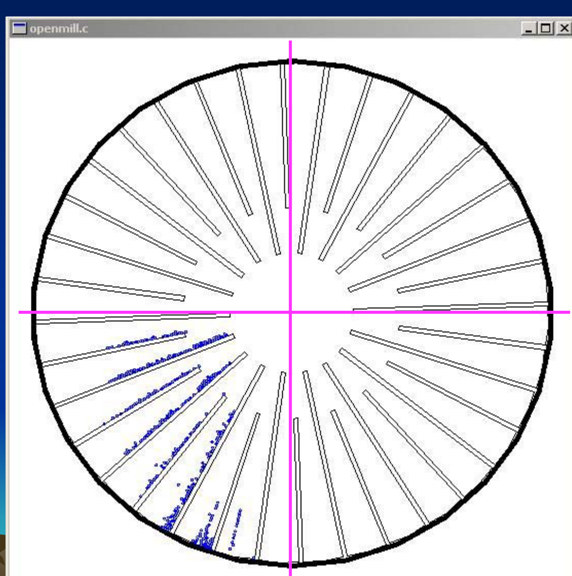
Improving Energy Efficiency via Optimized Charge Motion and Slurry Flow in Plant Scale SAG Mills

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

Pebbles Motion in Pulp Lifters

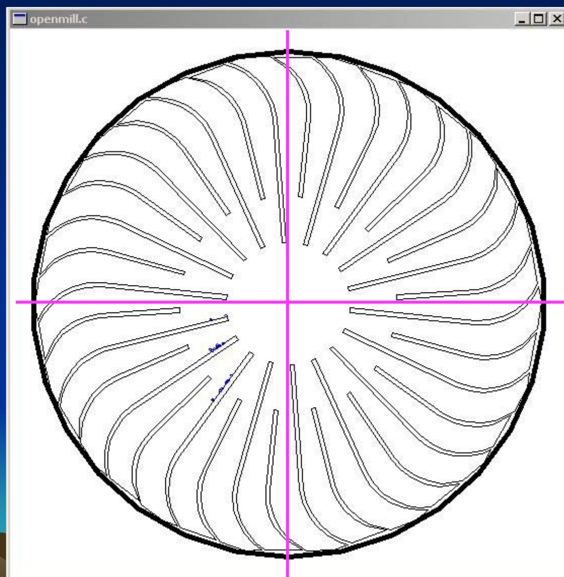
- Radial Pulp Lifter design
- Curved Pulp Lifter design

Flow of pebbles in radial pulp lifters

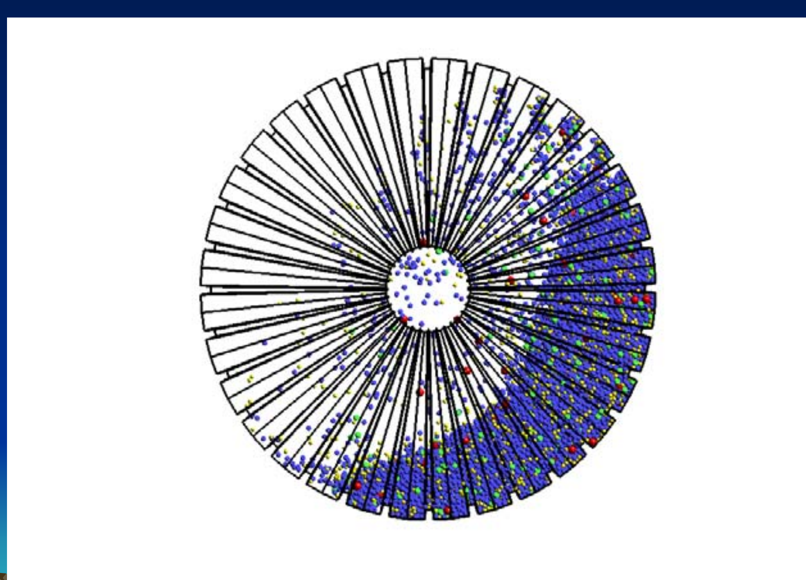


40 ft dia mill
74% CSpeed
63.5 mm pebble size
980 tph pebbles

Flow of pebbles in curved pulp lifters



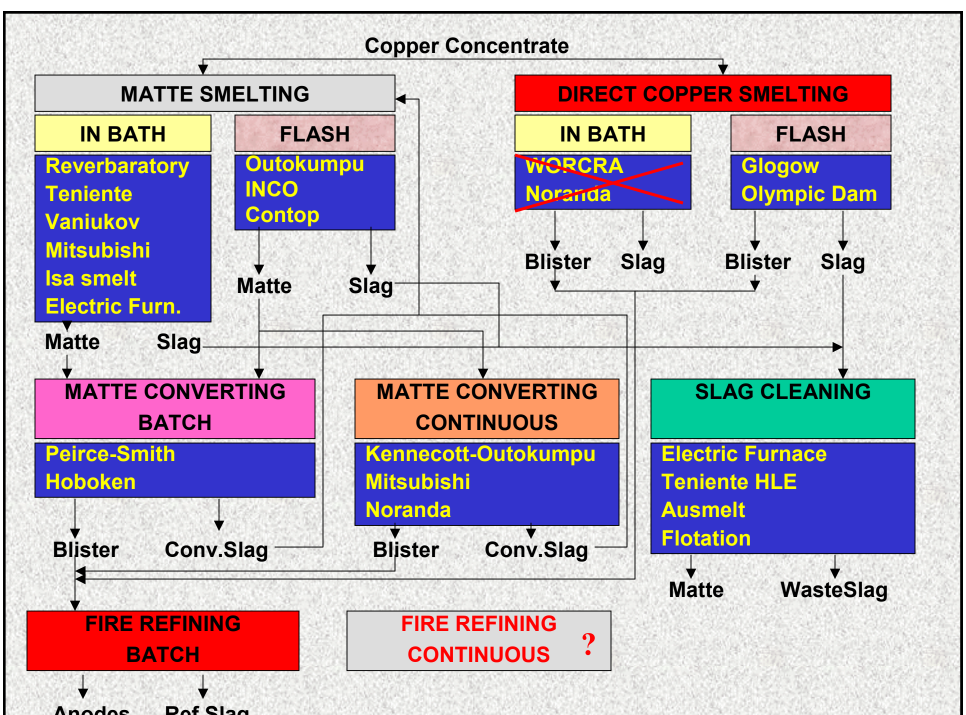
40 ft dia mill
74% CSpeed
63.5 mm Pebbles
980 tph Pebbles



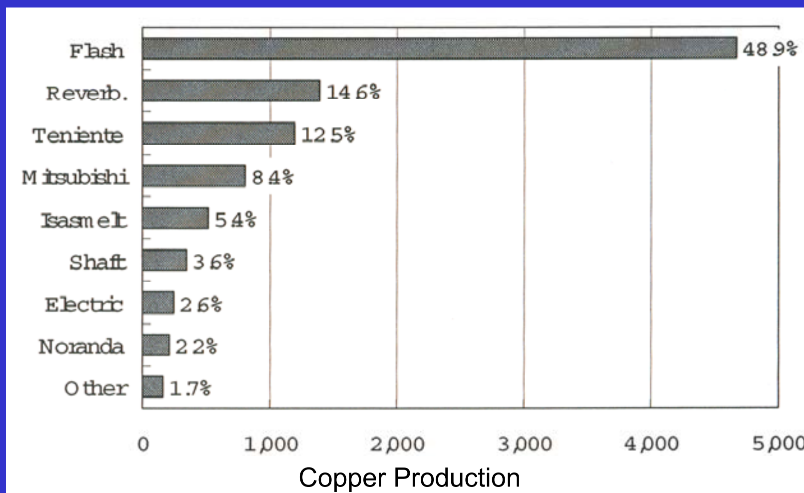
UNIVERSIDAD DE CHILE
FACULTAD DE CIENCIAS FISICAS Y MATEMATICAS
DEPARTAMENTO INGENIERIA DE MINAS

Andrzej Warczok and Gabriel Riveros

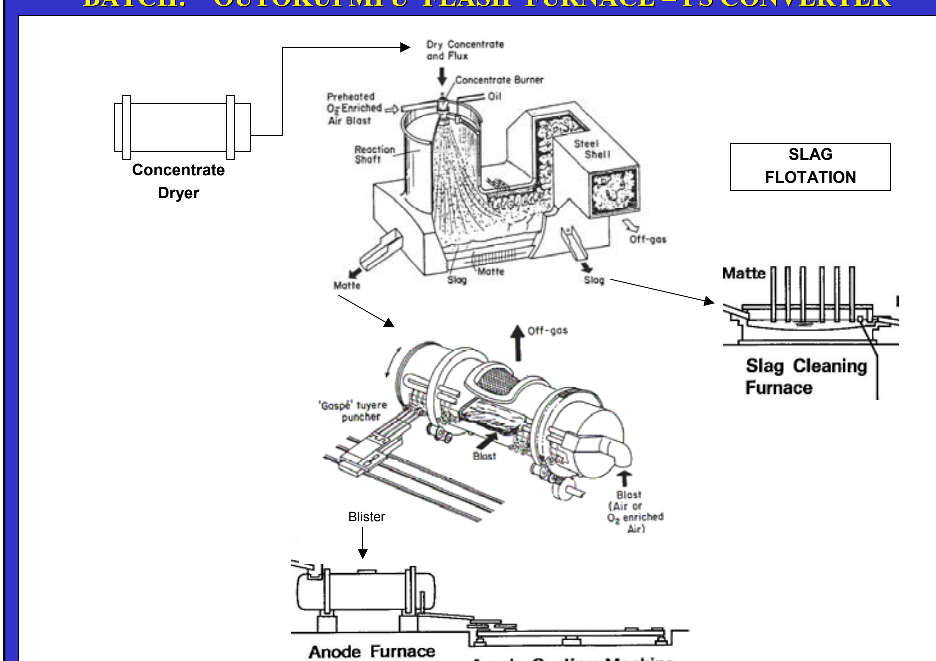
ENERGY EFFICIENCY IN BATCH, CONTINUOUS AND ONE-STEP COPPER PYROMETALLURGICAL PROCESSES



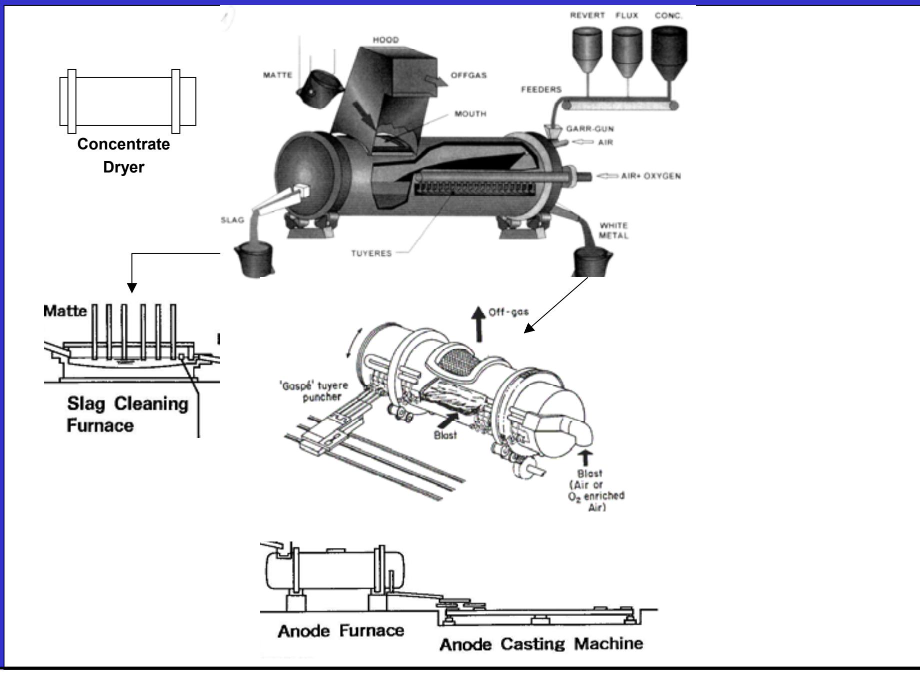
World Copper Production Classified by Smelting Process



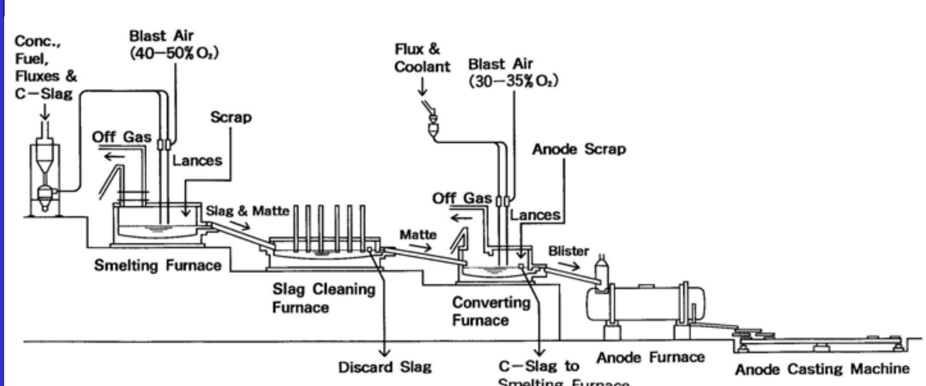
BATCH: OUTOKUPMPU FLASH FURNACE – PS CONVERTER



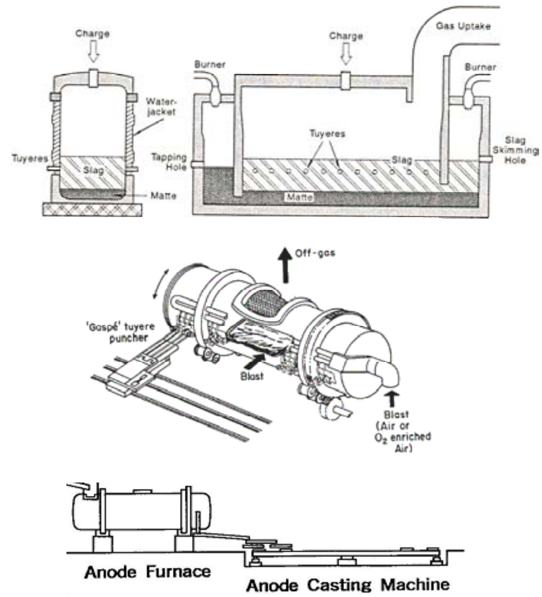
BATCH: TENIENTE CONVERTER – PS CONVERTER



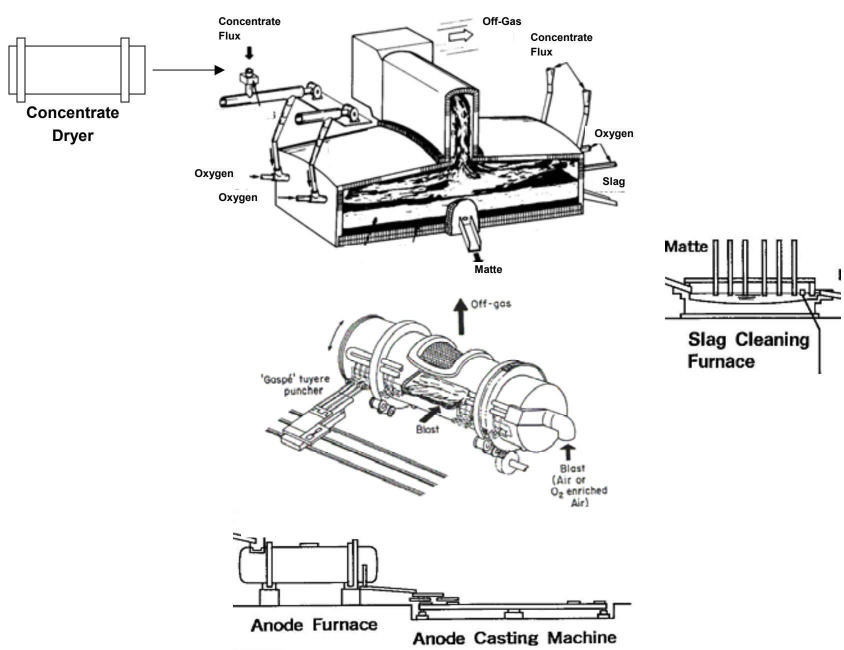
CONTINUOUS: MITSUBISHI PROCESS



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

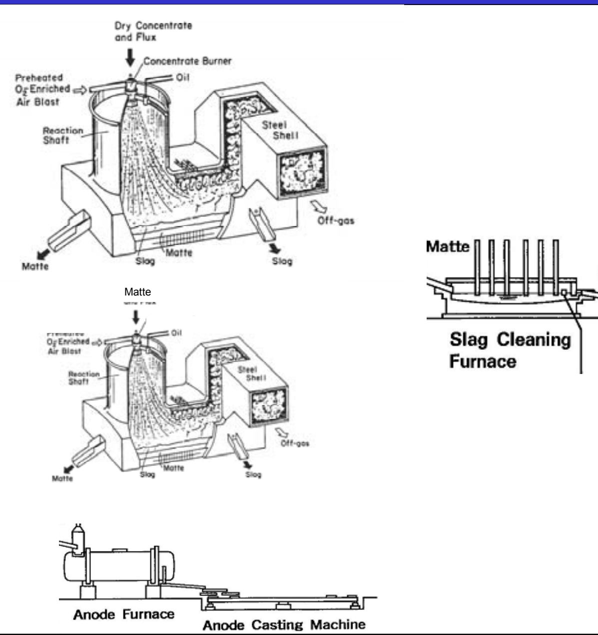
Continuous smelting and converting processes would be more energy efficient than conventional smelting and converting because heat loss in transferring the matte to the converter and the slag to slag cleaning unit would be eliminated or reduced.

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

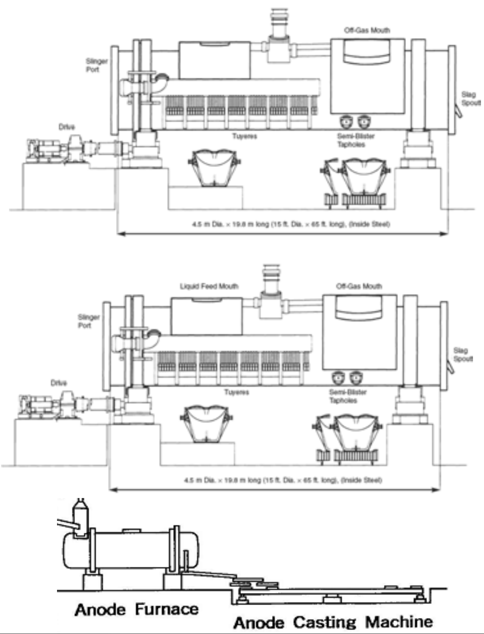
However, continuous Kennecott-Outokumpu flash converting process requires matte quenching and milling, what affects the total energy efficiency.

“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.

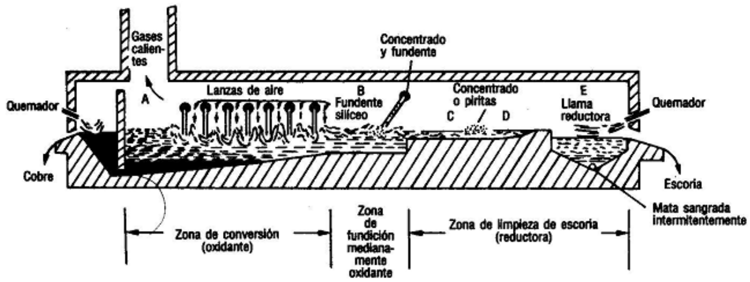
In 1896, Oliver Garretson described a logical process for continuous copper smelting, converting, and slag cleanup, but it remained in two dimensions.

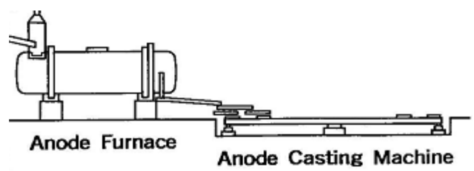
In 1968, Horward Warner described his WORCRA concepts, "which seek to maximize energy conservation" by "direct smelting-converting *in one furnace* in which both smelting, dispersed-phase refining and slag conditioning and settling are combined in distinct but communicating zones or branches."

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

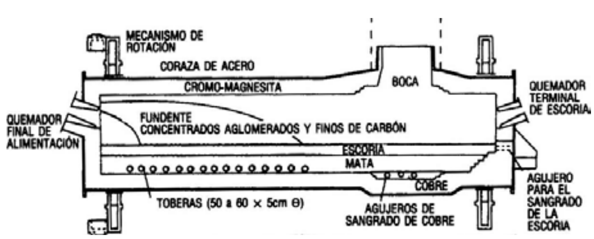
A genuine one-step process could result in a savings of 10 to 20 percent of the energy used in smelting and converting.

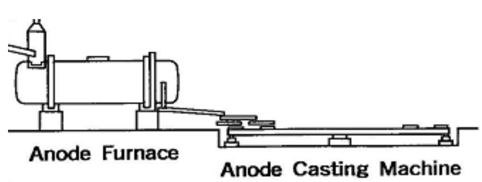
ONE STEP COPPER SMELTING : WORCRA PROCESS





ONE STEP COPPER SMELTING : NORANDA PROCESS

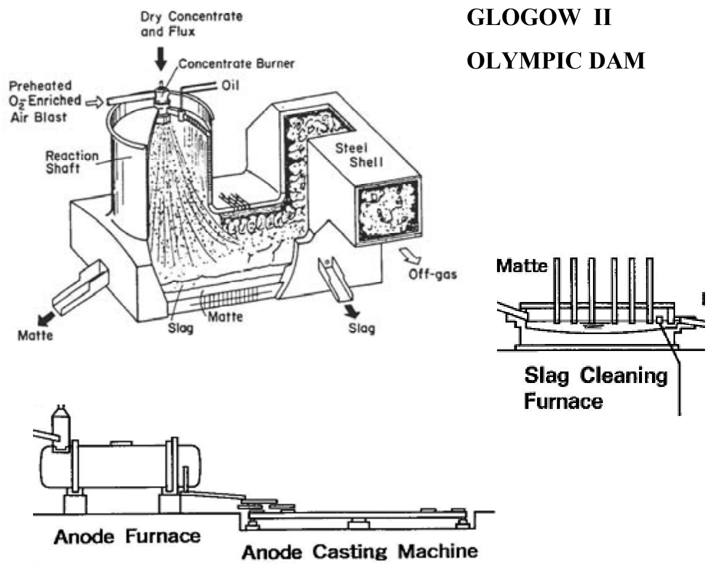




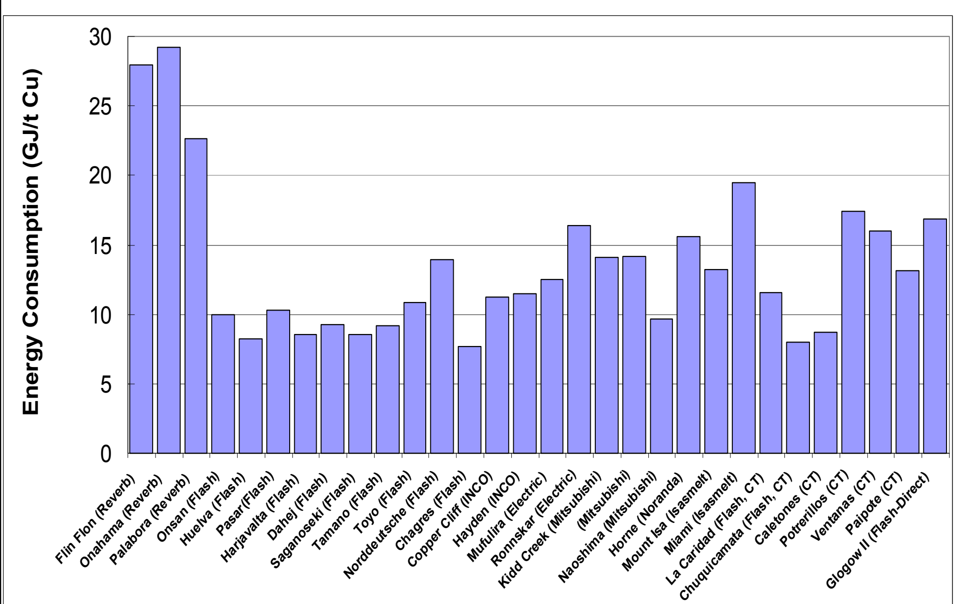
ONE STEP COPPER SMELTING : OUTOKUMPU FLASH PROCESS

GLOGOW II

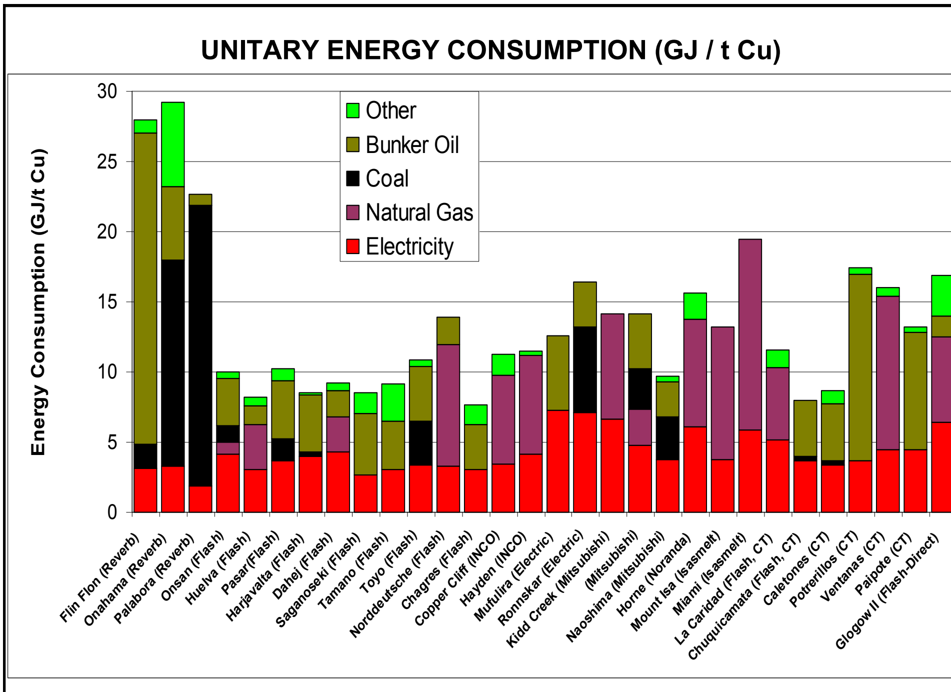
OLYMPIC DAM



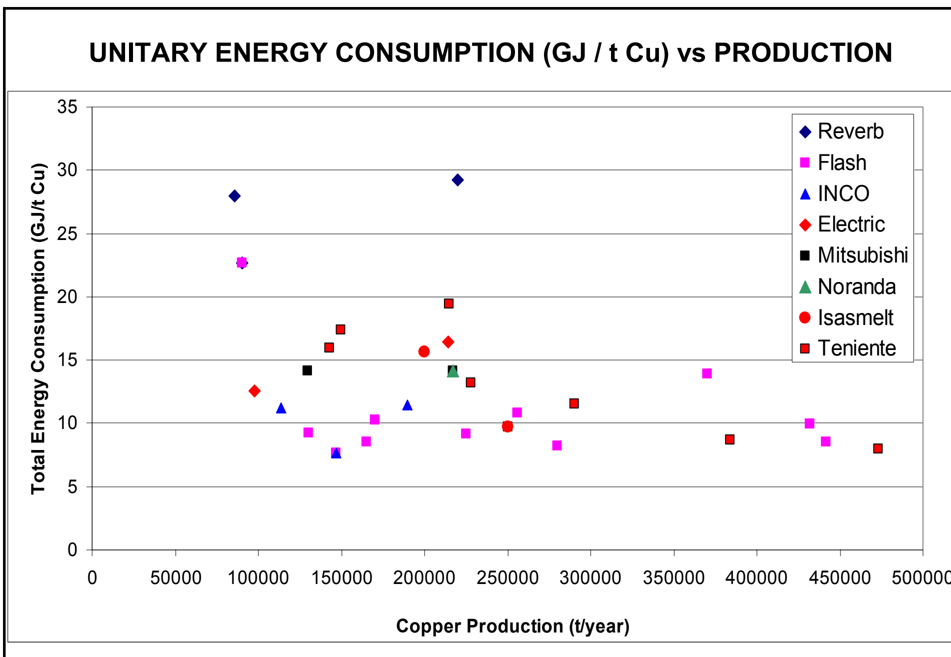
UNITARY TOTAL ENERGY CONSUMPTION (GJ / t Cu)



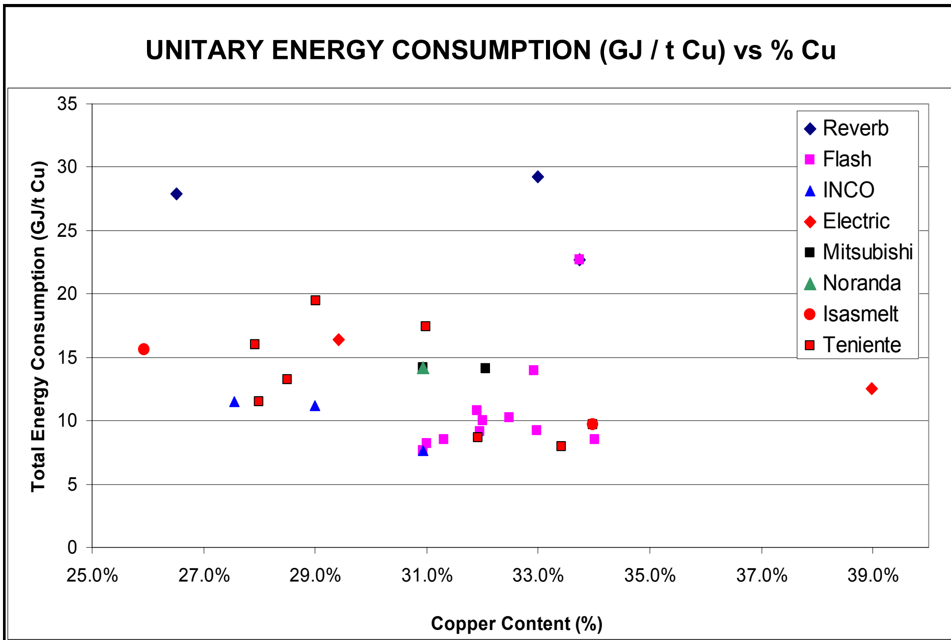
CRU International Ltd.: Copper Smelters



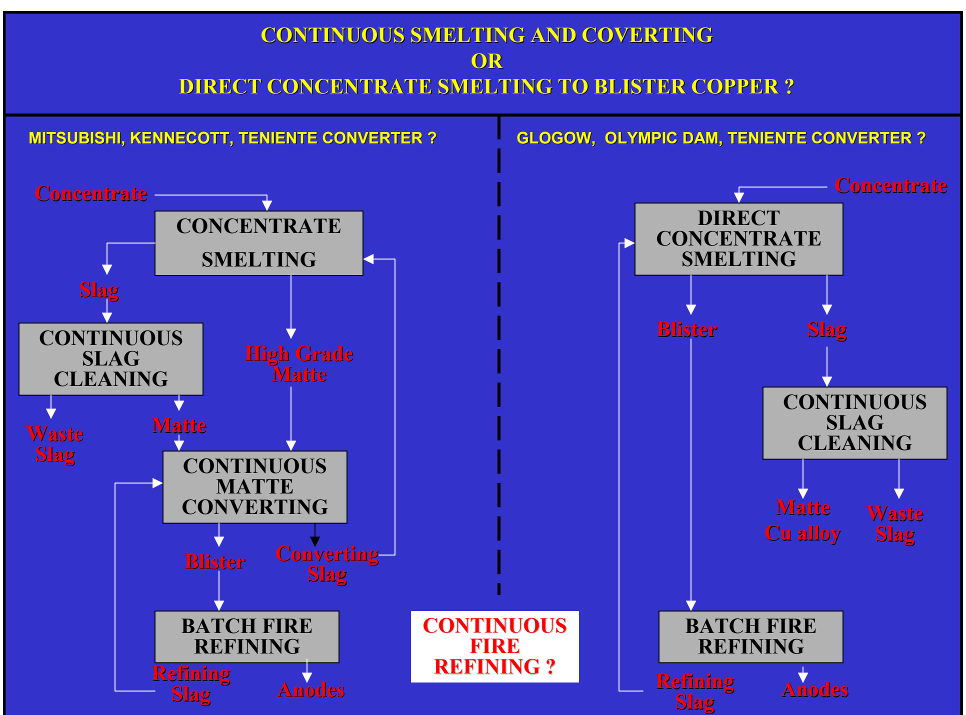
CRU International Ltd.: Copper Smelters



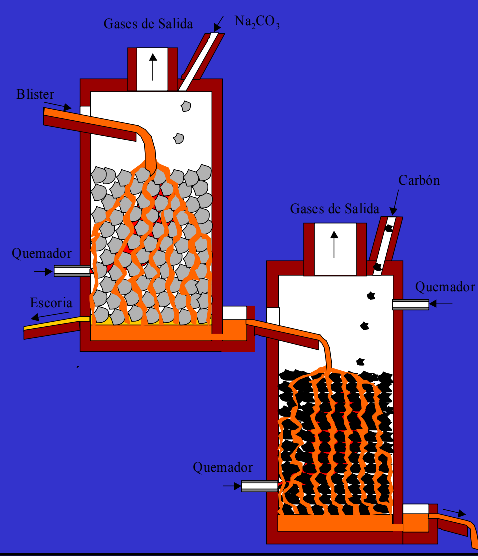
CRU International Ltd.: Copper Smelters



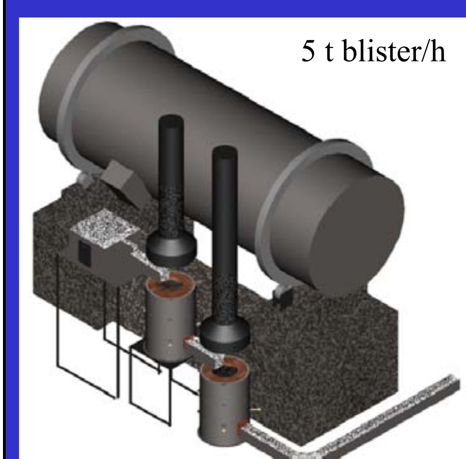
CRU International Ltd.: Copper Smelters

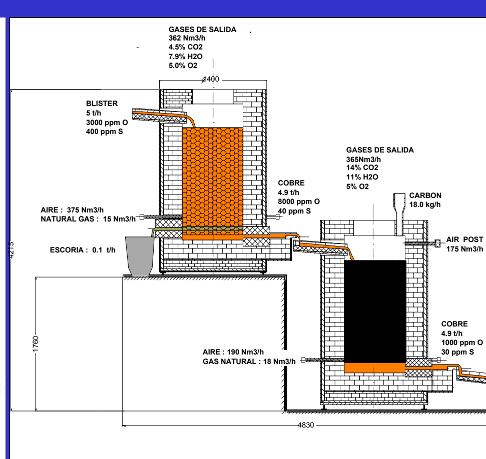


CONTINUOUS FIRE REFINING



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

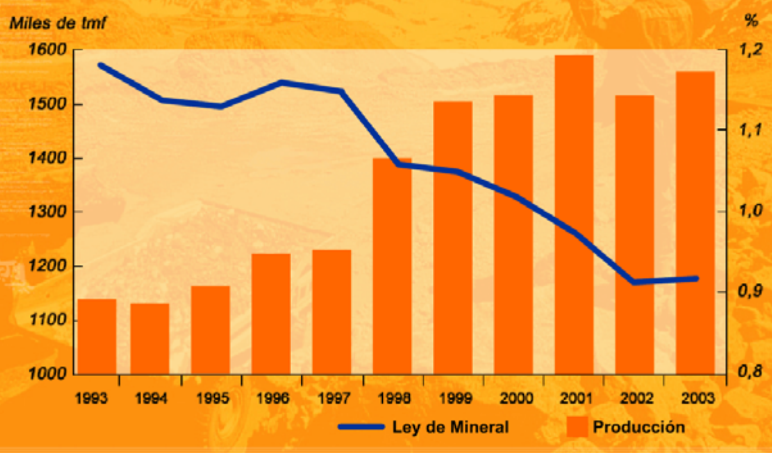
- Current Research and Development
- Opportunities and Challenges in medium Term
- Exploring future Challenges

R&D in Codelco

- Competitiveness Handles
- Innovation Model
- Results

Competitiveness Handles

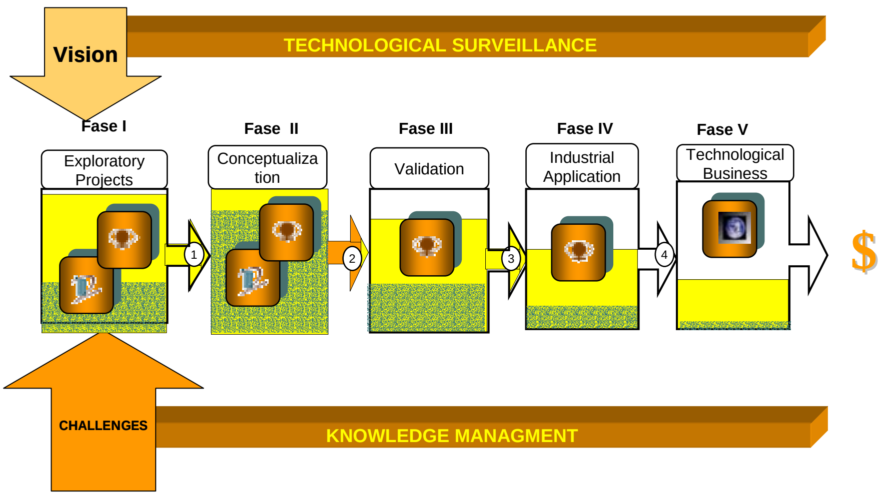
Producción y Ley de Mineral



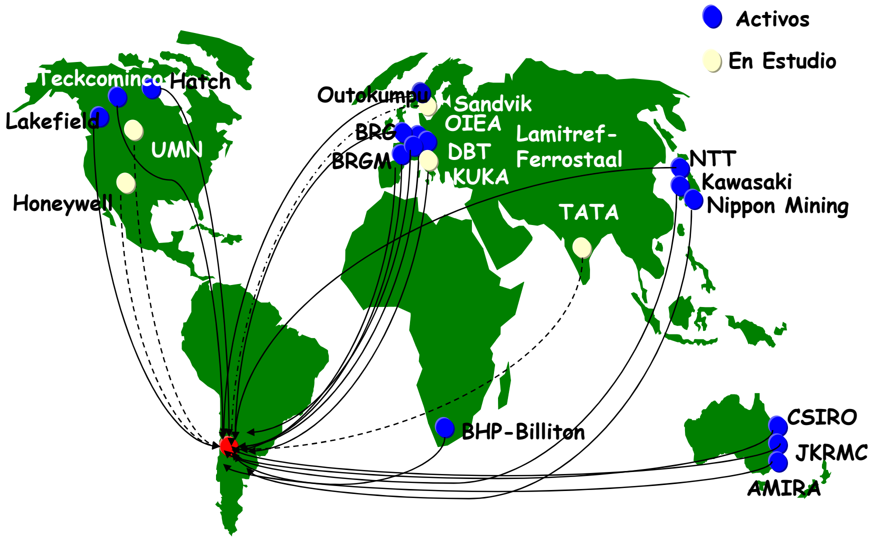
Competitiveness Handles

- **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**

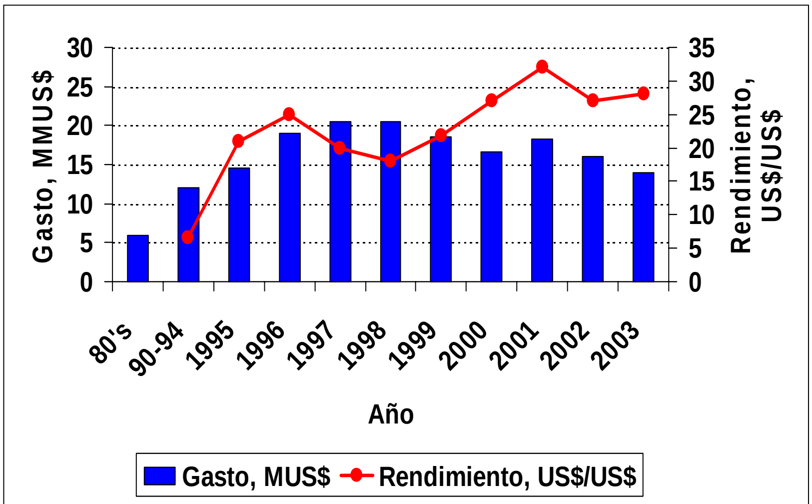
R&D Model



R&D Model
International Networking

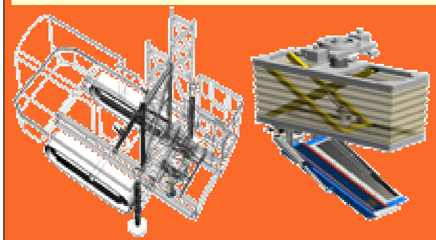


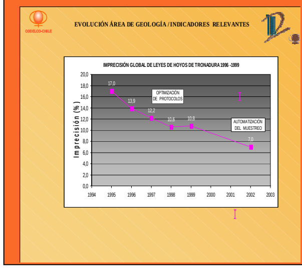
R&D Model
Results



R&D
Surface mining

Automatic Blasting Holes Sampler



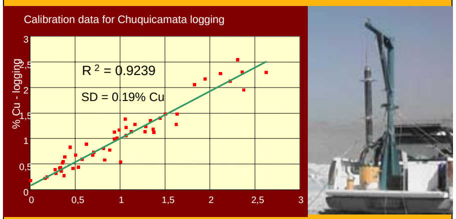


Benefits:

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

Nuclear sensors

Grade in Production holes

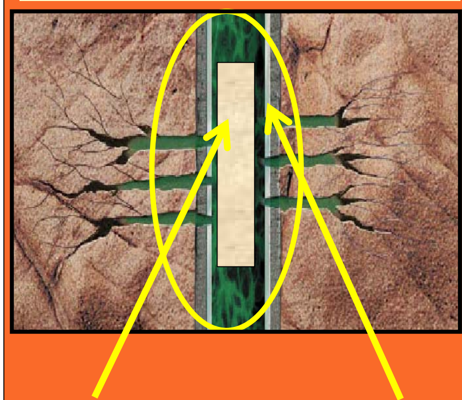


Equipment Development
- **Light Hopper**
- **Higher capacity**
- **Automated Trucks**

Precise Blasting Technology

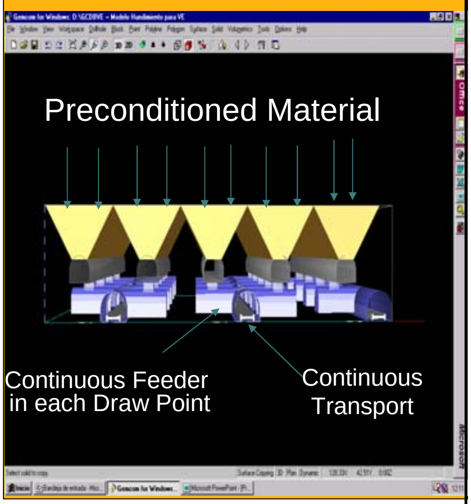
R&D
Underground Mining

Ore Body Preconditioning



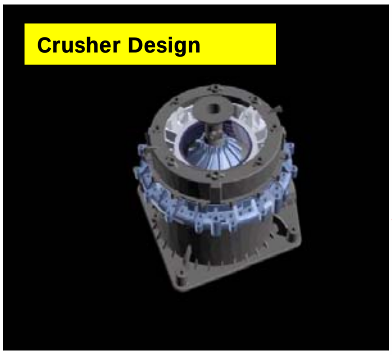
Hidraulic Fracturing **and / or** **Industrial Explosives And Precise Detonation**

Continuos and Automated Material Handling

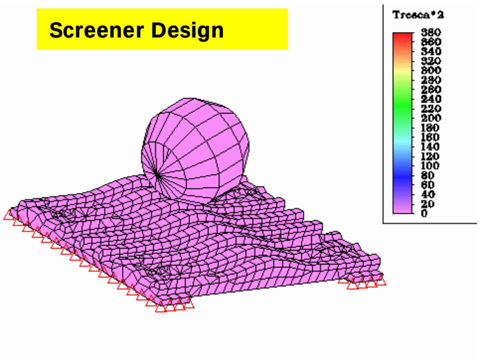


R&D
Mineral Processing

Crusher Design



Screener Design



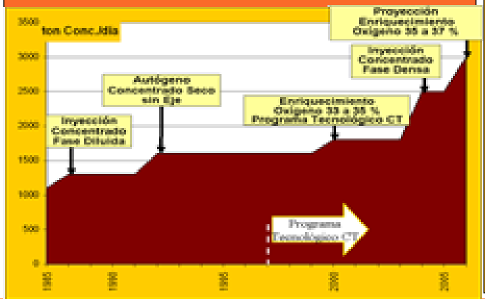
- **800.000 t/unit**
- **1.160.000 t/unit**

Result:

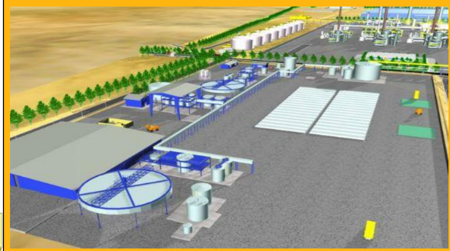
- 38% longer life

R&D
Smelter

Teniente Converter



Effluent Treatment Plant



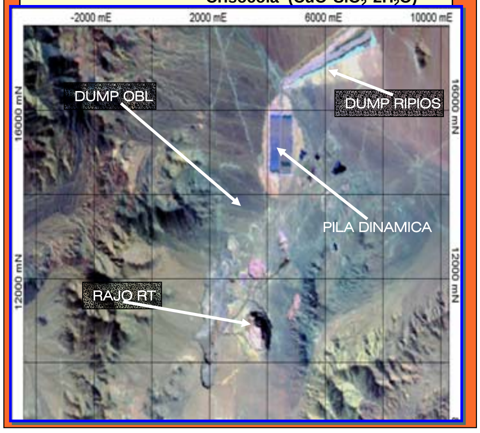
Benefits:

- 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 ($CuO*SiO_2*2H_2O$)

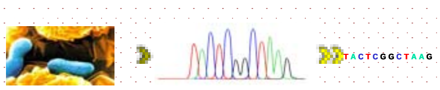


Acid Mist Suppression in EW Plant

Digital Inspection of EW Cathodes

R&D
Biomining

BioSigma **Alliance Copper**



Biotechnology for low grade ore processing

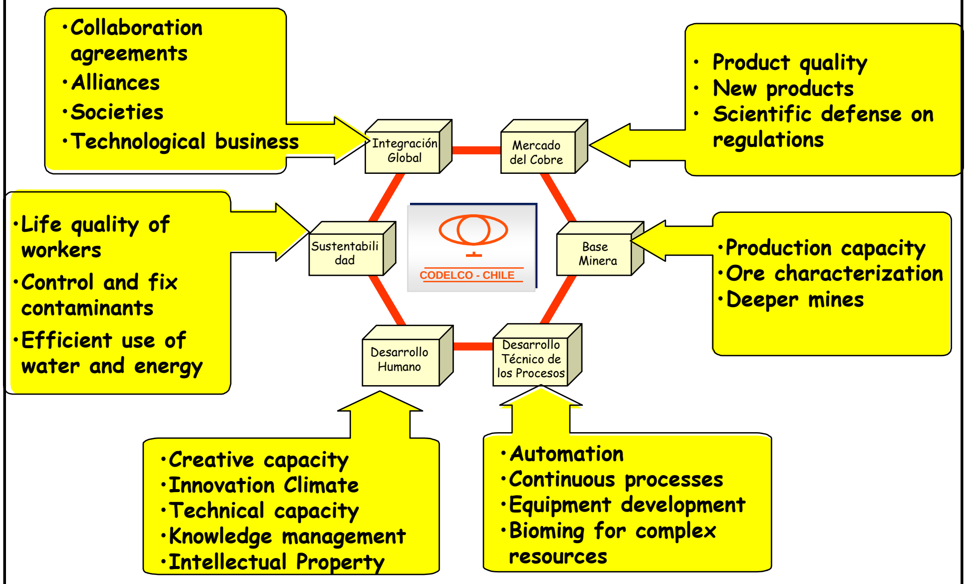
Industrial and Environmenmtal Microbiology

Genomic & proteomic of leaching microorganism

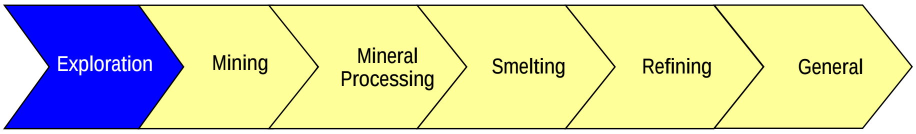
Develop, exploit and commercialize, bioleaching technology to process copper concentrate in agitated tanks.

Opportunities and Challenges in medium Term

Opportunities and Challenges in medium Term

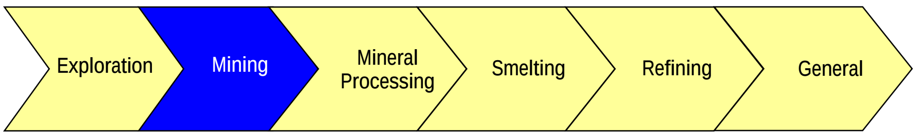


Future Technological Challenges



- **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

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

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

Future Technological Challenges

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

- **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

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

21, 22, 23 October 2004
Santiago Chile

Session 3: Policies for Improving Mining Energy Efficiency

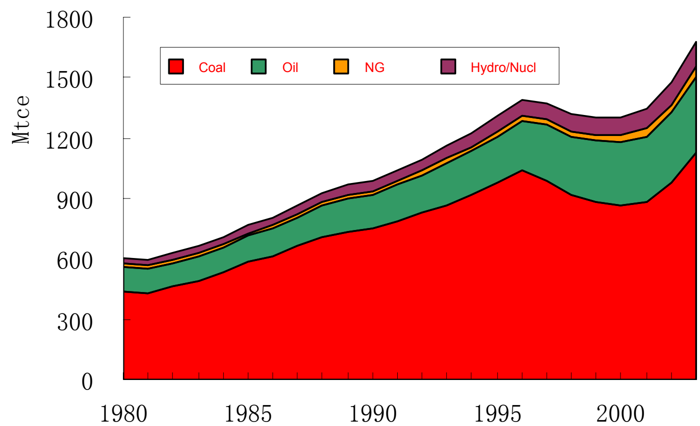
China's Energy Policy and Energy Efficiency Policies for Mining Industry

Yanjia Wang
Tsinghua University, China
Improving Energy Efficiency in the APEC Mining Industry
21-23 October 2004, Santiago Chile

Outline

- Energy Aspects in China– General and New Situation
- Outline of Medium-Long Term Energy Development Planning (2004-2020) (Draft)
- General Energy Efficiency Policies
- Energy Efficiency Policies for Mining Industry

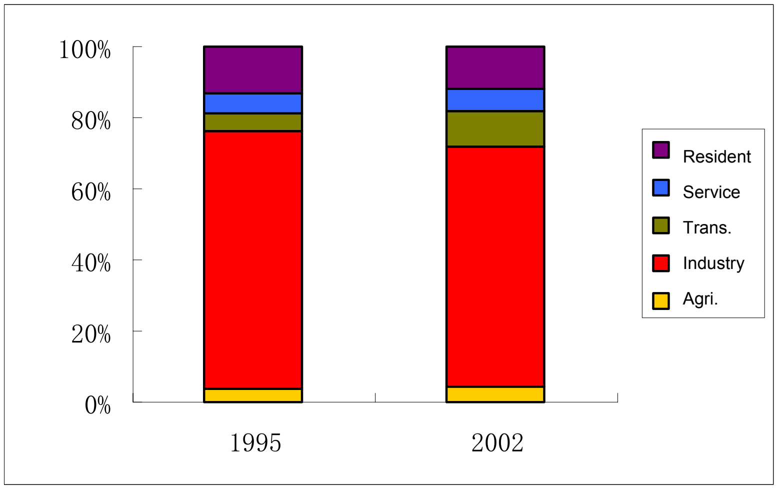
Primary Energy Consumption



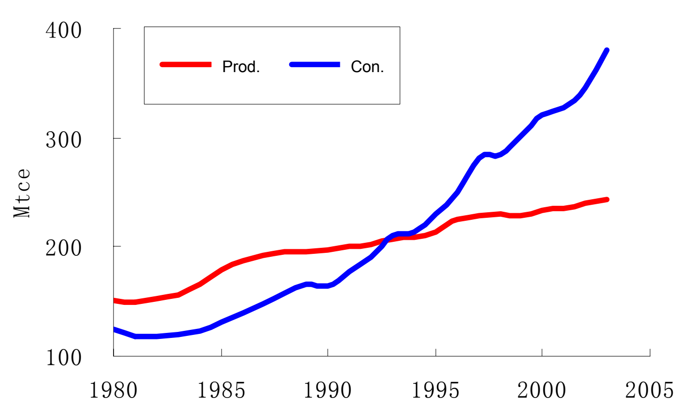
Primary Energy Mix（%）

	China				World
Year	1980	1990	2000	2003	2003
Coal	72.2	76.2	66.1	67.1	26.5
Oil	20.7	16.6	24.6	22.7	37.3
NG	3.1	2.1	2.5	2.8	23.9
Elec.	4.0	5.1	6.8	7.4	12.3

Industry is the Main Consumer



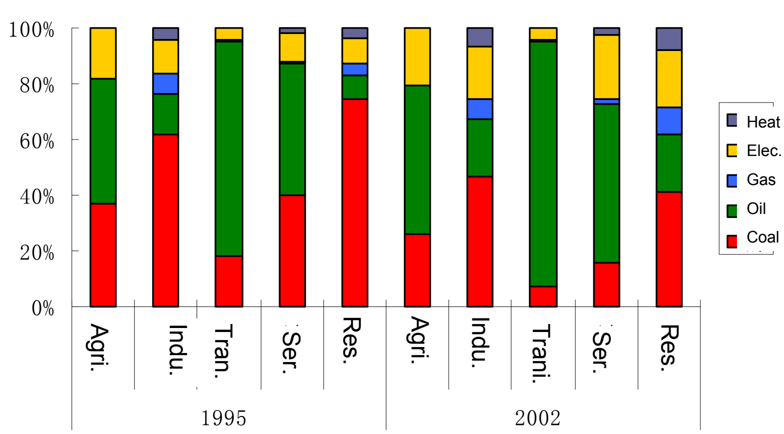
Higher and Higher Dependency on Import Oil



2nd Power Generation Industry in the World

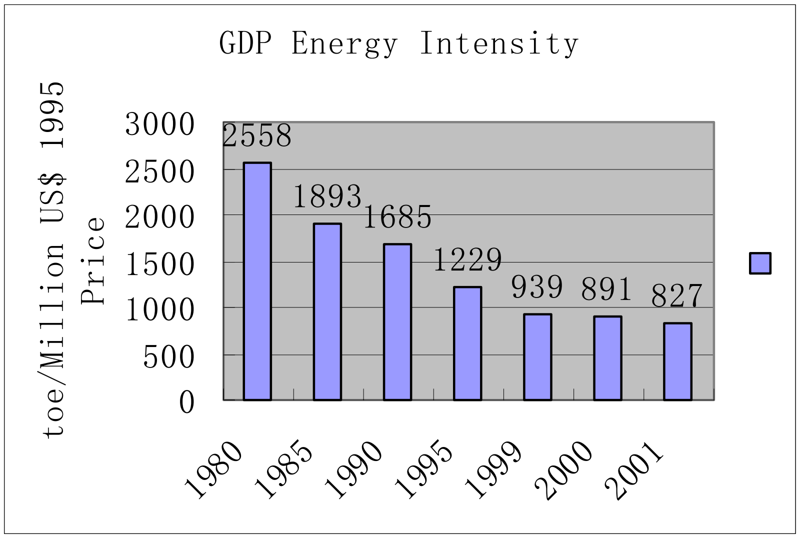
Year	Capacity/GW				Generation/TWh			
	Total	Thermal	Hydro	Nuclear	Total	Thermal	Hydro	Nuclear
1980	65.9	45.6	20.3		301	243	58	
1985	87.0	60.6	26.4		411	318	92	
1990	137.9	101.8	36.0		621	495	126	
1995	217.2	162.9	52.2	2.1	1007	807	187	13
2000	319.3	237.5	79.4	2.1	1369	1108	243	17
2001	338.5	253	83	2.1	1484	1205	261	18
2002	356.6	265.6	86	4.5	1654	1352	275	27
2003					1911			

Less Coal for Final Users

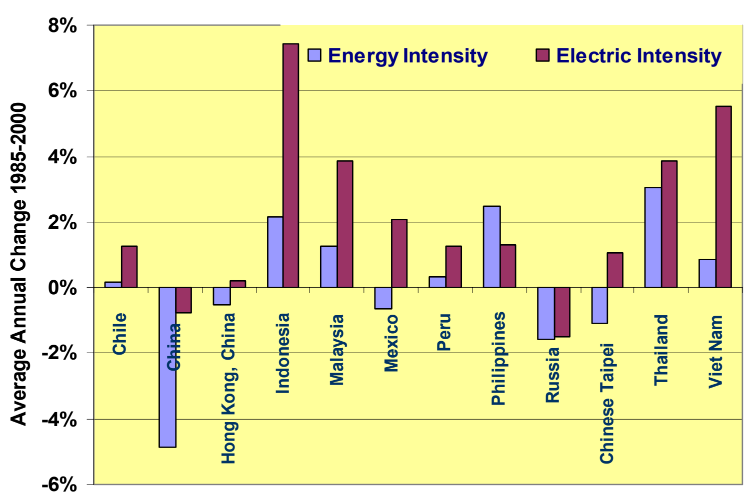


ENERGY EFFICIENCY IN CHINA

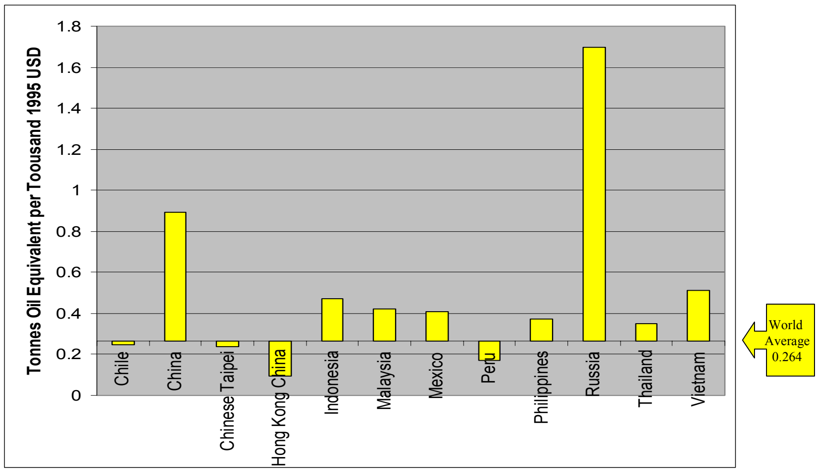
Source: Handbook of Energy & Economic Statistics in Japan, 2004



…has gone a long way



…but much remains …



Energy Intensity of Main Industrial Products

	Energy Intensity	1990	2000	2002	World Advanced
Power (including transmission loses)	gce/kWh	427	392	383	316
Steel (large-scale plant)	kgce/t	997	766	715	646
Cement (Large-scale)	kgce/t	201.1	193.8	172 (Estimated)	127.7
Ammonia (NG as feedstock)	kgce/t	1343	1273	1215	970

Driving Forces for Energy Conservation in China

- Energy shortage: black out, 3-day-stop and 4-day-run
- Cost reduction: pricing
- Pollution abetment: emission fee, fine
- Sustainable development

	1986		1996	
	Energy purchase cost (billion Yuan)	Proportion of energy cost (%)	Energy purchase cost (billion Yuan)	Proportion of energy cost (%)
Steel Industry	9.7	20.5	59.1	24
L/M plants	8.2	22	47.6	24.8

'Three Shortages and One Hot Topic'

- Three shortages: electricity, coal & oil
  - Quick switch from surplus to shortage
  - Broad range– 24 out of 29 provinces
  - Shortage in coal
- One hot topic: energy development strategy
  - Sustainable development strategy for oil and gas
  - Energy science and technology development planning
  - Outline of medium-long term energy development planning (2004-2020) (draft)

Outline of Medium-Long Term Energy Development Planning (2004-2020) (Draft)

- Main points:

1. Top priority given to energy conservation and efficiency improvement
2. To make adjustments on energy profile– coal dominant, power oriented, as well as oil, natural gas and new energy
3. Better distribution of energy facilities– east and west, urban and rural, transportation capacity

Outline of Medium-Long Term Energy Development Planning (2004-2020) (Draft)

- Main points:

4. Full utilization of domestic and overseas resources and markets– self sufficient and international cooperation
5. Rely on technology innovations
6. Make great efforts on minimizing environmental impacts by energy production and consumption

Outline of Medium-Long Term Energy Development Planning (2004-2020) (Draft)

- Main points:

7. Full attention given to energy security–diversification, stockpiles
8. Improvement of energy policy-making

Main Areas of Technology Development

1. Energy efficiency technologies
2. Higher efficient and cleaner utilization of coal
3. Technical system to support oil security
4. Advanced nuclear power technologies
5. Large-scale hydropower generation technologies
6. Increasing reliability of power grids
7. Renewable energy
8. Hydrogen and fuel cell

Energy Efficiency Policies

1. Administrative regulations
2. Energy efficiency management system
3. Laws and legal regulations
4. Financial incentives
5. Energy standards and labels
6. Voluntary agreements

Evolution of Energy Efficiency Policy in China

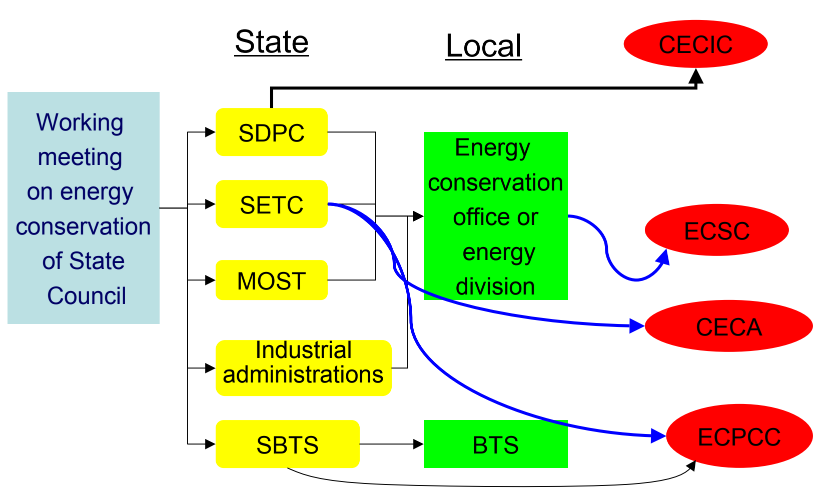
- ✓ Energy consumption quota (1980's)
- ✓ Publish guidance catalogues for technologies of comprehensive utilization and investment in energy conservation to provide investment direction for enterprises and financial organizations (1990's)
- ✓ Shutdown the small-scale, energy intensive industries (1990's)
- ✓ Policy Outline for Energy-Saving Technologies (1997)
- ✓ Outline for CHP Development (1998)
- ✓ Energy Conservation Law (January 1st 1998)

Evolution of Energy Efficiency Policy in China (cont'd)

- ✓ Energy conservation management system in key energy consuming entities(1999)
- ✓ Regulations on electricity consumption conservation (2000)
- ✓ Energy efficiency voluntary agreement for steel industry (pilot, 2002)
- ✓ Clean Production Promotion Law (Jan. 1st 2003)
- ✓ Environmental Impact Assessment Law (Sept. 1st 2003)
- ✓ Local regulations

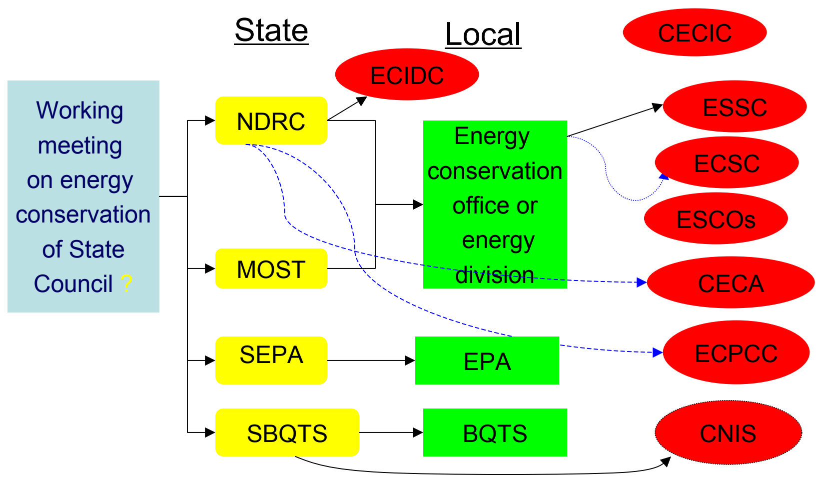
Energy Efficiency Management System

(planning economics orientated)



Energy Efficiency Management System

(take the advantages of market economics)



Energy Standards & Labels

- Appliance standards:Room A/Cs, audio radio receivers and recorders, clothes washers, fans, irons, refrigerators, rice cookers, TVs (1989 implementation, 1995 mandatory), fluorescent lamp ballasts (2000, mandatory) .
- Energy efficiency product certification system (1998)
- Appliance labelling (Voluntary): Refrigerator/freezers and combinations (1999), Lamps (2000)
- Energy-consuming equipment (design) standards: Industrial boiler, motor, fan, pump, transformer, automobile…
- Building codes for new buildings (Oct. 1st 2000, mandatory)
- New Standards for above products (2003-2006)

Financial Incentives

- Fixed asset tax exemption – investments in cogeneration facilities and energy efficient buildings(0%)
- Value added import tax exemption – importation of energy efficient and pollution reduction equipment
- Income tax exemption – projects that use advanced technology such as CBM are exempted from income taxes for the first 5 years
- Government subsidy low interest loan for energy conservation project(30% lower), technology demonstration project (50% lower) and pay the bank out of pretax income (before 1994)

Energy Efficiency Target

Double energy consumption to support fourfold GDP development target

- 50% reduction on energy intensity

Differences of Definition of Mining Industry

- Definition in China

  Mining and Quarrying Industry

  Ferrous Metals Mining and Dressing

  Nonferrous Metals Mining and Dressing

  Coal, Oil, NG, Nonmetal, Other Minerals, Timber and Bamboo

  Manufacturing Industry

  Smelting and Pressing of Ferrous Metals

  Smelting and Pressing of Nonferrous Metals

  Others

General Data of Mining Industry (2001)

Source: China Statistical Yearbook 2002

- Number of Enterprises: 7955 (4.64% of total industry)
- Gross Industrial Output Value: $106 billion(9.10% of total industry)
- Value-added: $ 28 billion(8.25% of total industry)
- Total Assets: $214 billion (10.23% of total industry)
- Total Final Energy Consumption: 164.7 million tce (26.4% of total industry)

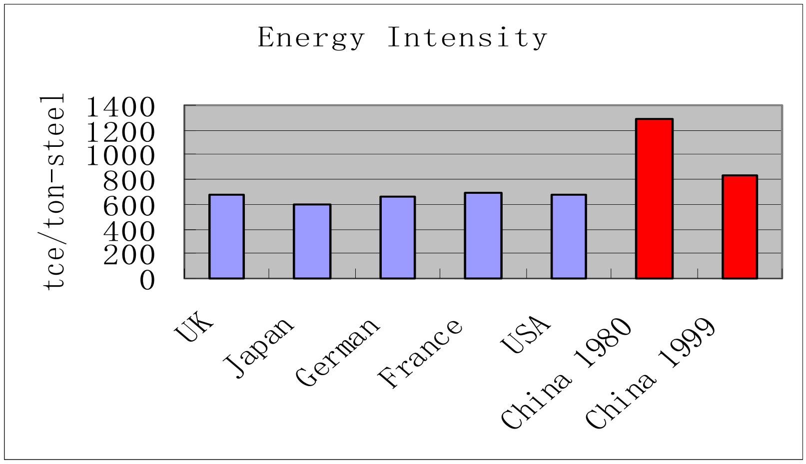
Energy Efficiency Policies for Mining Industry

- In general, no specific policies for mining industry
- More attentions given to downstream (energy consumption: upstream 2.3%, downstream 97.7%, iron & steel 85.6%)
- Tow steel plants were selected for demonstrating energy efficiency voluntary agreement

Adoption of Efficiency Technologies in Iron & Steel Industry

Available Technologies	Energy Recovery
Heat recovery from coke dry quenching (CDQ)	2000 kJ/ton-coke
Top pressure recovery turbine (TRT)	20-30 kWh/ton pig iron
Basic oxygen furnace gas recovery	0.37-0.84 GJ/ton-steel
Blast furnace gas recovery	2.24 GJ/ ton pig iron
Direct-current electric arc furnace (DC-EAF)	Decrease 3-5% electricity consumption

… a long way to go



ENERGY EFFICIENCY IN THE MINING INDUSTRY:
OPPORTUNITIES AND INSTITUTIONAL DESIGN

MALDONADO, PEDRO
Programa de Estudios e Investigaciones en Energía
Instituto de Asuntos Públicos
Universidad de Chile

1. INTRODUCTION

1.1 The energy efficiency as a strategic option for the copper industry.

The goal of this paper is to show the potentials of an energy efficiency policy in the copper industry, the barriers and the main components of such a policy. In order to highlight the pertinence of the efforts performed in this direction by our research team and the copper industry professionals, it is necessary to point out that Chile represents around 40% of the world copper production [1], [2].

For the companies involved in this kind of initiative, a successful energy efficiency project will allow it to reduce the production costs, to improve the productivity and to introduce the energy management into the environmental integrated systems, established in the context of the ISO 14 000 certification

On the other hand, the copper industry is responsible for an important percentage of the Chilean direct and indirect emissions of greenhouse gases (GHG) [3]. Even if Chile is not a signatory of the Kyoto protocol, it doesn’t mean that the country will not assume a part of the world efforts aiming to mitigate GHG, being the energy efficiency (EE) one of the most effective and profitable alternatives to achieve significant results in this field. It is almost certain that the Chilean copper industry will play an important role in the achievement of national GHG voluntarily assumed mitigation goals.

Even if most of efforts have been oriented to the improvement of the electricity use efficiency, it doesn't imply that the EE institutional building, the mechanisms, incentives and instructives conceived are not applied to fuels consumption as well.

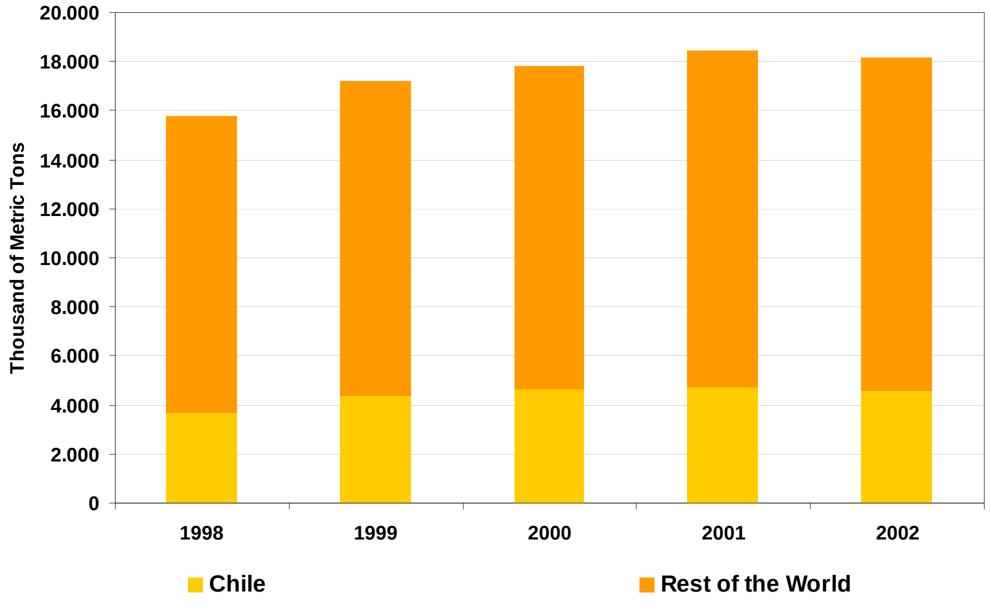
The importance assigned to the electricity is explained by the fact that the technological trends in copper smelters point to an autogenous operation, as a result of the extended use of technologies like the Teniente converter and Flash furnace replacing the reverberatory furnace and also due to the growing importance of the hydrometallurgical copper extraction process in relation to the conventional pirometallurgical process.

It should be said that the mining industry has performed some punctual and isolated efforts (the examples included in this paper show their results), but they should be considered as individual initiatives rather than a company policy. The results of the successful experiences, from the technical and economical point of view, had not been appropriately communicated and they are practically unknown to most of the workers of the related company. Finally, even if in some cases there are incentive payments for EE improvements, they don’t have effectiveness because they are excessively global, voiding the expected motivation for technological innovation.

2. COPPER MINING INDUSTRY: PRODUCTION AND ENERGY CONSUMPTION

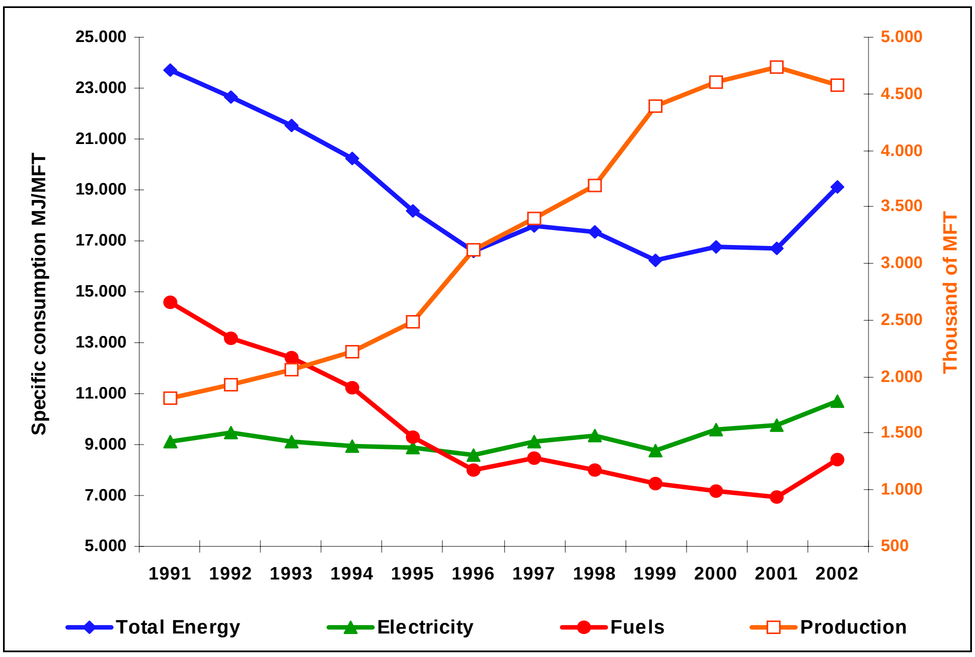
The following graph shows the relative importance of the Chilean copper production at the world level and their recent evolution.

Graph I:
World and Chilean copper production
(thousand metric tons of copper content)

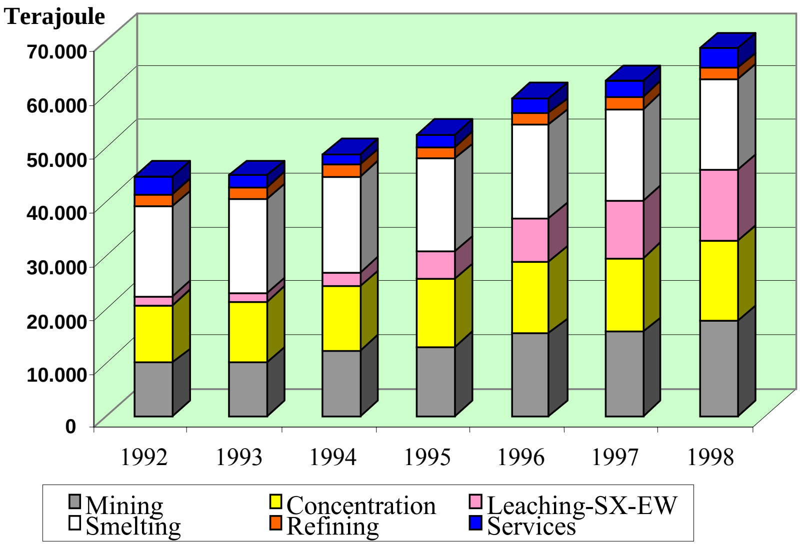


The following graphs summarized the evolution of the energy consumption by fuel and process. The technological changes already mentioned explain the significant trend changes shown in relation with the production and energy consumption, this is mainly the case of the fuels which reflects the effects of the refer change, by the other hand the slow increase of electricity consumption reflect the augmentation on oxygen requirements and the increasing importance of the hydrometallurgical process.

Graph II:
Copper mining specific energy consumption



Graph III:
Total Energy Consumption on Copper Mining



3. THE MINING INDUSTRY AND THE ENERGY EFFICIENCY CHALLENGES

It should be pointed out that the mining companies have unusual favorable conditions for a successful implementation of the EE measures. Indeed, those companies, because of their worldwide importance, have not only enough financial resources to invest in profitable EE projects but also a technical staff highly qualified, which, unfortunately, is not assigned to tasks related to energy management. Finally, in many cases the top management considers energy efficiency as an important subject. Cost reduction requirements and global competitiveness are also significant drivers for EE for the diffusion of energy efficiency technologies and good energy management practices. However, in spite of the favorable conditions described, the significant potentialities detected in some of them remain simply as mere potentials, because of the barriers detected by the University's research team .

3.1 Saving potentials

In one of the largest copper companies, object of the main analysis and source of the "replicable projects" described below, saving potential was estimated as a 15% of the present energy consumption. The EE actions considered were those technically feasible and also cost effective for the areas, processes or facilities where the selected technologies are supposed would be implemented.

Chart I
Saving potential results of the improvement options

Improvement options	Saving amount	Units
Operational improvements	226	GWh/year
Replicable projects	68	GWh/year
Benchmarking references	246	GWh/year
Others	99	GWh/year
TOTAL	639	GWh/year
% of the company consumption	15	%

If it is considered, for the referred company, an average electricity cost of 5¢/kwh, the estimated saving would be over US$30 millions/year, goal that would be reached in about ten years and under the conditions that an EE policy may modify the present situation. Indeed, the materialization of the savings indicated in the previous chart demands the implementation of a strong EE policy, whose success will depend on the highest management commitment. This commitment should be expressed by an adequate institutional framework; a master plan known by all workers, verifiable and periodically updated; a set of mechanisms and incentive payments; and control, follow up and monitoring systems [4].

3.2 Some examples of replicable projects

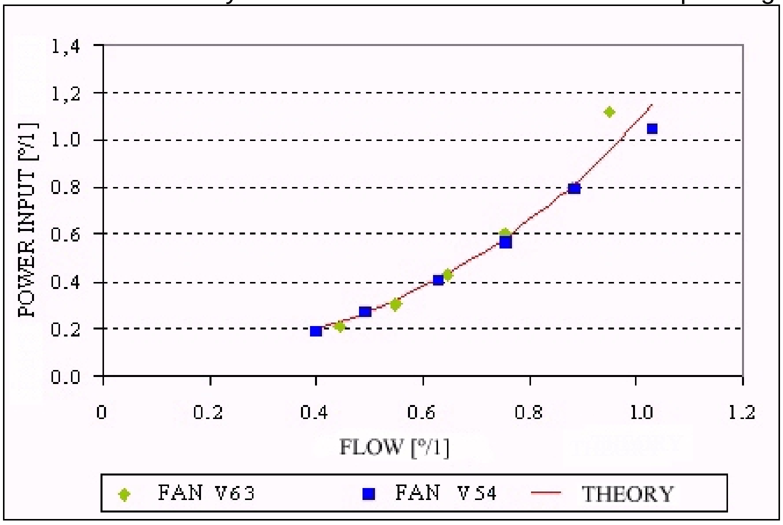
3.2.1 Application of frequency converters in the mine ventilation: savings achieved.

The introduction of frequency converters in the ventilation of an underground mine was evaluated during the first phase of the project [7], [8]. The analysis performed allows the empirical verification of the lineal relationship frequency-flow and the cubic relationship power-flow. The total savings estimated amount to 35%. The following graph summarizes the result obtained from two fans, 562 kW and 814.000 cfm and 341 kW and 717.000 cfm, respectively.

The theoretical model, relating flow and frequency, is Q = 1,15f–0,163;

And the model relating power consumed by the fan and the flow, is:
Pelectricity = 0,0214 (Q(0,318 (0,683 Q2)/0,951

Graph IV.
Power consumption versus air flow
Both models were confirmed by the field measurements of the corresponding parameters



3.2.2 Efficient lighting introduction in an specific area of one of the company facilities

It was analyzed the results of an efficient lighting project implemented in the smelter in one of the company facilities. The results show an improvement in the level of lighting, which presently are under the lighting standard requirements and a reduction in the energy consumption over 60% in relation to the present one.

The following chart shows the present consumption in lighting in the mentioned smelter. It should be noted that the lighting level was extremely below the international standards.

Chart II
Lighting levels before the project

Area of the smelter	**LIGHTING LEVEL [LUX]**			
	Minimum	Maximum	Average	Recommended
Anode and blister	40	250	141	300
Smelting	22	114	49	150
Oxygen and air	10	102	63	250
Load preparation	15	106	51	150

The next chart shows that the project under implementation not only reduces energy consumption but also improves in a significant way the level of lighting, fulfilling the standards requested by the smelter manager. The following table summarizes the project results.

Chart III
Project results: lighting levels and energy savings

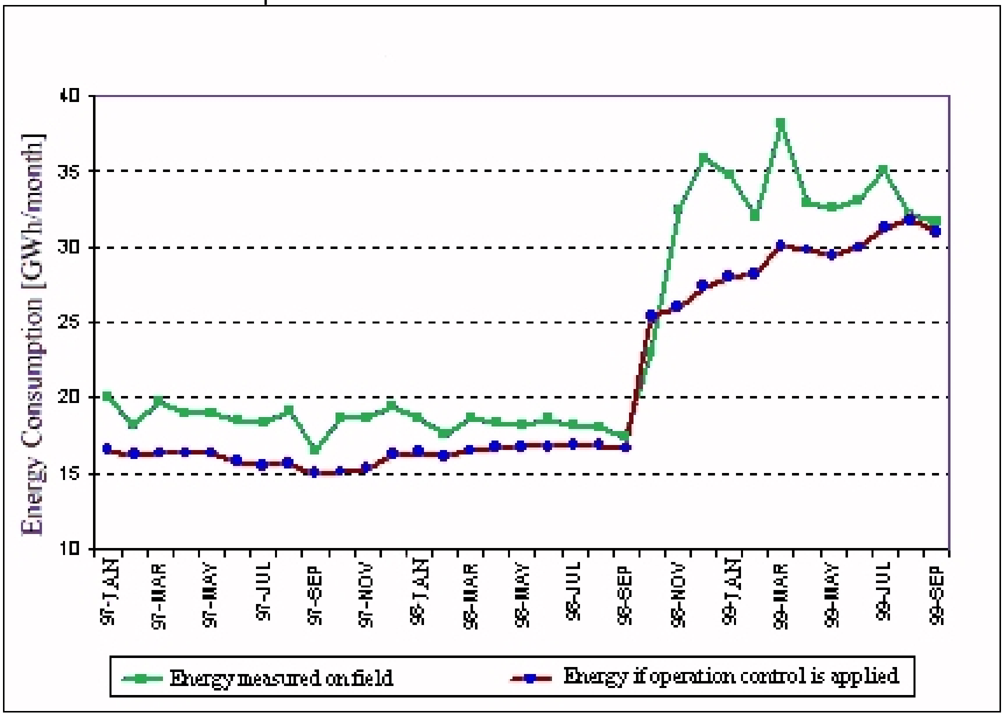
ÁREA OF SMELTER	**Lighting level [lux]**			**Power [kW]**		**Savings**
	present	proyect	standard	installed	proyect	MWh/year
Anode and blister	141	305	300	40.55	18.78	190.71
Smelting	49	180	170	99.06	37.50	539.26
Oxygen and air	63	257	250	33.73	11.10	198.20
Load preparation	51	137	123	39.51	16.59	485.39
TOTAL				**260.20**	**98.83**	**1,413.56**

3.2.3 Energy savings in the mineral concentration as a result of an improvement of operation control.

It was evaluated, for the concentration of minerals, the impact of a tight control of the operation in the different areas of the concentration process: primary and secondary crushing; tertiary and quaternary crushing; conventional milling; unitary milling; SAG milling and flotation. As a result of a simulation it was detected that an improvement in the operation control could be converted into savings amounting from 12% to 14% of the present consumption. The mineral concentration was selected as a demonstration example of the potential improvements to be obtained with a tight production control, as far as the same approach could be applied to other production areas.

The evolution of the specific consumption (EC) was followed during around 30 months, assuming that is adopted a tight operation control. In a conservative approach, it was considered as easily obtainable the third lowest specific consumption as an operational goal for the period of time analyzed (it should be pointed out that using monthly specific consumptions it is clearly, also a conservative approach) . The results are shown in the following graph, which compares the energy actually measured with the energy that the control will allow to obtain.

Graph V.
Operation control results in the concentrator



3.2.4 Load management: a successful experience.

In one of the facilities of the company it was carried out an effort to manage the maximum demand, being able to reduce this demand in 6 MW, what implied an annual saving of US $537.500, since according to the tariffs regulation, the impacts of the plan has effect 12 months after having adopted the corresponding change. Having this demand control, supposing constant the electric requirements (constant production), it is possible to reach a saving of US $758.900 and, as a result of the acquired learning it is possible to reach savings for US $1.012.000 per year in the near future.

3.3 Ex-post evaluation of high efficiency motor purchase

The company purchased 135 high efficiency motors adding up 18.000 HP (13 MW installed), with a consumption of around 94.000 MWh/year. The motor selection was done considering that are going to operate in a very aggressive environment. A suitable and tight predictive maintenance procedures and practices were implemented.

Even if the incremental investment due the purchase of more expensive motors was more than US$ 400.000, the benefits evaluated largely exceeded the investment cost, mainly due to the increase of the production reliability. In fact, the fails reduction, the increase on the maintenance span and the reduction of unexpected fails associated to the preventive maintenance generate higher monetary benefits than those related to the energy savings.

The following chart summarizes the results of an adequate motor selection and preventive maintenance program.

Chart IV
Benefits associated with motors in a risky scenario

Type of benefits	**Economic benefits (US$/year)**	**Assumptions**
Failure reduction	430.000	Annual failures reduced by one. Production reduced from 860 tons/day to 378 tons/day
Increased maintenance time span	175.000	A gain of 6 hours production due to maintenance delay
Reduction of unproductive time due to predictive maintenance	135.000	Time maintenance for unexpected failure: 12 hours and for planned stop: 6 hours
Energy savings	145.000	

3.4. Obstacles to energy efficiency

Although the main copper producers are relatively more sensitive to price signals than other industrial sectors and disposed to adopt investment decisions in function of their relative profitability, the national experience and even the international one, demonstrates that they invest insufficiently in energy efficiency for several reasons.

Even if some of the obstacles enumerated below (only the main obstacles are included here) are similar to those described by the specialized literature or they can be found in many international companies [5], it should be said that they are also present in most of the main Chilean copper companies. For the previous reasons, it is not necessary to describe in detail the barriers synthesized below:

- There isn't an explicit EE policy from which we can work out or establish objectives, goals, terms, procedures, incentive payments, resources and control, evaluation and monitoring programs.

- There isn't a specialized unit in charge of, among other tasks, mechanisms and incentive payments design, the identification and evaluation of technological options and the verification of procedure applications.

- There isn’t any goal for energy efficiency sufficiently scheduled in order to allow the evaluation of specific improvements and to consider the exogenous factors that affect the performance expected of the actions implemented.

- The incentives to EE, when they exist, are insufficient to motivate innovations and, in general, they don't give a reward to the people involved in the promotion and implementation of the EE project.

- There are difficulties to verify the accomplishment of the foreseen savings, because there aren’t any methodologies specially developed for this effect and recognized by the workers involved.

- Due to the investments approval procedures, it is easier to repair obsolete and highly expensive operation equipments than to purchase an efficient and cost effective equipment.

- Discontinuity in the efforts to improve the energy efficiency and lack of support to the teams or individuals that deploy those efforts.

- Insufficient endowment of instruments for electrical variables measurement in order to evaluate the efficiency of the installed equipments or to carry out reception test for equipment sent to the maintenance shop for important repairs (i.e. rewinding), difficulty to justify investments aiming at replacing inefficient equipments for others whose cycle of life costs are lower.

4. ENERGY EFFICIENCY POLICY

The barriers to EE mentioned above, and the research team experience, demonstrate that it is central and efficient to establish at the company a strong and deeply spread out energy policy. This policy should be made explicit by directives issued by the corporate top management, also is required an institutional framework devoted to energy efficiency, the existence of appropriate incentives and the corresponding guidelines.

4.1. Energy efficiency directives

Energy efficiency directives should be prepared for the top management consideration and approval. A detailed development of these directives is considered out of the scope in this paper. The main subjects to be included in the directives could be:

- Actions oriented to the development of the energy sources
- Actions in order to improve the efficiency on energy uses
- Energy management tools
- Legal and institutional aspects

4.2 Institutional framework

As it was pointed out, it becomes necessary to generate an institutional framework having a leadership, coordination, advisory, identification, evaluation, control and monitoring capability oriented to improve the efficiency in the company’s energy use. This should be understood in the context of an EE policy generated, introduced and supported by the highest level of the company management and turned into written and compulsory procedures that imply the production, service and administrative areas.

To reach the foreseen objectives and to insure that the important energy saving potentials are attained, it is suggested, in a schematic way, some of the elements that could define an organizational structure, at the holding and facility level, devoted to carry out the tasks deriving from the directives established in this field.

4.2.1 Holding level

At the holding level it is suggested to appoint an expert responsible for the application, follow up and evaluation of the holding EE policy, for the definition –jointly with facility staff- of facilities and holding goals, to evaluate the accomplishment of those goals, to evaluate the requirements of human and financial resources derived from the tasks demanded by the establishment and development of the company EE policy and inform results and to recommend to the company executive chairman the changes to the policy.

4.2.2 Facility level

At the facility level it is suggested the appointment of someone responsible for looking after the energy efficiency and the accomplishment of the global and detailed goals established for each of the main production and process areas, which concentrate the energy consumption (i.e. mining, mineral concentration, smelting, electrowinning and electrorefining). It is considered that this professional should have an exclusive and highly-priority dedication to the subject and should be directly below the area manager.

Also, it is considered necessary the existence –at each facility- of a specialized group in charge of the technical assistance given to the responsible of EE, in each of the main areas or processes mentioned previously, so as to accomplish the goals established to them.

After overcoming successfully this starting stage, the financial sources or incomes should derive from their services sale to the mentioned areas, this will be feasible if each area has to fulfill exactly the EE goals. In relation to the group size, it should be conformed by a specialist with a wide experience in the use of the energy, 2 to 3 engineers and 1 analyst.

4.3 Incentives and energy goals

An EE policy should overcome the internal barriers of the massive introduction of EE technologies. The experience shows that even if these technologies could be very attractive from the economic point of view, they are not always implemented in a spontaneous way, since they have to face technical, administrative and/or organizational barriers and, even, cultural obstacles. Obstacles such as: risk aversion to innovation, priorities assigned to other operation subjects and loose goals of energy consumption, are more important than the incentive payments. The EE subject is not included in the topics of concern for those in charge of operation audit and monitoring.

In order to insure that the efficiency indicators will fulfill what is expected, they should be simultaneously: global, detailed by areas, relevant from the energy consumptions point of view, representatives of an area or process or important machine, allow for comparison along the time and be linked to an instrumentation system insuring the energy consumption measuring of an area.

4.4 Guidelines and rules

4.4.1 Substitution of non profitable operation equipments.

It should be defined the rules for the substitution of: electric motors, distribution transformers, conductors and cables for distribution [6], lighting systems, considering the relative efficiency, differential investments (considering if the existing equipment should be repaired or not), efficiency estimation of the existing equipments, usual number of years considered in this type of analysis and financial parameters used by the company (the equipments to be replaced were identified by their serial number, power and installation place).

The suggested rule is based on the evaluation of the costs of the cycle of life of the alternatives in comparison, the existing equipment and the equivalent energetically efficient equipment. For instance, it was analyzed the case of electrical motors that present a high flaw rate (also defined as obsolete motors), normally operating under high mechanical stress or installed in areas contaminated with powder or corrosive substances.

The maintenance history of motors was analyzed, selecting those that had been subjected to more than 2 main repairs (rewinding or axle change). As a result of these analysis, it was estimated the probability of flaw for an obsolete motor and for an efficient new motor, in a 5 year-horizon. A simulation probability model was built in order to determine the moment and probability of occurrence for the next flaw.

Defined the respective flaw probabilities - for an installed motor that should be repaired or it is foreseen that it will fail soon and for an equivalent, but new and efficient motor-, the repair costs plus the costs of motor removing and reinstalling, it is estimated the cash flow that allows us to compare both alternatives. The approach developed should be considered as an innovation in relation to the conventional one, because in this new approach it is suggested a comparison between the present value of the cost of the possible future repairs corresponding to the eventual flaws of each alternatives.

4.4.2 Bidding specifications and bid evaluation method for electrical equipments required by new projects and facilities enlargement.

It should be defined, during the first phase of the project, the bidding procedures for new projects, including the specification, quotation conditions, analysis of alternatives and decision approach based on the life cycle costs of the different equipments: motors, transformers, cables and conductors, etc.

5. CONCLUSIONS

The author experience seems to prove that energy efficiency can be implemented in some specific enterprises, without a public policy in the field, but in order to get success in this challenge it is absolutely necessary to fulfill certain conditions [9].

The experience proves that the copper mining industry present favorable conditions to implement an energy efficiency program, because it is possible to obtain the support from the higher management level and also because financial resources for energy efficiency investment and a very qualified staff are potentially available, but this is not enough. Barriers to energy efficiency -similar to those existing in other companies around the world, not matter how sophisticated they could be, should be surmounted through the commitment of everybody and as the result of a relatively long process.

What is needed, additionally to those previously mentioned conditions, is to get in place a strong energy efficiency policy, defined by: the corresponding company directives; highly qualified and administratively supported groups, in charge of the implementation of those directives; the existence of a master plan, known by everybody at the company, controlled and periodically updated, specific goals by main areas and processes and incentives payments subject to the accomplishment of those goals; and specific instructions, concerning: the bidding process where the energy user equipment is involved, the methodology to evaluate if you will repair it or purchase a new one, and finally if we will replace the obsolete equipments or equipments subject to highly probability to fail.

Reference

[1] PRIEN, International Institute for Energy Conservation (IIEC), National Resources Defense Council (NRDC) (1995-1996), “Uso Eficiente de la Electricidad en Chile 1994-2020”, Santiago, Chile.

[2] PRIEN. Universidad de Chile – CONAMA (1999). “Mitigación de Gases de Efecto Invernadero. Chile 1994-2020”, Santiago, Chile.

[3] PRIEN. Universidad de Chile - CONAMA (1996), “Inventario de Gases de Efecto Invernadero Provenientes del Sector Energético: Uso de Energía, Procesos Industriales, y Solventes”. Santiago, Chile.

[4] PRIEN (1995), “La Política de Uso Eficiente de la Energía. ¿Es el Mercado el Motor de Dicha Política?”, CEPAL, LC/R. 1569, Santiago, Chile.

[5] U.S. Office of Technology Assessment (1993), “Energy Eficiency: Challenges and Opportunities for Electric Utilities”, Washington, USA.

[6] PRIEN (1997), “Definición de las Orientaciones Básicas y Elementos de un Programa de Trabajo para la Puesta al Día de las Normas de Conductores y Cables Eléctricos”. Santiago, Chile.
[7] Nadel, Shepard, Greenberg, Katz, de Almeida (1991), “Energy-Efficient Motor Systems”. American Council for an Energy-Efficient Economy Series on Energy Conservation and Energy Policy.
[8] Nilsson L., Larson E. (1989)., “Technology Menu for Efficient Energy Use”, internal report, University of Lund-Environmental and Energy Systems Studies, Sweden.
[9] PRIEN (1997), “Conservación y Eficiencia Energética en la Minería”, Ministerio de Minería, Santiago, Chile.

International Workshop
Improving Energy Efficiency in the APEC Mining Industry

ENERGY EFFICIENCY IN THE MINING INDUSTRY: OPPORTUNITIES AND INSTITUTIONAL DESIGN

Pedro Maldonado

Instituto de Asuntos Públicos

Universidad de Chile

Santiago, Chile, October 21-23, 2004

CONTENTS

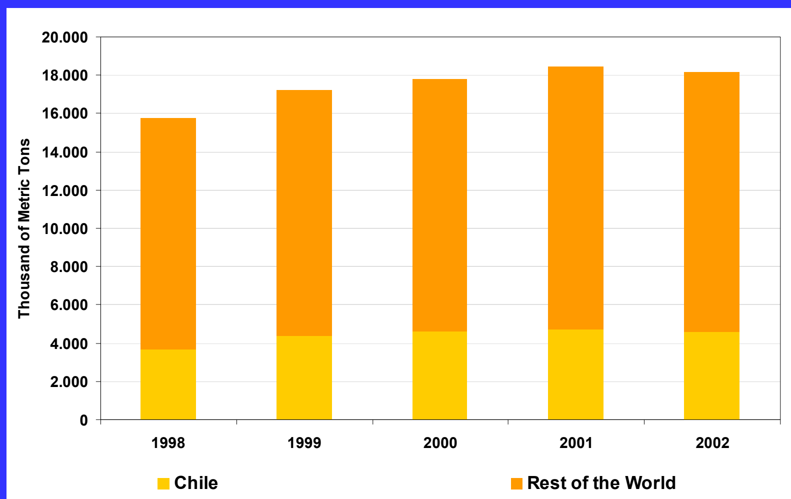
I. ENERGY EFFICIENCY: PRODUCTIVITY, GLOBAL COMPETITIVENESS AND MARKET EXPANSION

- **Energy efficiency and cost reduction**
- **Energy management and the industry commitment with an environmental integrated system (ISO 14 000)**
- **Copper industry leadership on energy efficiency: an effective tool to increase world copper demand (International Copper Association initiative)**

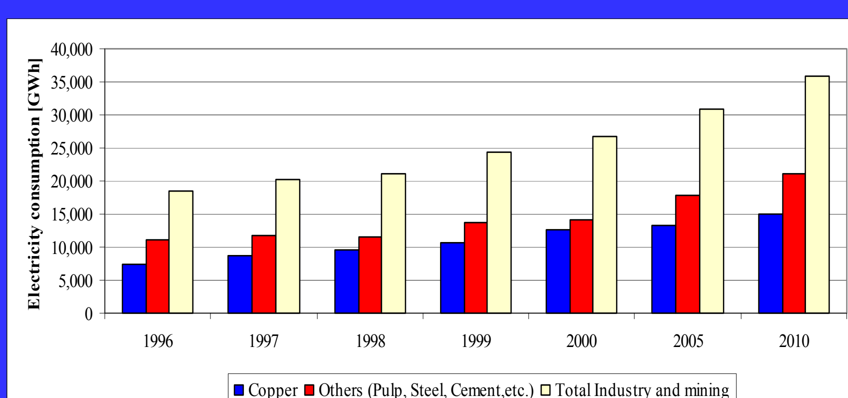
II. COPPER MINING INDUSTRY: PRODUCTION AND ENERGY CONSUMPTION

- **Chilean copper production**
- **Electricity consumption of copper industry in relation to other industries' consumption**
- **Evolution of specific energy consumption**
- **Energy consumption distribution in the copper industry**

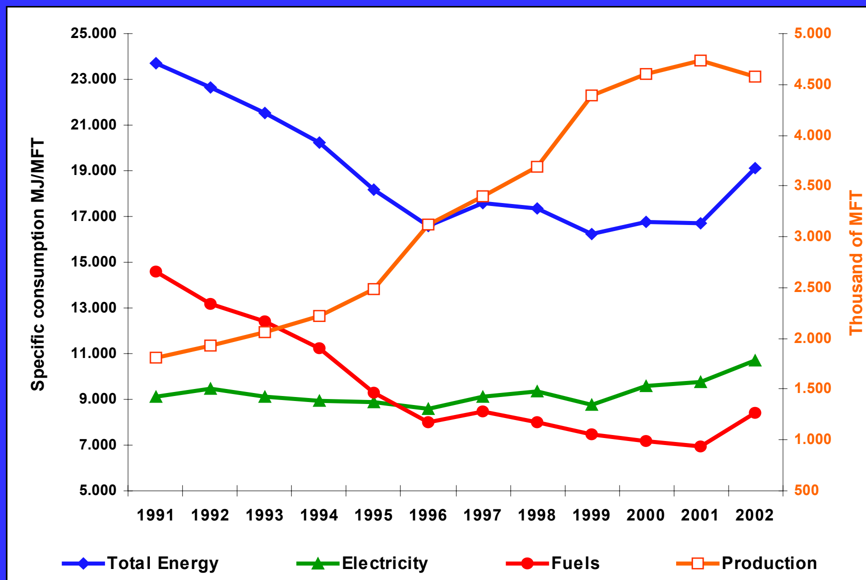
World and Chilean copper production (thousand metric tons of copper content)



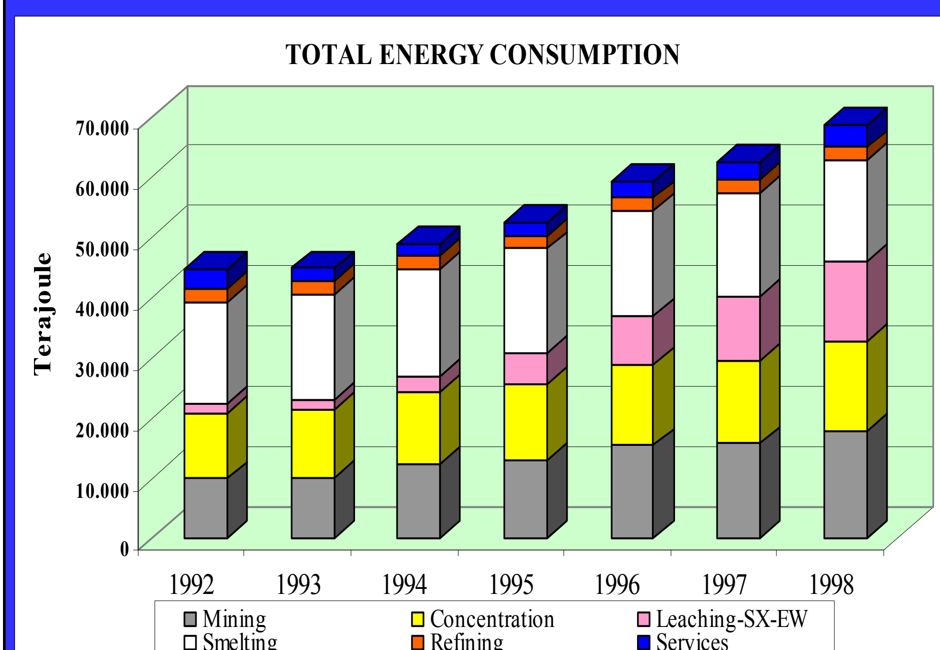
Industry and mining electricity consumption



Copper Mining Specific Energy Consumption



Based on CNE Energy Balances and COCHILCO, Production data



COCHILCO, 2001

III. THE MINING INDUSTRY AND THE ENERGY EFFICIENCY CHALLENGES

- Industry drivers and comparative advantages for diffusion of energy efficiency technologies and good energy management practices
  - Cost reduction requirements
  - Global competitiveness
  - Significant financial resources
  - Highly-qualified technical staff
- Isolated but important efforts underway
- Saving potentials: 15% (operational improvements, replicable projects, benchmarking references, etc)
- Examples with replication interest

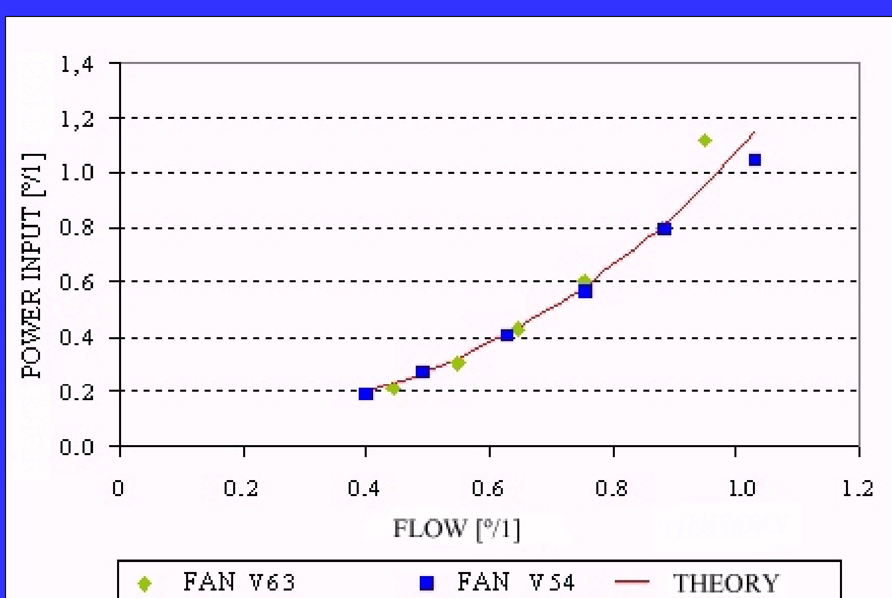
PROJECTS HAVING REPLICATION INTEREST

- Some examples of this kind of projects
  - Frequency converters in mine ventilation
  - Efficient lighting in the smelter area
  - Flotation cells multipole motor use
  - Load management
  - Operation control at the mineral concentration area
- Ex-post evaluation of high efficiency motor purchase

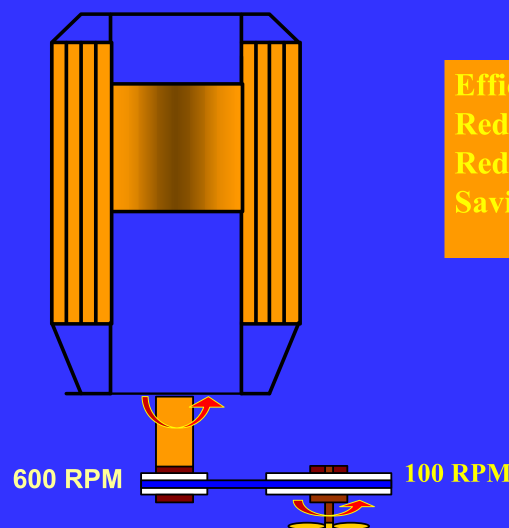
Project results: lighting levels and energy savings

SMELTER AREA	Lighting level [lux]			Power [kW]		Savings
	present	project	standard	installed	project	MWh/year
Anode and blister	141	305	300	40.55	18.78	190.71
Smelting and conversion	49	180	170	99.06	37.5	539.26
Oxygen and air	63	257	250	33.73	11.1	198.2
Load preparation	51	137	123	39.51	16.59	485.39
TOTAL				**260.2**	**98.83**	**1,413.56**

Power consumption versus air flow

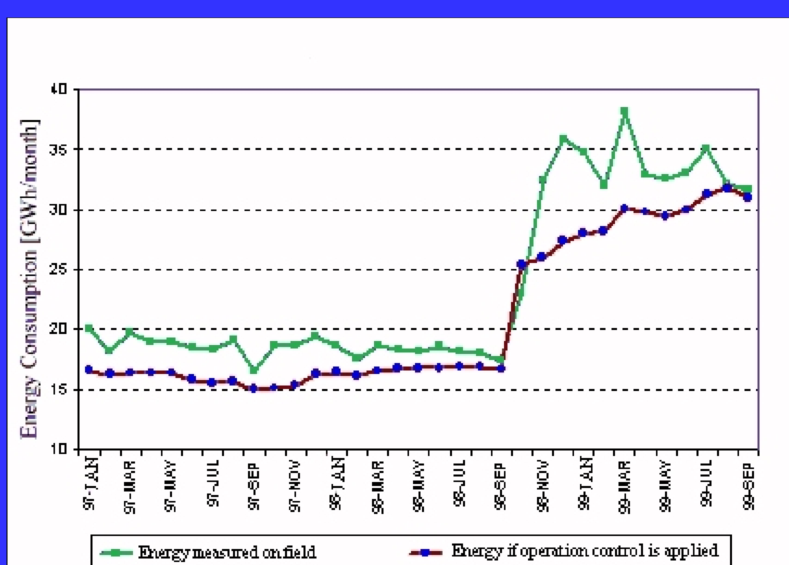


Multi pole motors for flotation cells

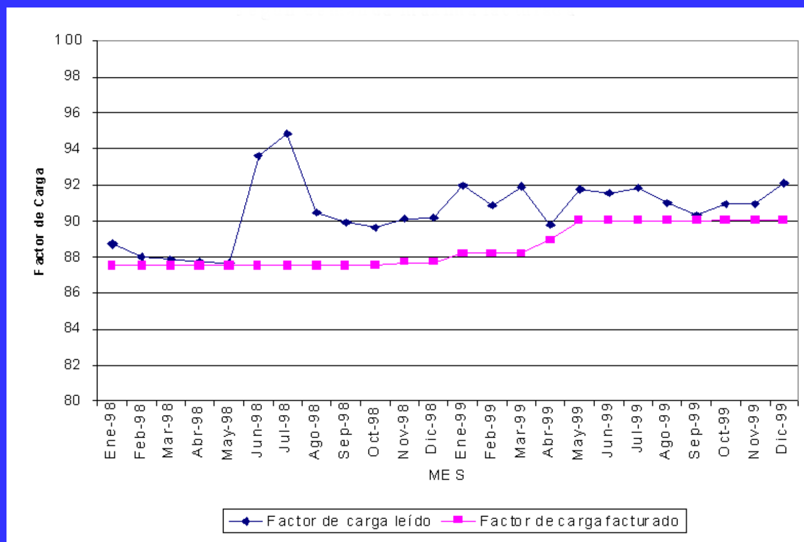


Efficient motor
Reduced flaws
Reduced noise
Savings around 10%

Operation control at the concentration area



Demand management



EX-POST EVALUATION OF HIGH EFFICIENCY MOTOR PURCHASE

- 135 high efficiency motors adding up 18.000 HP (13 MW installed), with a consumption of around 94.000 MWh/year were purchased to operate in a very aggresive environment and having very tigh predictive maintenance procedures and practices.
- The incremental investment was US$ 415.000
- Benefits were associated to the fails reduction, increase maintenance time span and reduction of unexpected fails due to preventive maintenance

Adequate selection and maintenance

Benefits associated with motors in a risky scenario

- Failure reduction due to specific working environment motor selection — US$ 427 177
- Increased maintenance time span — US$ 175 118
- Reduction of unproductive time due to predictive maintenance — US$ 133 297

Time maintenance for unexpected failure: 12 hours and for planned stop: 6 hours

Energy Savings: 143.833 US$/year

IV. OBSTACLES TO ENERGY EFFICIENCY

- Institutional and operational obstacles to energy efficiency
  - Non-existence of EE policy
  - EE organizational structure
  - EE procedures, incentives and goals
  - Instrumentation and maintenance

OBSTACLES TO ENERGY EFFICIENCY

- Lack of an explicit EE policy with established objectives, goals, procedures, incentives and resources, and of control, evaluation and monitoring programs
- Lack of a specialized unit at the holding and company divisions level in charge of the EE program
- The incentives to EE are insufficient to motivate innovations and, because they are so aggregate, they don't reward people involved in the identification and implementation of EE projects
- Investment approval procedures are an incentive to repair obsolete and expensive operation equipment instead of purchasing efficient ones
- Lack of infrastructure and methodologies to evaluate field and maintenance shop efficiency of existing motors

V. ENERGY EFFICIENCY POLICY

ENERGY EFFICIENCY DIRECTIVES

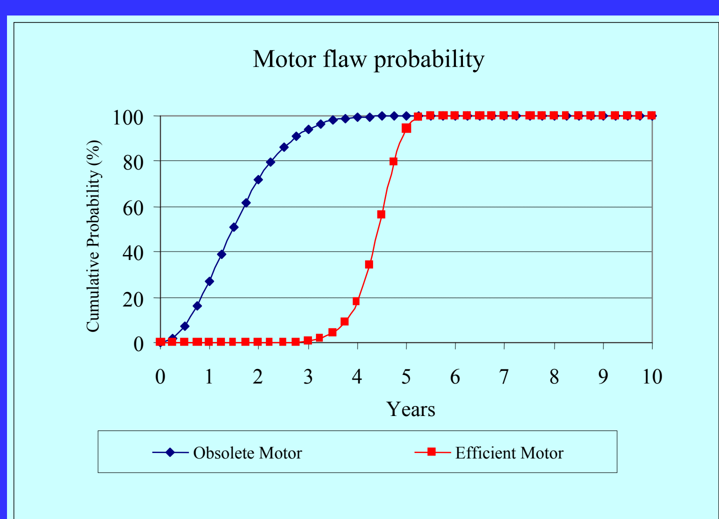
- Actions oriented to develop energy sources
- Actions oriented to improve the efficiency of energy use
- Energy management tools

INSTITUTIONAL FRAMEWORK

- Incentives and definition of energy goals
- Procedures

V. ENERGY EFFICIENCY POLICY(cont.)

- Procedures
  - Substitution of non-profitable operation equipment
  - Bidding specifications and bidding evaluation method for new project equipment (motors, lighting, transformers and distribution cables and conductors)
- Technical handbook for efficiency measurement of electrical motors in the field or at the maintenance shop after a major maintenance (i.e. rewind)



VI. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

- Innovation dynamics on EE should be introduced at the different facilities of the company
- The EE projects uses to generate synergies for transversal projects between
- Process reliability should be integrated for the substitution analysis of existing equipment

VI. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS (cont.)

- The following concepts should be introduced in a quantitative way for bidding evaluation
  - Maintenance costs and reliability
  - Energy consumption

VI. CONCLUSIONS AND RECOMMENDATIONS

6.2 RECOMMENDATIONS

- Adoption by the highest management of the EE directives, procedures, incentives and corresponding organizational structure
- Generate a methodology to monitor EE projects
- Generate adequate energy indicators for the main processes
- Insure permanent behavioral changes aiming to get a wide commitment for EE in the company

International Workshop
Improving Energy Efficiency in the APEC Mining Industry

ENERGY EFFICIENCY IN THE MINING INDUSTRY: OPPORTUNITIES AND INSTITUTIONAL DESIGN

Pedro Maldonado

Instituto de Asuntos Públicos

Universidad de Chile

Santiago, Chile, October 21-23, 2004

Asia-Pacific
Economic Cooperation

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

21, 22, 23 October 2004
Santiago Chile

Debate and Synthesis Session

DEBATE AND SYNTHESIS SESSION

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

The quality of the speeches, the variety of the topics developed along the Workshop and the level of the debate will, most probably, leave different seeds of learning inside the heads of the participants and these seeds will spring and grow up differently in each of them. Not with the idea of developing nor covering the topics in full nor within complex limits, we can make some general conclusions about the workshop or we can stand out issues to think of, among other issues, we can mention:

* *the importance of the electricity consumption in the minerals grinding as web as the multiplicity of parameters that take part in it*. In this aspect, the improvements aim at making better the materials feeding, reducing the wearing down of the inner coverings of the grinding machines, making better the design of the semi-autogeneous "lifters", minimize machine stoppings, optimize the size reductions, the products homogeneity and the mineral pulp flux. The simulations become central because the mills operation is similar is similar to the operation of a "black box".

* *along with the above-mentioned ideas, it is important to stand out some general tendencies in the menace or threat*. The improvements aim at, among other objectives, increasing the speed, increasing the power, increasing the real production, making the granulemetry better, reducing the maintenance, reducing the wearing down, making better the attack angles). An important part of the efforts made in this field are being made in existing mills.

* *the comparison of the global results between the Semi-Autogenous Grinding (SAG) and the standard grinding*. The issue turned out to be controversial because the comparison between the specific consumptions for both kinds of grindings was not necessarily on favor of the former kind of grinding, namely SAG. However, the predictability would be higher in the SAG grinding machines –compared to the predictability in the standard grinding, if there was a change of design in both.

* *the melting process, along with the transport, is the area that concentrates most of the energy consumption level in the copper mining*. The technological development aims, in the short run, at finding or devising Flash-like solutions, and in the long run, at the melting and continuous conversion (in this field, we work at the level of low scale pilot plants, which is the case of the working scenario of the different researches that are being carried out at the University of Chile). The above-mentioned idea should not led us to ignore the advantages that El Teniente Conveyor has.

* *the mining companies are beginning to incorporate alternative fuels in the process of minerals melting because of the high prices that are being asked when you buy or purchase conventional fuels*. There are important efforts that are being made to make the efficiency better in the melting and converting processes as a whole (reduction of the solid or gas effluents to their minimum levels). Additionally, in the calcinations of the lime stone, for the production of the clinker and at the melting plants, people are beginning to consider the use of tires as fuels, the reused oils and others (depending on the local prices charged for the energy, in many countries, more or less 35% of the operation costs of a melting plant corresponds to the use of energy).

* *we made analyses of certain cases in which, the study of the production costs from a systemic viewpoint, showed reductions in the consumption of natural gas down to 50%*. The moving of the mineral through using the cascade system (a mixture of theory and empiric evidence), the reduction in the size of the pieces of mineral placed into the oven, the reduction of the manganese crust, the increase of the temperature of the combustion air, the reduction in the number of production equipments by means of the change in the processing, were some of the measures taken as part of the strategy of energetic optimization of each stage of the process.

* *the development of indicators carrying no energy efficiency is a topic which is particularly relevant*. We showed the results gotten from a systematic and detailed analysis of the pieces of information about the effective energy consumption in the mining industry in Chile (considering almost 100% of the universe of copper mining industries along Chile). It was said that this is an effort, which has no parallel in almost any other country around the world. Likewise, it was stood up how the Chilean Government used these pieces of data during the natural gas crises, which added an extra value to the effort that had been made.

* *control over the processes is a central issue for the improvement of the efficiency in the use of the energy*. The discussion of this topic let us evaluate the replacement of existing equipments and machinery, optimize operations, to pinpoint or detect failures in the procedures in place, etc. Relevant examples of the application of the technology showed were the managing of the minerals grinding, letting us increase the production as well as reduce the use of energy almost 10%. During the debate, there was a doubt in relation to its applicability in the cases that the control and measuring instruments re not enough (which is the case at most of the industrial and mining plants) and the efficiency of the inferences you arrive at using "the observer" method, which was suggested by the speaker.

* *A foresight of the mining industry not only in the economy-related aspects, but also in the social aspects of it.* The social responsibility of the mining industry was stood out in many opportunities along the workshop. Another principle for the future development on which there were many coincidences in opinion, was the need to safeguard the continuity of operations (which let us reduce significantly the energy consumption).

* *¿is there going to be enough energy for the mining developments in the future?* The answer was a yes, the problem is going to be the price charged for it. It was very clear that the price tendency is towards the increase of it was also clear that the prices we are paying at present will the just a remembrance; for example, it was stated that, in South America, it is very difficult that Argentina or Bolivia keep the prices for the natural gas at US$ 3,5 per a million of BTU, and the most probable scenario is that such price will increase twice just as it happens to the international price of it. Something similar should happen to oil prices. What has just been said should make us increase our efforts to make an efficient use of the energy and, therefore, there will be less air pollution. On the same discussion table, it was forecasted the closure or finishing of the copper concentrates melting plants, which was discussed and it was rebated later on.

* *the concepts of efficiency right, mining environmental liabilities and the increase of the price of the energy due to sustainability reasons*. This issue follows the same line of thinking that was followed for the valuation of external factors, conceptual and practical emptiness to be solved because of their importance to the energy and environmental policy, despite the theoretical complexities it implies. Finally, and consistent to the above-mentioned ideas, it was said that the environmental sustainability of the mining exploitations must be paid by the users (most of whom are placed in the developed countries)

* *the technological development and the future challenges in the mining industry*. The future challenges in the mining industry not only have to do with the energy, but also, with the fact that the law is out of force, making the resources more complex, making the mineral fields or mineral deposits deeper, the need to have available the human resources required and to make sure the sustainable development of the activity. In general terms, we integrate under the same perspective the business challenges as well as the technological challenges. Of special importance was the proposal in relation to the fact that the innovation is the most profitable investment. Such statement, being duly appreciated by the participants, had a counter statement, which stated that the investment on talented young students is even more profitable. Other option which is starting life in Chile, consists of the fact that Chile integrates internationally with companies of the mining sector, suppliers and excellency centers so as to make profitable and to speed up the process of innovation. In this case, the direct investment on I&D may show a tendency to the low, despite the recognition given to the profitability of this kind of investment.

* *the reduction in materials transportation due to the impact of the energy on the costs constitutes a central goal of the I&D*. Along with that and in different time scenarios, the continuity of the operations constitutes another goal of the I&D, just like the bio-mining, the human development, the sustainability in its broadest sense and the market development (quality of products and new applications). Even the submarine exploration is beginning to be a high relevance topic.

* *relevance of the biotechnologies in mining, in relation to the most conventional options*. It was stated that biotechnology opposes or goes against the permanence and development of the pyro-metallurgy, on the contrary, it goes along with it because they are complementary technologies (people stood out the advantages of the pyro-metallurgy in the recovery of cooper and precious metals).

* *the specific analysis of the use of the efficient energy use in China*. In China, energy efficiency is a need because of the constant “black outs” that strike the country because of the lack of capacity in the generation of energy and transmission lines, of the lack of coal, oil and electricity supplies, of the competitiveness of the industry (in the case of the steel industry, the energy represents the 25% of the cost), of the reduction in the pollution levels and of the sustainable development. Although the energetic intensity was lowered almost 4% a year during 20 years, there’s still along way to go yet. Due to the above-mentioned reasons, China is incorporating a mid-term plan, which aims at, among other objectives or goals, introducing energy efficiency laws, technological development, money incentives to lower the environmental impacts, paying attention to the supply safety, improvements in the way of designing the energetic policies, voluntary agreements, etc.

Pedro Maldonado
Instituto de Asuntos Públicos
Universidad de Chile

Asia-Pacific
Economic Cooperation

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

21, 22, 23 October 2004
Santiago Chile

Conclusions and Main Lines of Action

WORKSHOP
IMPROVING ENERGY EFFICIENCY IN THE APEC MINING INDUSTRY
Santiago, Chile October 21-23, 2004
Radisson Hotel, Ciudad Empresarial

CONCLUSIONS AND MAIN LINES OF ACTION

The workshop held on October 21-23, 2004 in Santiago, Chile, was the result of a project submitted by the Expert Group on Minerals and Energy Exploration and Development (GEMEED), jointly with the Expert Group on Energy Efficiency and Conservation (EGEE&C). Participants came from government, industry and academia of APEC economies.

Workshop delegates agree on the following conclusions and lines of action in relation to energy efficiency in mining:

1. **Continuity of work on energy efficiency in the APEC mining industry**

   The improvement of energy efficiency in mining is a task that requires continuity in its development, congruence between objectives and activities, and concerted actions by government, industry and academic and research institutions. Two work areas were identified as having priority:

   - ***Harmonise energy efficiency indicators used in APEC economies***. This task will permit the development of projects having a solid and comparable definitional base.

   - ***Identify a project related to the use of "best practices in energy efficiency in the APEC mining industry"***, that can be carried out jointly with the mining industry and other EWG expert groups, and in a time frame of two to five years.

2. **Energy security and the right to energy efficiency**

   Workshop participants consider that energy efficiency is a public good of a global nature, as it essentially contributes to the environment. The inverse equation between energy intensity and development must be examined and solved, linking the improvement in energy efficiency with energy security and development. The goal is to have a secure supply of energy in the medium and long term, while at the same time have more and better tools for humanity's development.

3. **Generation of an energy efficiency policy in mining as part of the contribution of mining to sustainable development**

   Delegates consider important that the concept of increased energy efficiency be incorporated in public policy, both in the mining and energy sectors, as well as in sustainable development.

4. Energy efficiency research and development

Workshop participants consider that energy efficiency research and development is a key element that will provide greater sustainability to the mining industry. Therefore, APEC economies should reinforce their energy efficiency programmes.

5. Recommendations for GEMEED

Given the good results obtained in the workshop, delegates considered indispensable that GEMEED give continuity to this work, recommending that it:

- ***Continue to develop projects and work programmes that relate mining and energy efficiency***, fulfilling the mandate in its terms of reference.
- ***Foster the joint work of industry, government and academia***, for a better generation and implementation of future programmes and work related to energy efficiency in mining.

Tomás Astorga
Chair
GEMEED - APEC

Santiago de Chile, 23rd October 2004.