THE ECONOMIC IMPLICATIONS OF IMPURITIES AND CONTAMINANTS IN SEMI FINISHED MINING PRODUCTS

David Dreisinger, University of BC, Canada

INDUSTRIAL RESEARCH CHAIR IN HYDROMETALLURGY

MINING AND MINOR ELEMENTS

- Mining is one of the oldest professions
- Extraction of elements, minerals and compounds from the earth provides the raw materials for modern society
- Recycling and conservation of precious resources are increasingly themes of modern mining companies
- The days of “Earth first – We’ll mine the other planets later” are passing!

MINING AND MINOR ELEMENTS

- As modern technological development continues the focus is not just on major raw materials such as iron, aluminum, copper, zinc, lead, nickel, cobalt, manganese, but increasingly on the so-called minor metals
- These metals support vast sectors of modern technology and are arguably “critical” to the continuation of development of civilization
- Many of these metals are available in semi-finished products (eg. Concentrates)

SELECTED EXAMPLES OF CRITICAL MATERIALS - 2015

Technology	Key elements
Grid storage batteries	Lithium, vanadium
Fuel cells	Platinum group metals, lanthanum, cobalt, cerium, yttrium
Nuclear power	Indium, cobalt, gadolinium
Vehicle light-weighting	Magnesium, titanium
Gas turbines	Yttrium
Catalytic converters	Platinum group metals, cerium
Photovoltaic cells	Indium, gallium, tellurium, silver, ruthenium
Thermoelectrics	Tellurium, various rare earth element

Critical Materials – US Department of Energy, Feb, 2015

CHALLENGE TO THE COPPER INDUSTRY

- The mining and processing of copper provides valuable and critical by-products for modern technology and development
- How can the copper industry ensure that these additional elements and products contribute to the economic sustainability of the sector?
- The mining and processing of copper also creates waste and hazardous products that may impact economic sustainability and limit exploitation of new resources
- Let’s look at some of these factors

SELENIUM

Metallurgy Uses – Additive to Mn EW Cells for Higher CE

World Refinery Production and Reserves. Se Reserves in China estimated based on Cu reserves Selenium production estimates for China not available

	Refinery Production(t)		Reserves (t)
	2015	**2016**	
United States	W	W	10,000
Belgium	200	200	-
Canada	154	150	6,000
China	NA	NA	26,000
Finland	94	94	-
Germany	660	660	-
Japan	773	750	-
Peru	40	40	13,000
Poland	90	90	3,000
Russia	135	135	20,000
Other Countries	50	50	21,000
World Total (rounded)	2200	2200	100,000

Price in September

2016 - $34/lb

US Geological Survey, Mineral Commodity Summaries, January 2017

TELLURIUM

Cadmium Telluride – Solar Cells

World Refinery Production and Reserves. Te reserves based on Te in Cu reserves with 1/2 Te recoverable.

	Refinery Production(t)		**Reserves (t)**
	2015	**2016**	
United States	W	W	3,500
Canada	9	10	800
Japan	37	30	
Peru			4
Russia	35	35	NA
Sweden	33	33	670
Other Countries	NA	NA	16,000
World Total (rounded)	NA	NA	25,000

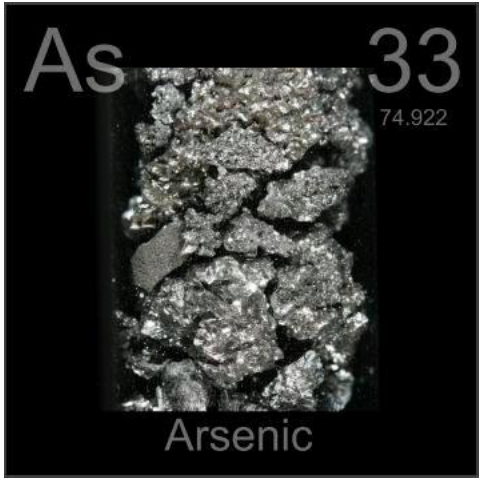
Price of $34/kg in 2016

US Geological Survey, Mineral Commodity Summaries, January 2017

ARSENIC

Chromated Copper Arsenate (CCA), GaAs, InAs, GaInAs

World Refinery Production and Reserves.



	Production (t)	
	(Arsenic Trioxide)	
	2015	2016
United States		
Belgium	1,000	1,000
Bolivia	50	50
China	25,000	25,100
Japan	45	45
Morocco	6,900	7,000
Namibia	1,960	1,900
Russia	1,500	1,500
World Total (rounded)	36,500	36,500

\$0.88/lb of As and \$0.30/lb of As_2O_3

US Geological Survey, Mineral Commodity Summaries, January 2017

ANTIMONY

Ceramics, Glass, Rubber Products, Flame Retardants, Alloying of Lead

$3.52/lb of Sb in 2016

	Mine Production (t)		Reserves (t)
	2015	2016	
United States	-	-	60,000
Australia	3,700	3,500	160,000
Bolivia	4,200	4,000	310,000
Burma	3,000	3,000	NA
China	110,000	100,000	530,000
Mexico	NA	NA	18,000
Russia (recoverable)	9,000	9,000	350,000
South Africa	-	-	27,000
Tajikistan	8,000	8,000	50,000
Turkey	2,500	2,500	NA
Vietnam	1,000	1,000	NA
World Total (rounded)	142,000	130,000	1,500,000

US Geological Survey, Mineral Commodity Summaries, January 2017

BISMUTH

Chemicals and Pharmaceuticals, Lead Substitute

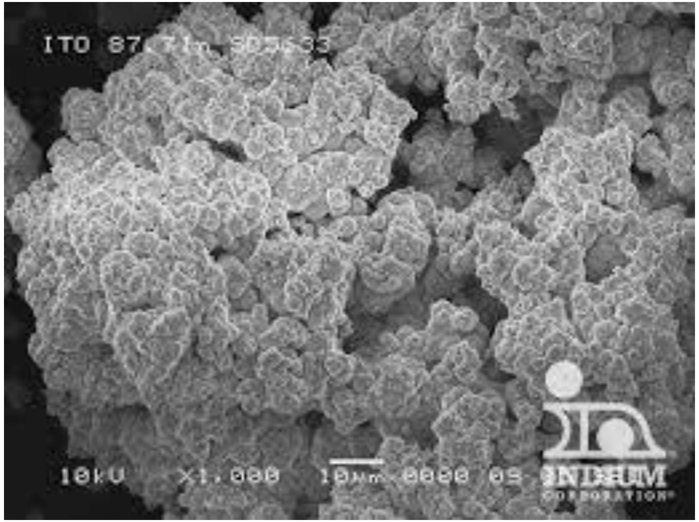
	Mine Production (t)		Reserves (t)
	2015	**2016**	
United States	-	-	-
Bolivia	10	10	10,000
Canada	3	3	5,000
China	7,500	7,400	240,000
Mexico	700	700	10,000
Russia	40	40	NA
Vietnam	2,000	2,000	53,000
Other Countries	-	-	50,000
World Total (rounded)	10,300	10,200	370,000

Price of \$4.70/lb (max) in 2016

US Geological Survey, Mineral Commodity Summaries, January 2017

INDIUM

Indium Tin Oxide (ITO) for Electronics



	Mine Production (t)		Reserves (t)
	2015	2016	
United States	-	-	NOT
Belgium	20	25	AVAILABLE
Canada	70	65	
China	350	290	
France	41	-	
Japan	70	70	
Korea	195	195	
Peru	9	5	
Russia	4	5	
World Total (rounded)	759	655	

$240/kg of In

US Geological Survey, Mineral Commodity Summaries, January 2017

GALLIUM

Gallium Compounds (GaAs, GaN) for Semiconductor and Optoelectronic Markets

Production (t)

375 tons of low-grade primary gallium in 2016, decreased from 470 tons in 2015

China, German, Japan, Ukraine, Hungary, Korea, Russia

180 tons primary refined high purity gallium in 2016.

$400/kg

US Geological Survey, Mineral Commodity Summaries, January 2017

GERMANIUM

Fiber Optics, Infrared Optics, Electronics and Solar Applications

	Refinery Production (kg)		Reserves
	2015	2016	
United States	W	W	NOT
China	115,000	110,000	AVAILABLE
Russia	5,000	5,000	
Other Countries	40,000	40,000	
World Total (rounded)	160,000	155,000	

$950/kg in 2016

US Geological Survey, Mineral Commodity Summaries, January 2017

TRENDS IN VALUE AND PENALTIES

- Toll treatment of concentrates has often benefited from receiving minor elements in concentrate without payment to miner and in some cases even penalizing the miner!
- For example,
  - Germanium in zinc concentrates
  - Indium in copper concentrates or zinc concentrates
  - Bismuth, antimony in copper concentrates
  - Selenium, tellurium in copper concentrates

COPPER CONCENTRATE ANALYSIS

N=119	Cu	Sb	As	Zn	Pb	Ni	Ag	Cd	Co
MIN	14	0	0	0	0	0	0	0	0
p50%	26.67	0.01	0.11	0.62	0.14	0.002	0.006	0.004	0.005
p60%	27.57	0.015	0.139	1.307	0.266	0.004	0.008	0.006	0.009
p70%	28.452	0.022	0.18	2.872	0.562	0.008	0.011	0.01	0.013
p80%	29.958	0.042	0.272	3.652	1.478	0.01	0.017	0.014	0.024
p90%	34	0.102	0.41	5.632	2.91	0.024	0.068	0.026	0.04
MAX	51.05	7.25	7.5	9.28	12.71	1.03	1.907	0.072	0.25

European Copper Institute 2014 Survey of 119 Concentrates

SELENIUM AND TELLURIUM

- Se and Te are potentially high value elements in copper concentrates
- May be recovered from the anode slimes from copper refining
- High purity Se and Te may be produced – often by further processing of intermediates (eg. 5NPlus)
- Se market threat – move to “Se Free” Mn EW processing in China
- Se is a significant environmental threat in mine waste waters (Canada < 1 ppb Se)

ARSENIC PENALTY

- Smelter contracts have a limit on arsenic (typically 0.2 to 0.5%)
- Above the limit a penalty is paid per additional unit of arsenic or arsenic + antimony
- A typical penalty for arsenic might be \$3/dmt for every 0.1% As (or As + Sb) over the limit.
- Some Cu smelter/refinery complexes have been “As deficient” in the past – requiring purchase of arsenical feeds to control copper anode chemistry and microstructure

EL INDIO ORE AND CONCENTRATE ANALYSIS

Samp.	P80	Analysis (wt% or g/t)							
	(um)	Cu	Fe	As	Sb	S_{tot}	S^{2-}	Au	Ag
Ore	95	2.54	9.52	0.93	0.09	11.3	11.1	8.8	66.7
Conc.	54	22.6	18.0	8.6	0.46	35.4	35.4	61	844
Tails	na	0.13	7.62	0.04	0.007	9.04	8.94	1.9	23.1

COST OF ARSENIC IN COPPER CONCENTRATES

- Strategic Cost – will I be able to toll treat the concentrate through a smelter?
- Blending Cost – cost to blend with clean concentrate to reduce penalty or achieve acceptance
- Toll Treatment Cost – cost under smelter contract
- True Smelter Cost – cost of arsenic fixation, cost of arsenic management, workplace hazard cost, possible social license cost
- Response is to treat dust (Ecometales), build roaster (Codelco), Process high As concentrates locally (PLCC)

ARSENIC PENALTY AT $3/0.1% AS OVER 0.2% AS

As (%)	As Penalty ($/t of concentrate)	Cost (cents per lb of Cu Paid in Concentrate)
0.2	0	
0.5	9	
1	24	0.04
2	54	0.08
3	84	0.13
4	114	0.18
5	144	0.23
6	174	0.27
7	204	0.32
8	234	0.37
9	264	0.41
10	294	0.46

Based on 30% Cu in Concentrate and 1 Unit Deduction

VALUE TO PROCESSING PLANT FOR HIGH AS CU CONC TREATMENT

- Assume 100,000 t/a of Cu Concentrate at 10% As
- Penalty value would be \$294/t X 100,000 = \$29.4 M
- Significant extra revenue to pay CAPEX and OPEX
- Other Strategies
  - As removal from concentrates – eg. MH
  - Smelter flue dust treatment – eg. Chuquicamata/Ecometales
  - Autoclaving of high As feedstocks – eg. Ecometales PLCC: (PROYECTO PARA TRATAR CONCENTRADOS COMPLEJOS)

ANTIMONY AND BISMUTH

- Sb and Bi are potentially valuable by-products from copper smelting
  - 0.1% Sb → 2.2 lbs/t → $8/t
  - 0.1% Bi → 2.2 lbs/t → $10/t
- Too much Sb and Bi – problems with refinery chemistry
- Sb and Bi recovered from refinery solution (IX or SX processing)
- Smelter opportunity to charge penalty and recover for value

INDIUM, GALLIUM AND GERMANIUM

- Potential value from these elements in copper (and other concentrates)
- Zinc industry is taking full value of these elements in zinc processing
- Opportunity in zinc for penalty for Ge and recovery for value
- Security of supply to feed recovery plants is a major issue – changing concentrate sources may undermine economics to justify investment and operation
- Recovery from copper smelter flue dusts

OTHER IMPURITIES (EXAMPLES)

- Lead, Zinc, Tin – Penalty above ~ 3% combined and limit on Pb
- Mercury – Penalty above low threshold (eg. 20-30 ppm) and limit
- Fluorine, Chlorine and Iodine – Penalty above 300-500 ppm and limit of F at 800-1000 ppm
- Cadmium – Penalty above 0.01% and limit of 0.04 to 0.05%
- Nickel – Penalty above 0.2-0.3% and limit of 1%
- Uranium, Thorium, Polonium and Radionuclides – Various penalties and limits for smelting and international shipping (IAEA)
- Pb, Zn, Sn, Ni, U for value, Rest Cost

OTHER METALS OF VALUE

- Molybdenum and Rhenium
- Precious Metals – Au, Ag, Pt, Pd, Rh, Ir, Ru, Os

THE FUTURE FOR MINOR ELEMENTS IN SEMI FINISHED MINING PRODUCTS

- We live in the age of critical materials
- Minor elements in semi-finished mining products are a key current and potential source for these elements
- Need a strategy to extract and build value from these elements
- Example of China in Rare Earth Elements (after D. Kingsnorth, Curtin U, Aus)
    - 1970's: Rare Earth Mineral Concentrates
    - 1980's: Mixed Rare Earth Chemical Concentrates
    - Early 1990's: Separated Rare Earth Oxides and Metals
    - Late 1990's: Magnets, Phosphors, Polishing Powders
    - 2000's: Electric Motors, Computers, Batteries, LCDs, Mobile Phones, Evs, Hybrid Vehicles

SUMMARY

- Minor elements are potential sources of additional value for semi-finished mining products
- Wide range of possibilities
- Miner – focus is on avoiding penalties and obtaining additional credits
- Smelter/Processing Facility – focus is on additional values (maximum penalty, maximum byproduct value)
- Long term – minor elements have strategic value in the establishment of downstream and value adding processes

THANK YOU!