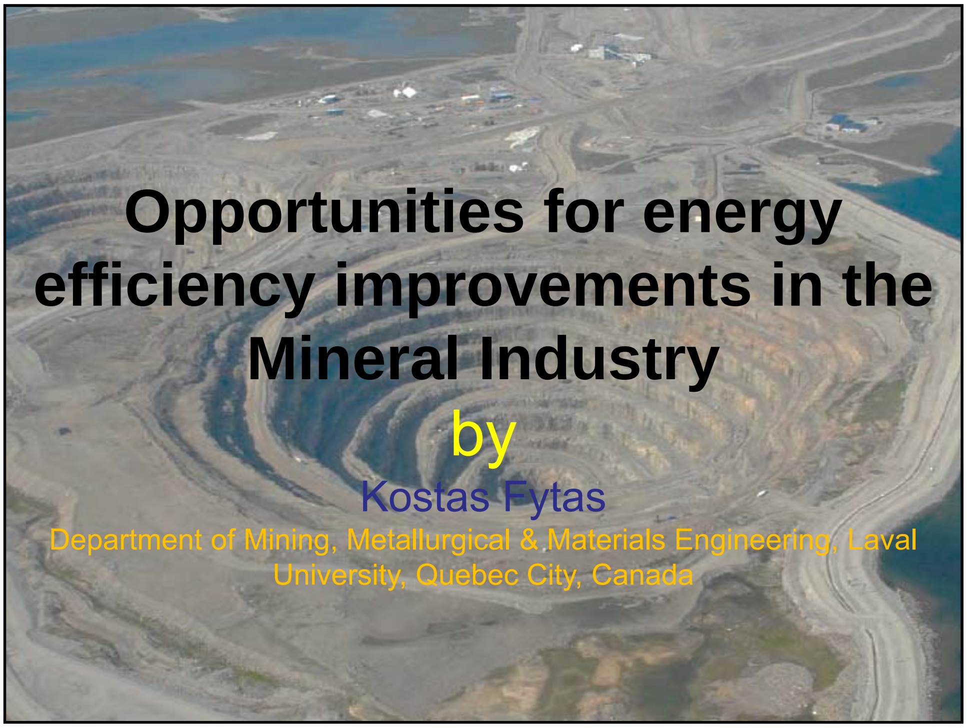


Opportunities for energy efficiency improvements in the Mineral Industry

by

Kostas Fytas

Department of Mining, Metallurgical & Materials Engineering, Laval University, Quebec City, Canada

Importance of energy efficiency

- 7 in 10 executives around the world believe energy management is extremely or very important to their organizations1

ENERGY EFFICIENCY INDICATOR

2011 Global Results

[1]2011 Energy Efficiency Indicator (EEI), Institute for Building Efficiency, 2011 (http://www.greenbiz.com/sites/default/files/EEI-2011-Global-Results.pdf)

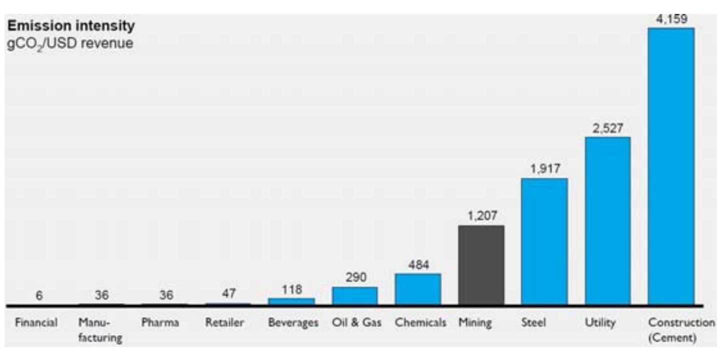
Mining, energy & GHG

- Mining consumes a lot of energy:
  - Mining and oil & gas consume 30% of industrial energy use in Canada[1]
  - In Chile the mining industry accounts for 16% of total fuel consumption[2]
  - In South Africa mining accounts for 6% of overall energy consumption[3]
  - In Brazil, Vale consumes 4% of the country's energy[4]
  - In the US the mining industry uses 3% of industrial energy[4]

[1]Statistics Canada 2010 (http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgdmnd/ndstrlnrgscnd2010/ndstrlnrgscnd-eng.html#a1)
[2]International Energy Agency, 2009 (http://www.eia.gov/forecasts/ieo/industrial.cfm)
[3]Mining Weekly.Com (http://www.miningweekly.com/article/mining-industry-challenged-to-cut-energy-consumption-15-by-2015-2007-06-01)
[4]Cleantech magazine - Fuel Cell Special, Sept/Oct 2010 (http://www.cleantechinvestor.com/portal/fuel-cells/6422-mining-and-energy.html)

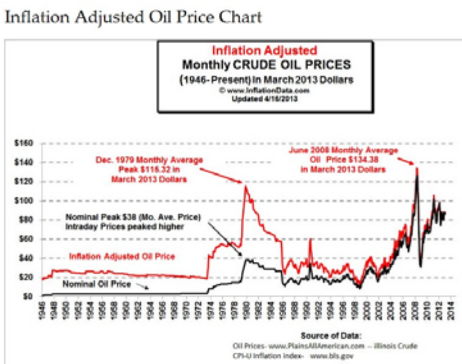
Mining, energy & GHG

- The mining sector accounts for 7% of the world's energy use[1],
- High emission intensity
- Direct or indirect carbon charges expected globally by 2025 (~25$/tonne CO_{2e})[2]



Assessing the Environmental Impacts of Consumption and Production Priority Products and Materials, UNEP, 2010, p.108
Philpott, A., Mindful mining, Innovative, Sustainable & Profitable Mining Conference, Perth, November 2010, Statistics Canada 2010

Price of oil has more than tripled since 2002



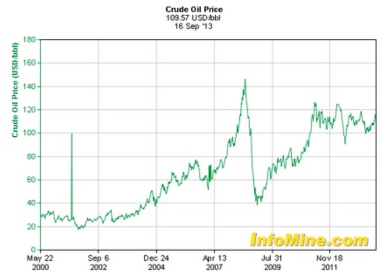
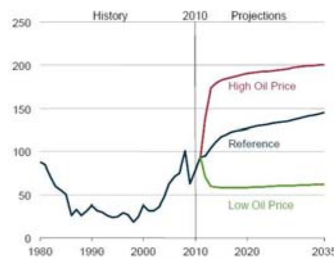


Figure 18. Average annual world oil prices in three cases, 1980-2035 (2010 dollars per barrel)

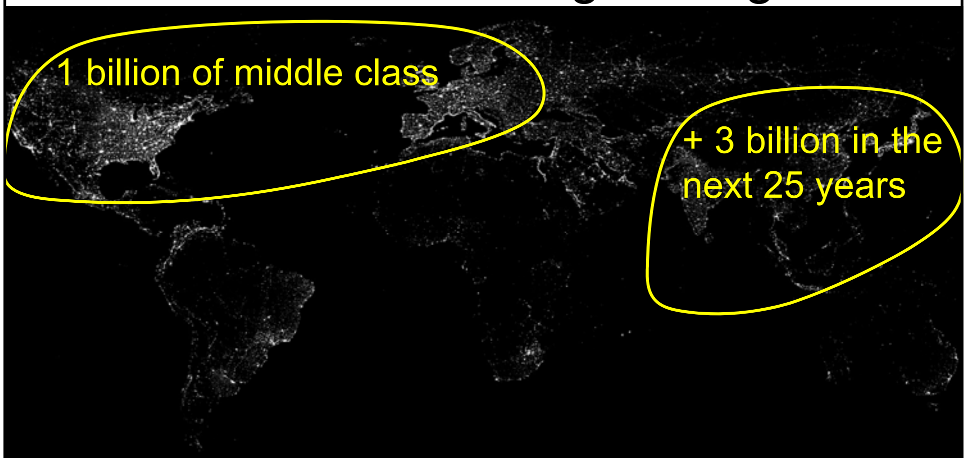


- World oil reserves are depleting fast
  - Loss of 4M barrels/day/year!
- No major oil discoveries

EIA outlook 2012

Why?

Earth satellite image at night

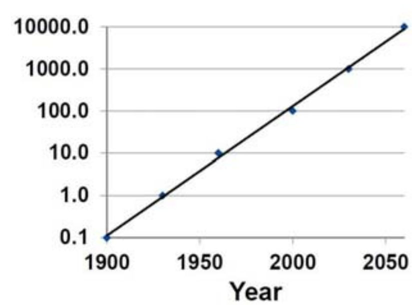


- 120 millions of cars in China (2012) + 22 millions/year
- 100 millions of cars in India (2012) → 400M in 2030!
- Mining production should triple in the next 25 years!

Mining 101 - Douglas Morrison, CEMI, OCE-CEMI-NSERC Mining Funding Initiative and Partnership Forum, June 28, 2012
http://indiatransportportal.com/2012/11/vehicles-in-india/

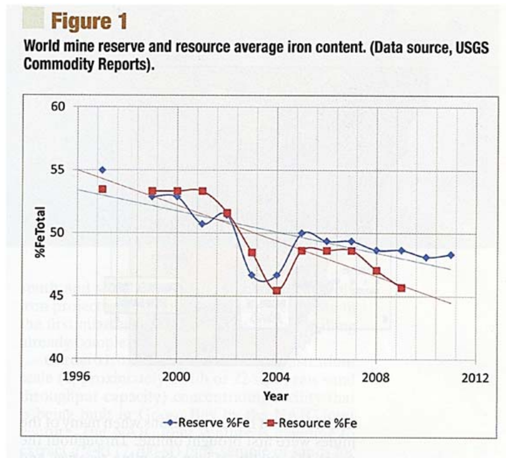
Open pit mine trends in 21st century

- Open pits becoming bigger & bigger, daily rate:
  - 100's tonnes in 1900
  - 1000's tonnes in 1930
  - 10,000's tonnes in 1960
  - 100,000's tonnes in 2000's
  - 1M's tonnes by 2030
  - 10M's tonnes by 2060
- Big oil sands mines ~ 1M tonnes/d
- Big base metal mines ~ 0,3 to 0,6M tonnes/d



Mine water solutions in extreme environments- Challenges, technology and solutions, A. M Robertson, Robertson GeoConsultants Inc.

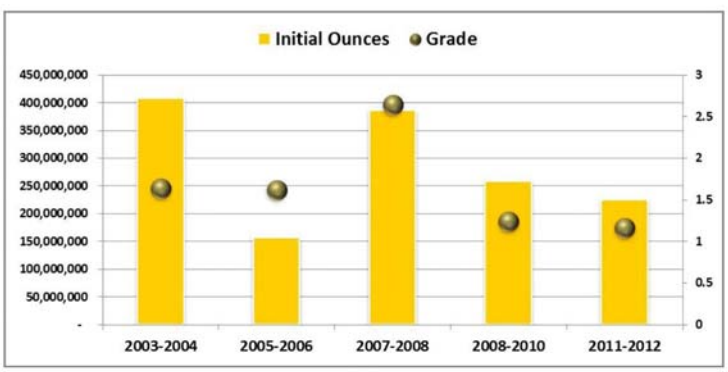
Evolution of iron deposit grades



- Diminishing trend of Fe grades

New approach to developing the optimal mineral processing flowsheet, G. E. Hoffman & S. J. Ripke, Mining Engineering, March 2012, pp.23

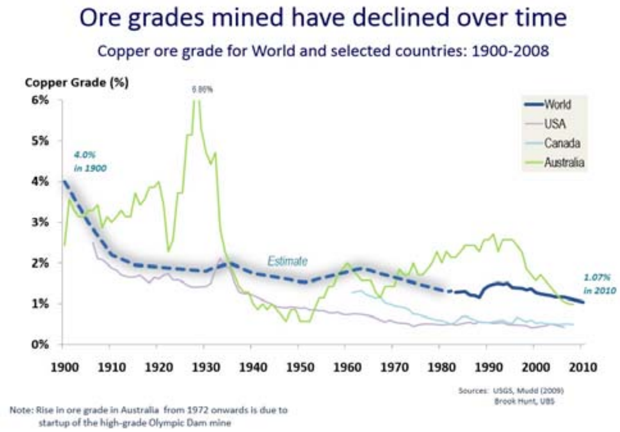
Quality of newly discovered gold deposits around the world (quantity-quality)



- Last 10 years (since 2013) quality & quantity is diminishing

New gold discoveries decline by 45%, IntierraRMG, http://www.intierrarmg.com/Libraries/Brochures_and_Flyers/New_gold_discoveries_decline_45_-_25_March_2013.sflb.ashx

Evolution of copper grades around the world



- Diminishing trend

The key drivers behind resource growth: an analysis of the copper industry over the last 100 years, R. Schodde, 2010 MEMS Conference Mineral and Metal Markets over the Long Term, Joint Program with the SME annual meeting in Phoenix, March 3 2010

Lower grades → more energy/tonne

- Between 2002 and 2011 the amount of energy used to produce 1 tonne of copper fines increased 31% because of the mineral grade lowering, depth of deposits and labor interruptions.
- Energy represents (2011) between 15% and 20% of cash cost which could even reach a value “between 35% and 45% of costs by 2020

Chilean copper mining costs triple during last decade, Nueva mineria y energia, December 6, 2012, http://www.nuevamineria.com/revista/2012/12/06/chilean-copper-mining-costs-triple-during-last-decade/

Mining industry has a very low energy efficiency

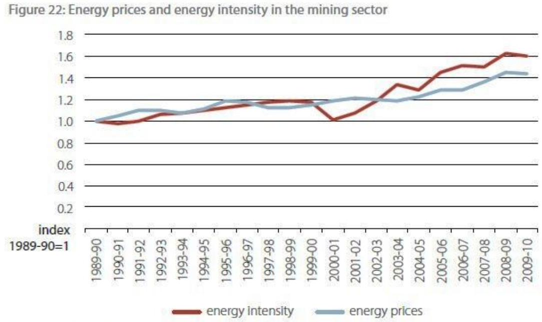
According to a study carried out by Sandvik Mining and Construction

- The total proportion of energy and carbon emission costs in mining operations could rise from a current 15–20% to as high as 50% in the next 10–15 years
- Only 5–10% of the energy used in mining is directly linked to the value adding components of ore mining, transportation and processing. The rest is lost mostly in auxiliary systems or the extraction and processing of worthless rock!

Meet Sandvik 2010-03 A cleaner way of mining, http://demo.aubema.de/sandvik/0010/Internet/Global/SE03351.nsf/Alldo

Energy intensity of mining in Australia

Figure 22: Energy prices and energy intensity in the mining sector



Source: Energy prices from the International Energy Agency (IEA) (2011).

- Energy intensity (energy/tonne of extracted metal) increases by 2,3%/year

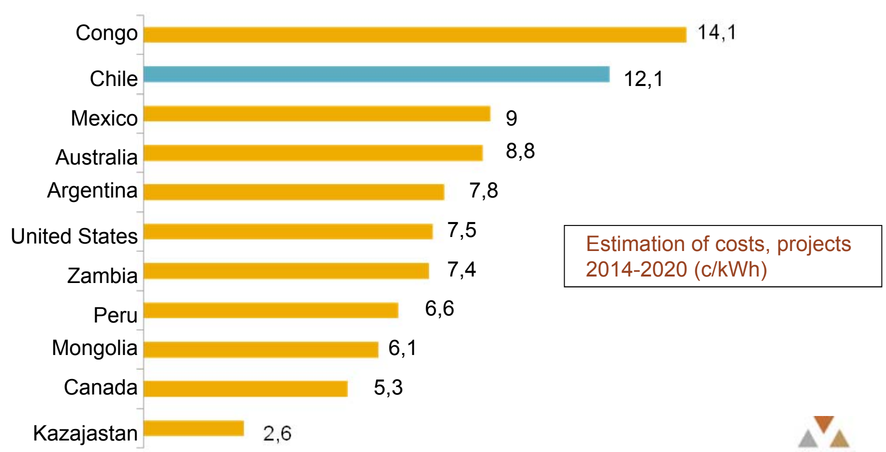
Economic Analysis of End-use Energy Intensity in Australia, Australian government, Bureau of Resources and Energy Economics, May 2012

Energy challenge of the mining industry

- New large operations face huge challenges to secure affordable power supply
- Power requirements of new large operations require a significant change and development of power grids of many developing nations (ex. Oyu Tolgoi in Mongolia)
- Mining has to become more sustainable while decreasing energy consumption and greenhouse gas (GHG) emissions in order to stay competitive in a greener world

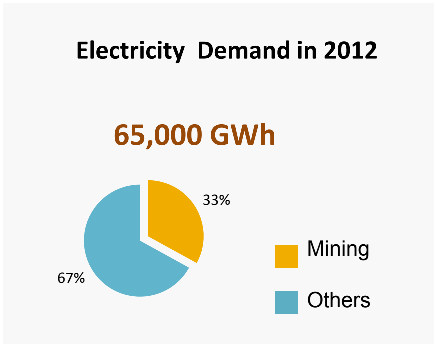
Energy, very important factor, the case of Chile

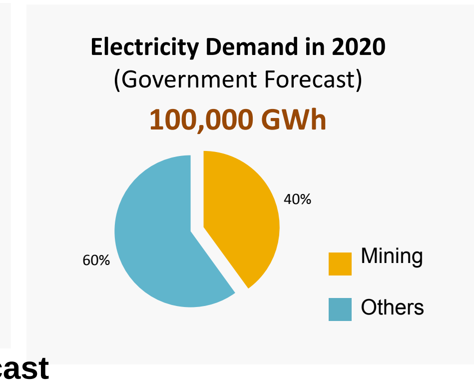
Electricity cost in copper producing countries



Energy and Mining in Chile, J. Villarino, Consejo Minero de Chile, ENERMIN 2012 , 2nd International Seminar on Energy Management in the Mining Industry, September 10, Salvador, Brazil, 2012

Energy, very important factor, the case of Chile





2012-2020 Government Forecast

6% annual growth rate for country demand

6.7% annual growth rate for mining demand: US$100 billion investment portfolio +50% production (5.6 to 8.4 million of tons)

CONSEJO MINERO

Energy and Mining in Chile, J. Villarino, Consejo Minero de Chile, ENERMIN 2012 , 2nd International Seminar on Energy Management in the Mining Industry September 10, 2012

Oyu Tolgoi (Mongolia)

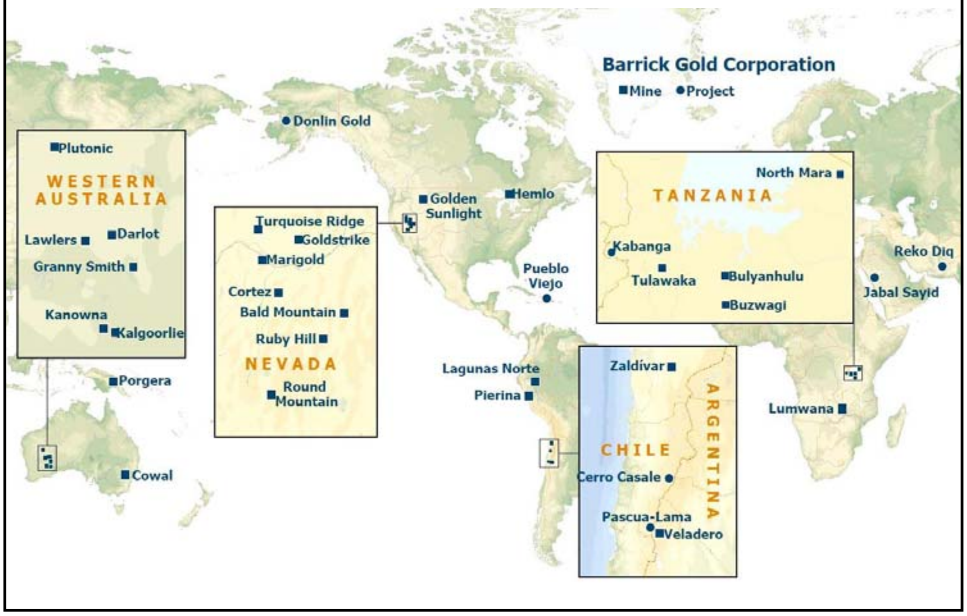
- Power need: 280MW
- Import electricity from China until 2016 when a new 600MW power station will be completed

Summary production and financial results

Description	Reserve Case	Life-of-Mine Sensitivity Case
Inventory	Mineral Reserve	Mineral Reserve plus Inferred Resources
Peak Production Rate	58 mt/a	58 mt/a
	160,000 tpd	160,000 tpd
Total Processed	1.393 billion tonnes	3.013 billion tonnes
Copper Grade	0.93%	0.89%
Gold Grade	0.37g/t	0.35g/t
Copper Recovered	25.2 billion lb.	52.5 billion lb.
Gold Recovered	13.1 million oz.	26.4 million oz.
Mine Life	27 years	59 years
10 Year Cash Cost (net of gold credits)	0.45 cents/lb	0.44 cents/lb.
Initial Capital (excluding sunk costs)	US$4.617 billion	US$4.617 billion
NPV (8%) After Tax	US$4.536 billion	US$5.614 billion
IRR After Tax	16.33%	16.73%
Payback Period	6.32 years	6.22 years

NPV based on copper $2.00/lb, gold $850/oz

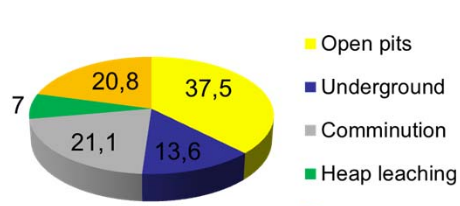
Barrick Gold Co. And energy



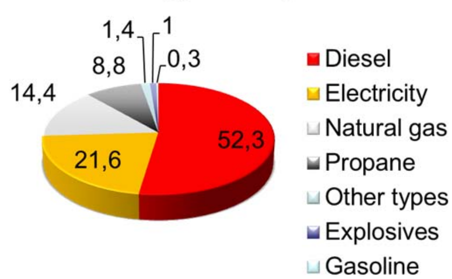
Energy profile of Barrick Gold Co.

- 51 Millions GJ consumed/y (1GJ = 26L of diesel or 278 KWH)[1]
- Annual cost ~1 billion $
- Energy represents 25-30% of operating cost
- 5 millions tonnes of emissions $CO_{2\ \text{équiv.}}$
- Diesel fuel is the most important energy item

Barrick's energy profile - process



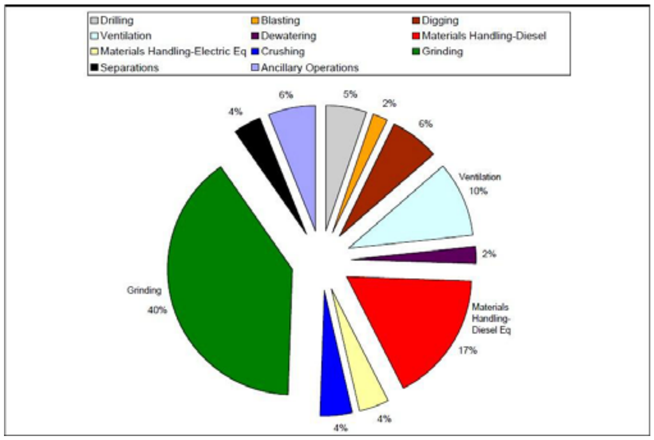
Energy source profile[2]



[1] Improving energy efficiency in Barrick grinding circuits, Lloyd Buckingham et al., 5th SAG 2011, September 25 to 29, 2011, Vancouver, Canada
[2] Energy and climate change, Barrick Gold Co, 2010, on http://barrickresponsibility.com/2012/material-issues/energy-and-climate-change/

Energy profile of US mining industry

- In the US the mining industry uses 3% of industrial energy



Mining Industry Energy Bandwidth Study, DOE, 2007

Underground mines

- The largest energy users in UG mining are
  - Ventilation systems (25 to 40% of total energy costs)
  - Compressed air systems
  - Hoisting systems
  - Mining (mucking, drilling and ore transport)

G. D. Scott, Energy Conservation Opportunities in Ontario's Mining Industry, Ontario Mining Association, 2008

Operation	Proportion
Mining (mucking, drilling and ore transport)	10%
Hoisting	10%
Ventilation (includes heating)	40 to 50%
Mine dewatering	5%
Compressed air	10 to 12%
Underground other	8 to 10%
Surface buildings	5%

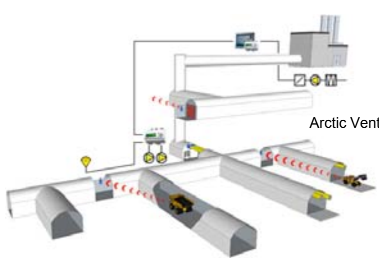
EST1030 Atlas COPCO uses 40% less energy and produces 40% less heat as compared to diesel
E&MJ, April 2013, vol. 5, p.152

Mine Ventilation

- The heaviest user of energy in underground mines
- Examples in Canada:
  - Typical medium depth (400m, 2200tonnes/day)
    - 300 000$/y for electricity (fans) & 2$M/y for heating
  - A deep mine (3000m, 6000tonnes/day)
    - 5,2$M/y for electricity (fans), 7$M for air conditioning & 8$M for heating (total of 20,2$M/year)
  - A mine in the Canadian North, (240m)
    - 4$M/year for fans and heating (electricity at 30¢/kWh)

Mine Ventilation

- Ventilation on demand (VOD)→
  - 30-50% reduction of energy consumption for ventilation
- Eliminate diesels UG
  - Electric, hybrid or fuel cell models
- Refrigeration on demand (ROD)



Arctic Vent Control, http://www.gefasystem.se/arcticventcontrol/ventilation_eng.html

Allen, C. & Tran, T., Ventilation-on-demand control system's impact on energy savings and air quality, CIM meeting, Montreal, 2011

Compressed air systems

- Compressing air is only about 8% mechanically efficient (92% of the energy → heat) & requires kilometers of high-strength piping to reach drills at the face
- Replace air with water for drilling (replace pneumatic with hydraulic drilling) exploiting the water column pressure
- This could cut the capital costs of equipping a new mine by up to 60%
- Detect and eliminate air leaks (10-20% energy reduction)
- AngloGold Ashanti has achieved since 2004 a 30% reduction of compressed air consumption in its deep underground South African operations by off-peak pressure reduction, optimal compressor scheduling and leak repair strategies

A fresh solution, Mining Magazine, April 2011, pp.10-14

Drilling

- Only 30 – 40% of the energy used when drilling is applied to breaking the rock
- A compressor management system can save ~50% of fuel for drills

Philpott, A., Mindful mining, Innovative, Sustainable & Profitable Mining Conference, Perth, November 2010

Surface mines

- ~1/6 of surface mines operating cost is power
- 50-60% of the energy in an open pit mine is consumed in grinding
- 10-12% of energy is consumed in dewatering in mineral processing
- 10-12% of power cost is for drilling-blasting, hauling & pumping water
- 5-10% is consumed in crushing & conveying
- 10-12% pumping tailings & reclaimed water

Power to the pits, Canadian Mining Journal, March, 2009, pp.18-20

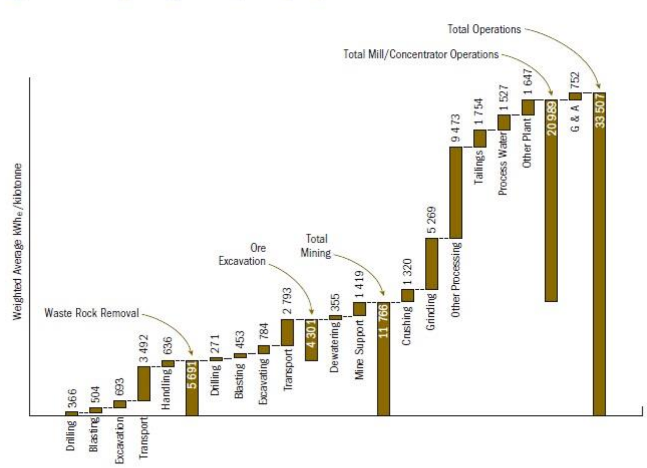
Operation	Proportion
Drilling	17%
Blasting	42%
Excavation	6%
Rock transport	25%
Dewatering	3%
Support	6%

G. D. Scott, Energy Conservation Opportunities in Ontario's Mining Industry, Ontario Mining Association, 2008

Energy profile in Canadian open pits

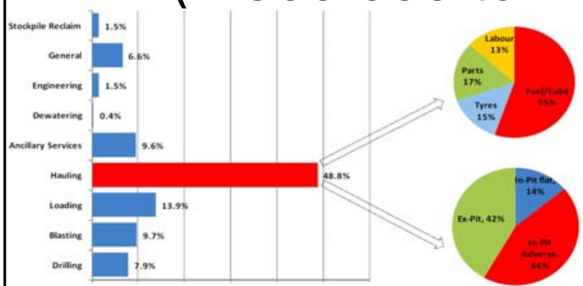
- Mining & oil industry consume 30% of industrial energy in Canada

Figure 3.5 – Average Energy Consumption by Stage of Production



Benchmarking the energy consumption of Canadian open pit mines, CIPEC, 2005 (Ressources Naturelles Canada)

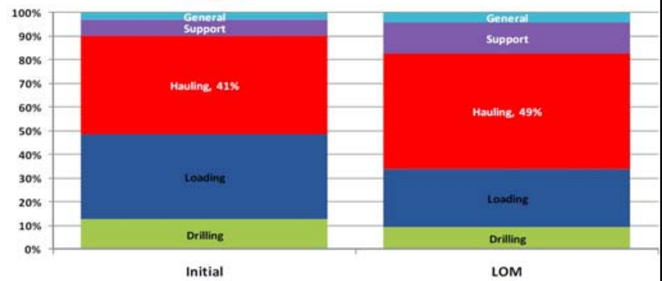
Big open pits (Chile, USA) (> 500 000 tonnes/day)



Capital costs

In shovel-truck big mines haulage ~50% of capital & operating cost & 50% uphill

Operating costs

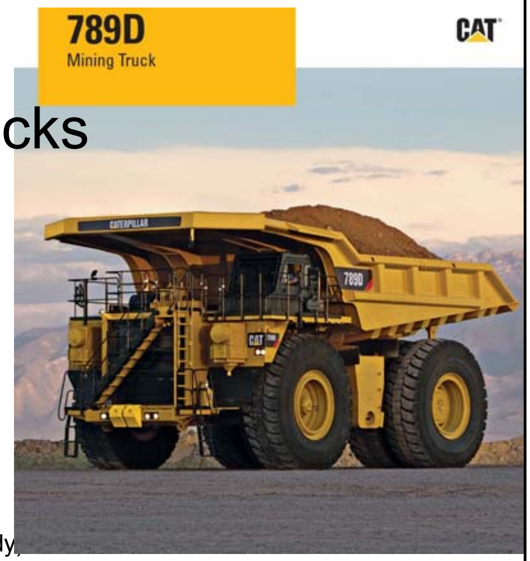


Tutton D.& Streck W., The application of mobile in-pit crushing and conveying in large, hard rock open pit mines, Mining Magazine Congress, Niagara-on-the-Lake, Ontario, Canada, October 9, 2009

Off highway trucks

- Truck haulage: the most expensive component of mine operating cost
- Diesel fuel: the most important item of truck operating cost

Off highway trucks



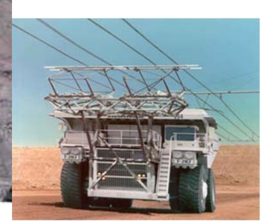
CAT 789D

- Capacity 181 tonnes
- Empty weight 143 tonnes
- We spend 45% of fuel to move the empty weight!
- Can we lighten up the empty weight (thinner, higher strength steel for body)
- A 25% reduction in body weight can save 2,3% in fuel

Materials handling Trolley assisted haulage

- Trolley assisted haulage
  - Reduction in fuel consumption of 70 – 80 % over the entire haul cycle[1]
  - Increase in productivity (10 – 20%)
  - At Rössing Uranium in Namibia fuel consumption with a payload of 182 tonnes is cut dramatically from 350 down to 25 L/hour/truck
  - Cost: +180 000$/truck, 2 200$/m of ligne[2]

Each ultra class mine truck consumes more than 1 ML of fuel/year



Rio Tinto Review (2010) With Trucks Like Trolley Buses Rio Tinto

[1]Koellner, Walter. 2007 The Future of Trolley Assist with AC Drives. Siemens Energy and Automation, Inc, Mining Technologies, http://www.sea.siemens.com/us/SiteCollectionDocuments/WSSResources/Internet/Misc/2008-04-25_10/TrolleyAssist.pdf

[2] Freeman, S, Golosinski, T.S. 1994. Economic feasibility of introducing trolley assisted haulage to an Australian open pit mine, International journal of surface mining, reclamation and environment. Vol 8, No. 4, pp. 141-144

Materials handling
Trolley assisted haulage

- Grootegeluk mine, South Africa, coal mine, 14,5M tonnes/year
  - Cost of operation 174,37$/h (vs. 385$/h conventional)

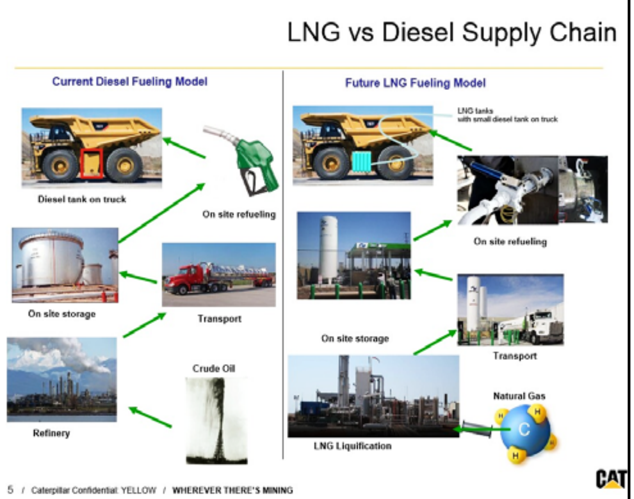
Komatsu 730E - 190 Tonne	Non-trolley	Trolley
Speed (Km/H)	12.2	23.7
Fuel Use (Litres/Hour)	367	37.4
Electricity Use (kW)	0	1930
Cost of Fuel ($1.05/L)	$ 385.35	$ 39.27
Cost of Power ($0.07/KwH)	$ -	$ 135.10
Total Cost ($/Hour)	$ 385.35	$ 174.37

Grootegeluk Coal mine in South Africa

Trolley Assisted Mine Trucks, Python mining consultants, http://www.pythongroup.ca/mining-news/article/id/35 Trolley assist to optimise hauling cycles with electric trucks - Trolley assist to optimise hauling cycles with electric trucks , Vicente E. Alvarado, http://www.sacea.org.za/.%5Cdocs%5CTROLLEY%20ASSIST%20TO%20OPTIMISE%20HAULING%20CYCLES%20WITH%20ELECTRIC%20TRUCKS%20.pdf

Trucks powered by a mix of diesel fuel & liquefied natural gas

- Explosion of natural gas production in North America
- Natural gas costs 25% less than diesel fuel
- -40% NO_x, -60% PM,-20% CO_2
- Economies for emission costs (25$/tonne?)
- New motors using a mix of LNG/diesel → 70%



LNG Mining Truck Launch Review, CIM Annual Meeting, Edmonton, May 2012

Natural gas for off-highway trucks

- Convert mining trucks to → natural gas

Landmark LNG conversion deal for GFS at Eagle Butte

After an 18 month pilot program operating the world's first liquid natural gas powered mine haul trucks, Alpha Coal West has placed an order with GFS Corp to convert its entire fleet of Caterpillar 793s at the Eagle Butte mine near Gillette, Wyoming, to the EVO-MT™ 7930 system. In June 2012, Alpha Coal West became the first mining company to operate mining haul trucks using natural gas, having initiated a pilot program on three trucks in conjunction with GFS, the maker of the EVO-MT conversion system.

Late last year, the company converted a fourth truck. After a year and a half of daily operation and proof of concept, Alpha Coal West has decided to move forward with the conversion of 12 additional trucks at Eagle Butte. GFS Corp will convert the balance of Alpha Coal West's Caterpillar 793 fleet at its Eagle Butte Coal Mine to GFS's NG+D™, natural gas plus diesel conversion system. The 12 truck conversion will phase in over time with the last conversions scheduled for October 2014. Along with the truck conversions, Alpha Coal West is installing permanent, full scale LNG fuel storage and dispensing infrastructure to replace the temporary solution used during the pilot.

"We are pleased that our pilot project with Alpha Coal West has led to a commercial implementation our of EVO-MT system," said Jason Green, GFS Corp's President. "Alpha is to be commended for being the first mining company in the world to use LNG in haul truck operations. There has been a lot of talk about using LNG in mining operations, but Alpha Coal West is actually doing it and we are very proud that our NG+D technology is enabling their transition."

GFS Corp currently offers conversion kits for the mechanical drive Caterpillar 777 and 793 as well as the electric drive Komatsu 830 and 930. Conversions for other truck models are under development. All of the systems are available now and the company is taking orders for the limited quantity of 2014 delivery positions on all four of the systems.

www.gfs-corp.com

International Mining, February 2014, p.12

In pit crushing and conveying, IPCC

- Fixed crushing station
- Semi-fixed crushing station
- Mobile crusher

Fixed crushing station

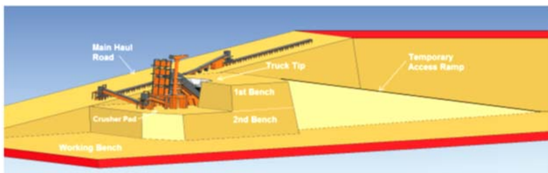
Mobile Crusher Relocation

Semi mobile unit relocated by SPMWT

Walter Kung, Minimizing the cost of overburden removal, Mining Magazine Congress, Niagara-on-the-Lake, Ontario, Canada, October 9, 2009

Materials handling In pit crushing and conveying (IPCC)

- specific energy requirement: truck transport 1.09-1.17 kW/t&km, whereas for a conveyor belt system 0.14 to 0.25/t&km (1/5) [1]
- specific CO_2 emission rates: truck transport 0.331 kg/t and km, whereas for a belt system 0.055 kg/t and km (1/6) [1]
- Over 15 case studies IPCC generated operating savings ranging from US$0.18 to US$0.82/tonne moved compared to trucks [2]



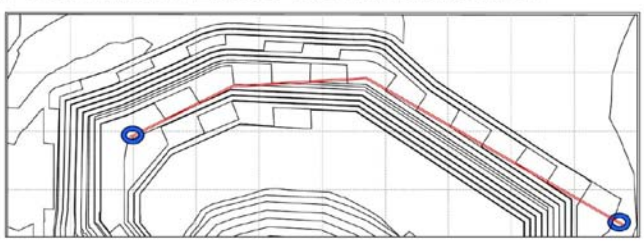
www.sandvik.com

www.flsmidth.com

[1] IPCC Innovations, international Mining, June 2009, pp.8-14
[2] Turnbull D. & Cooper A., In-Pit Crushing and Conveying (IPCC) – A Tried and Tested Alternative to Trucks, The AusIMM New Leaders Conference, Brisbane, Qld, 29 - 30 April 2009, pp.59-66

Mobile crusher and conveyors

RAMP CONVEYOR VERSUS TRUCK ECONOMICS



- Assume Diesel at $0.70/l, Power at $0.10/kWh and labour at k$65/a
- Transport system capable of 250kt/d
- Truck transport based on 360t units
- Total Cost of Ownership (TCO)
  - Truck haulage $0.39/t or $0.19/t.km
  - Conveyor haulage $/0.12/t or $0.06/t.km

Tutton D.& Streck W., The application of mobile in-pit crushing and conveying in large, hard rock open pit mines, Mining Magazine Congress, Niagara-on-the-Lake, Ontario, Canada, October 9, 2009

Mobile crusher and conveyors Capital costs

Mobile IPCC case

Equipment Capital Cost	Qty	Cost [000 US$]
Drills	3	9.500
Rope Shovel	1	28.000
Excavator	2	18.500
Loaders	2	12.200
Trucks in Coal	4	18.000
Trucks in overburden	5	22.500
Dozers (1 for trackshift)	4	3.800
Water trucks	2	3.600
Graders	2	1.200
Ancilliary Equipment	1	6.500
Fully mobile Sizer	1	35.000
Ramp conveyor	1	16.500
Dump conveyor	1	26.000
Tripper Spreader	1	29.000
Transport Crawler	1	4.100
Overall E&I	1	6.300
Civil Earthworks	1	9.500
EPCM cost	1	8.300
TOTAL		**258.500**

Truck/Shovel case

Equipment Capital Cost	Qty	Cost [000 US$]
Drills	3	9.500
Rope Shovel	2	52.000
Excavator	1	9.500
Loaders	2	12.200
Ultra class trucks	18	81.000
Dozers	5	5.000
Water trucks	3	5.400
Graders	3	1.800
Ancilliary Equipment		6.500
TOTAL		**182.900**

Walter Kung, Minimizing the cost of overburden removal, Mining Magazine Congress, Niagara-on-the-Lake, Ontario, Canada, October 9, 2009

Mobile crusher and conveyors Operating costs

Operating costs (US $/T)	IPCC	Shovel / truck
Drilling	4,5	11
Blasting	11	11
Loading	11,5	11,5
Hauling	11,2	40,5
Crushing	4,55	0
Conveying	2,5	0
Spreading	1,5	0
Ancillaries	7	9,7
Dewatering and other	6,5	7,3
Administration	15	15
Total	75	106

Walter Kung, Minimizing the cost of overburden removal, Mining Magazine Congress, Niagara-on-the-Lake, Ontario, Canada, October 9, 2009

Mobile crusher and conveyors

- For big open pits with long mine life
- Longer development period and higher initial capital costs
- Poor flexibility
- Besides the ramp it requires a corridor (slot) for the conveyor passage

Figure 18 - Examples of a conveying slot and associated waste crushing facilities (left and middle, Chuquicamata 1997 (Photo by author 1997) , right Carmeaux)

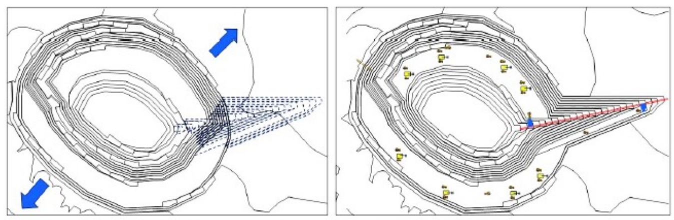


Figure 19 - Concept of conveying slot and relocatable crushing stations

Tutton D.& Streck W., The application of mobile in-pit crushing and conveying in large, hard rock open pit mines, Mining Magazine Congress, Niagara-on-the-Lake, Ontario, Canada, October 9, 2009

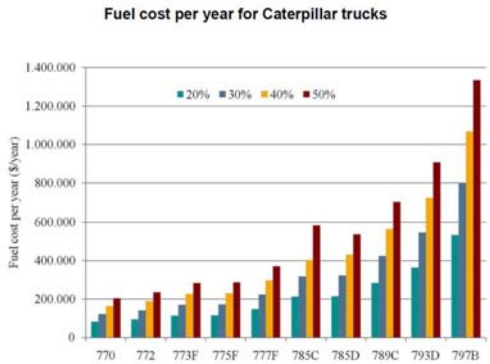
Example of energy economies by using IPCC

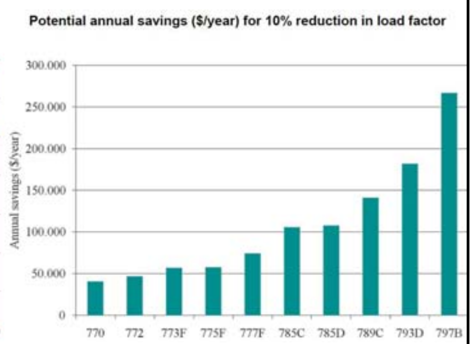
– Penasquito mine by Goldcorp (Mexico) 500000 tonnes/day
– IPCC helped reduce the number of required trucks (Komatsu 930E) by 35
– Each 930E consumes 228 L/h emitting 560g of CO_{2e} /h or 3700 tonnes CO_{2e} / year
– Over the life of the mine (next 15 years) GHG emission savings of 2,2 Mtonnes CO_{2e}

The road to IPCC, IMM, May 2012, p.18

Fuel consumption vs. Engine load factor of trucks

- LF: portion of full power required by the truck LC=10% idling & 100% accelerating
- LF: Low 20%-30% (Continuous operation at an average gross weight less than the recommended. Excellent haul roads. No overloading)
- LF: Medium 30%-40% (Continuous operation at an average gross weight approaching the recommended. Minimal overloading. Good haul roads);
- LF: High 40% - 50% (Continuous operation at or above maximum recommended gross weight.
- Overloading. Poor haul roads)





Haul Truck Fuel Consumption And CO2 Emission Under Various Engine Load Conditions, SME Annual Meeting, V. Kecojevic,& D. Komljenovic, Feb. 27 - Mar. 02, 2011, Denver, CO

Fuel consumption optimisation for mine trucks

- Truck capacity
- Truck model

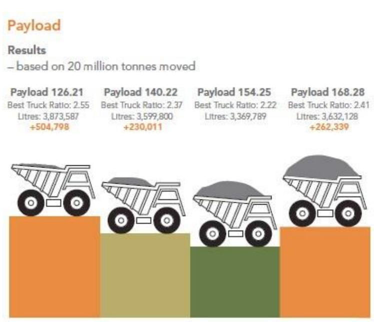


Figure 8: Optimising payload using the Leighton Contractors Best Truck Ratio

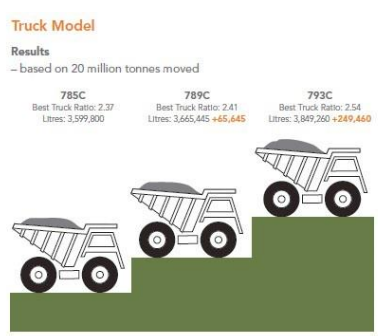


Figure 9: Optimising truck selection using the Leighton Contractors Best Truck Ratio

Analyses of Diesel Use for Mine Haul and Transport Operation, Energy efficiency opportunities, Fortescue Metals Groups Ltd , Downer Edi Mining Pty Ltd, Leighton Contractors Pty Limited , Australian Government, Department of Resources, energy and Tourism, 2008

Fuel consumption optimisation for mine trucks

- Best haulage ramp grade: 12%
- Transporting of 20 M tonnes of material on a humid road (high rolling resistance) → fuel consumption increases by 820 000L (25%)

Figure 10: Optimising road grade using the Leighton Contractors Best Truck Ratio

Figure 11: Comparing rolling resistance using the Leighton Contractors Best Truck Ratio

Analyses of Diesel Use for Mine Haul and Transport Operation, Energy efficiency opportunities, Fortescue Metals Groups Ltd , Downer Edi Mining Pty Ltd, Leighton Contractors Pty Limited, , Australian Government, Department of Resources, energy and Tourism, 2008

Effect of under inflating mine truck tyres (Iron Ore Company)

- A 10% under inflation of mine truck tyres increases the energy consumed annually by 2%

Effect of underinflating truck tyres			
Underinflating (%)	Increase in wear (%)	Increase in fuel consumption (%)	Increase in GHG emissions (CO_2)/year (tonnes)
10	5	2	16668
20	16	4	33336
30	33	6	50005
40	57	8	66673
50	78	10	83340

Mine au Port, IOC, hiver 2009

Comminution

- Comminution consumes 2-3% of world energy total of which 80-90% is for grinding[1]
- Less than 1% of the total energy in grinding is used in rock breakage and 85% is dissipated as heat[2]
- In the 21st century we are still using the grinding technology of the 19th century! (Hit & miss)!

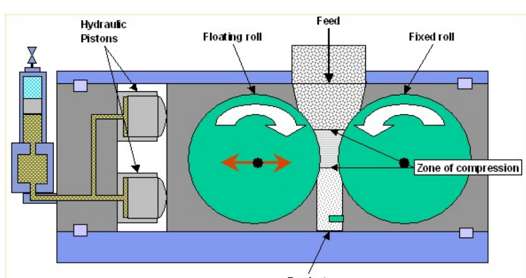
Typical annual electricity bill for a gold mine in Canada (700 ktonnes/year)

- Total 105000 MWh (5,3$M)
- 60000 MWh for milling (3$M)

[1]Johnson, N.W., Review of Existing Eco-Efficient Comminution devices,http://ceecthefuture.org/abstracts/review-of-existing-eco-efficient-comminution-devices
[2]Alvarado, S., et al, Energy-exergy optimization of comminution, Energy, Vol 23, No 2; pp153-158, 1998

Comminution

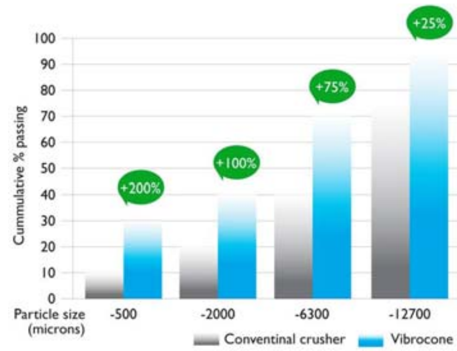
- High pressure grinder rolls (HPGR)
  - HPGR crushing typically consumes approximately 20% to 50% less power /tonne than conventional crushing plants producing the same product
  - Ideal for harder, more competent, abrasive, primary ores
- Example: Anglo Platinum's Mogalakwena North mine in South Africa saved 15-20% with a HPGR versus conventional crushing (on a monthly electricity consumption of 33,000MWh it is enormous)



Johnson, N.W., Review of Existing Eco-Efficient Comminution devices, on http://ceecthefuture.org/abstracts/review-of-existing-eco-efficient-comminution-devices
Much ado about crushing, Mining Magazine, March, 2012, pp. 17-18

Comminution- New developments

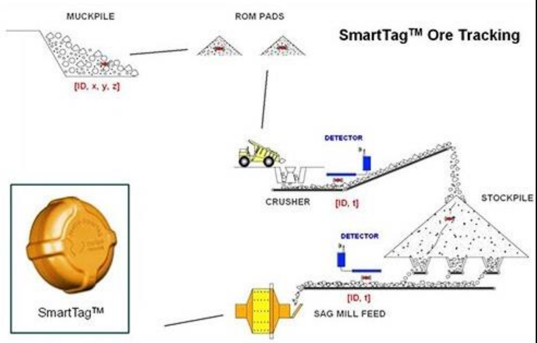
- VIBROCONE™ - a crusher with grinding performance. The Vibrocone crusher produces a much finer feed to the mills and enables up to 30% energy savings in downstream processing.



Johnson, N.W., Review of Existing Eco-Efficient Comminution devices, on http://ceecthefuture.org/abstracts/review-of-existing-eco-efficient-comminution-devices

Integrated fragmentation – crushing & grinding

- Blasting energy (powder factors) has greatly increased recently
- Today, with electronic detonators we could better distribute blasting energy without increasing dilution or causing wall damage
- Selective blasting ? (ore moves towards ore, and waste away from ore)
- With pre-separation of waste material we could save energy in grinding



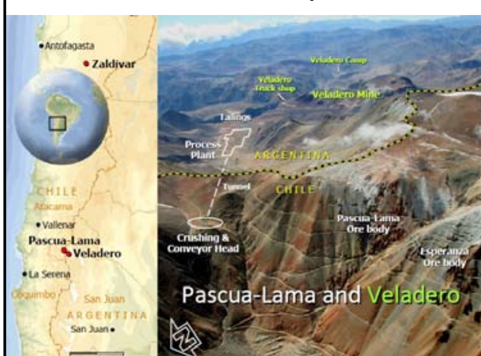
Unlocking Energy Efficiency in the Mining Process, Kristy-Ann Duffy, Metso (PTI), ENERMIN 2012 , 2nd International Seminar on Energy Management in the Mining Industry, September 10, Salvador, Brazil, 2012

Apply energy efficiency technologies for motors

- Crushers and mills are variable load equipment
- Electric motors are sized to handle the max. throughput which does not occur 100% of the time
- Electric motors operate at very low efficiencies (20-40%)
- An electric motor operates most efficiently at ~75% of the full rated load, when copper loss (heat produced by electrical current) is equal to iron loss (magnetic loss)
- Applying reduced voltage motor controllers could save money & GHG emissions

Improving motor efficiency in the mining industry, E&MJ, December 2007

Wind power in Veladero mine (Barrick Gold Co.



- **Altitude of 4000m**

- Wind turbine of 2MW (8$ million) (the highest in the world) in Veladero mine (Chile Argentina) covers 15% of the power needs of the mine

Wind power in Diavik mine, NWT, Canada

- Investment of $33 millions by Rio Tinto, 8 ans de récupération de capital
- Le parc éolien situé le plus au nord au monde
- Bénéfices environnementaux, réduction annuelles de
- 4 millionsL de diesel – 10% (l'équivalent de 100 charges de camion citerne)
- 12,000 tonnes d'émissions de CO_{2e} (6% de GES)
- Caractéristiques techniques:
- 9.2 MW de puissance installée
- 17 GWh/an production énergétique
- Diamètre des pâles 70m, opération → -40° C (avec déglaçage)
- Poids du générateur 55 tonnes
- Hauteur totale de 100 m

http://www.diavik.ca/ENG/ouroperations/565_wind_farm.asp

Wind power, Barrick Gold Co.

Mining Matters

Volume 132 December 2011

Barrick completes $50M wind farm in Chile

Barrick Gold Corporation announces the completion of the $50-million Punta Colorado Wind Farm, located in the town La Higuera in the Coquimbo Region of Chile. The project, consisting of 10 wind turbines that generate 20 megawatts of power, is enough to supply the need of 10,000 families. The farm has the capacity to expand to 18 turbines and generate 36 megawatts, which would raise the total investment in the project to $70 million. The power generated by the wind farm feeds into Chile's Central Interconnected System power grid.

Aerial views of the Punta Colorado Wind Farm and a closer look (inset) gives a clearer picture of how large the turbines are.

- Canadian Mining Journal, décembre 2011, page 6

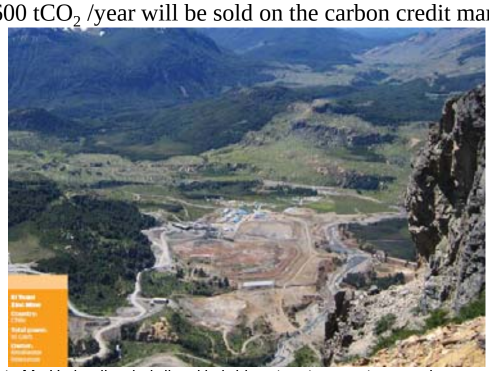
Wind power in mines

- MSPL Ltd., one of India's largest iron ore mining companies, has the largest installed wind power generation capacity in India.
- MSPL developed and owns seven wind farms country-wide totaling 127.8 MW of power and providing all of the company's energy needs. Additionally, the excess power produced, is used to provide electricity for 200,000 homes in nearby communities.
- MSPL also started using its own iron ore to produce the turbines.

Michele Ashby, Is the mining industry ready to go green?, Mining Engineering, November 2008, pp. 33-36

El Toqui (Chile)

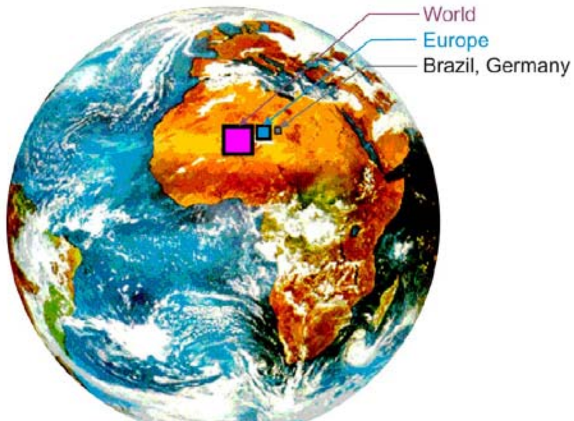
- The El Toqui zinc underground mine, remote area in southern Chile
- Hydraulic-wind-diesel to generate electricity
- Of a total power consumption of 40728 GWh 38,5% came from the mine's hydro power (river-run with no water storage capacity), 13,9% from wind power and the remaining from diesel generation
- The river's low flow season is typically in the summer, when winds are more stable
- Realized carbon credit of 2 600 tCO_2 /year will be sold on the carbon credit market



Gridley N., Banto M., Hydraulic-wind-diesel hybrid system to operate an underground zinc mine at El Toqui, Chile, Proceedings of ENERMIN 2010 conf., 14-16 November, 2010, Santiago, Chile, pp.46-47.

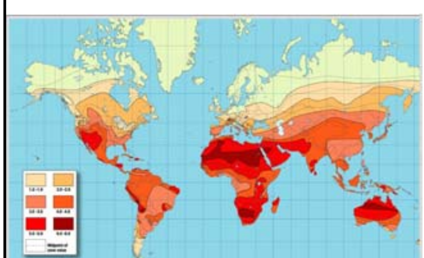
Solar energy

Area necessary for energy supply via photovoltaics

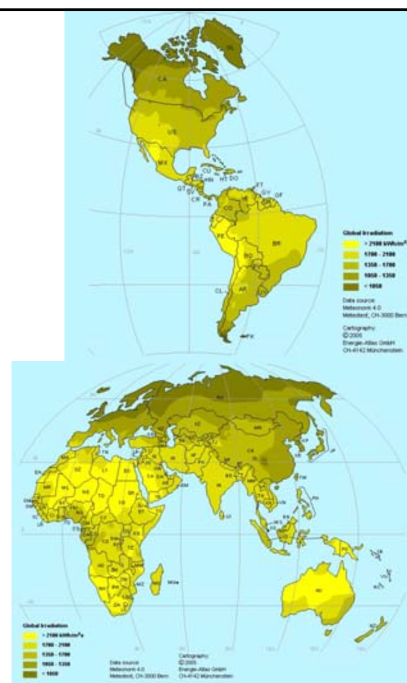


References: DGS
Lutwig-Bölkow-Systemtechnik

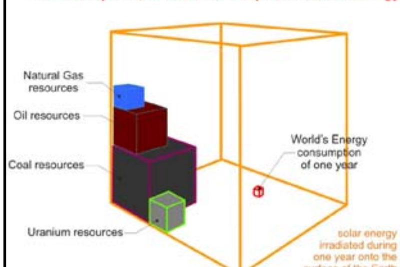
Solar energy



This map shows the amount of solar energy in hours, received each day on an optimally tilted surface during the worst mor year.
(Based on accumulated worldwide solar insolation data.)



Consumption, resources and potentials of Energy



Ref. Photovoltaics for Climate Protection–Opportunities for Brazil, prof., Stefan Krauter

Atacama desert

- The Atacama Desert in northern Chile gets up to 9.28 kWh of sun power/m^2/day
- Atacama Solar has applied for a permit to build a $773 million, 250-MW solar farm
- Solarpack Corp. Tecnologica opens a 1-MW plant at a mine owned by Codelco (cost 10-14 ¢/kWh)
- Chilean utilities sell electricity 12 ¢/kWh (some mines have contracts for 8 ¢/kWh)

Stefan Nielsen, A Solar Mother Lode for Chile's Mines, February 10, 2011, www.businessweek.com, February 10, 2011

Solar energy Barrick Gold Co., Nevada

- Solar farm of 1MW on 3,2 hectares (2008), Nevada
- Auxiliary to a natural gas power plant of 118 MW

http://www.ledcor.com/our-projects/power/renewable-energy/barrick-solar-farm?from=list

Geothermal energy

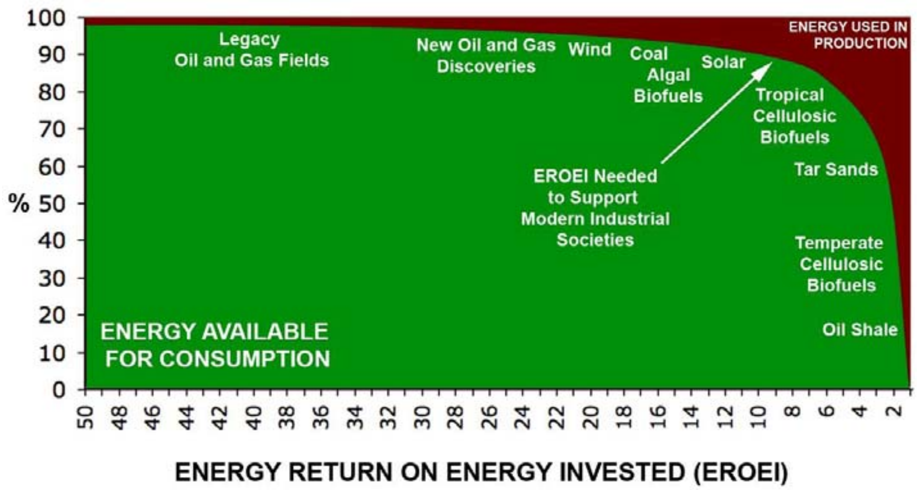
- Lihir Gold Mine located on the remote Lihir island in the Bismarck Archipelago approximately 800 km north east of Port Moresby, the capital of Papua New Guinea
- A geothermal power plant installed on a volcanic island is rated at 57 MW and generates 75% of the mine's power requirements. It is proposed to extend the capacity of the plant so that the entire mine will be run on geothermal power. The plant captures steam released from the ore body by drilling to drive steam turbines and generate power
- In 2007, at US1¢ a kWh, geothermal power compared well with US12¢ a kWh fuel generated power. Lihir expects to generate as much as $US 5 million a year from the sale of carbon credits

Melaku M., Geothermal Development at Lihir – An Overview, Proceedings of World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005, pp.1-4.

Conclusions

- Mining is one of the highest power intensity industrial sectors in the world
- Mining is also one of the highest emission intensity industrial sectors
- In the next 5 years energy consumption could be easily reduced by 10–15% companies employ more energy efficient methods
- If the mining industry converts from diesel engines to those driven by electricity generated by alternatives made from renewable sources, carbon emissions could further decrease

Net energy cliff



Year in review—EROI or energy return on (energy) invested , D.J. Murphy & C. Hall, Ann. N.Y. Acad. Sci. 1185 (2010) 102–118.

Easter island civilisation collapse

- the clearest example of a society that destroyed itself by overexploiting its own resources

Energy consumption in fragmentation

Operation	Feed	Product	Energy (kW/tonne
Blasting	∞	1 m	< 0,1
Coarse crushing	1 m	100 mm	0,15 - 0,75
Fine crushing	100 mm	10 mm	0,75 - 3
Coarse grinding	10 mm	1 mm	3 - 10
Fine grinding	1 mm	0,1 mm	10 - 40