

# Mining, Sustainable Development & Global Transitions

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**ReSToRE Summer School – Sustainable Resources**

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**That Ye Olde Cliché:**

***IF WE DON'T GROW IT***

***WE MINE IT***

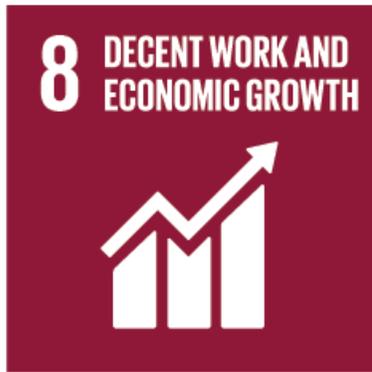
Nicholson  
9 Dec  
1997

WHAT?!  
YOU WANT A  
FRIDGE  
AS WELL AS  
A RADIO?



A GREENHOUSE NIGHTMARE ...

# UN Sustainable Development Goals (SDGs):



## Georgius Agricola (1556) :

“... the strongest argument of the detractors is that the *fields are devastated by mining operations* ... Also they argue that the *woods and groves are cut down*, for there is need of an endless amount of wood for timbers, machines, and the smelting of metals. And when the woods and groves are felled, then are exterminated the beasts and birds, very many of which furnish a pleasant and agreeable food for man. Further, when the ores are washed, *the water which has been used poisons the brooks and streams*, and either destroys the fish or drives them away. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers, find great difficulty in procuring the necessaries of life. Thus it is said, it is clear to all that *there is greater detriment from mining than the value of the metals which the mining produces.*”

## ***D F Hewett (1929) :***

***“But even in our modern world, with its diverse sources of foods and textile materials, **human’s** unit consumptive capacity for these products does not greatly change from one year to another. On the other hand, **their** consumption of metals grows with the increasing complexity of civilization and it seems now as if **their** appetite would never be satisfied.”***

# The World of Extractives: The Periodic Table

Period

1 1 A 2 18 VIII A

1 1s **H**  $\pm 1$  **He**  $\pm 2$   
hydrogen 1.008 helium 4.003

2 2s **Li**  $\pm 1$  **Be**  $\pm 2$   
lithium 6.941 beryllium 9.012

3 3s **Na**  $\pm 1$  **Mg**  $\pm 2$   
sodium 22.99 magnesium 24.31

4 4s **K**  $\pm 1$  **Ca**  $\pm 2$   
potassium 39.10 calcium 40.08

5 5s **Rb**  $\pm 1$  **Sr**  $\pm 2$   
rubidium 85.47 strontium 87.62

6 6s **Cs**  $\pm 1$  **Ba**  $\pm 2$   
cesium 132.9 barium 137.3

7 7s **Fr**  $\pm 1$  **Ra**  $\pm 2$   
francium 223 radium 226

3d **Sc**  $\pm 3$  **Ti**  $\pm 4, 3, 2$  **V**  $\pm 5, 2, 3, 4$  **Cr**  $\pm 3, 2, 6$  **Mn**  $\pm 2, 3, 4, 6, 7$  **Fe**  $\pm 3, 2$  **Co**  $\pm 2, 3$  **Ni**  $\pm 2, 3$  **Cu**  $\pm 2, 1$  **Zn**  $\pm 2$   
scandium 44.96 titanium 47.87 vanadium 50.94 chromium 52.00 manganese 54.94 iron 55.85 cobalt 58.93 nickel 58.69 copper 63.55 zinc 65.41

4d **Y**  $\pm 3$  **Zr**  $\pm 4$  **Nb**  $\pm 5, 3$  **Mo**  $\pm 6, 3, 5$  **Tc**  $\pm 7, 4, 6$  **Ru**  $\pm 4, 3, 6, 8$  **Rh**  $\pm 3, 4, 6$  **Pd**  $\pm 2, 4$  **Ag**  $\pm 1$  **Cd**  $\pm 2$   
yttrium 88.91 zirconium 91.22 niobium 92.91 molybdenum 95.94 technetium 98 ruthenium 101.1 rhodium 102.9 palladium 106.4 silver 107.9 cadmium 112.4

5d **Lu**  $\pm 3$  **Hf**  $\pm 4$  **Ta**  $\pm 5$  **W**  $\pm 6, 4$  **Re**  $\pm 7, 4, 6$  **Os**  $\pm 4, 6, 8$  **Ir**  $\pm 4, 3, 6$  **Pt**  $\pm 2$  **Au**  $\pm 3, 1$  **Hg**  $\pm 2, 1$   
lutetium 175.0 hafnium 178.5 tantalum 180.9 tungsten 183.8 rhenium 186.2 osmium 190.2 iridium 192.2 platinum 195.1 gold 197.0 mercury 200.6

6d **Lr**  $\pm 3$  **Rf** **Db** **Sg** **Bh** **Hs** **Mt** **Ds** **Rg** **Cn**  
lawrencium 262 rutherfordium 261 dubnium 262 seaborgium 266 bohrium 264 hassium 277 meitnerium 268 darmstadtium 281 roentgenium 272 copernicium 285

3p **Al**  $\pm 3$  **Si**  $\pm 4$  **P**  $\pm 3$  **S**  $\pm 2$  **Cl**  $\pm 1$  **Ar**  
aluminum 26.98 silicon 28.09 phosphorus 30.97 sulfur 32.07 chlorine 35.45 argon 39.95

4p **Ga**  $\pm 3$  **Ge**  $\pm 4, 2$  **As**  $\pm 3$  **Se**  $\pm 2$  **Br**  $\pm 1$  **Kr**  
gallium 69.72 germanium 72.64 arsenic 74.92 selenium 78.96 bromine 79.90 krypton 83.80

5p **In**  $\pm 3$  **Sn**  $\pm 2$  **Sb**  $\pm 3, 5$  **Te**  $\pm 2$  **I**  $\pm 1$  **Xe**  
indium 114.8 tin 118.7 antimony 121.8 tellurium 127.6 iodine 126.9 xenon 131.3

6p **Tl**  $\pm 1, 3$  **Pb**  $\pm 2, 4$  **Bi**  $\pm 3, 5$  **Po**  $\pm 2, 4$  **At**  $\pm 1$  **Rn**  
thallium 204.4 lead 207.2 bismuth 209.0 polonium 209 astatine 210 radon 222

7p **Uut**  $\pm 1, 3$  **F1**  $\pm 2, 4$  **Uup**  $\pm 3, 5$  **Lv**  $\pm 2, 4$  **Uus**  $\pm 1$  **Uuo**  
ununtrium 284 flerovium 289 ununpentium 288 livermorium 292 ununseptium 293 ununoctium 294

lanthanides (rare earth metals)  $\pm 4f$  **La**  $\pm 3$  **Ce**  $\pm 3, 4$  **Pr**  $\pm 3, 4$  **Nd**  $\pm 3$  **Pm**  $\pm 3$  **Sm**  $\pm 3, 2$  **Eu**  $\pm 3, 2$  **Gd**  $\pm 3$  **Tb**  $\pm 3, 4$  **Dy**  $\pm 3$  **Ho**  $\pm 3$  **Er**  $\pm 3$  **Tm**  $\pm 3, 2$  **Yb**  $\pm 3, 2$   
lanthanum 138.9 cerium 140.1 praseodymium 140.9 neodymium 144.2 promethium 145 samarium 150.4 europium 152.0 gadolinium 157.3 terbium 158.9 dysprosium 162.5 holmium 164.9 erbium 167.3 thulium 168.9 ytterbium 173.0

actinides  $\pm 5f$  **Ac**  $\pm 3$  **Th**  $\pm 4$  **Pa**  $\pm 5, 4$  **U**  $\pm 6, 3, 4, 5$  **Np**  $\pm 5, 3, 4, 6$  **Pu**  $\pm 4, 3, 5, 6$  **Am**  $\pm 3, 4, 5, 6$  **Cm**  $\pm 3$  **Bk**  $\pm 3, 4$  **Cf**  $\pm 3$  **Es**  $\pm 3$  **Fm**  $\pm 3$  **Md**  $\pm 3, 2$  **No**  $\pm 2, 3$   
actinium 227 thorium 232.0 protactinium 231.0 uranium 238.0 neptunium 237 plutonium 239 americium 243 curium 247 berkelium 247 californium 251 einsteinium 252 fermium 257 mendelevium 258 nobelium 259

atomic # → **29**  $\pm 2, 1$  ← ions commonly formed  
atomic symbol → **Cu**  
English element name → copper  
← atomic mass (rounded) 63.55

☐ Gases ☐ Liquids ☐ Metalloids

# Critical Minerals: Fundamental but Vulnerable



**LCD screen**  
• Europium  
• Yttrium  
• Cerium

**Glass and mirrors polishing powder**  
• Cerium

**UV cut glass**  
• Cerium

**Diesel fuel additive**  
• Cerium  
• Lanthanum

**Component sensors**  
• Yttrium

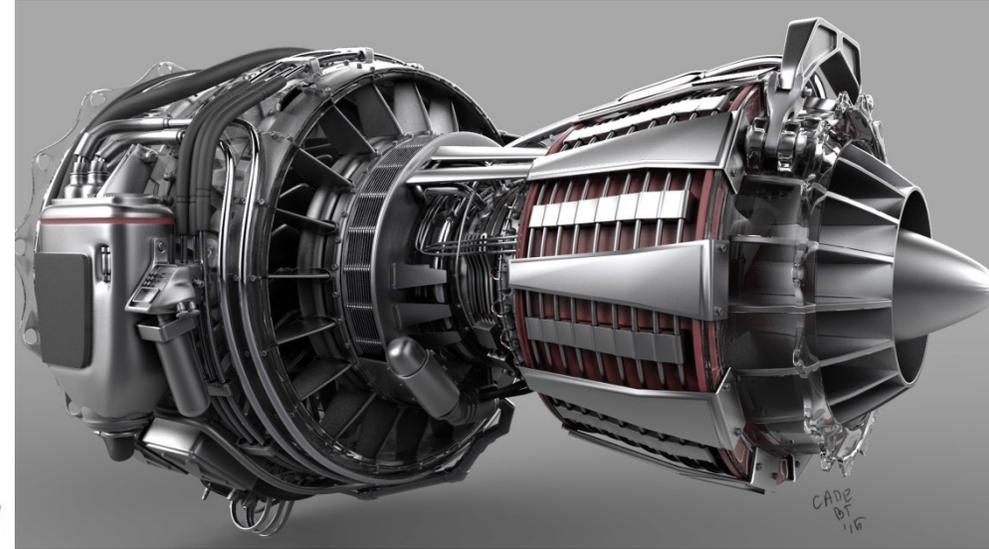
**Hybrid electric motor and generator**  
• Neodymium  
• Praseodymium  
• Dysprosium  
• Terbium

**Headlight glass**  
• Neodymium

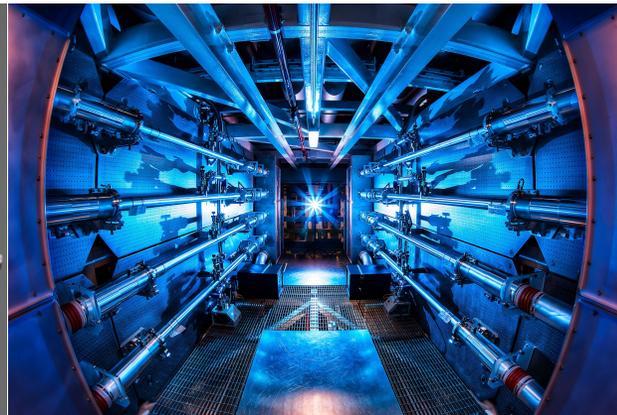
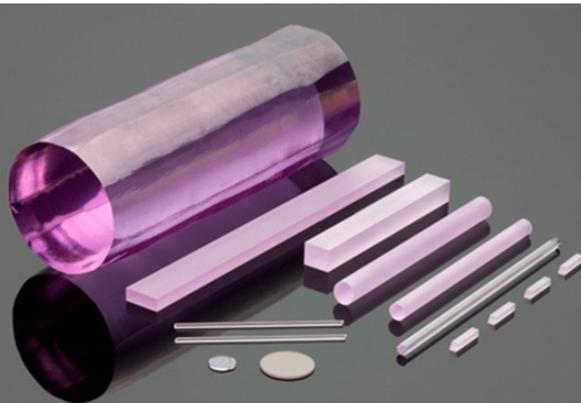
**25+ electric motors throughout vehicle**  
• Neodymium magnets

**Hybrid NiMH battery**  
• Lanthanum  
• Cerium

**Catalytic converter**  
• Cerium  
• Lanthanum

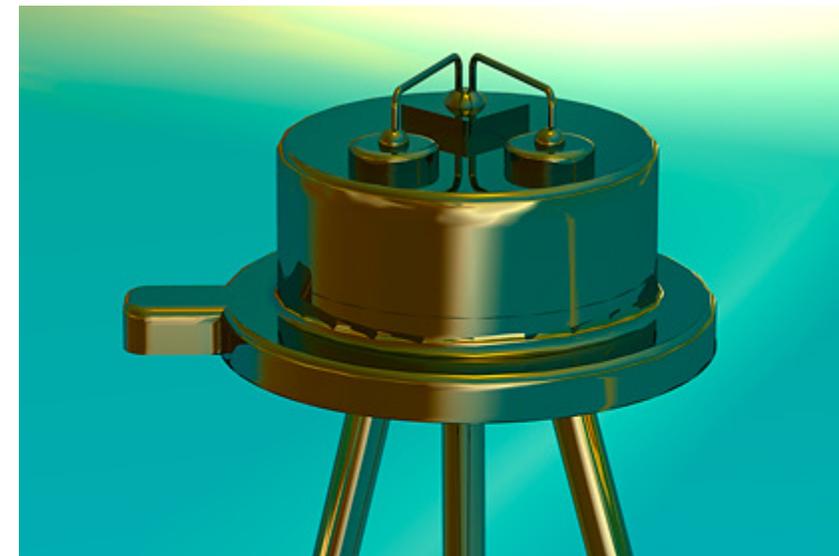


**Rhenium use in superalloys in jet engines**

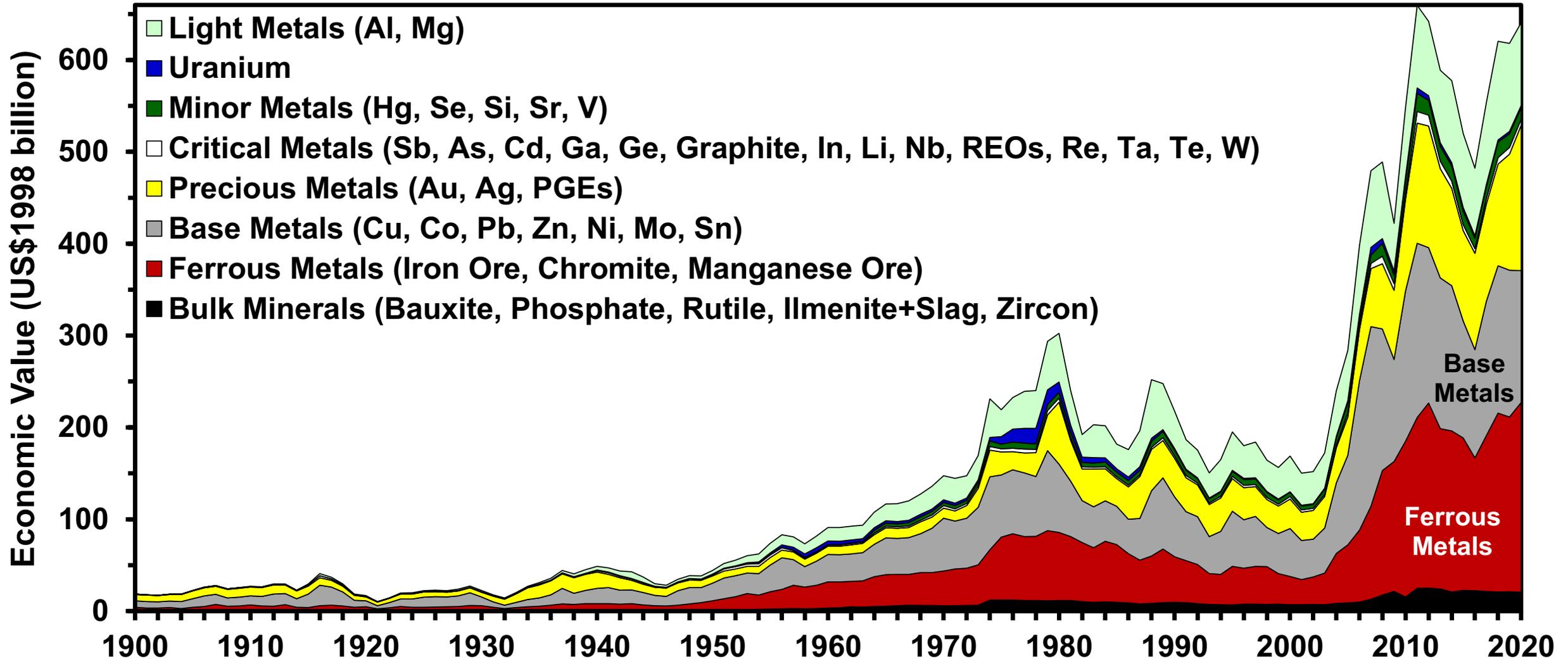


**Germanium use in semiconductors**

*Courtesy S. Jowitt*



# Mining's Global Real Value Since 1900



# (A 'Simplistic') Overview of Mining vs SD

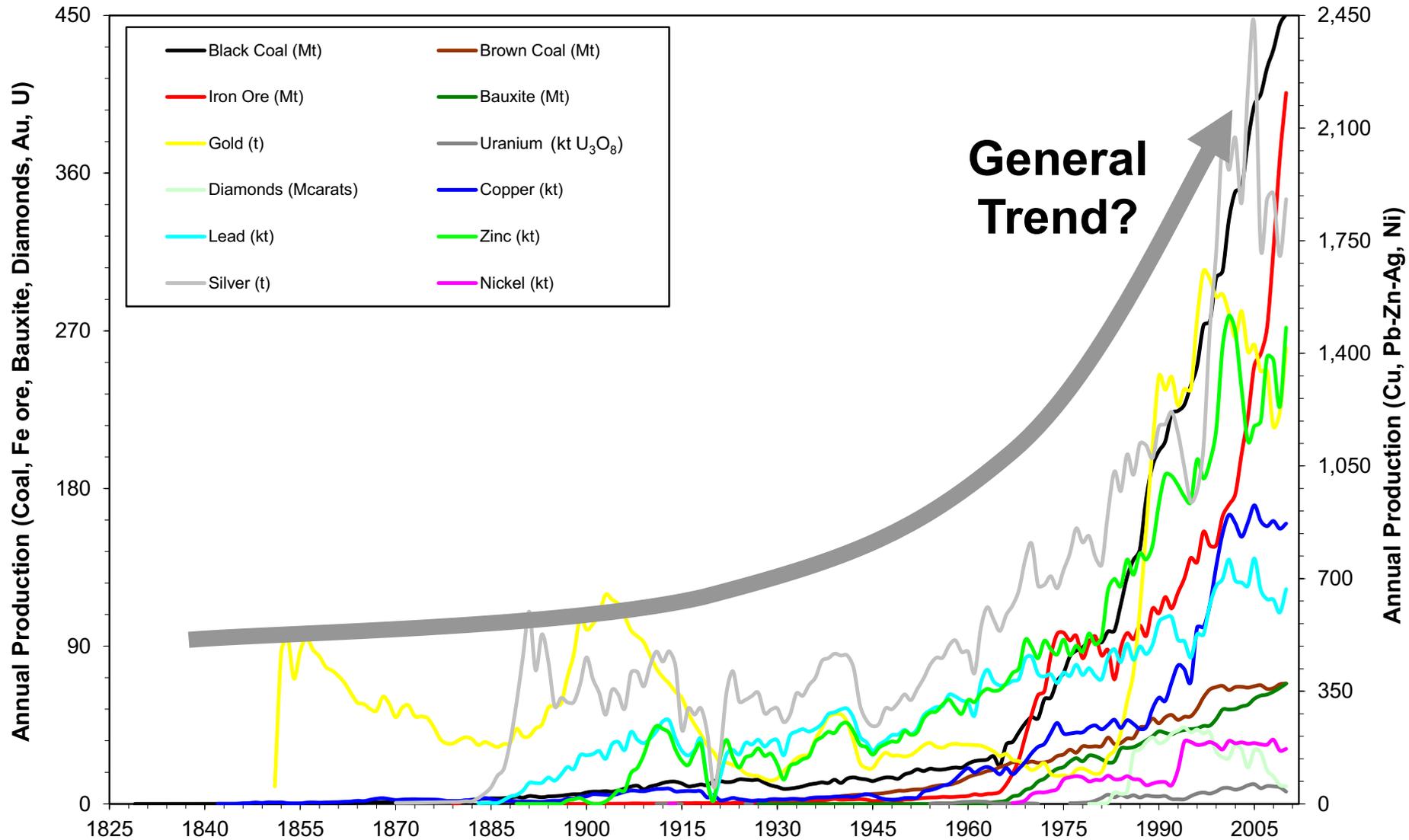
- Mineral deposits, are by their nature, 'finite' – i.e. ***non-renewable***
- Global production of metals and minerals almost always increases over time to meet growing market demands
- Yet we know of more mineral resources now than ever, enough to meet growing demands for many decades (or even centuries)

***Quite the paradox !!***

- Clearly, this paradox shows that there is more to sustainable mining than just production alone ...

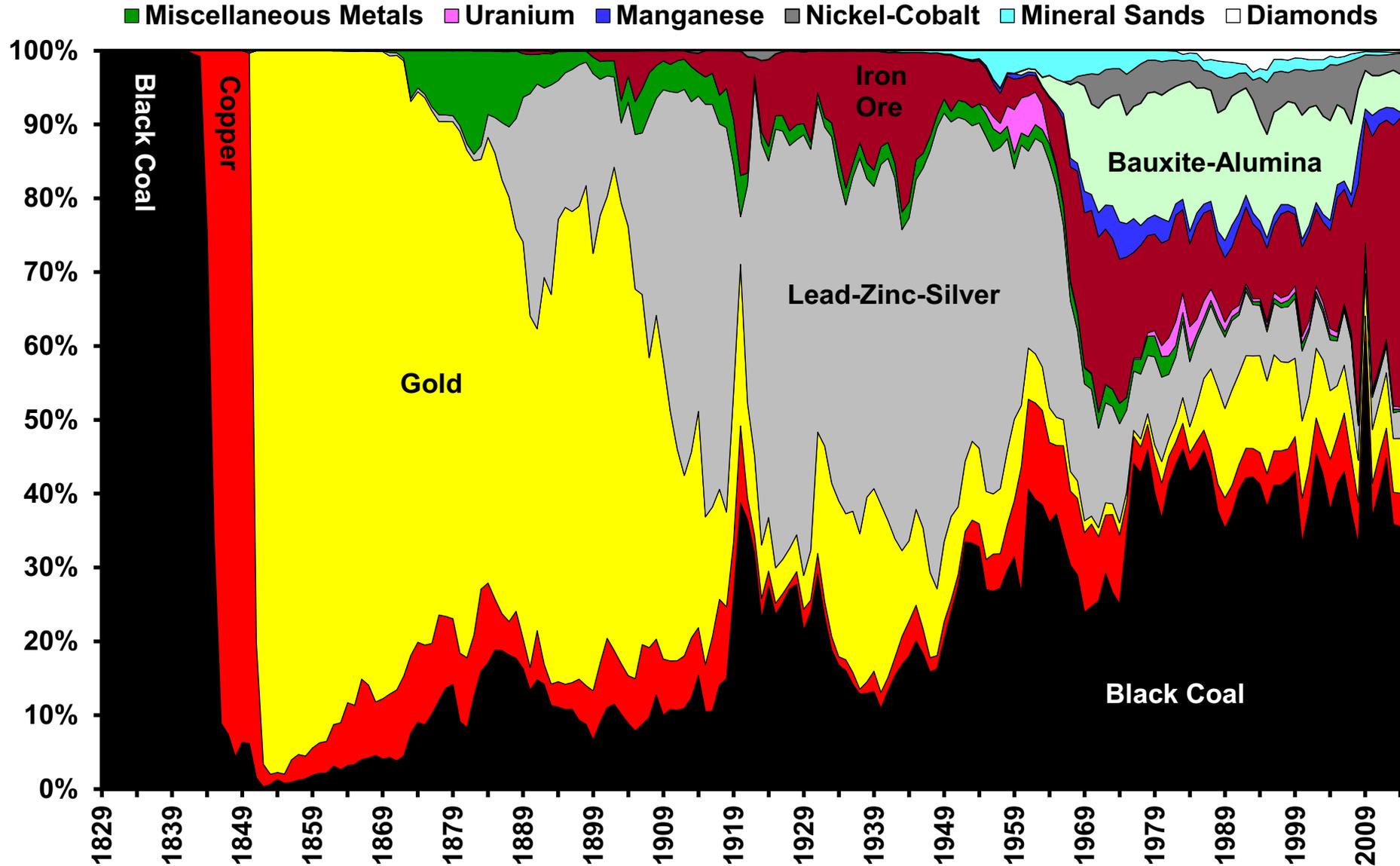
***(IMNSHEO) KEY: Environmental Impacts are Growing!!***

# Australian Mining Production



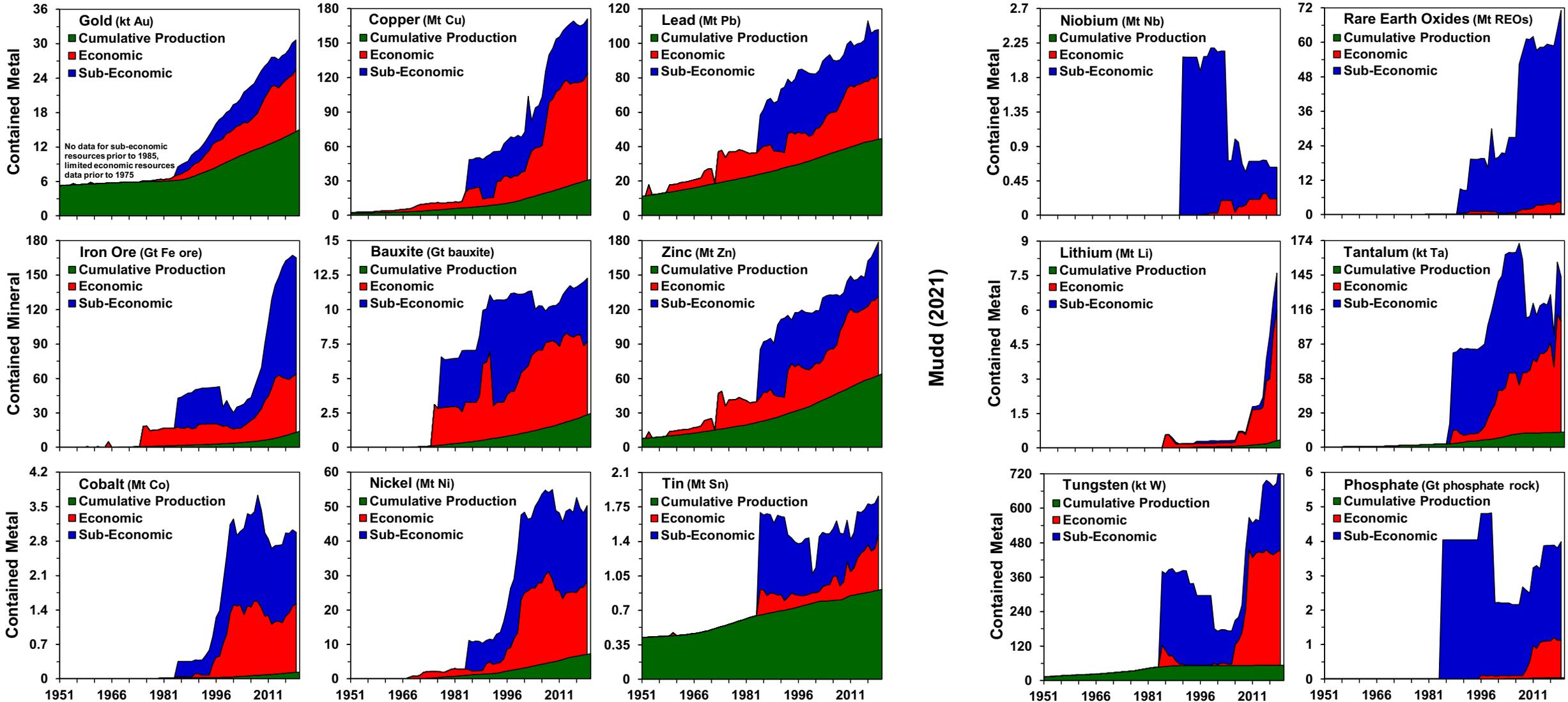
Mudd, 2009, Sustainability of Mining in Australia

# Australian Mining Production

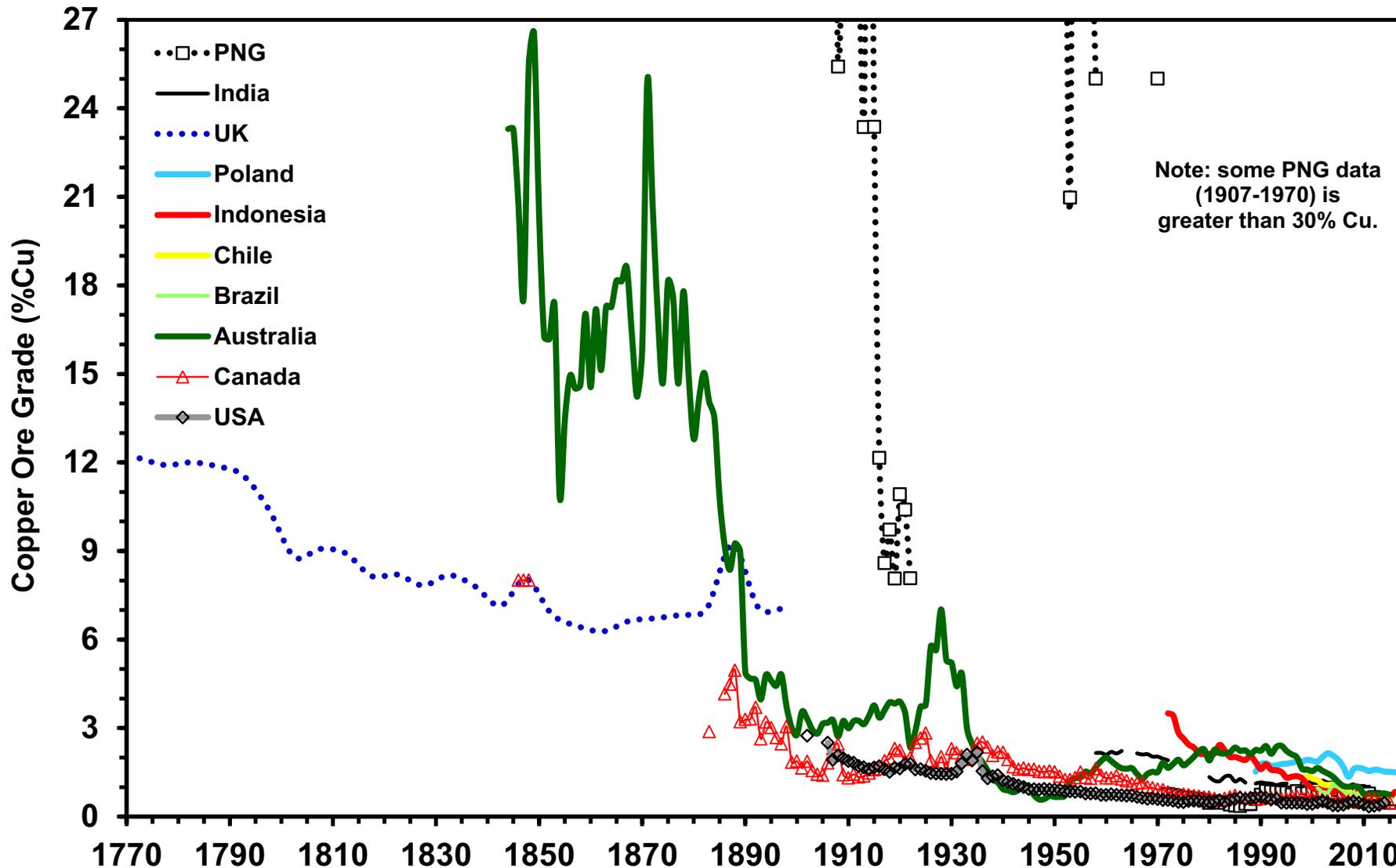


Mudd-Jowitt, 2018,  
Key Trends in Australian Mineral Resources  
and Production.

# World's Growing Resource Endowment: True!

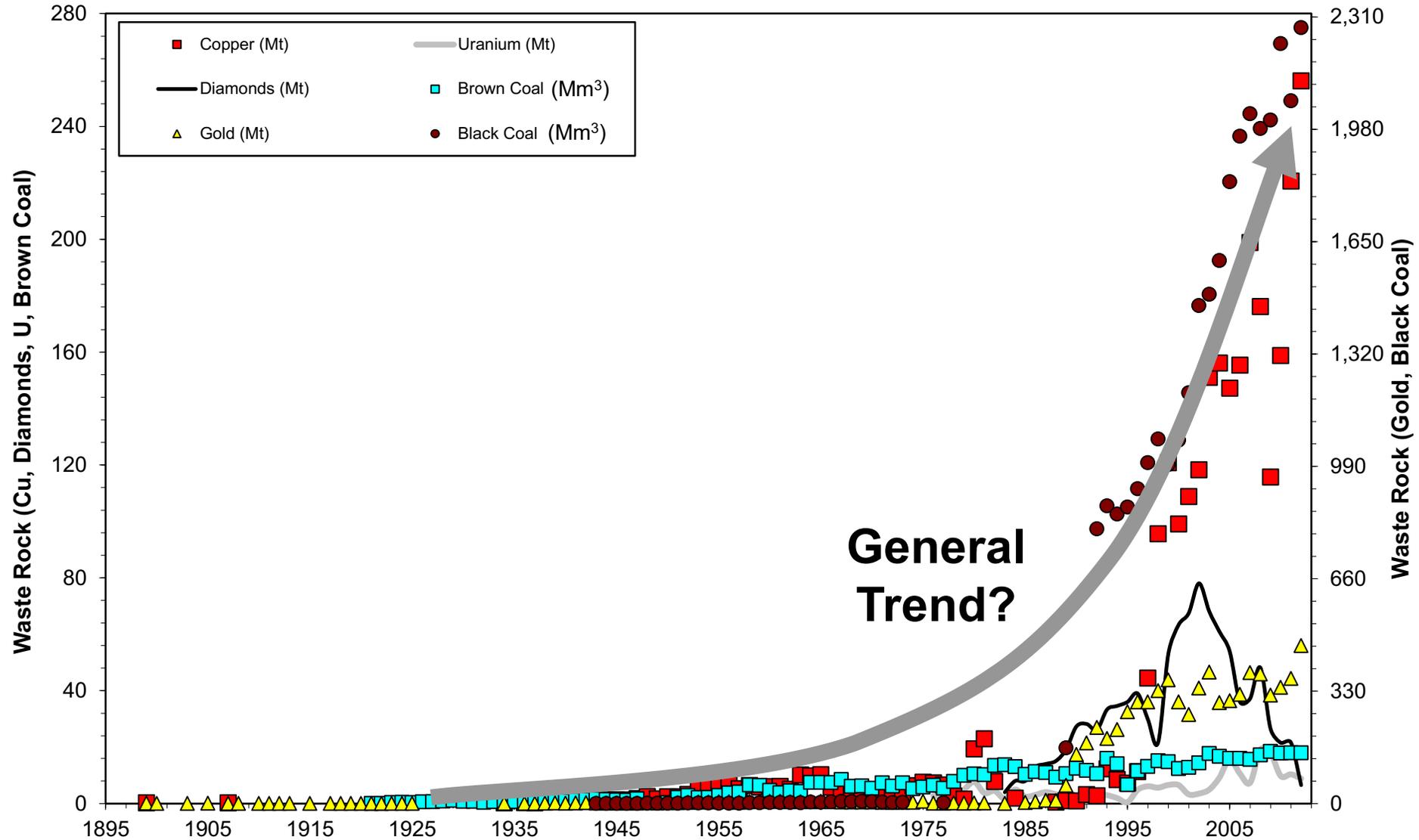


# Global Copper Ore Grades



Mudd-Jowitt (2018)

# Waste Rock – Australia



# Global Mine Waste Estimate (2014)

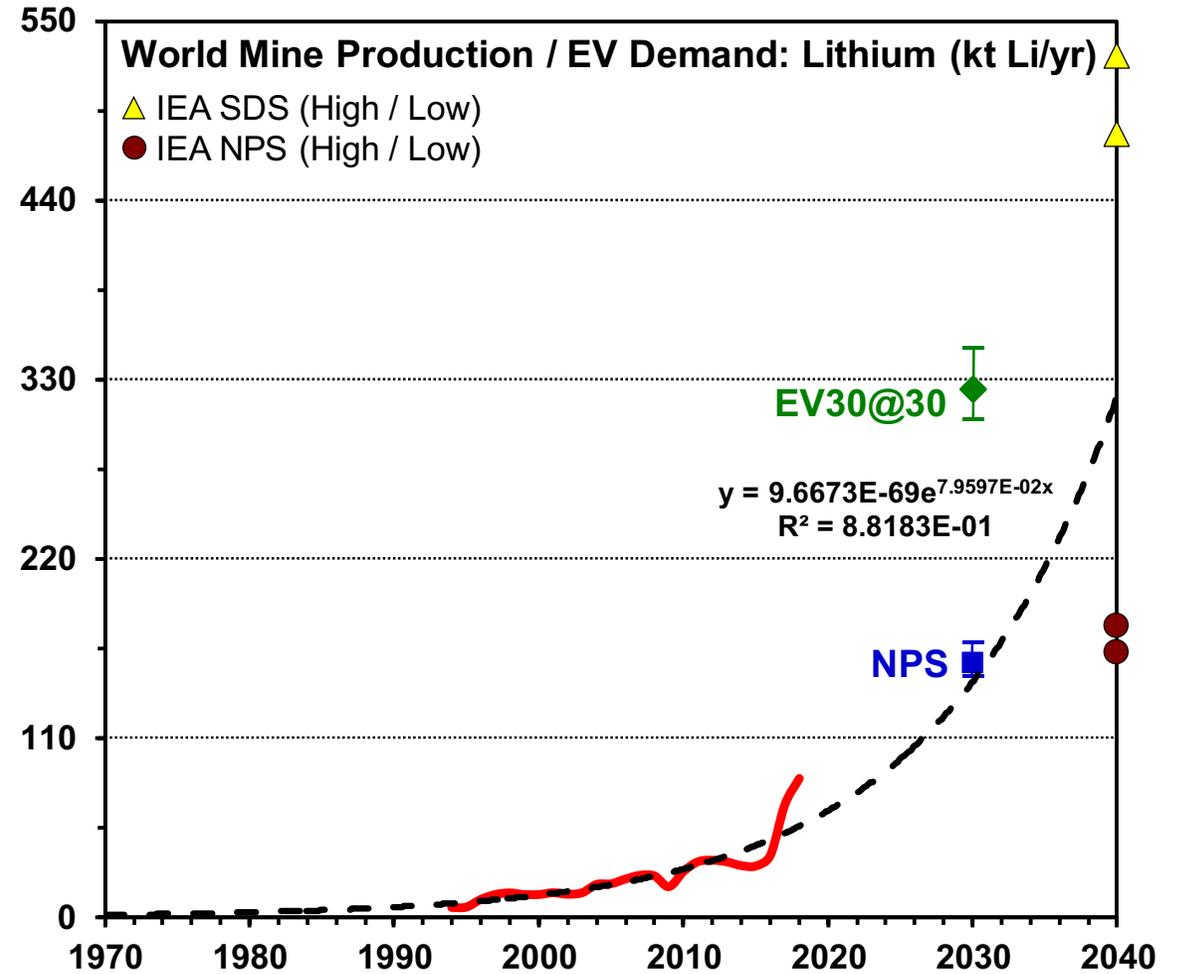
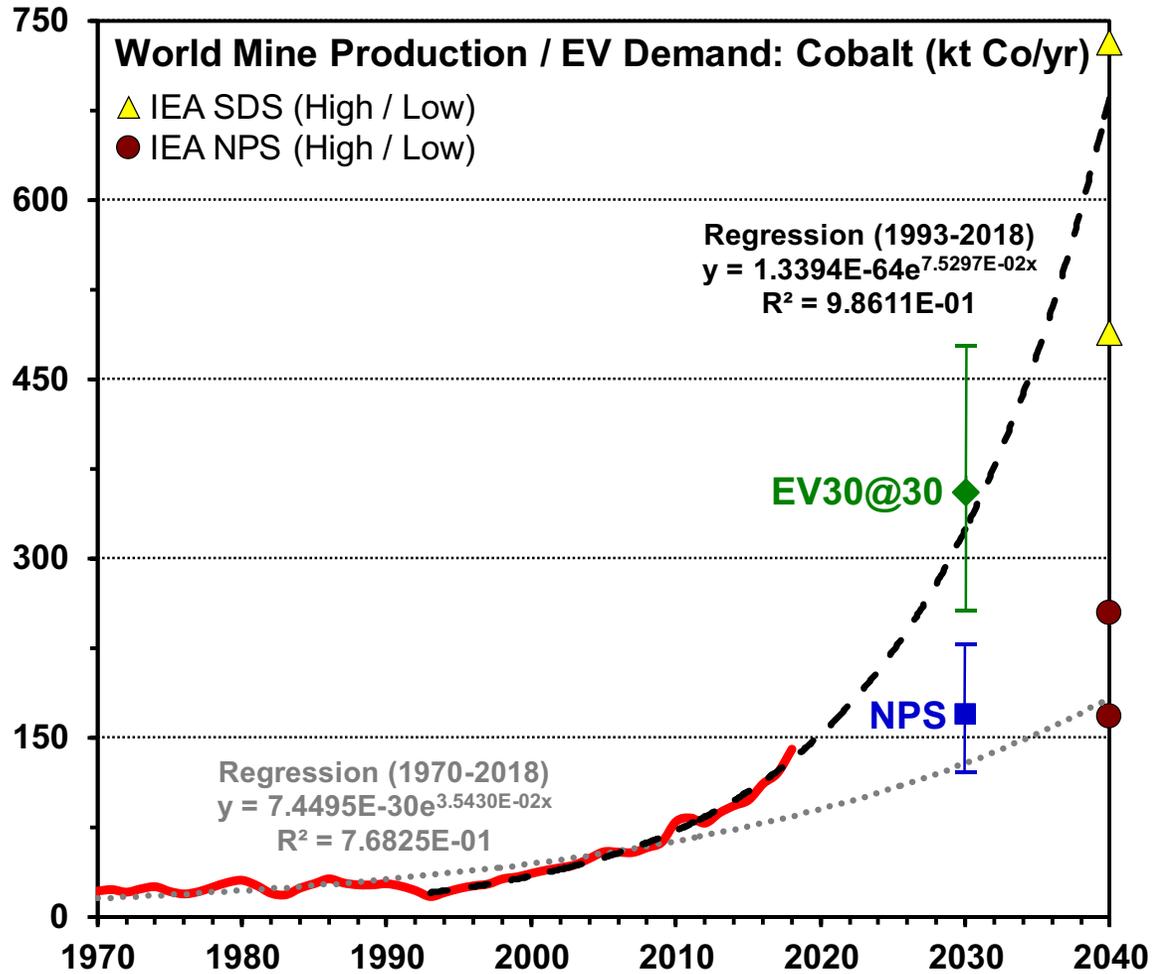
Sector	Fe ore	Coal	Bauxite	Copper	Lead-zinc	Nickel	Gold	Uranium	PGEs	Diamonds	Totals
2014 production	3220 Mt ore	8165 Mt	234 Mt	18.7 Mt Cu	5.46 Mt Pb, 13.3 Mt Zn	2.4 Mt Ni	2860 t	56.2 kt U	400 t	65 Mcarats	
Typical grades	50% Fe	-	40% Al <sub>2</sub> O <sub>3</sub>	0.6% Cu	2% Pb, 5% Zn	1.3% Ni	2 g/t Au	0.1% U	3.9 g/t 4E	0.75 carats/t	
Ore processing (Mt)	4025	9072	312	3896	~338	246	1682	62	90	87	19 798
Mill recovery	80%	90%	75%	80%	80% Pb, 85% Zn	75%	85%	90%	90%	-	
% Open cut	98%	75%	100%	85%	50%	50%	75%	30%	10%	85%	
Waste:ore (UG)	0.2	0.25	0	0.2	0.1	0.2	0.25	0.5	0.1	0.25	
Waste:ore (OC)	2	<b>55</b>	2	3	5	2	5	5	10	5	<b>82</b>
Tailings (Mt)	1025	<b>Gt</b>	78	3828	300	237	1681	62	89	87	<b>Gt</b>
Waste rock (Mt)	7905		624	10 051	862	271	6414	116	98	372	

UG – underground; OC – open cut; PGE – platinum group elements.

# So, What Metals & Minerals do We *Really* Need?

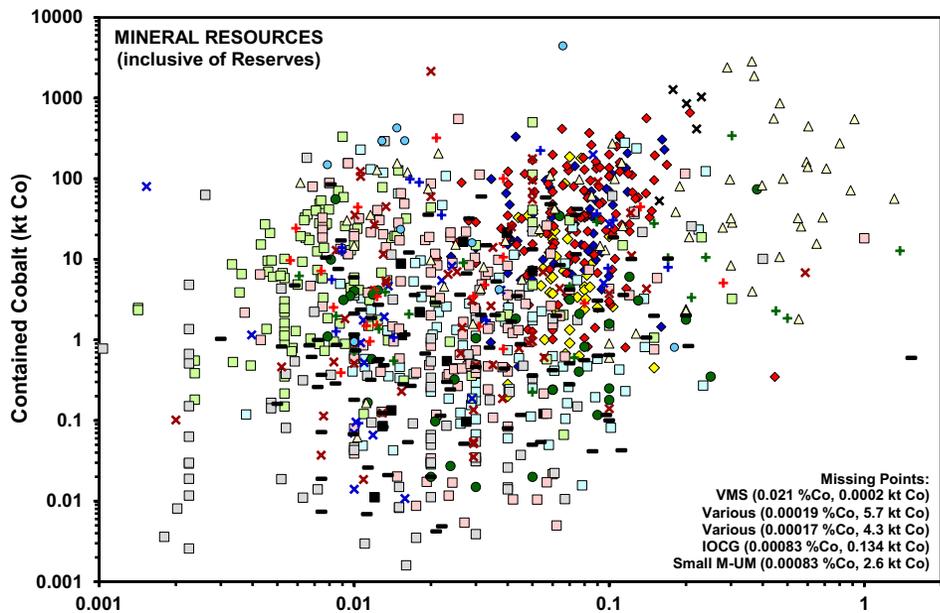
- Energy is changing, FAST: fossil fuels & uranium are declining
- Gold: can meet supply from by-product mines (not Au-only)
- Transformation of energy and rapid rise of electric vehicles means we need HEAPS more ‘battery metals’: lithium, nickel, cobalt, manganese (or potentially others)
- New renewable energy technologies often need by-product metals – such as indium, cadmium, tellurium, selenium, gallium, ...
- Concentrated, small markets often mean by-products are ‘critical’
- Such by-product metals can only be sourced from their primary hosts – primary deposits don’t exist, nor do we have the stocks **yet**

# Rise of the (EV) Machines: Li-NMC vs LFP ...

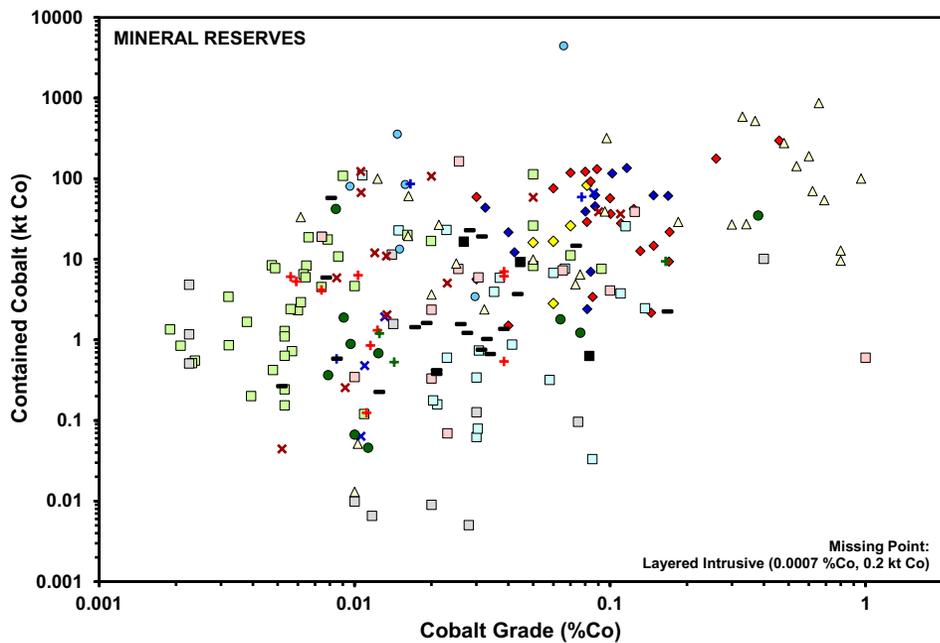
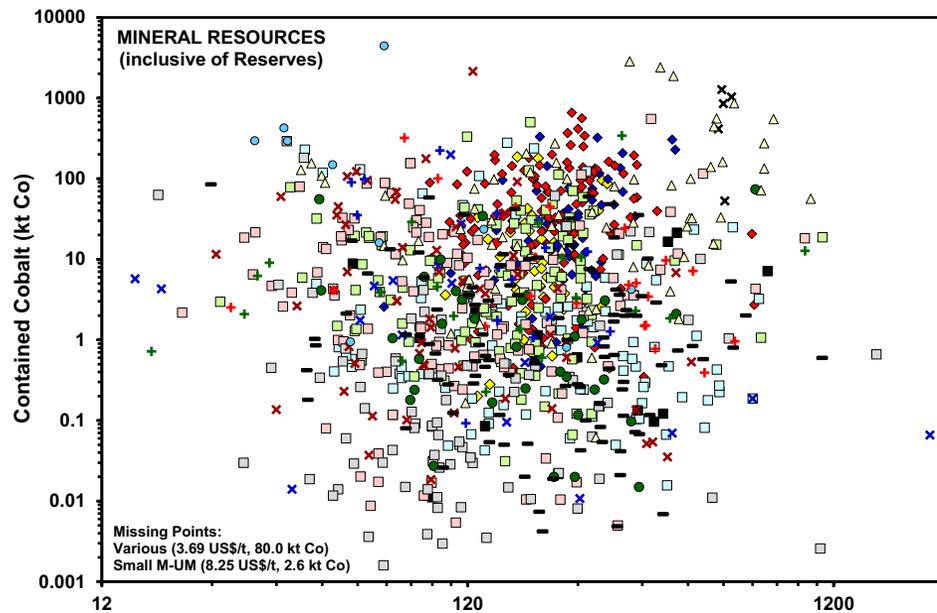


# Global Cobalt Reserves (left) & Resources (right)

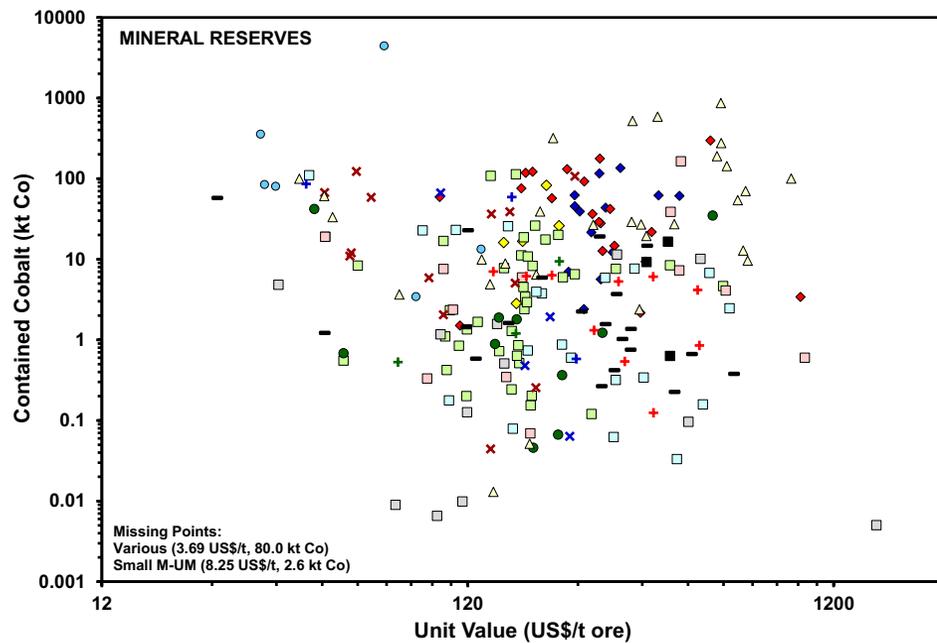
To be published soon ... true story!



- ◆ Lat: Clay Silicate
- ◆ Lat: Hydrous Mg Silicate
- ◆ Lat: Oxide
- MagS: Komatiites
- MagS: Impact-Related
- MagS: Layered Intrusive
- MagS: Small M-UM Intrusion
- MagS: Miscellaneous
- x Manganese Nodules
- x Various
- x IOCG
- Orogenic Au
- Porphyry
- + Sediment-Hosted Pb-Zn
- △ Sediment-hosted Cu
- + Skarn
- + Tailings & Stockpiles
- VMS

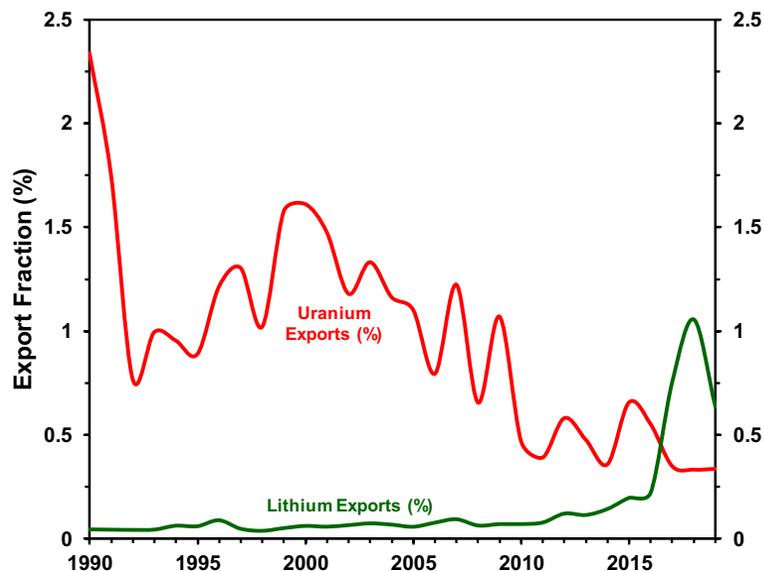
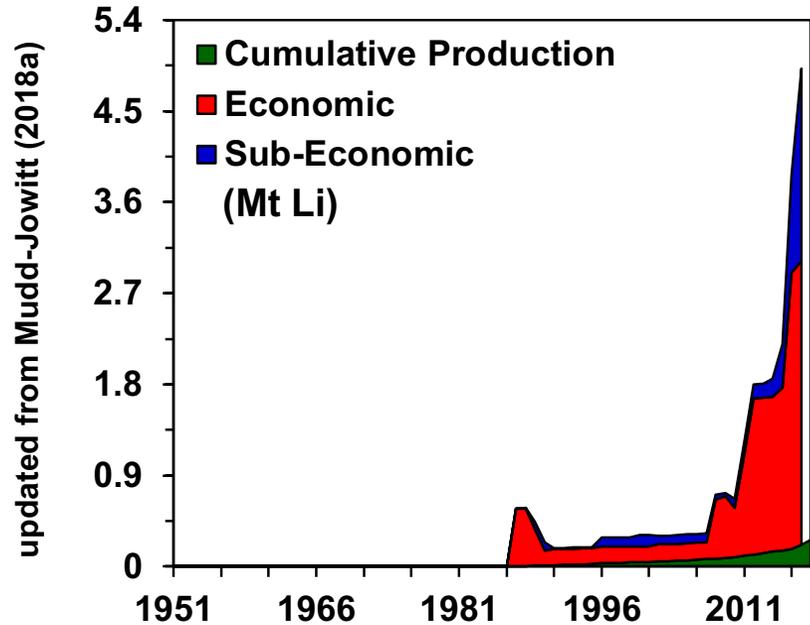


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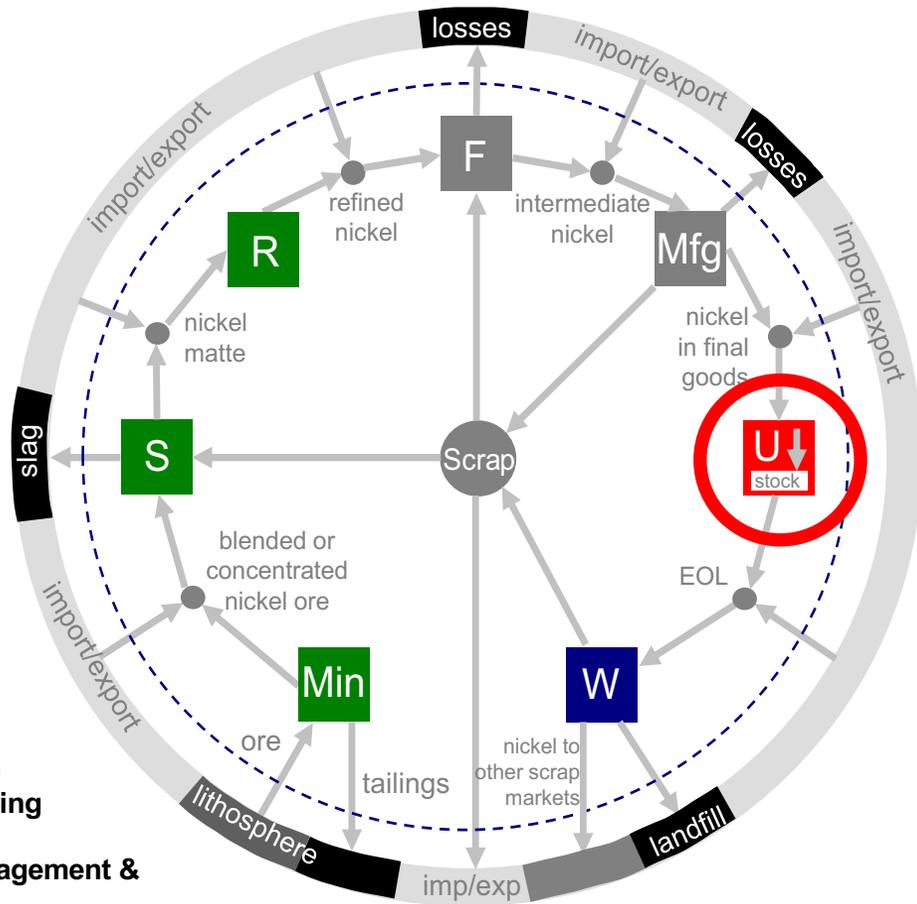


# Aussie Lithium

- Despite only a single Li mine for years, Australia has been a major spodumene producer since 1983
- Recent revolution has seen the number of mines grow to 8, more under active assessment
- 2018 production ~42 kt Li (world was ~77 kt Li)
- **Li has now overtaken U in value**

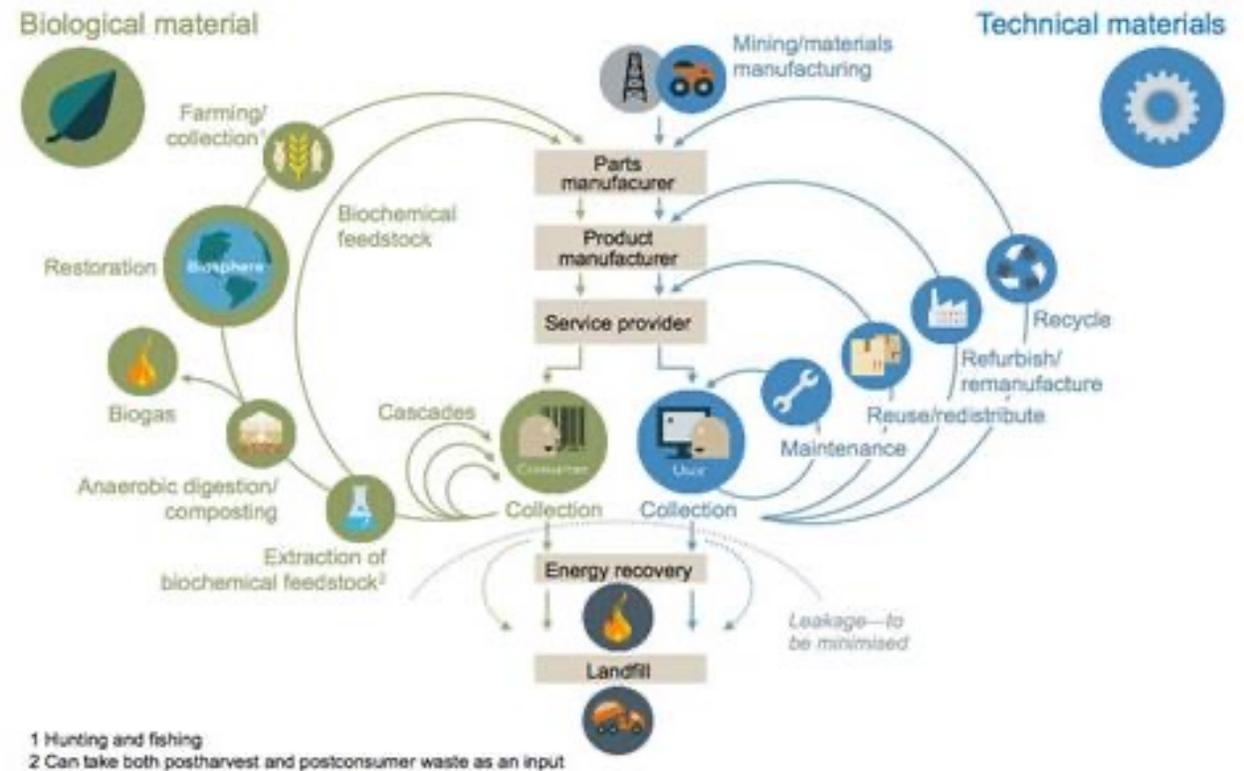


# Circular Economy '102': Key Concepts



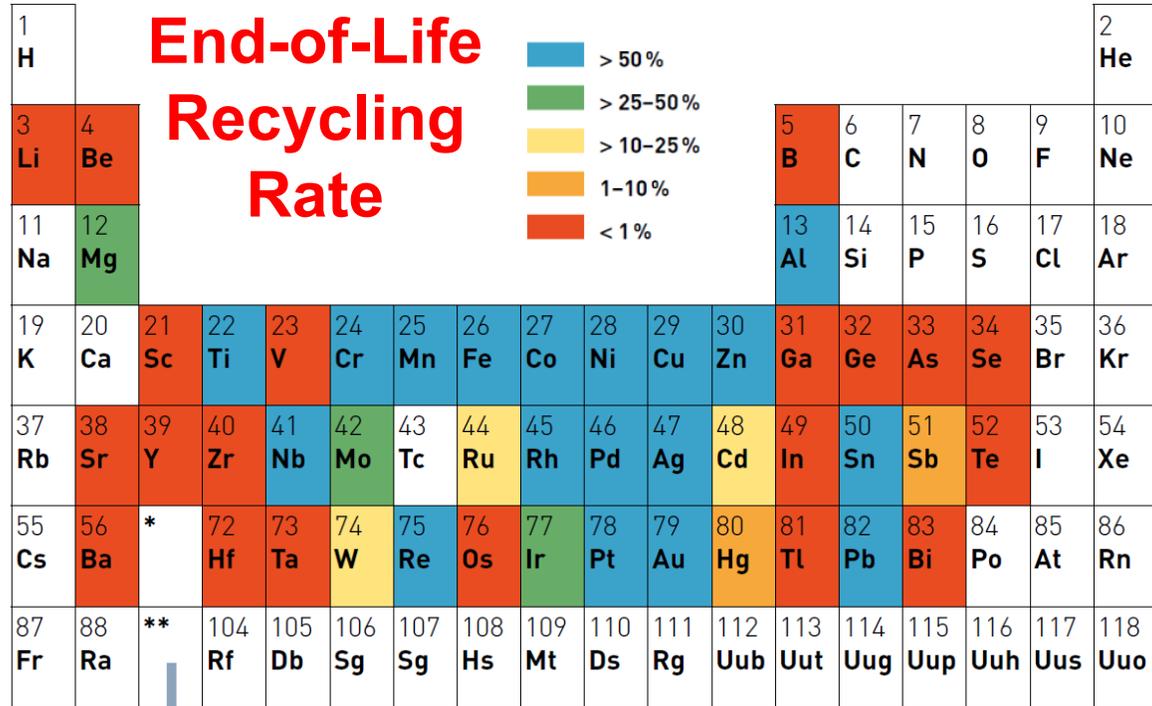
- Min Mine & Mill
- S Smelter
- R Refinery
- F Fabrication
- Mfg Manufacturing
- U Use
- W Waste Management & Recycling
- EOL End-of-Life flows

© Yale University



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# Extent of Metals Recycling ...

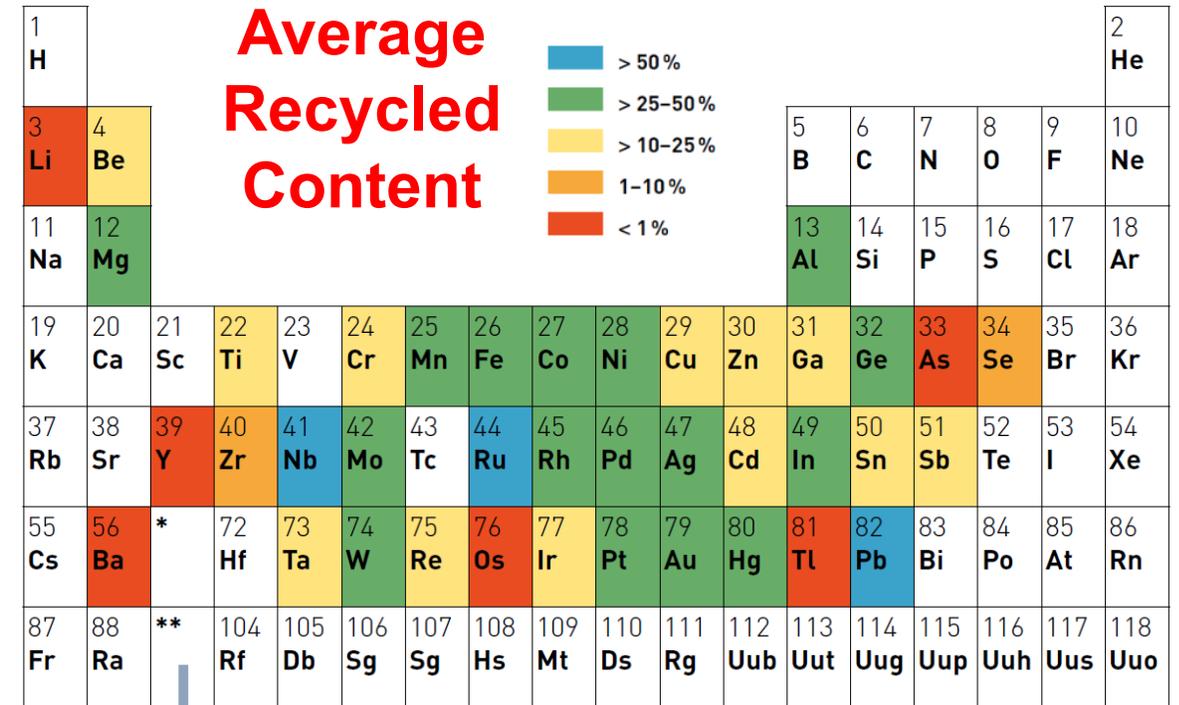


\* Lanthanides

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
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\*\* Actinides

89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr
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UNEP, 2013

# Future Thinking: e.g. Boliden

- A major future trend will have to be efficient recycling systems
- e.g's include computers, mobile phones & 'eWaste', Pt-Pd in cars, Li batteries, urban infrastructure ...
- In other words – implement the **CIRCULAR ECONOMY**

## RECYCLING ELECTRONIC SCRAP PAYS

### 1 TONNE OF MOBILE TELEPHONES YIELDS:

50–150 kg copper  
500–700 g silver  
150–400 g gold

### 1 TONNE OF ORE YIELDS:

3,7 kg copper  
4,2 g silver  
0,2 g gold



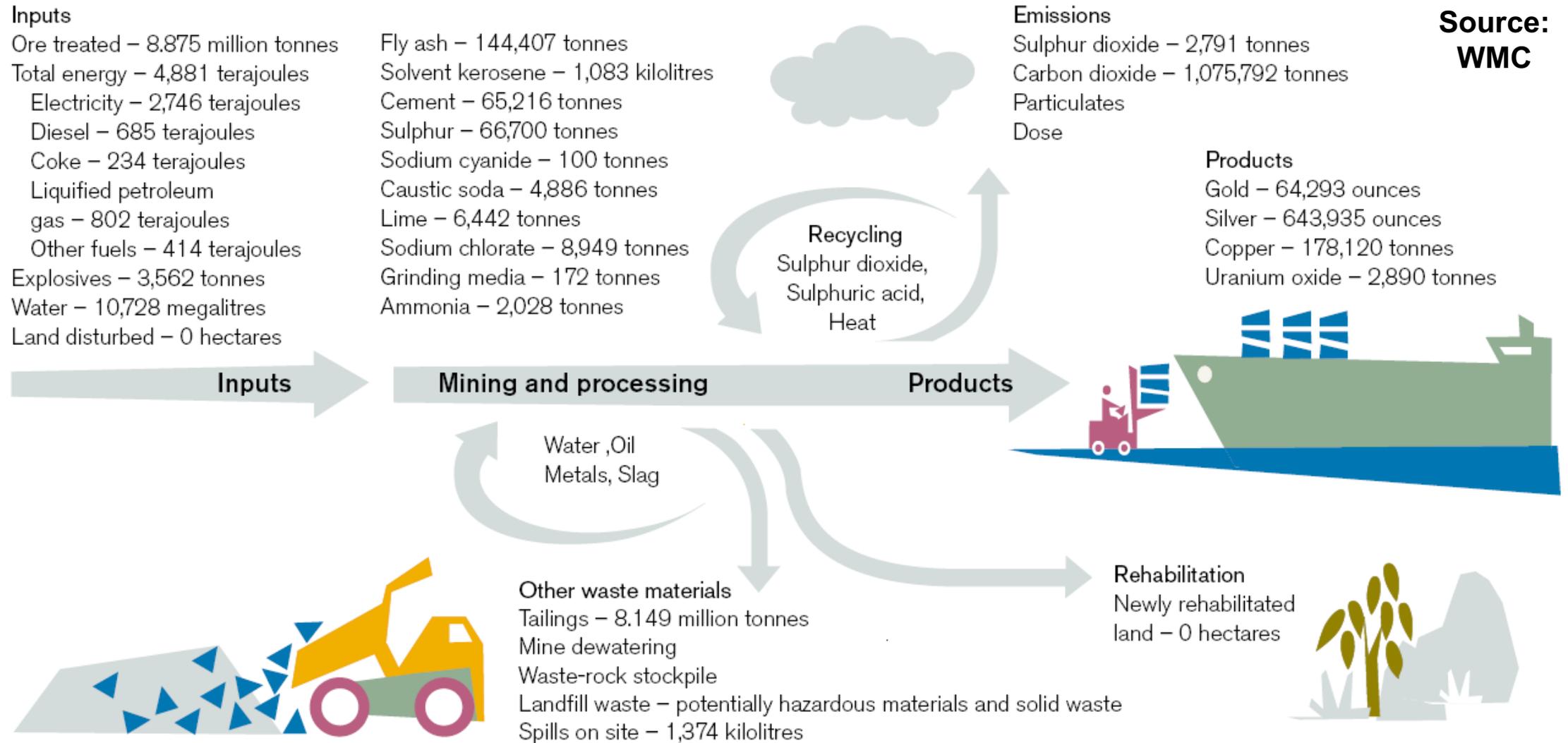
**Boliden, 2007, Sustainability Report.**

# Reporting & Transparency: KEY

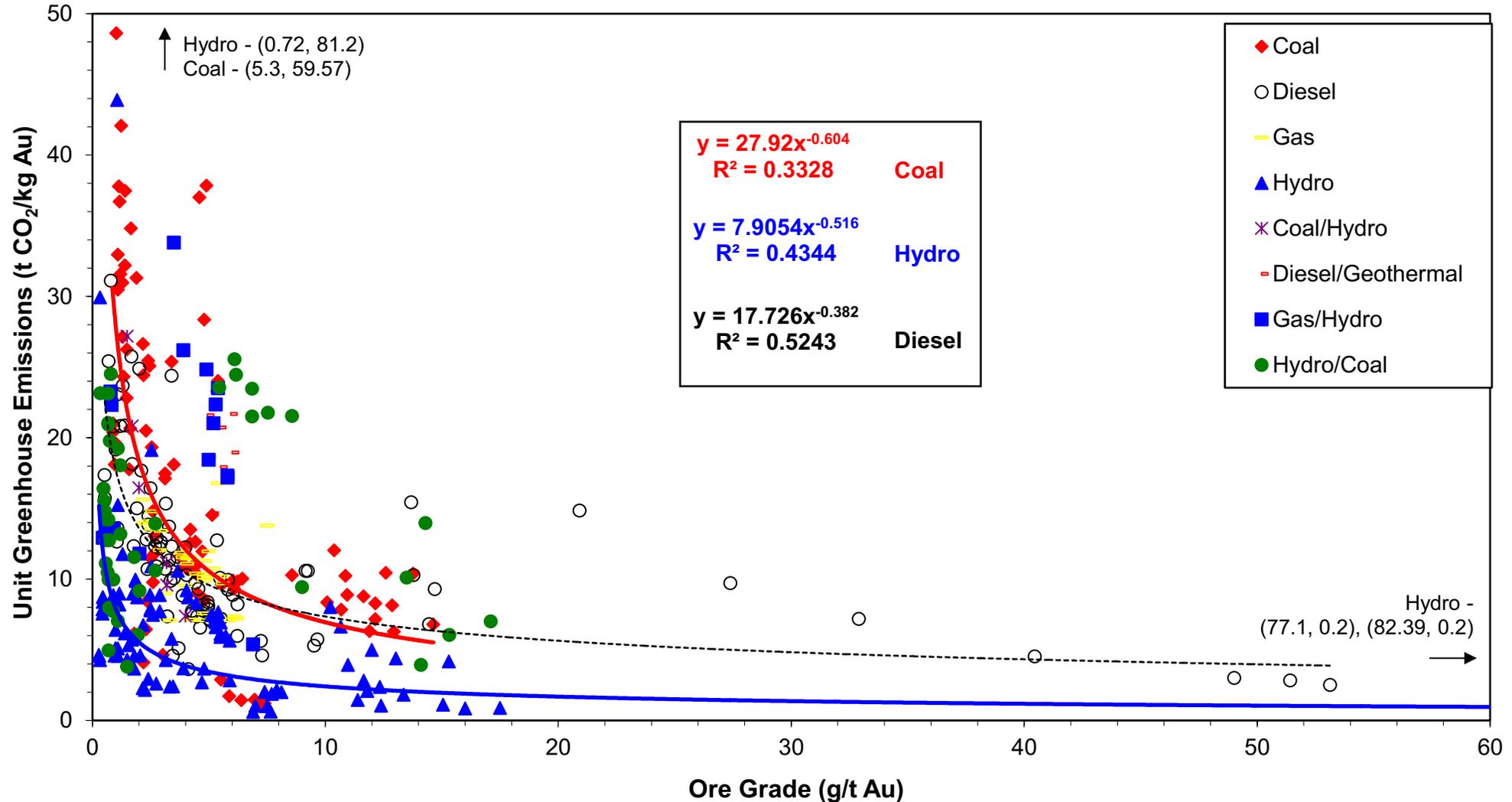
- There is a strong trend towards demonstrating a mine or company is 'responsible' – but how do you do this? **Not Easily!**
- The 1990s saw the rise of 'environmental progress' reporting
- From 2000s saw 'sustainability' reporting – which the global mining industry signed up to through the 'MMSD' process at Johannesburg
- Major frameworks have evolved, including the Global Reporting Initiative (GRI), Kimberley Process, former Dodd-Frank rules, CDP, EITI, RMI, RJC, ARM, Fairmined, TSM, ICMM, ...
- Now comes **IRMA: Initiative for Responsible Mining Assurance**

Boliden, 2007, Sustainability Report.

# Sustainability Reporting: Good Example?



# Using Sustainability Rep. v Life Cycle Assessment



# IRMA ENGAGEMENT MAP

increasing transparency and catalyzing connections between mining stakeholders



# Summary: Mining, SD & CE

- Mining provides the metals, minerals and energy the modern world needs & wants ... **BUT**
- Mining can present a range of social-environmental-economic benefits and impacts, but the ever increasing scale is making this more complex to assess & manage
- Environmental impacts per unit metal / mineral are increasing
- Sustainable development requires a thorough approach to understanding the links between S-E-E aspects, and sustainability reporting is critical to achieve this
- Many see the 'Circular Economy' as the best way forward

# Acknowledgements

- UCD iCRaG Team
- Mineral Policy Institute (Australia), many eNGOs
- CSIRO Mineral Resources Flagship, Geoscience Australia
- PhD students Zhehan Weng, Stephen Northey, Tim Werner
- Many communities across the world (esp. Peter Diehl)
- Prof. Tom Graedel (Yale) & many other academic colleagues

***Email me if interested in the numerous papers !!***

