Journey to the 40% Mine

Sector-wide reduction of energy consumption associated with mining to 40% of year 2000 levels, by 2040

McGill University, 30th October, 2015

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Cooling

What is a 40% Mine?

The 40% Mine:

Identification of a portfolio of energy conservation, energy efficiency, energy storage and renewable energy technologies to bring primary energy consumption associated with mineral production down to 40% of that today, by the year 2040.

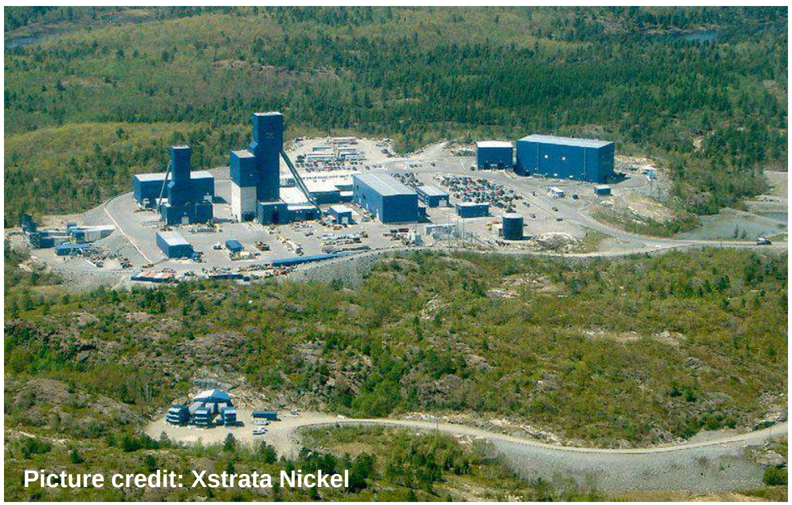
Motivation:

The research considers targeted energy solutions for mining operators that bring about the benefits of lower energy consumption, lower cost and lower environmental impact.

Why do we need a 40% Mine?

Wherever it goes on, mineral production is an energy intensive process; energy costs are dictating mine economics

1st equation:


Picture credit: Xstrata Nickel

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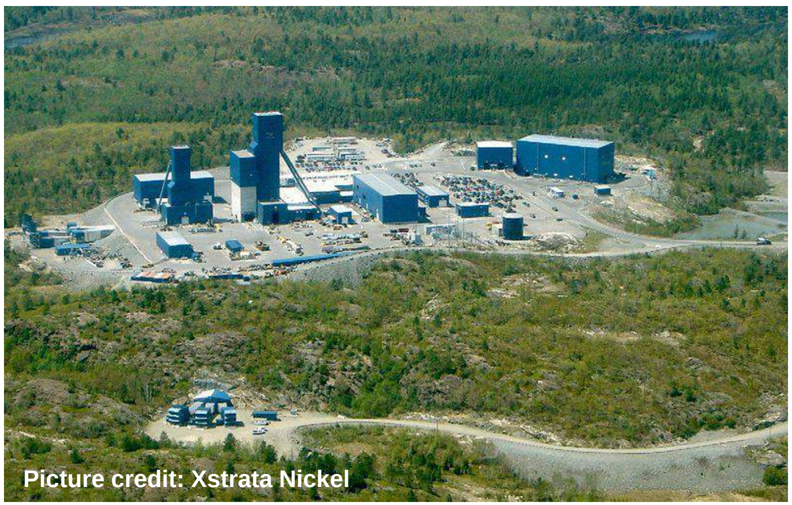
Picture credit: The Sudbury Star

Nickel Rim South

- Discovered: 2001
- Nameplate production achieved: 2011
- Initial producing life: 15 years

Wherever it goes on, mineral production is an energy intensive process; energy costs are dictating mine economics

1st equation:



Picture credit: Xstrata Nickel

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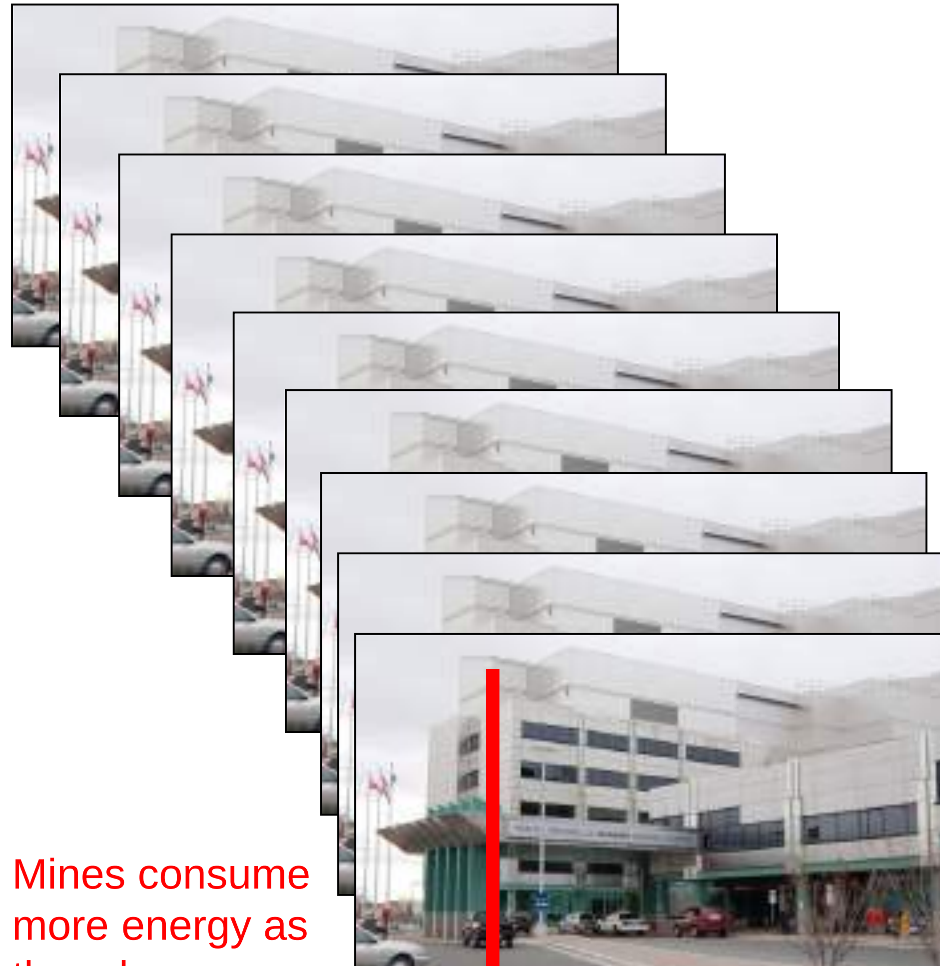
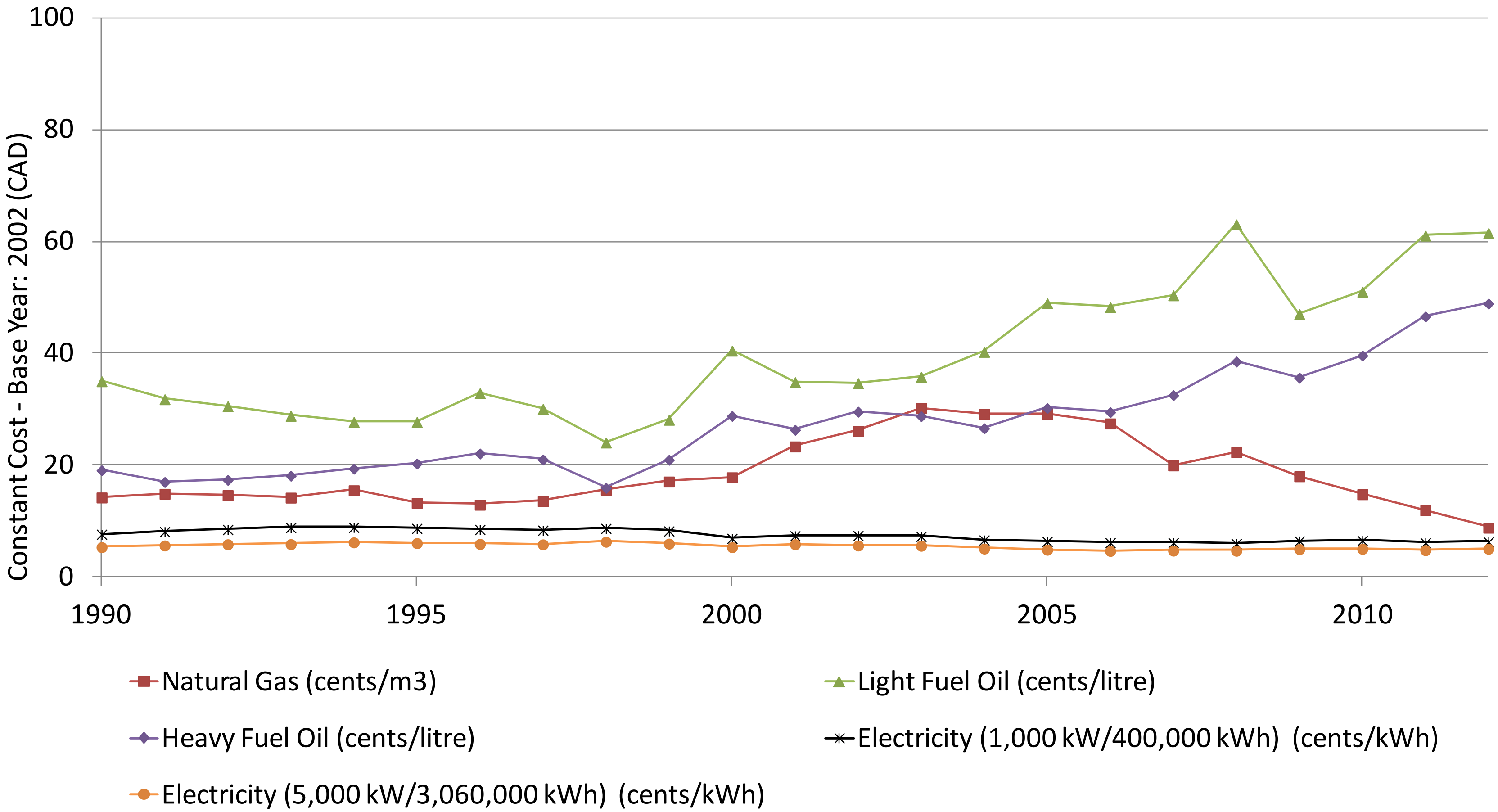


Mines consume more energy as they deepen

Nickel Rim South
- Discovered: 2001
- Nameplate production achieved: 2011
- Initial producing life: 15 years

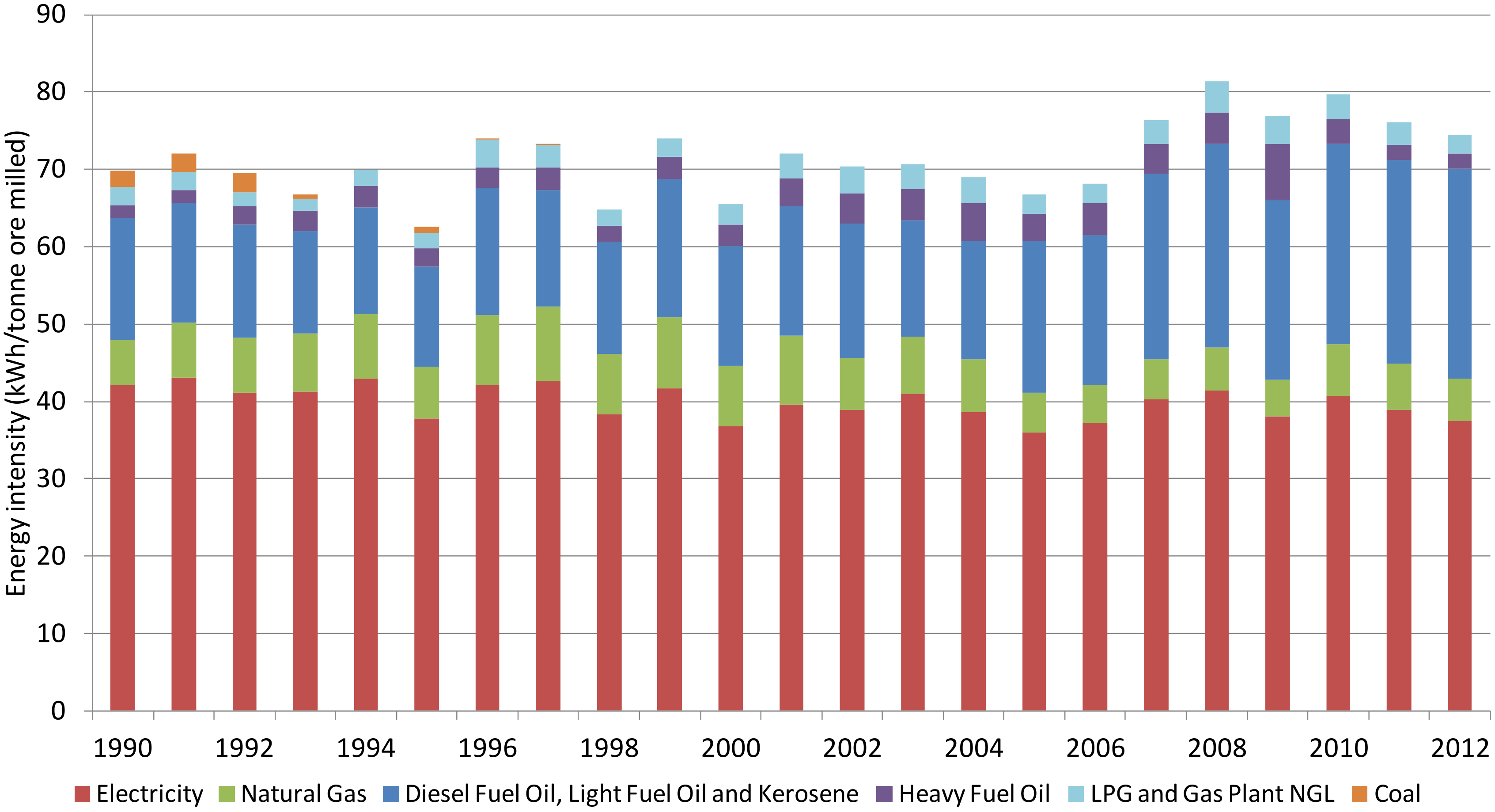
Diesel prices have risen since 1990



(Natural Resources Canada ca. 2014, Statistics Canada 2015)

Levesque, M., Millar, D. and Paraszczak, J., 2014. Energy and mining – the home truths. Journal of Cleaner Production, 84(0), pp. 233-255

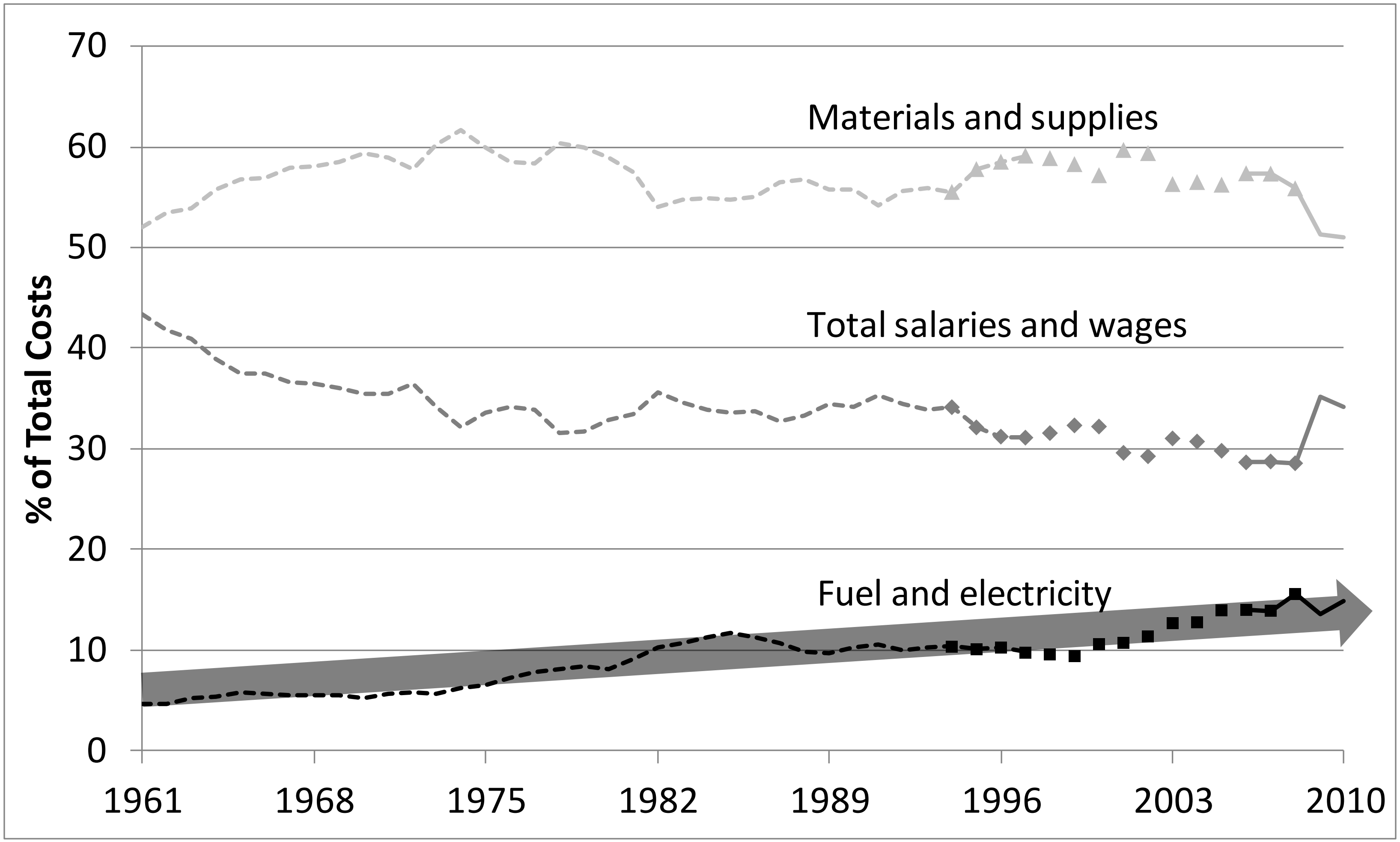
It appears that electricity savings have enabled increased diesel consumption



Canadian copper, nickel, lead and zinc mines energy intensity 1990-2012 (Natural Resources Canada, nd)

Levesque, M., Millar, D. and Paraszczak, J., 2014. Energy and mining – the home truths. Journal of Cleaner Production, 84(0), pp. 233-255

Proportion of total costs allocated to energy for metal mines in Canada has risen to 15%



Levesque, M., Millar, D. and Paraszczak, J., 2014. Energy and mining – the home truths. Journal of Cleaner Production, 84(0), pp. 233-255

How could we do a 40% Mine 'for real'?

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Practical options for a 40% Mine today must have Technology Readiness Level (TRL) >8

TRL	Description of Level
Level 9	Actual technology proven through successful deployment in an operational setting.
Level 8	Actual technology completed and qualified through tests and demonstrations.
Level 7	Prototype ready for demonstration in an appropriate operational environment.
Level 6	System/subsystem model or prototype demonstration in a simulated environment.
Level 5	Component and/or validation in a simulated environment.
Level 4	Component and/or validation in a laboratory environment.
Level 3	Analytical and experimental critical function and/or proof of concept.
Level 2	Technology concept and/or application formulated.
Level 1	Basic principles of concept are observed and reported.

Source: Canada Mining Innovation Council (CMIC): http://www.cmic-ccim.org/

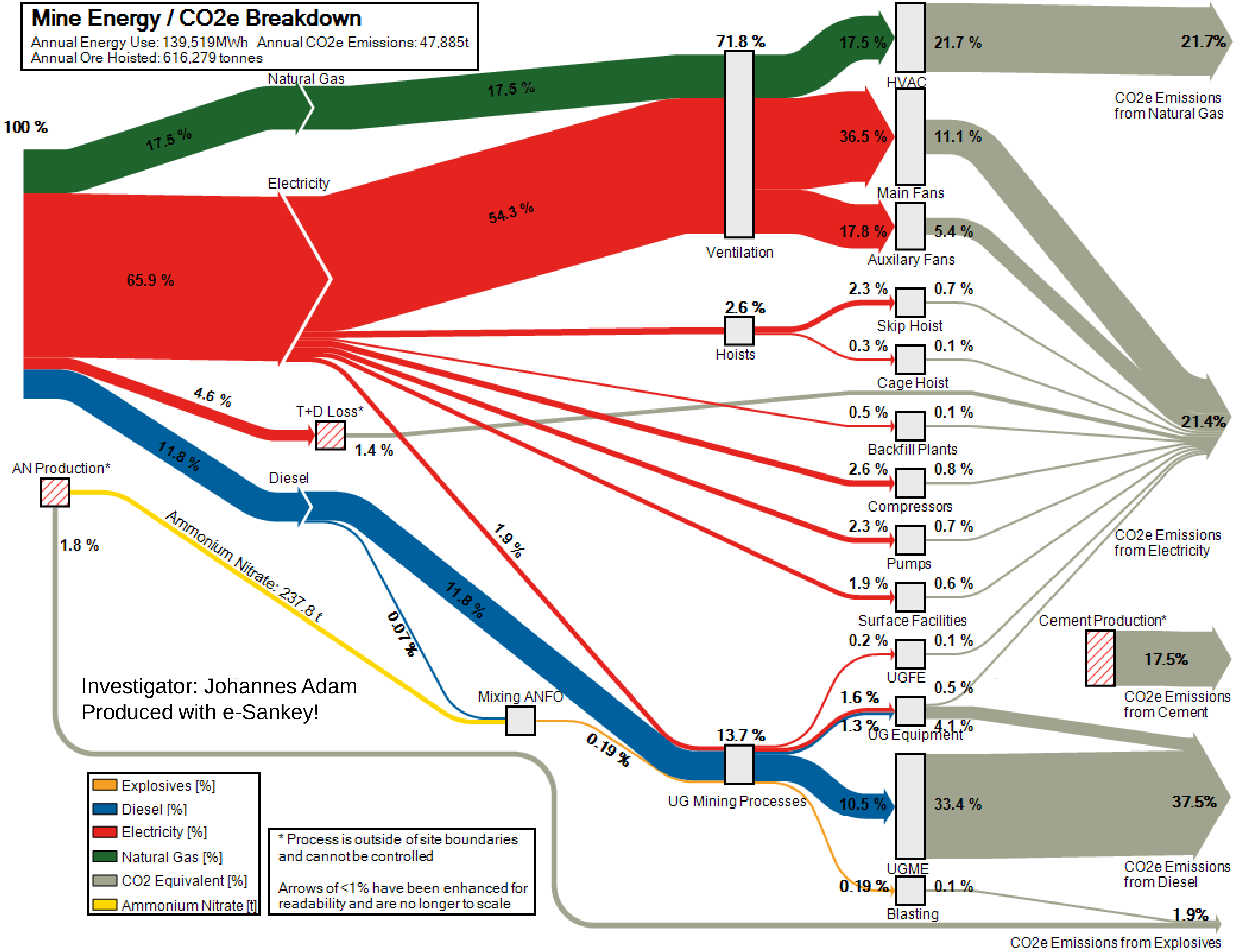
CMIC has identified a range of technology options

- Waste heat recovery in mines (TRL 8 or 9)
  - Use warm exhaust air to heat up cold intake air
- VAM / methane drainage (TRL 7 to 9)
- Kalina cycle / Organic Rankine Cycle (TRL 8 or 9)
  - Low temperature thermal resources
- Hydropower generation (TRL 9)
  - Low flow/ high head applications: Minewater, hydraulic fill, paste fill
- Hydropowered mining equipment (TRL 9)
  - Northam Platinum Mine, Mponeng Mine,
- Regenerative breaking of downward mass flows (TRL 9)
  - Conveyors, Archimedian Screw Turbine, Electric vehicles, Trolley assist
- Seasonal Storage of thermal and mechanical power (TRL 9)
  - Stobie Ice Stope / Creighton Mine Natural Heat Exchange Area

40% Mine Strategy

- Reduce wasted energy
  - Eliminate obvious waste
  - Improved control systems
  - Storage of wasted energy for future use
- Use energy more efficiently
  - Improved control systems
  - Storage systems
  - Higher efficiency technology
- Technological solutions
  - Renewables
  - Re-newed technology

Example 1



Mine Energy / CO2e Breakdown
Annual Energy Use: 139,519MWh Annual CO2e Emissions: 47,885t
Annual Ore Hoisted: 616,279 tonnes
100 %
Natural Gas
17.5 %
17.5 %
Electricity
65.9 %
54.3 %
71.8 %
Ventilation
17.5 %
HVAC
21.7 %
21.7%
CO2e Emissions from Natural Gas
36.5 %
Main Fans
11.1 %
17.8 %
Auxilary Fans
5.4 %
2.6 %
Hoists
2.3 %
Skip Hoist
0.7 %
0.3 %
Cage Hoist
0.1 %
4.6 %
T+D Loss*
1.4 %
0.5 %
Backfill Plants
0.1 %
21.4%
2.6 %
Compressors
0.8 %
2.3 %
Pumps
0.7 %
CO2e Emissions from Electricity
1.9 %
Surface Facilities
0.6 %
AN Production*
1.8 %
11.8 %
Diesel
Ammonium Nitrate: 237.8 t
11.8 %
0.07 %
1.9 %
0.2 %
UGFE
0.1 %
Cement Production*
17.5%
CO2e Emissions from Cement
Investigator: Johannes Adam
Produced with e-Sankey!
Mixing ANFO
0.19 %
13.7 %
UG Mining Processes
1.6 %
1.3 %
UG Equipment
0.5 %
4.1 %
10.5 %
UGME
33.4 %
37.5%
CO2e Emissions from Diesel
0.19 %
Blasting
0.1 %
1.9%
CO2e Emissions from Explosives
Explosives [%]
Diesel [%]
Electricity [%]
Natural Gas [%]
CO2 Equivalent [%]
Ammonium Nitrate [t]
* Process is outside of site boundaries and cannot be controlled
Arrows of <1% have been enhanced for readability and are no longer to scale

Initial energy, cost and emissions statement

Process	Proportions of Base Consumption			
	Type	Energy %	Cost %	Emissions %
HVAC	Natural Gas	17.5%	5.2%	21.7%
Main Fans	Electricity	36.5%	38.5%	11.1%
Auxiliary Fans	Electricity	17.8%	18.8%	5.4%
Skip Hoist	Electricity	2.3%	2.4%	0.7%
Cage Hoist	Electricity	0.29%	0.31%	0.09%
Backfill Plants	Electricity	0.46%	0.49%	0.14%
Compressors	Electricity	2.6%	2.7%	0.8%
Pumps	Electricity	2.3%	2.4%	0.7%
Surface Facilities	Electricity	1.9%	2.0%	0.58%
UG FE (Crusher)	Electricity	0.23%	0.24%	0.07%
UG Equipment	Electricity	1.6%	1.7%	0.48%
UG Equipment	Diesel	1.3%	2.4%	4.1%
UG ME	Diesel	10.5%	19.4%	33.4%
ANFO Blasting	Diesel	0.07%	0.14%	-
ANFO Blasting	Explosives	0.19%	3.49%	1.9%
Paste Plant	Cement			17.5%
T + D Losses	Electricity	4.6%	4.83%	1.39%
Totals:	**Totals:**	**100.0%**	**100.0%**	**100.0%**

Ventilation: 54.3%
Ventilation + Winter air heating: 71.8%

Investigator: Dr Michelle Levesque

Measure 1: Slippery, well installed, auxiliary ventilation ducting + Ventilation On Demand (TRL = 9)

Auxiliary ventilation duct strings can be designed and assessed with a useful, freely downloadable, tool:

https://zone.biblio.laurentian.ca/dspace/handle/10219/2301

70% savings against layflat and fixed speed fans, ~1 year payback

Source: Levesque, 2015. An improved energy management methodology for the mining sector. PhD Thesis, Laurentian University

Other initiatives:

Inflatable, velcro fixed exhaust cones
Improved characterization of leakage

Source: http://www.plastiquesgplus.com/en/ventilation

Source: http://www.bestech.com/Downloads/ProductSheets/BESTECH_NRG1-ECO.pdf

Measure 1: Slippery, well installed, auxiliary ventilation ducting + VOD

Process	Proportions of Base Consumption				Saving
	Type	Energy %	Cost %	Emissions %	
HVAC	Natural Gas	17.5%	5.2%	21.7%	
Main Fans	Electricity	36.5%	38.5%	11.1%	
Auxiliary Fans	Electricity	17.8%	18.8%	5.4%	70%
Skip Hoist	Electricity	2.3%	2.4%	0.7%	
Cage Hoist	Electricity	0.29%	0.31%	0.09%	
Backfill Plants	Electricity	0.46%	0.49%	0.14%	
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UG ME	Diesel	10.5%	19.4%	33.4%	
ANFO Blasting	Diesel	0.07%	0.14%	-	
	Explosives	0.19%	3.49%	1.9%	
Paste Plant	Cement			17.5%	
T + D Losses	Electricity	4.6%	4.83%	1.39%	
Totals:	**Totals:**	**100.0%**	**100.0%**	**100.0%**	

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Cage Hoist	Electricity	0.3%	0.31%	0.09%
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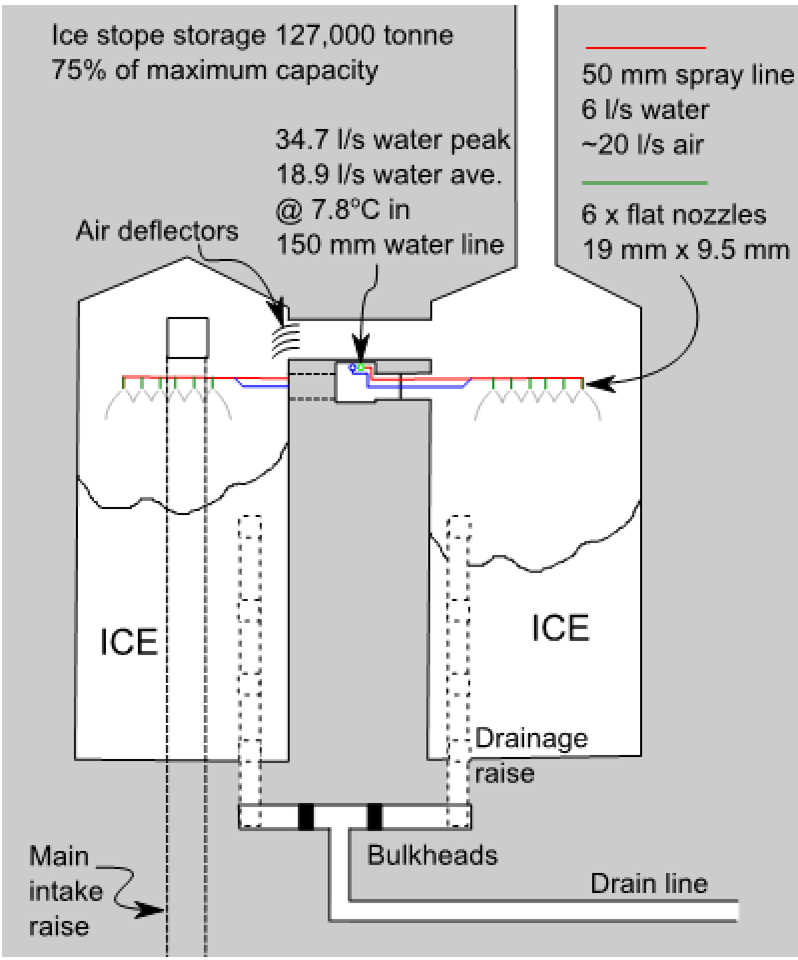
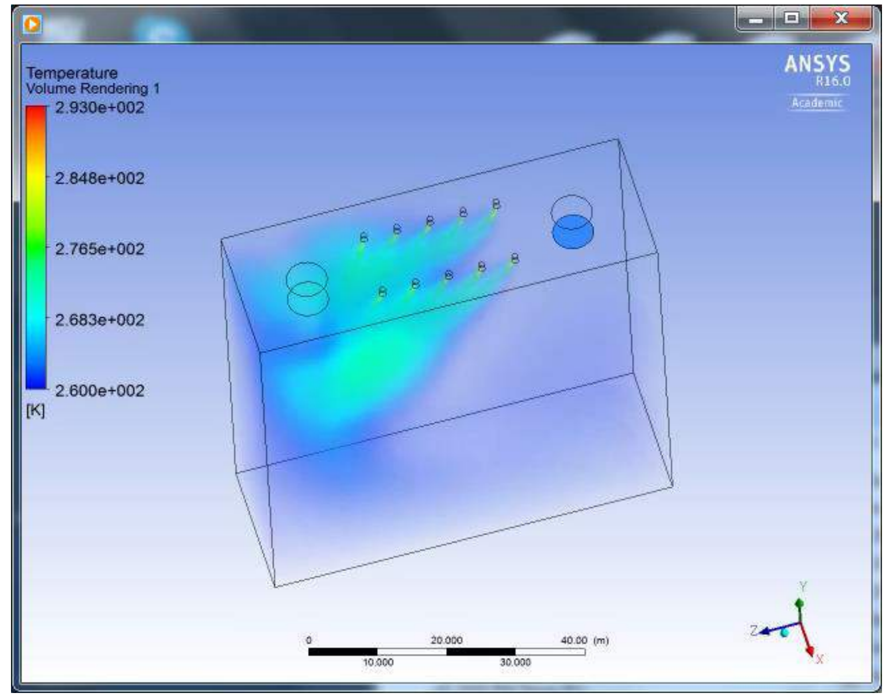
UG ME	Diesel	10.5%	19.4%	33.4%
ANFO Blasting	Diesel	0.1%	0.14%	-
	Explosives	0.2%	3.49%	1.9%
Paste Plant	Cement			17.5%
T + D Losses	Electricity	4.6%	4.83%	1.39%
Totals:	**Totals:**	**87.5%**	**86.9%**	**96.2%**

Measure 2: Eliminate natural gas usage completely through use of snow cannons and open stopes / voids (TRL = 9)



Air heating system at Stobie Mine, Sudbury



CAPEX (excavation) : CAD 10/m^3
Mine pumps already lift warm water
Main fans already provide air movement

Millar, D., Trapani, K., & Romero, A., 2015. Deep Mine Cooling, a Case for Northern Ontario: Part I Int. J. of Min. Sci. & Tech., In press.

Measure 2: Snow cannons and open stopes / voids

Process	Proportions of Base Consumption				Saving
	Type	Energy %	Cost %	Emissions %	
HVAC	Natural Gas	17.5%	5.2%	21.7%	100%
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Backfill Plants	Electricity	0.46%	0.49%	0.14%	
Compressors	Electricity	2.6%	2.7%	0.8%	
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UG Equipment	Electricity	1.6%	1.7%	0.48%	
	Diesel	1.3%	2.4%	4.1%	
UG ME	Diesel	10.5%	19.4%	33.4%	
ANFO Blasting	Diesel	0.07%	0.14%	-	
	Explosives	0.19%	3.49%	1.9%	
Paste Plant	Cement			17.5%	
T + D Losses	Electricity	4.6%	4.83%	1.39%	
Totals:	Totals:	100.0%	100.0%	100.0%	

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	Type	Energy %	Cost %	Emissions %
HVAC	Natural Gas	0.0%	0.0%	0.0%
Main Fans	Electricity	36.5%	38.5%	11.1%
Auxiliary Fans	Electricity	5.3%	5.6%	1.6%
Skip Hoist	Electricity	2.3%	2.4%	0.7%
Cage Hoist	Electricity	0.3%	0.31%	0.09%
Backfill Plants	Electricity	0.5%	0.49%	0.14%
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Pumps	Electricity	2.3%	2.4%	0.7%
Surface Facilities	Electricity	1.9%	2.0%	0.58%
UG FE (Crusher)	Electricity	0.2%	0.24%	0.07%
UG Equipment	Electricity	1.6%	1.7%	0.48%
	Diesel	1.3%	2.4%	4.1%
UG ME	Diesel	10.5%	19.4%	33.4%
ANFO Blasting	Diesel	0.1%	0.14%	-
	Explosives	0.2%	3.49%	1.9%
Paste Plant	Cement			17.5%
T + D Losses	Electricity	4.6%	4.83%	1.39%
Totals:	Totals:	70.1%	81.7%	74.5%

Measure 3: Electrification of sub-surface mining equipment will improve worker health, with similar cost and save energy


Source: Sudbury Mining Solutions

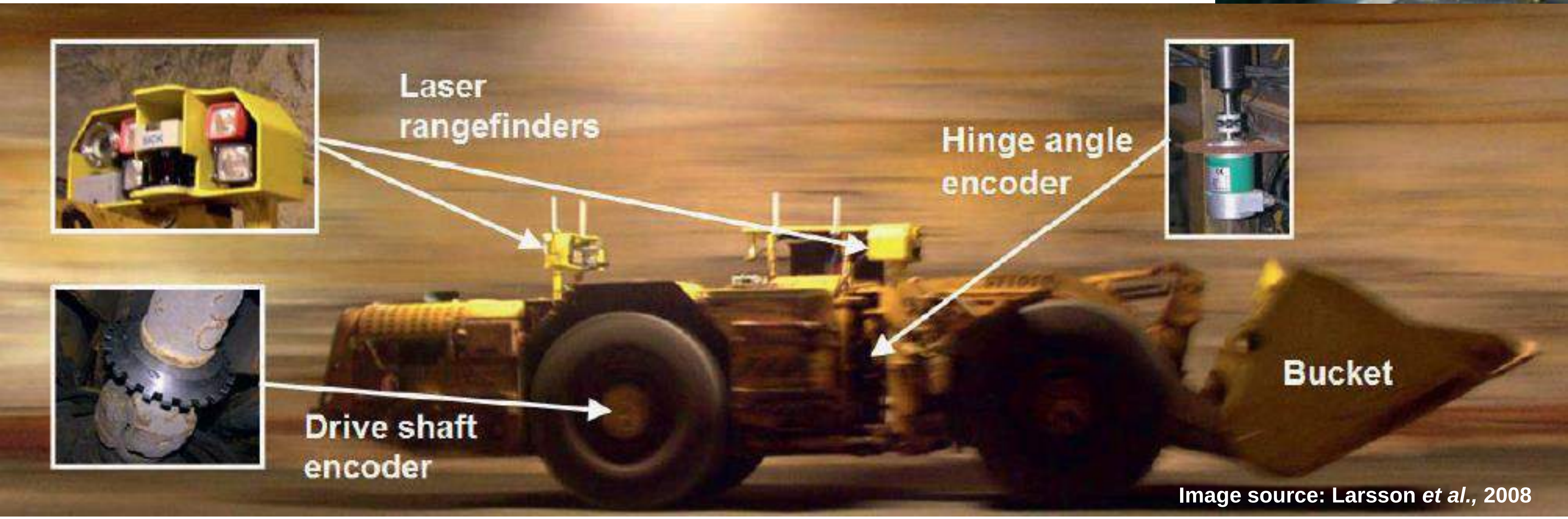

Image source: Larsson *et al.*, 2008

- Substantially reduced ventilation requirements due to lower airborne contaminants and less heat (electric motors are efficient prime movers)
- For mobility/flexibility: run on conventional batteries, flow batteries or fuel cells
- Modern communications: remotely operated (to improve worker health & safety)
- Automate operation for enhanced productivity
- There is now appreciable effort deployed in R&D sector and by OEMs in development of battery-electric production equipment

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Kirkland Lake Gold

- Battery electric scoops were 164% of diesel scoop costs (130 kW)
- Battery electric haul trucks are reported to have 65% of diesel cost per hour (170 kW)
- Trends positive: reliability improving, costs reducing

Source: Schuman, M. 2015. Case study: Battery powered underground mobile equipment. Presentation at Energy and Mines Summit, Toronto, 23rd October.

The ratings of battery electric production equipment are becoming greater

ScoopTram BEST7

- 7t bucket capacity
- Built on same chassis as diesel for commonality
- Lithium Ion battery packs
- Quick battery change out in 10 minutes
- Runtime on one battery is 3-4 hours depending on application

MineTruck BEMT2010

- 20t payload capacity
- Runtime on one battery is ~3 hours loaded up ramp.
- Consider your mine design to travel down ramp loaded, and up empty.
- Regenerative braking.

Source: Travis Battley. Atlas Copco, Pers. Comm.

Measure 3: Electrification (TRL = 8 now, but TRL = 9 by 2020)

Process	Proportions of Base Consumption				Saving
	Type	Energy %	Cost %	Emissions %	
HVAC	Natural Gas	17.5%	5.2%	21.7%	100%
Main Fans	Electricity	36.5%	38.5%	11.1%	
Auxiliary Fans		17.8%	18.8%	5.4%	70%
Skip Hoist		2.3%	2.4%	0.7%	
Cage Hoist		0.29%	0.31%	0.09%	
Backfill Plants		0.46%	0.49%	0.14%	
Compressors		2.6%	2.7%	0.8%	
Pumps		2.3%	2.4%	0.7%	
Surface Facilities		1.9%	2.0%	0.58%	
UG FE (Crusher)		0.23%	0.24%	0.07%	
UG Equipment		1.6%	1.7%	0.48%	-3.9%
	Diesel	1.3%	2.4%	4.1%	100%
UG ME		10.5%	19.4%	33.4%	100%
ANFO Blasting		0.07%	0.14%	-	
	Explosives	0.19%	3.49%	1.9%	
Paste Plant	Cement			17.5%	
T + D Losses	Electricity	4.6%	4.83%	1.39%	
Totals:	Totals:	100.0%	100.0%	100.0%	

Process	Proportions of Base Consumption			
	Type	Energy %	Cost %	Emissions %
HVAC	Natural Gas	0.0%	0.0%	0.0%
Main Fans	Electricity	36.5%	38.5%	11.1%
Auxiliary Fans		5.3%	5.6%	1.6%
Skip Hoist		2.3%	2.4%	0.7%
Cage Hoist		0.3%	0.31%	0.09%
Backfill Plants		0.5%	0.49%	0.14%
Compressors		2.6%	2.7%	0.8%
Pumps		2.3%	2.4%	0.7%
Surface Facilities		1.9%	2.0%	0.58%
UG FE (Crusher)		0.2%	0.24%	0.07%
UG Equipment		5.4%	5.7%	1.65%
	Diesel	0.0%	0.0%	0.0%
UG ME		0.0%	0.0%	0.0%
ANFO Blasting		0.1%	0.14%	-
	Explosives	0.2%	3.49%	1.9%
Paste Plant	Cement			17.5%
T + D Losses	Electricity	4.6%	4.83%	1.39%
Totals:	Totals:	62.2%	64.0%	38.2%

Measure 4: Revise ventilation system loading due to reduced DPM emissions (TRL = 9)

2^{nd} Equation: (for the main mine fans):

$$\mathrm{MWh} \propto RQ^3$$

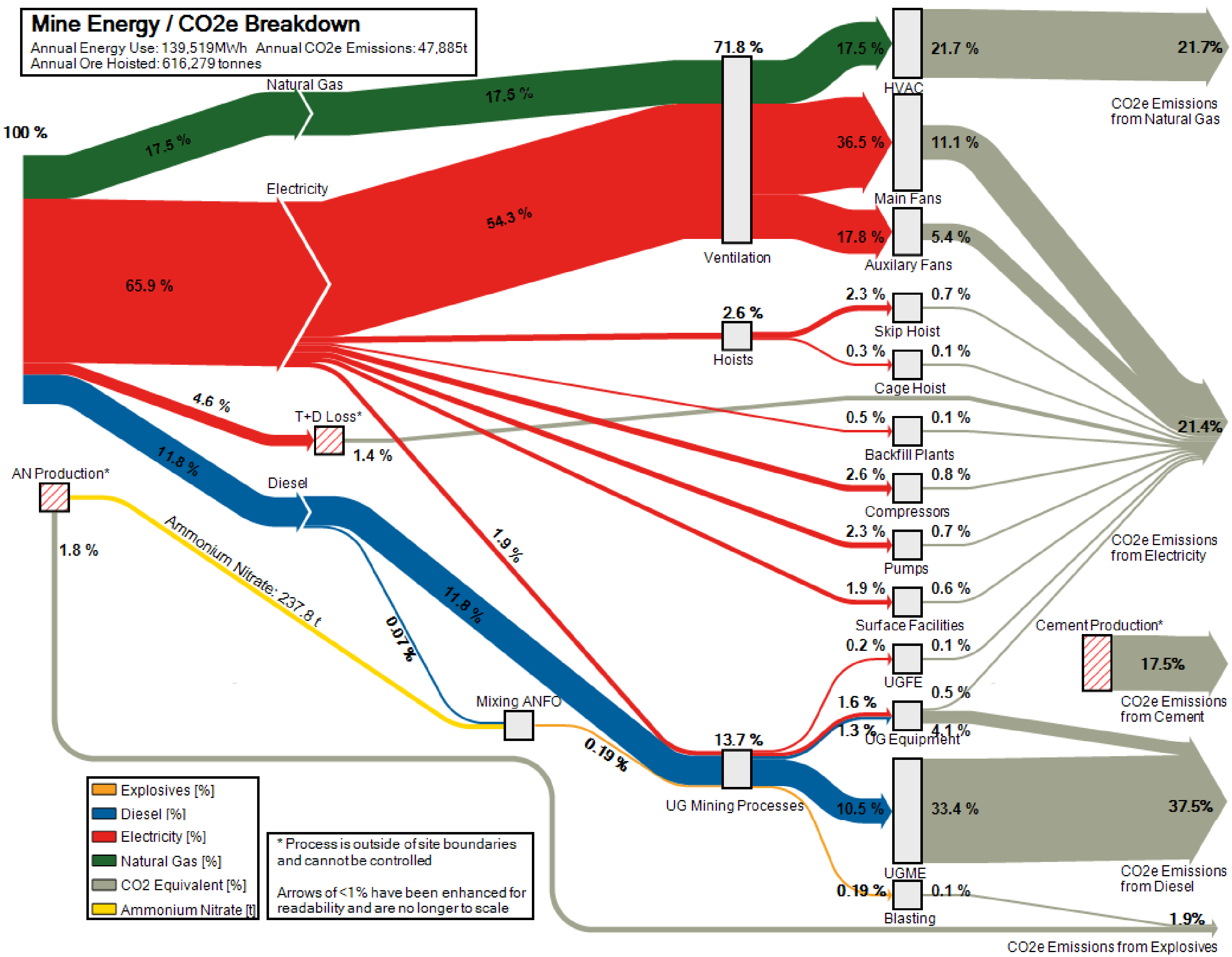
so reducing air flow volume to 73% of its former value will reduce the electrical energy consumed by the fan to 39% of its former value

Measure 4: Modulate main fans for reduced airborne contaminant

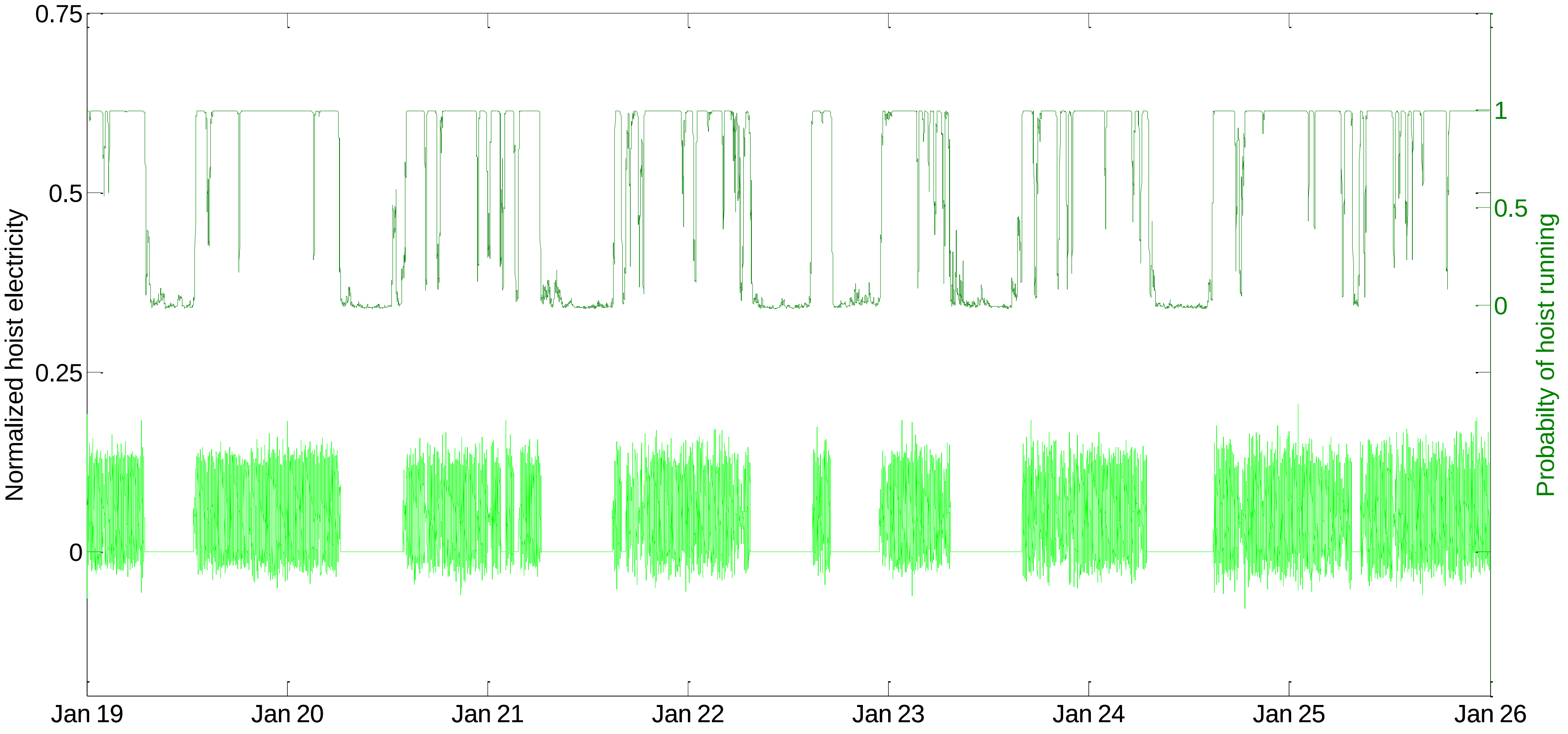
Process	Proportions of Base Consumption				Saving
	Type	Energy %	Cost %	Emissions %	
HVAC	Natural Gas	17.5%	5.2%	21.7%	100%
Main Fans	Electricity	36.5%	38.5%	11.1%	61%
Auxiliary Fans		17.8%	18.8%	5.4%	70%
Skip Hoist		2.3%	2.4%	0.7%	
Cage Hoist		0.29%	0.31%	0.09%	
Backfill Plants		0.46%	0.49%	0.14%	
Compressors		2.6%	2.7%	0.8%	
Pumps		2.3%	2.4%	0.7%	
Surface Facilities		1.9%	2.0%	0.58%	
UG FE (Crusher)		0.23%	0.24%	0.07%	
UG Equipment		1.6%	1.7%	0.48%	-3.9%
	Diesel	1.3%	2.4%	4.1%	100%
UG ME		10.5%	19.4%	33.4%	100%
ANFO Blasting		0.07%	0.14%	-	
	Explosives	0.19%	3.49%	1.9%	
Paste Plant	Cement			17.5%	
T + D Losses	Electricity	4.6%	4.83%	1.39%	
Totals:	**Totals:**	**100.0%**	**100.0%**	**100.0%**	

Process	Proportions of Base Consumption			
	Type	Energy %	Cost %	Emissions %
HVAC	Natural Gas	0.0%	0.0%	0.0%
Main Fans	Electricity	14.2%	15.0%	4.3%
Auxiliary Fans		5.3%	5.6%	1.6%
Skip Hoist		2.3%	2.4%	0.7%
Cage Hoist		0.3%	0.31%	0.09%
Backfill Plants		0.5%	0.49%	0.14%
Compressors		2.6%	2.7%	0.8%
Pumps		2.3%	2.4%	0.7%
Surface Facilities		1.9%	2.0%	0.58%
UG FE (Crusher)		0.2%	0.24%	0.07%
UG Equipment		5.4%	5.7%	1.65%
	Diesel	0.0%	0.0%	0.0%
UG ME		0.0%	0.0%	0.0%
ANFO Blasting		0.1%	0.14%	-
	Explosives	0.2%	3.49%	1.9%
Paste Plant	Cement			17.5%
T + D Losses	Electricity	4.6%	4.83%	1.39%
Totals:	**Totals:**	**39.9%**	**40.6%**	**31.4%**

The thin lines in the Sankey diagram need investigation too, for increased cost savings, via load levelling



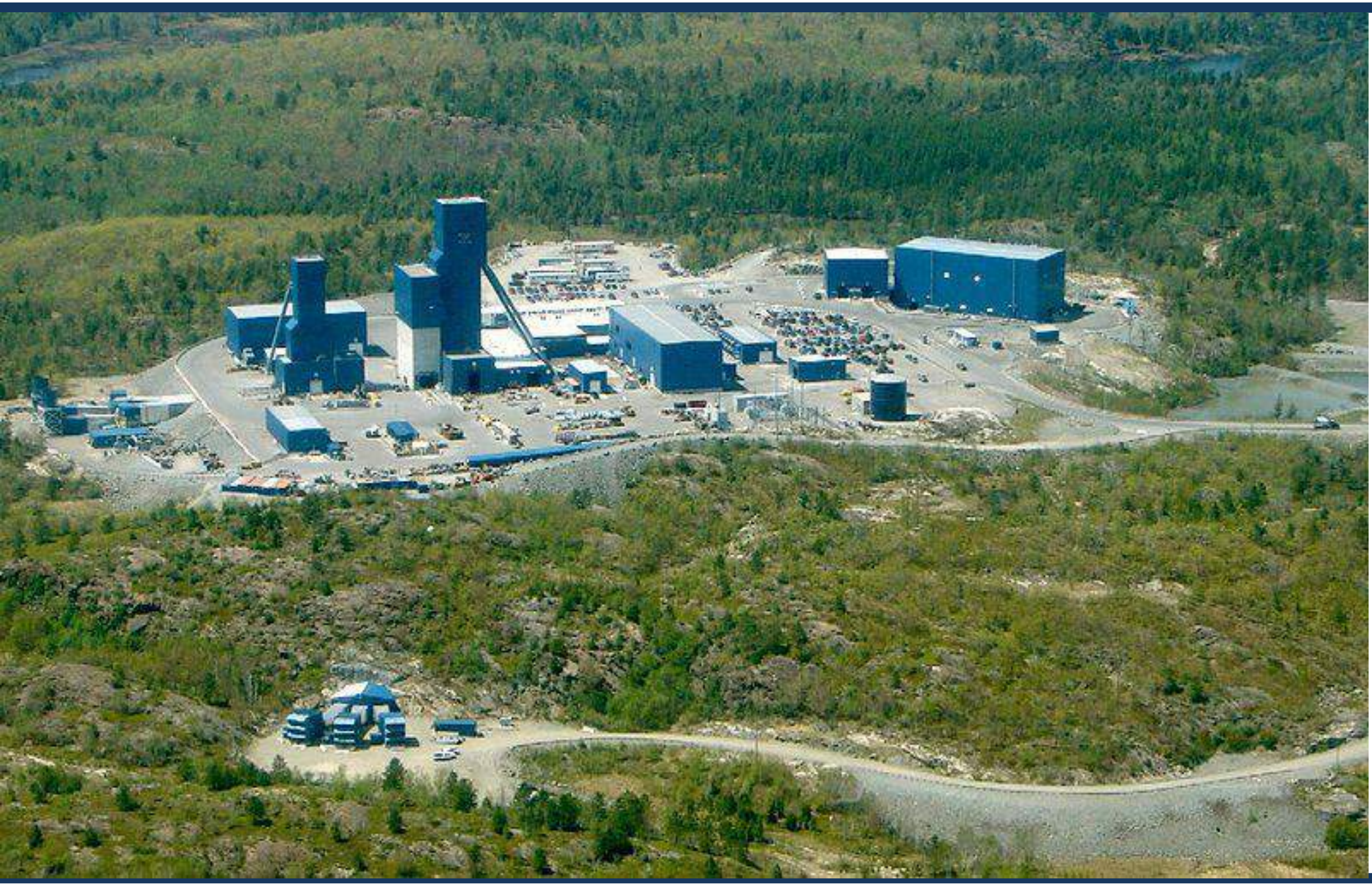
The hoist consumed 4% of the total electricity at the mine



Are all 40% Mines the same?

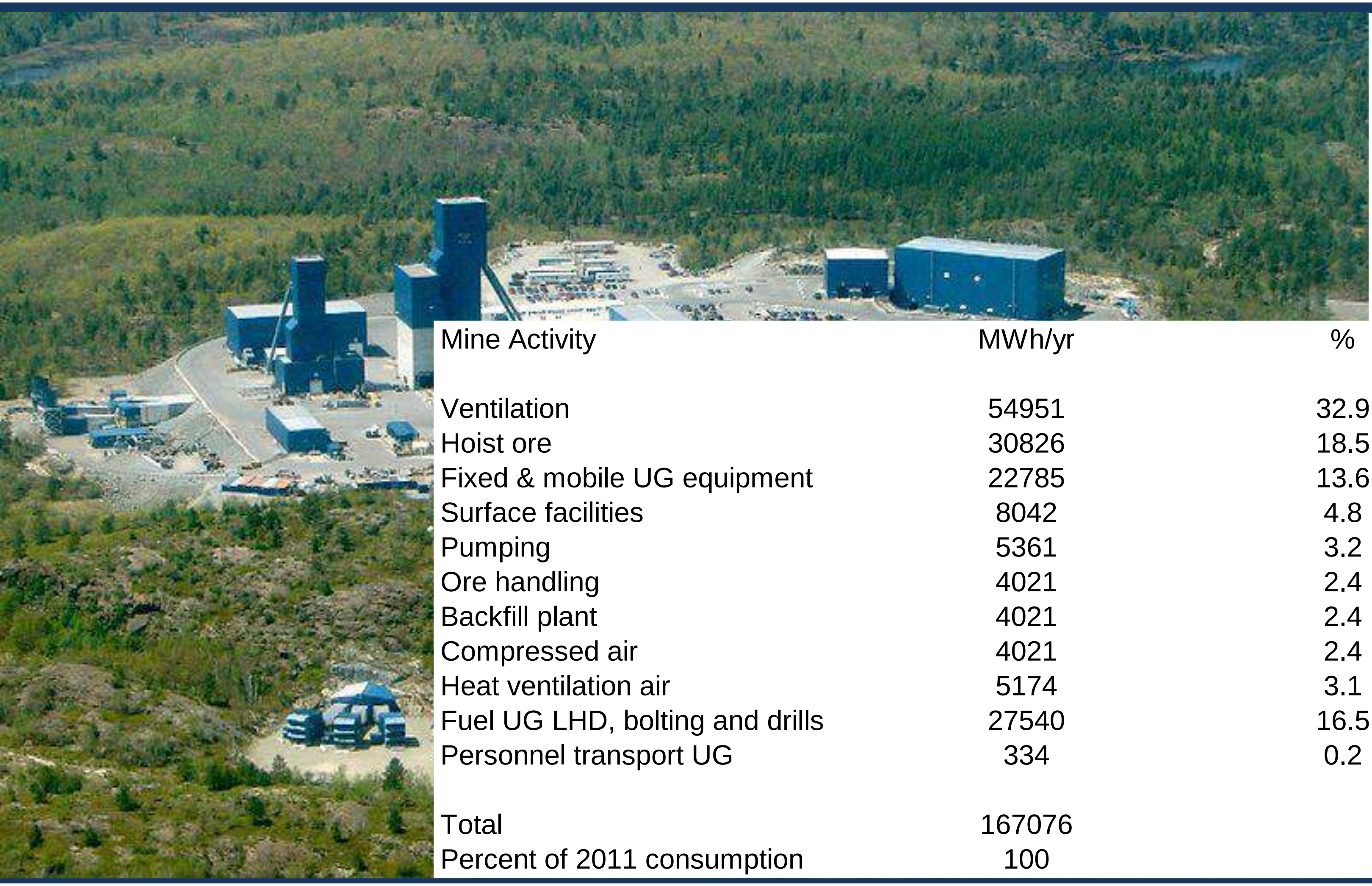
No!

Example 2: A mine consuming 40% of the energy it does today, in 2040



Picture credit: Xstrata Nickel

In a new mine, some of the 'easy wins', such as VOD, are already employed, with the result that ventilation energy is already lower

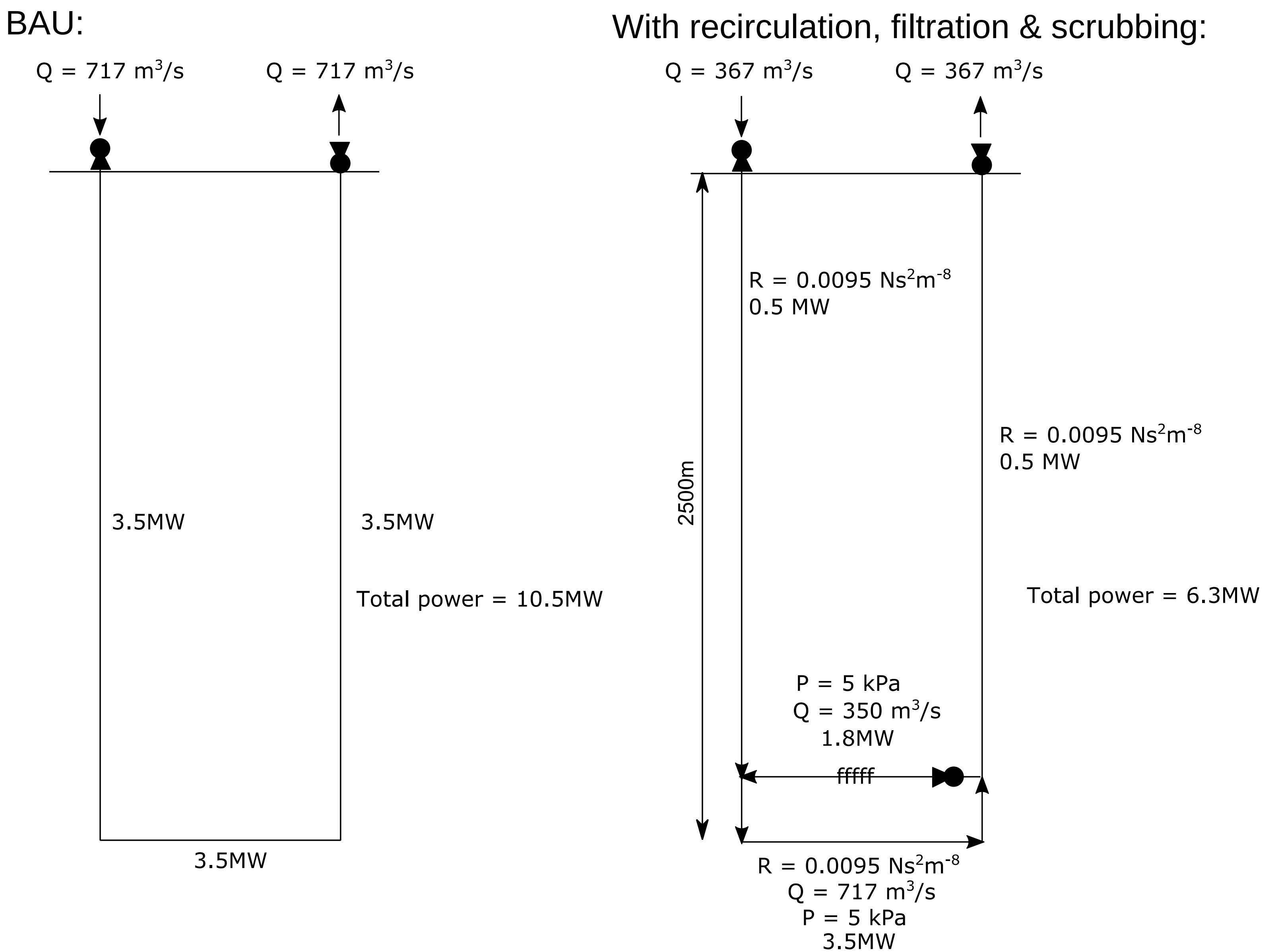


Mine Activity	MWh/yr	%	Energy Type
Ventilation	54951	32.9	Electricity
Hoist ore	30826	18.5	Electricity
Fixed & mobile UG equipment	22785	13.6	Electricity
Surface facilities	8042	4.8	Electricity
Pumping	5361	3.2	Electricity
Ore handling	4021	2.4	Electricity
Backfill plant	4021	2.4	Electricity
Compressed air	4021	2.4	Electricity
Heat ventilation air	5174	3.1	Natural Gas
Fuel UG LHD, bolting and drills	27540	16.5	Diesel
Personnel transport UG	334	0.2	Gasoline
Total	167076		
Percent of 2011 consumption	100		

Picture credit: Xstrata Nickel

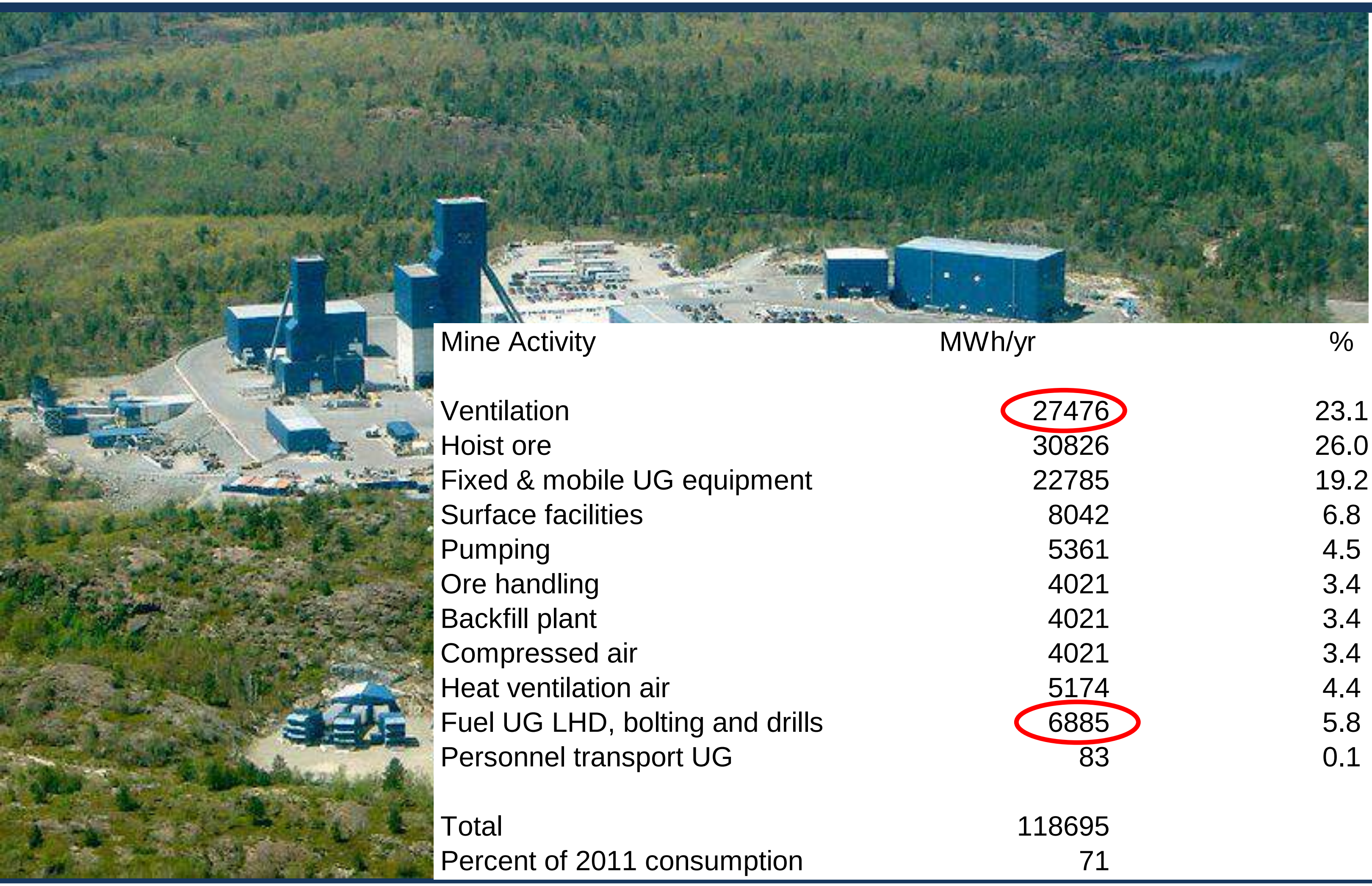
Source: Bartsch, 2011. Nickel Rim South Mine: Leveraging Infrastructure for Energy Management and Optimization. ARC Orlando Forum, 2011

Substantial savings could be obtained by recycling mine air (TRL = 5)



Data source: O'Connor, Gibson, MacKay, & Grupp (2002) Creighton Mine, #11 shaft exhaust fan upgrade, 9th US Mine Ventilation Symposium

The most significant impact of use of electric vehicles on the energy budget is reduced consumption for ventilation

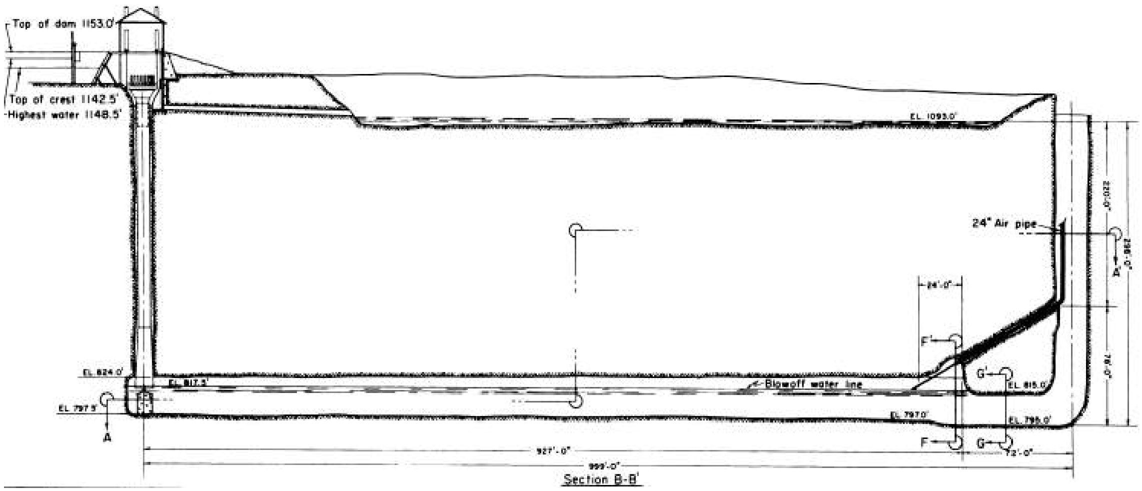


Mine Activity	MWh/yr	%	Energy Type
Ventilation	27476	23.1	Electricity
Hoist ore	30826	26.0	Electricity
Fixed & mobile UG equipment	22785	19.2	Electricity
Surface facilities	8042	6.8	Electricity
Pumping	5361	4.5	Electricity
Ore handling	4021	3.4	Electricity
Backfill plant	4021	3.4	Electricity
Compressed air	4021	3.4	Electricity
Heat ventilation air	5174	4.4	Natural Gas
Fuel UG LHD, bolting and drills	6885	5.8	Electricity
Personnel transport UG	83	0.1	Electricity
Total	118695		
Percent of 2011 consumption	71		

Picture credit: Xstrata Nickel

mirarco ENERGY

Clean, green, cheap compressed air can be produced efficiently and re-newably by modernization of a 19th century technology (TRL = 9 / 7)



Charles Havelock Taylor & Family

- The hydraulic air compressor has no moving parts
- After commissioning, the Ragged Chutes HAC operated for 70 years, only being stopped twice for repairs to the intake heads
- Operated using falling water from Montreal river
- Produced air for ~29 silver mines in Cobalt, 20 km distant

Millar, D.L., 2014. A review of the case for modern-day adoption of hydraulic air compressors. Applied Thermal Engineering. 69, 1-2, pp 55-77.

Mirarco ENERGY

Bringing comminution plant into the sub-surface will present new opportunities for transporting ore material to surface

A new generation of rock crusher uses 30% less energy to reduce size to ~3mm (Sandvik, 2012) TRL = 9

A semi-autogeneous grinding mill underground (TRL = 9)

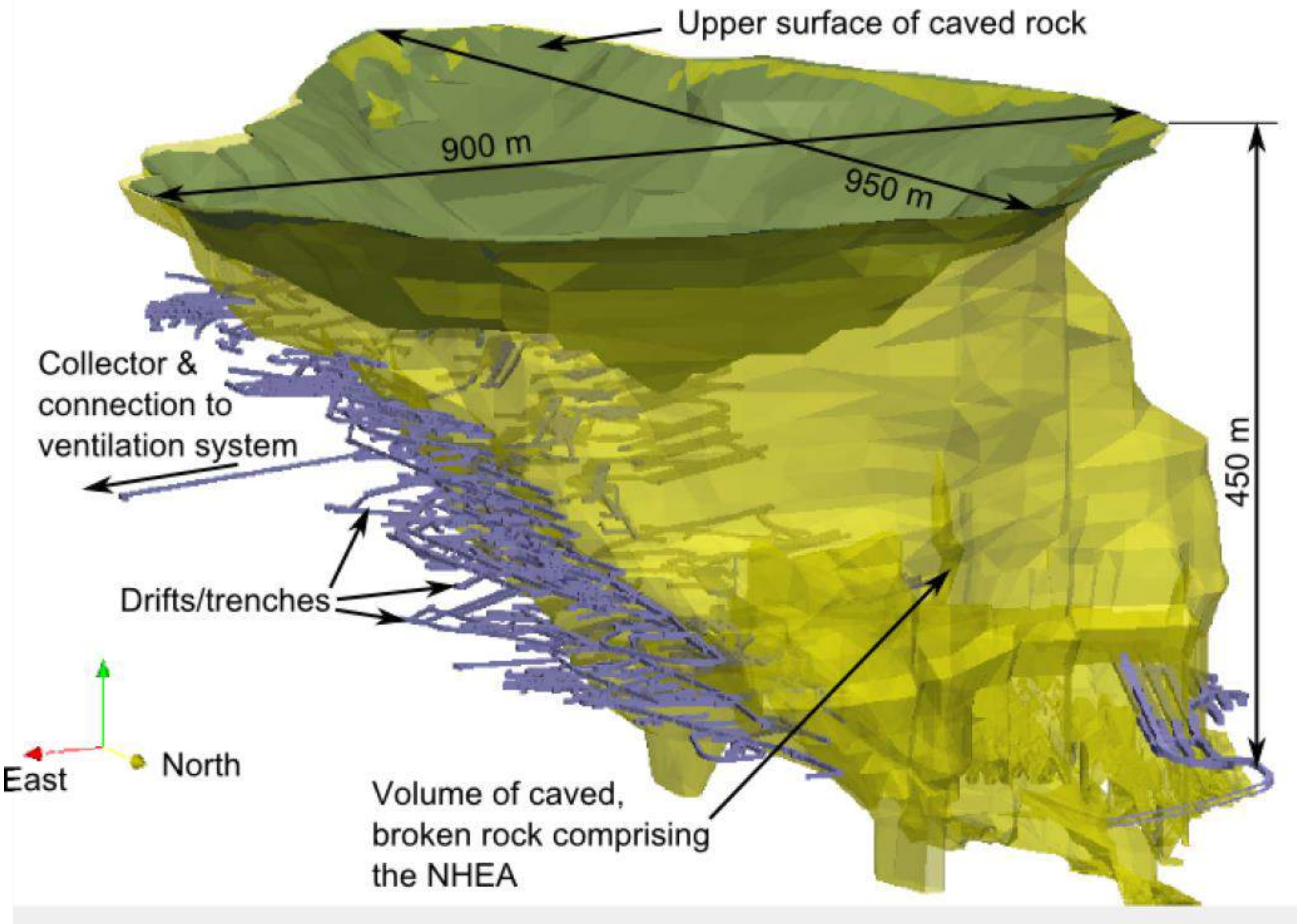
MIRARCO ENERGY

Substantially more energy than the fundamental potential energy is used to lift 1.25 million tonnes of ore to surface

Mine Activity	MWh/yr	MWh/yr (renewables)	%	Energy Type
Ventilation	27476		28.0	Electricity
Hoist ore		10275	10.5	Air lift
Fixed & mobile UG equipment	22785		23.2	Electricity
Surface facilities	8042		8.2	Electricity
Pumping	5361		5.5	Electricity
Ore handling	4021		4.1	Electricity
Backfill plant	4021		4.1	Electricity
Compressed air		4021	4.1	HAC Hydropower
Heat ventilation air	5174		5.3	Natural Gas
Fuel UG LHD, bolting and drills	6885		7.0	Electricity
Personnel transport UG	83		0.1	Electricity
Total	83848	14296		
Percent of 2011 consumption	50			

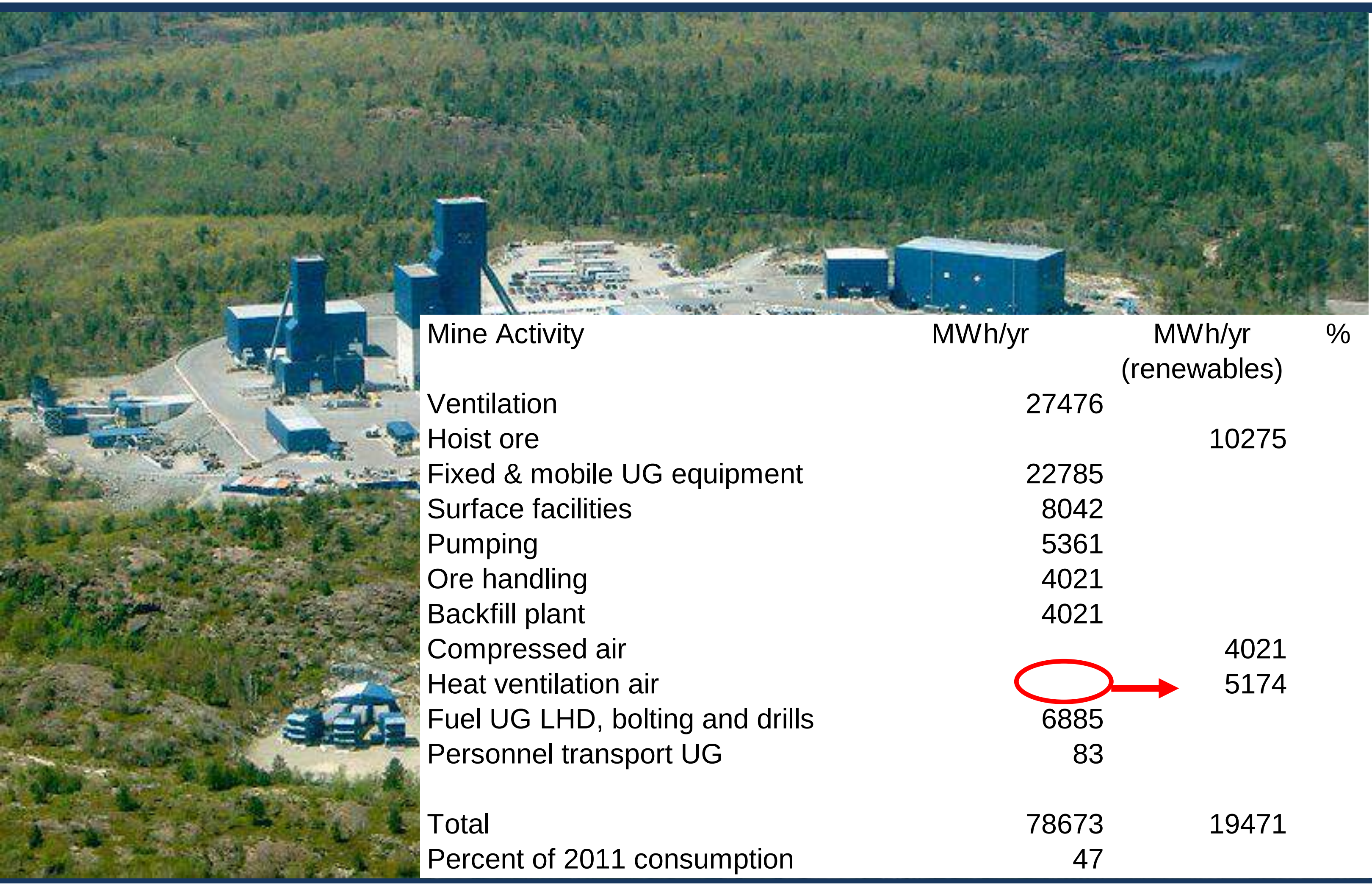
Picture credit: Xstrata Nickel

Cold winter mine air is warmed by heat captured from the warm summer air, and stored in a massive body of broken rock (TRL = 9)



Investigators: Dr Lorrie Fava, Alberto Romero, Negar Saeidi

Upcast air heat recovery systems, ice stopes, heat exchange areas, or combinations could eliminate natural gas consumption



Mine Activity	MWh/yr	MWh/yr (renewables)	%	Energy Type
Ventilation	27476			Electricity
Hoist ore		10275		Air lift
Fixed & mobile UG equipment	22785			Electricity
Surface facilities	8042			Electricity
Pumping	5361			Electricity
Ore handling	4021			Electricity
Backfill plant	4021			Electricity
Compressed air		4021		HAC Hydropower
Heat ventilation air		5174		Ice stope
Fuel UG LHD, bolting and drills	6885			Electricity
Personnel transport UG	83			Electricity
Total	78673	19471		
Percent of 2011 consumption	47			

Picture credit: Xstrata Nickel

EXISTING FLOATING PV PROJECTS: 2007 - 2014

2007

Aichi, JAPAN,
National Institute of Advanced Industrial Science & Technology - 20kW

2008

Far Niente Wineries, CALIFORNIA (US),
SPG Solar - 175kW

Gundlach Bunshu Wineries, CALIFORNIA (US),
SPG Solar - 30kW

2009

Bubano, ITALY,
Bryo - 500kW

Agost, SPAIN
CELEMIN ENERGY & Polytechnic University of Valencia - 24kW

Solarolo, ITALY,
D.A.I.E.T. - 20kW

2010

Petra Winery, ITALY,
Terra Moretti Holding - 200kW

Agost, SPAIN (Expansion)
CELEMIN ENERGY & Polytechnic University of Valencia - 300kW

2011

Lake Colignola, ITALY,
Scienza Industria Technologia - 30kW

Avetrana, ITALY,
D.A.I.E.T. - 20kW

Piolenc, FRANCE,
Ciel et Terre - 14kW

Petaluma, CALIFORNIA (US),
SPG Solar - 350kW

Vendée, FRANCE,
Osesol - 4kW

Canoe Brook Water Treatment Facility, NEW JERSEY (US),
ENERActive - 112kW

2012

Cheongju, SOUTH KOREA,
Techwin - 20kW

Hapcheon Dam, SOUTH KOREA,
K-Water - 500kW

Pommeraie - sur - Sevre, FRANCE,
Osesol - 100kW

2013

Bishan Park, SINGAPORE,
Phoenix Solar - 5kW

Sudbury, CANADA,
MIRARCO - 0.5kW

Okegawa, JAPAN,
Ciel et Terre - 1,157kW

2014

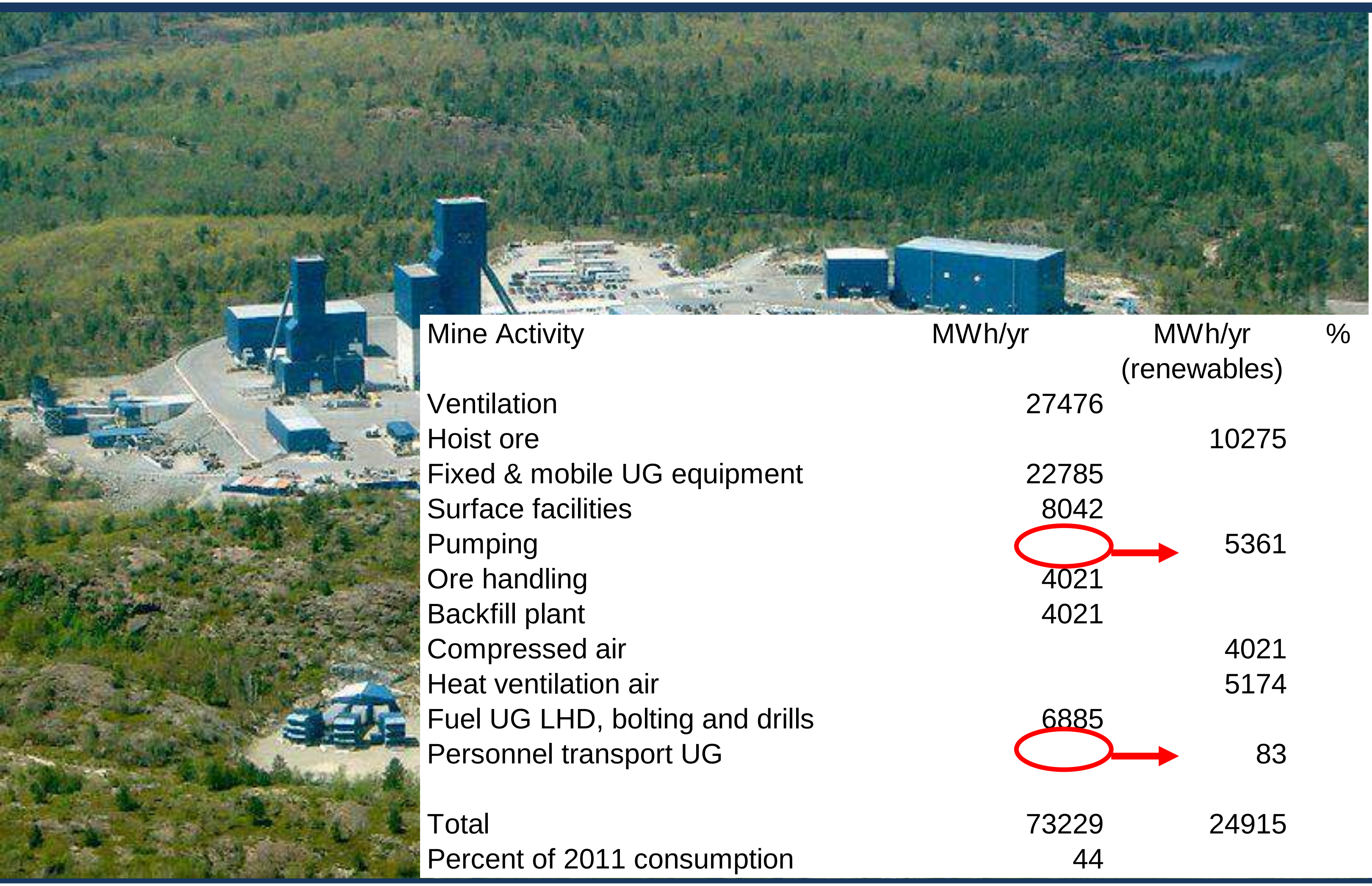
mirarco ENERGY

Having learnt a great deal ourselves through testing a small scale flexible, direct contact prototype in a calm pond in Sudbury, we are deploying a 20kW$_p$ demonstrator in the Mediterranean Sea, off the coast of Malta

Victor Mine
Courtesy De Beers Canada

Victor Mine
Courtesy De Beers Canada

A 3MW$_p$ flexible, floating, photovoltaic array could offset dispatchable electrical loads, such as dewatering pumps



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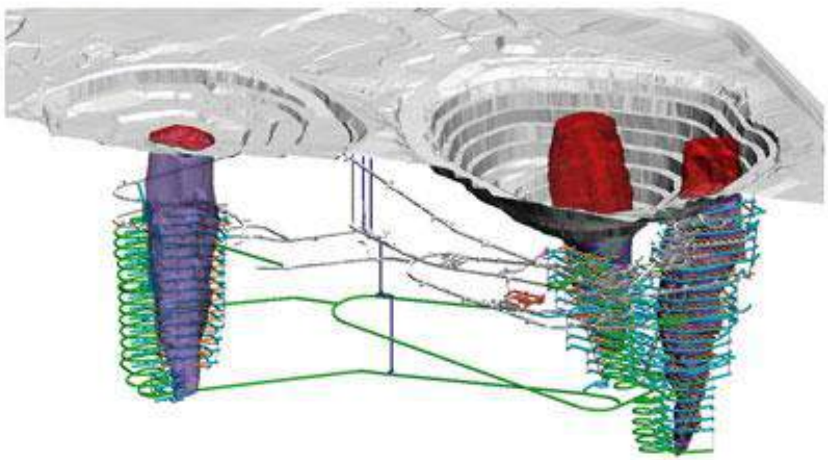
Ventilation	27476			Electricity
Hoist ore		10275		Air lift
Fixed & mobile UG equipment	22785			Electricity
Surface facilities	8042			Electricity
Pumping		5361		PV Electricity
Ore handling	4021			Electricity
Backfill plant	4021			Electricity
Compressed air		4021		HAC Hydropower
Heat ventilation air		5174		Ice stope
Fuel UG LHD, bolting and drills	6885			Electricity
Personnel transport UG		83		PV Electricity
Total	73229	24915		
Percent of 2011 consumption	44			

Picture credit: Xstrata Nickel

As mines are worked deeper, specific energy consumption (kWh/tonne) rises, and reliance on electricity increases



After 3 years of operations, the yield from the turbines in ~10% higher than planned (CF=0.25)

Diavik Diamond Mine:

- 50 million litres of diesel / year
- Annual fuel cost of $70 million
- 2012: Transition to underground mining

Solution: Diavik wind farm

- 4 x Enercon (Germany) E70 turbines
- $33 million investment
- 9.2 MW installed capacity
- 10% reduction in diesel consumption
- 6% reduction in CO_2 footprint
- Fitted with innovative blade de-icing technology, operation to temperatures of -40°C
- 28th Sept 2012 – Wind farm operational

Graphic / photograph courtesy of the Diavik Diamond Mine

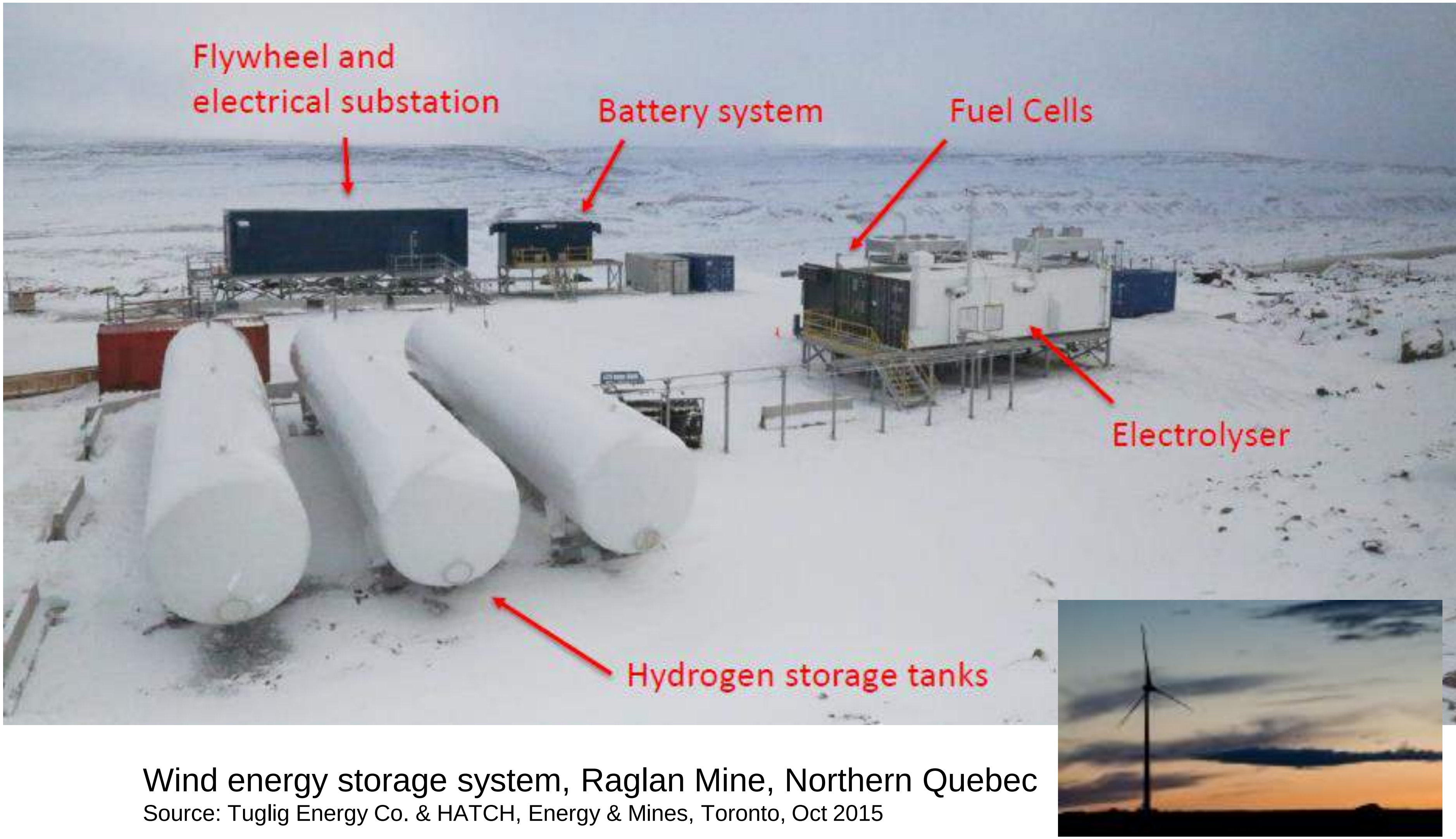
mirarco ENERGY

Liezl van Wyk

Rio Tinto

Wind energy pioneer

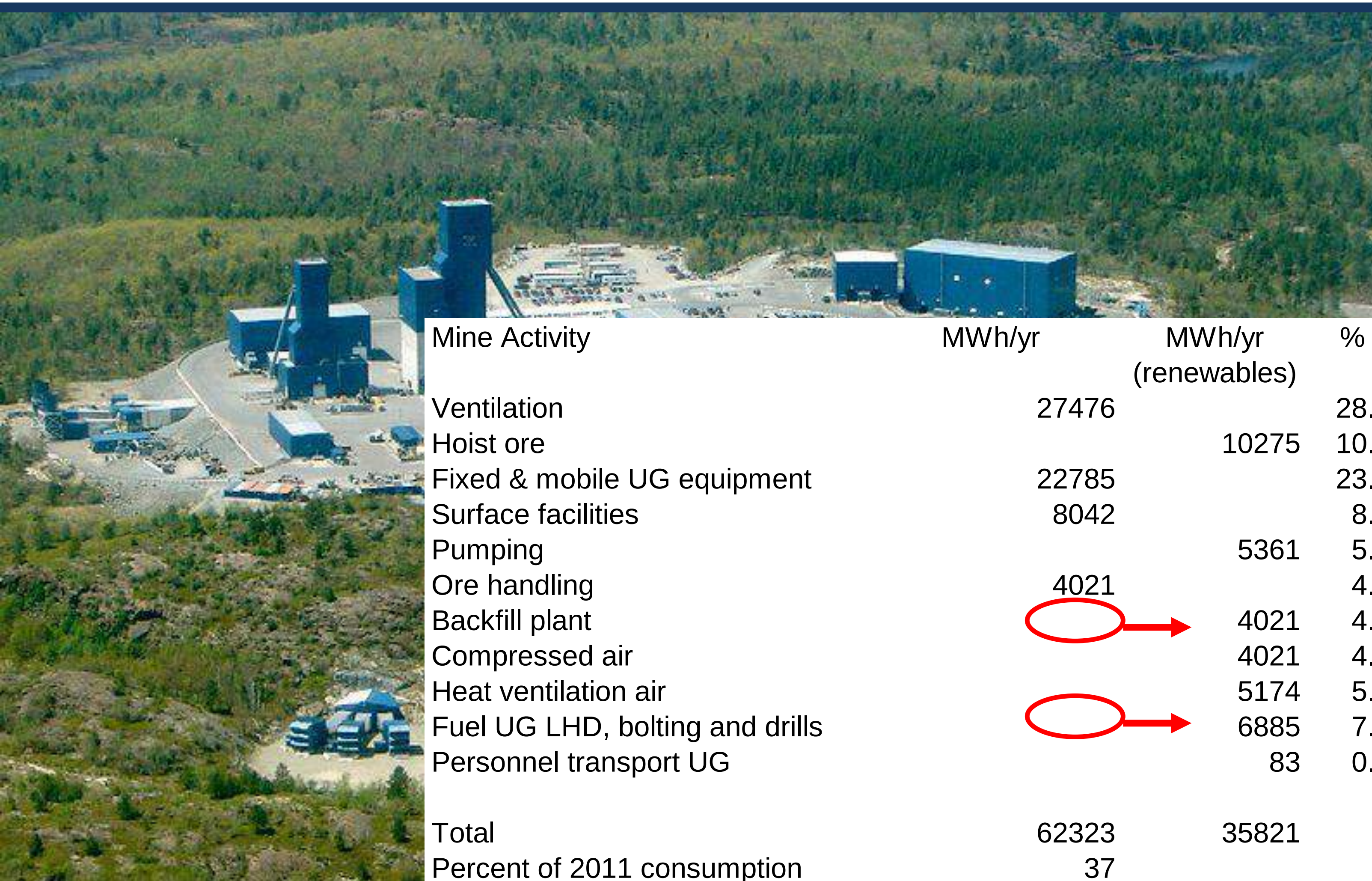
A key priority of renewable energy in mines is firmness of supply. Power quality is important too.



Wind energy storage system, Raglan Mine, Northern Quebec

Source: Tuglig Energy Co. & HATCH, Energy & Mines, Toronto, Oct 2015

Electricity from wind turbines could displace electricity supplied for batch processes and charge battery powered equipment



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Fixed & mobile UG equipment	22785		23.2	Electricity
Surface facilities	8042		8.2	Electricity
Pumping		5361	5.5	PV Electricity
Ore handling	4021		4.1	Electricity
Backfill plant		4021	4.1	Wind electricity
Compressed air		4021	4.1	Hydropower
Heat ventilation air		5174	5.3	Ice stope
Fuel UG LHD, bolting and drills		6885	7.0	Wind electricity
Personnel transport UG		83	0.1	PV Electricity
Total	62323	35821		
Percent of 2011 consumption	37			

Picture credit: Xstrata Nickel

A 40% Mine vision is not unrealistic at all

- TRL 8/9 technologies are 'out there' at reasonable cost
- Different mines have different, and dynamic, energy flow maps, and so what works in one mine may not work in another…
- …but a portfolio of technology options exists so that 40% Mine solutions can be formulated for most mines
- 60% reduction in energy:
  - <60% reduction in energy cost
  - >60% reduction in emissions
- Not necessarily a 'green' solution, but definitely an integrated solution
- The mining industry is already on the journey

mirarco ENERGY

3rd equation:

Energy + Mining =

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