Mining & Its Growing Environmental Impacts

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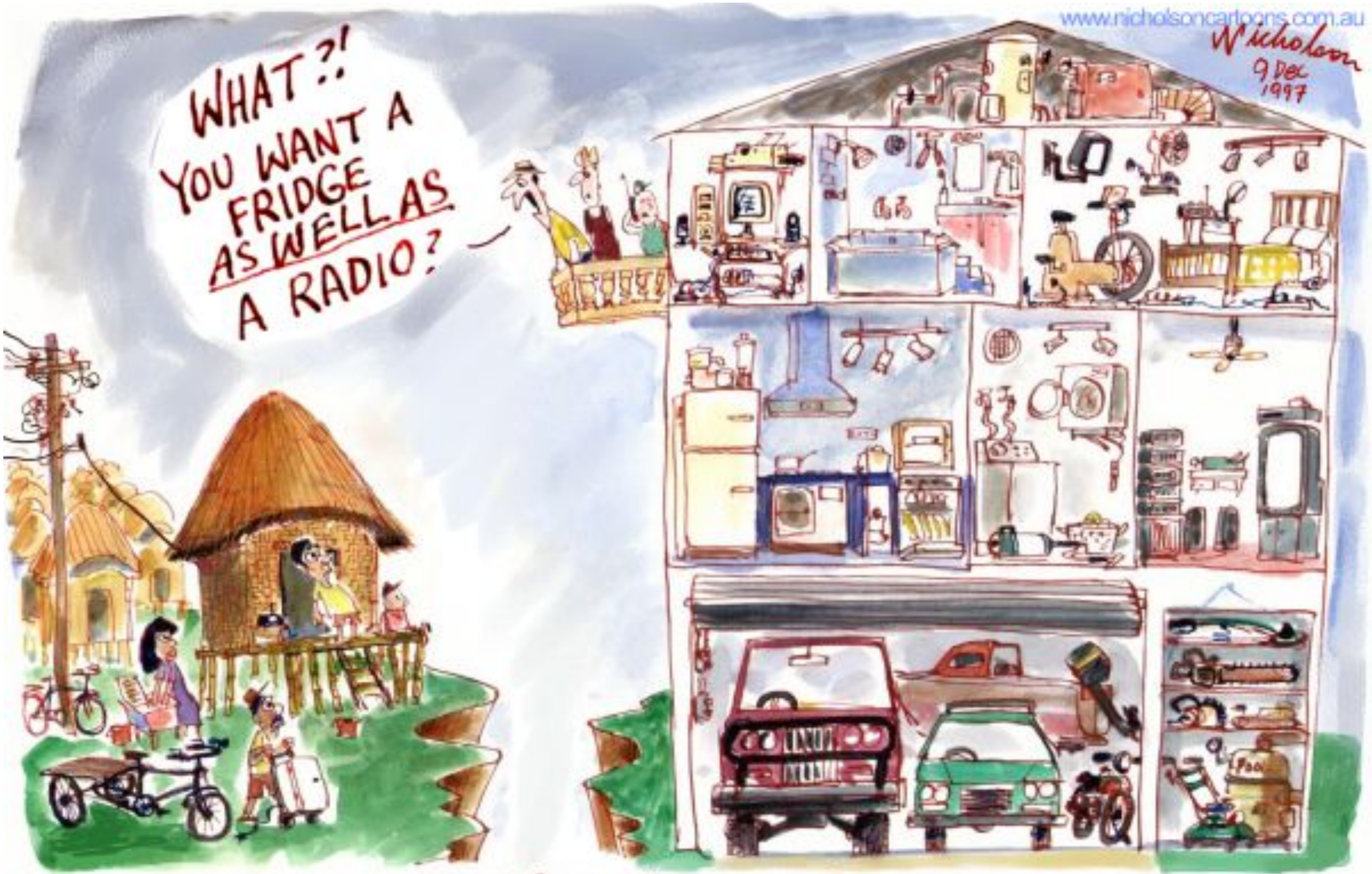


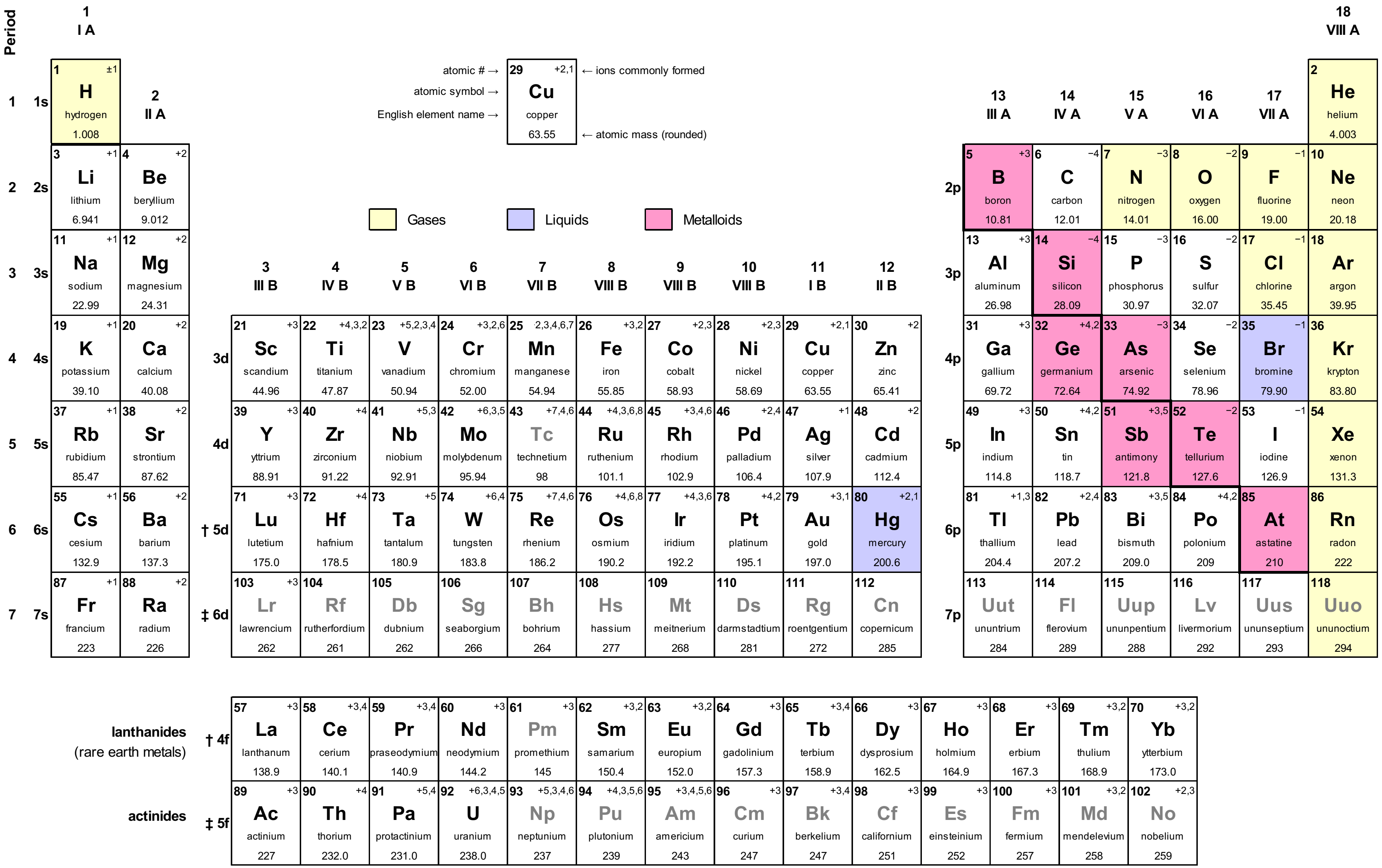
A GREENHOUSE NIGHTMARE...

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*."

The World of Extractives: The Periodic Table



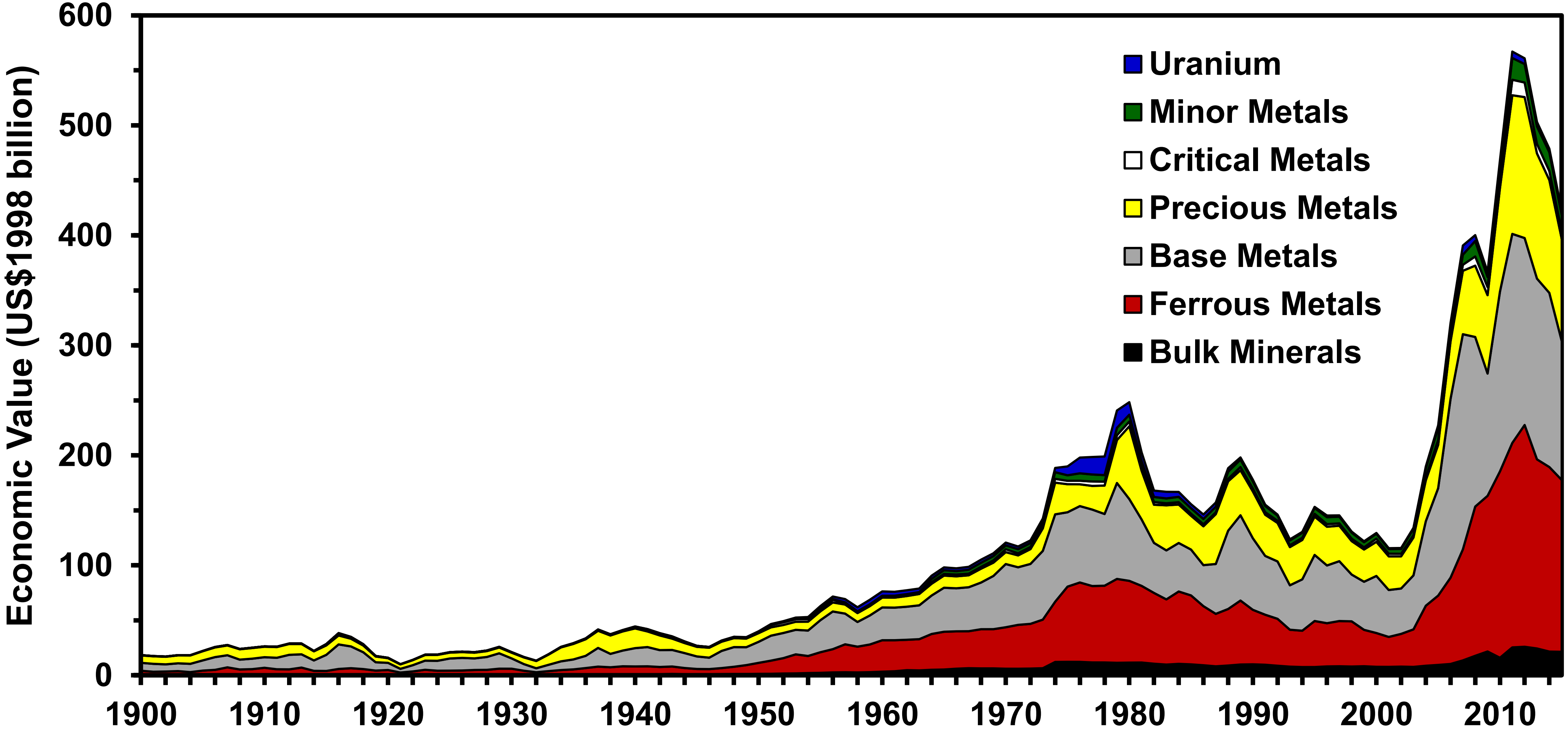
atomic # → 29 +2,1 ← ions commonly formed
atomic symbol → Cu
English element name → copper
63.55 ← atomic mass (rounded)

🟨 Gases 🟦 Liquids 🟥 Metalloids

Period		1 I A	2 II A		3 III B	4 IV B	5 V B	6 VI B	7 VII B	8 VIII B	9 VIII B	10 VIII B	11 I B	12 II B		13 III A	14 IV A	15 V A	16 VI A	17 VII A	18 VIII A
1	1s	🟨 1 ±1 **H** hydrogen 1.008																			🟨 2 **He** helium 4.003
2	2s	3 +1 **Li** lithium 6.941	4 +2 **Be** beryllium 9.012												2p	🟥 5 +3 **B** boron 10.81	6 −4 **C** carbon 12.01	🟨 7 −3 **N** nitrogen 14.01	🟨 8 −2 **O** oxygen 16.00	🟨 9 −1 **F** fluorine 19.00	🟨 10 **Ne** neon 20.18
3	3s	11 +1 **Na** sodium 22.99	12 +2 **Mg** magnesium 24.31												3p	13 +3 **Al** aluminum 26.98	🟥 14 −4 **Si** silicon 28.09	15 −3 **P** phosphorus 30.97	16 −2 **S** sulfur 32.07	🟨 17 −1 **Cl** chlorine 35.45	🟨 18 **Ar** argon 39.95
4	4s	19 +1 **K** potassium 39.10	20 +2 **Ca** calcium 40.08	3d	21 +3 **Sc** scandium 44.96	22 +4,3,2 **Ti** titanium 47.87	23 +5,2,3,4 **V** vanadium 50.94	24 +3,2,6 **Cr** chromium 52.00	25 2,3,4,6,7 **Mn** manganese 54.94	26 +3,2 **Fe** iron 55.85	27 +2,3 **Co** cobalt 58.93	28 +2,3 **Ni** nickel 58.69	29 +2,1 **Cu** copper 63.55	30 +2 **Zn** zinc 65.41	4p	31 +3 **Ga** gallium 69.72	🟥 32 +4,2 **Ge** germanium 72.64	🟥 33 −3 **As** arsenic 74.92	34 −2 **Se** selenium 78.96	🟦 35 −1 **Br** bromine 79.90	🟨 36 **Kr** krypton 83.80
5	5s	37 +1 **Rb** rubidium 85.47	38 +2 **Sr** strontium 87.62	4d	39 +3 **Y** yttrium 88.91	40 +4 **Zr** zirconium 91.22	41 +5,3 **Nb** niobium 92.91	42 +6,3,5 **Mo** molybdenum 95.94	43 +7,4,6 **Tc** technetium 98	44 +4,3,6,8 **Ru** ruthenium 101.1	45 +3,4,6 **Rh** rhodium 102.9	46 +2,4 **Pd** palladium 106.4	47 +1 **Ag** silver 107.9	48 +2 **Cd** cadmium 112.4	5p	49 +3 **In** indium 114.8	50 +4,2 **Sn** tin 118.7	🟥 51 +3,5 **Sb** antimony 121.8	🟥 52 −2 **Te** tellurium 127.6	53 −1 **I** iodine 126.9	🟨 54 **Xe** xenon 131.3
6	6s	55 +1 **Cs** cesium 132.9	56 +2 **Ba** barium 137.3	† 5d	71 +3 **Lu** lutetium 175.0	72 +4 **Hf** hafnium 178.5	73 +5 **Ta** tantalum 180.9	74 +6,4 **W** tungsten 183.8	75 +7,4,6 **Re** rhenium 186.2	76 +4,6,8 **Os** osmium 190.2	77 +4,3,6 **Ir** iridium 192.2	78 +4,2 **Pt** platinum 195.1	79 +3,1 **Au** gold 197.0	🟦 80 +2,1 **Hg** mercury 200.6	6p	81 +1,3 **Tl** thallium 204.4	82 +2,4 **Pb** lead 207.2	83 +3,5 **Bi** bismuth 209.0	84 +4,2 **Po** polonium 209	🟥 85 **At** astatine 210	🟨 86 **Rn** radon 222
7	7s	87 +1 **Fr** francium 223	88 +2 **Ra** radium 226	‡ 6d	103 +3 **Lr** lawrencium 262	104 **Rf** rutherfordium 261	105 **Db** dubnium 262	106 **Sg** seaborgium 266	107 **Bh** bohrium 264	108 **Hs** hassium 277	109 **Mt** meitnerium 268	110 **Ds** darmstadtium 281	111 **Rg** roentgentium 272	112 **Cn** copernicum 285	7p	113 **Uut** ununtrium 284	114 **Fl** flerovium 289	115 **Uup** ununpentium 288	116 **Lv** livermorium 292	117 **Uus** ununseptium 293	🟨 118 **Uuo** ununoctium 294

lanthanides (rare earth metals)	† 4f	57 +3 **La** lanthanum 138.9	58 +3,4 **Ce** cerium 140.1	59 +3,4 **Pr** praseodymium 140.9	60 +3 **Nd** neodymium 144.2	61 +3 **Pm** promethium 145	62 +3,2 **Sm** samarium 150.4	63 +3,2 **Eu** europium 152.0	64 +3 **Gd** gadolinium 157.3	65 +3,4 **Tb** terbium 158.9	66 +3 **Dy** dysprosium 162.5	67 +3 **Ho** holmium 164.9	68 +3 **Er** erbium 167.3	69 +3,2 **Tm** thulium 168.9	70 +3,2 **Yb** ytterbium 173.0	
actinides	‡ 5f	89 +3 **Ac** actinium 227	90 +4 **Th** thorium 232.0	91 +5,4 **Pa** protactinium 231.0	92 +6,3,4,5 **U** uranium 238.0	93 +5,3,4,6 **Np** neptunium 237	94 +4,3,5,6 **Pu** plutonium 239	95 +3,4,5,6 **Am** americium 243	96 +3 **Cm** curium 247	97 +3,4 **Bk** berkelium 247	98 +3 **Cf** californium 251	99 +3 **Es** einsteinium 252	100 +3 **Fm** fermium 257	101 +3,2 **Md** mendelevium 258	102 +2,3 **No** nobelium 259	

Mining's Global Real Value Since 1900



(A 'Simplistic') Overview of Mining vs SD

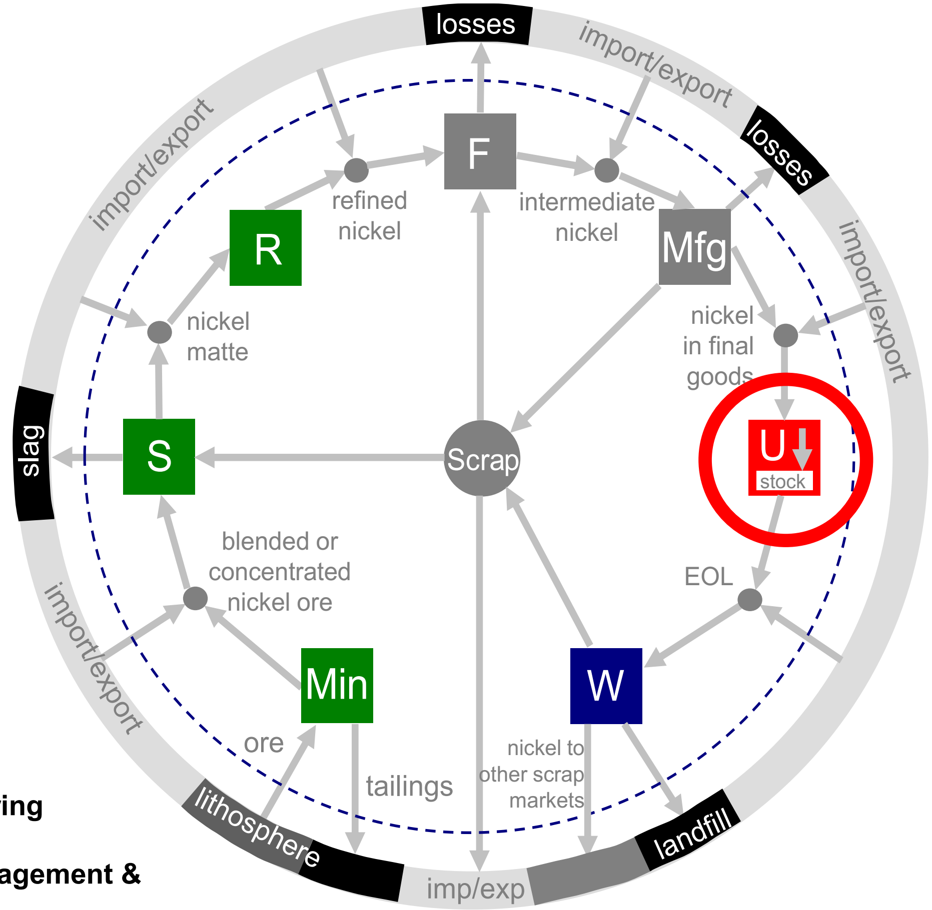
- Mineral deposits, are by their nature, 'finite' – and non-renewable
- Global production of metals and minerals almost always increases over time to meet growing market demands
- Yet we know of more mineral resources now than ever, enough to meet growing demands for many decades (or even centuries)

Quite the paradox !!

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

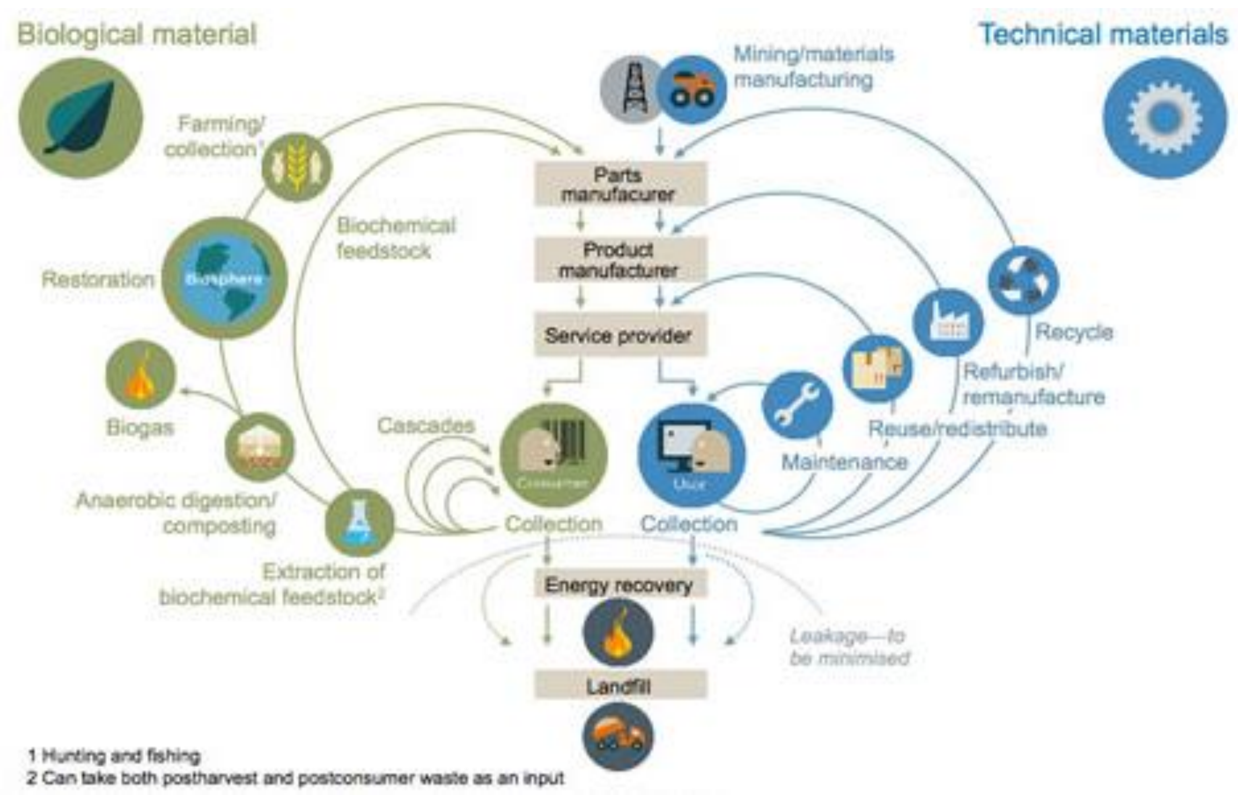
(IMNSHEO) KEY: Environmental Impacts are Growing!!

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



1 Hunting and fishing
2 Can take both postharvest and postconsumer waste as an input

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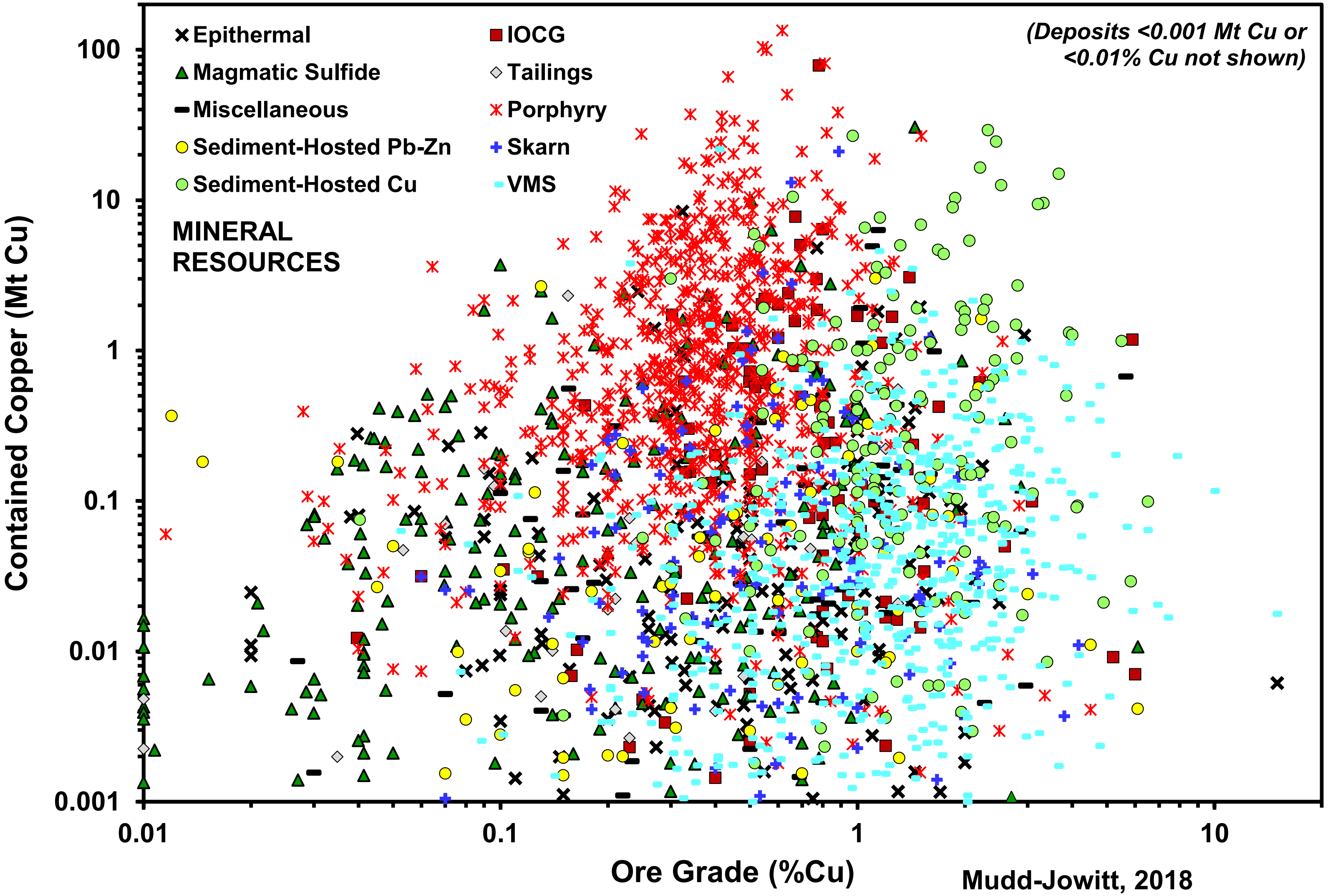
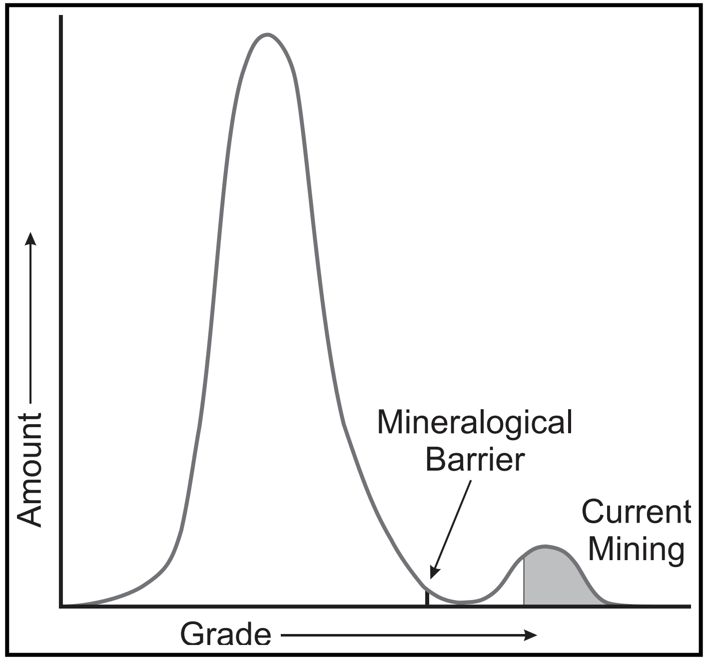
Global Copper Mineral Resources

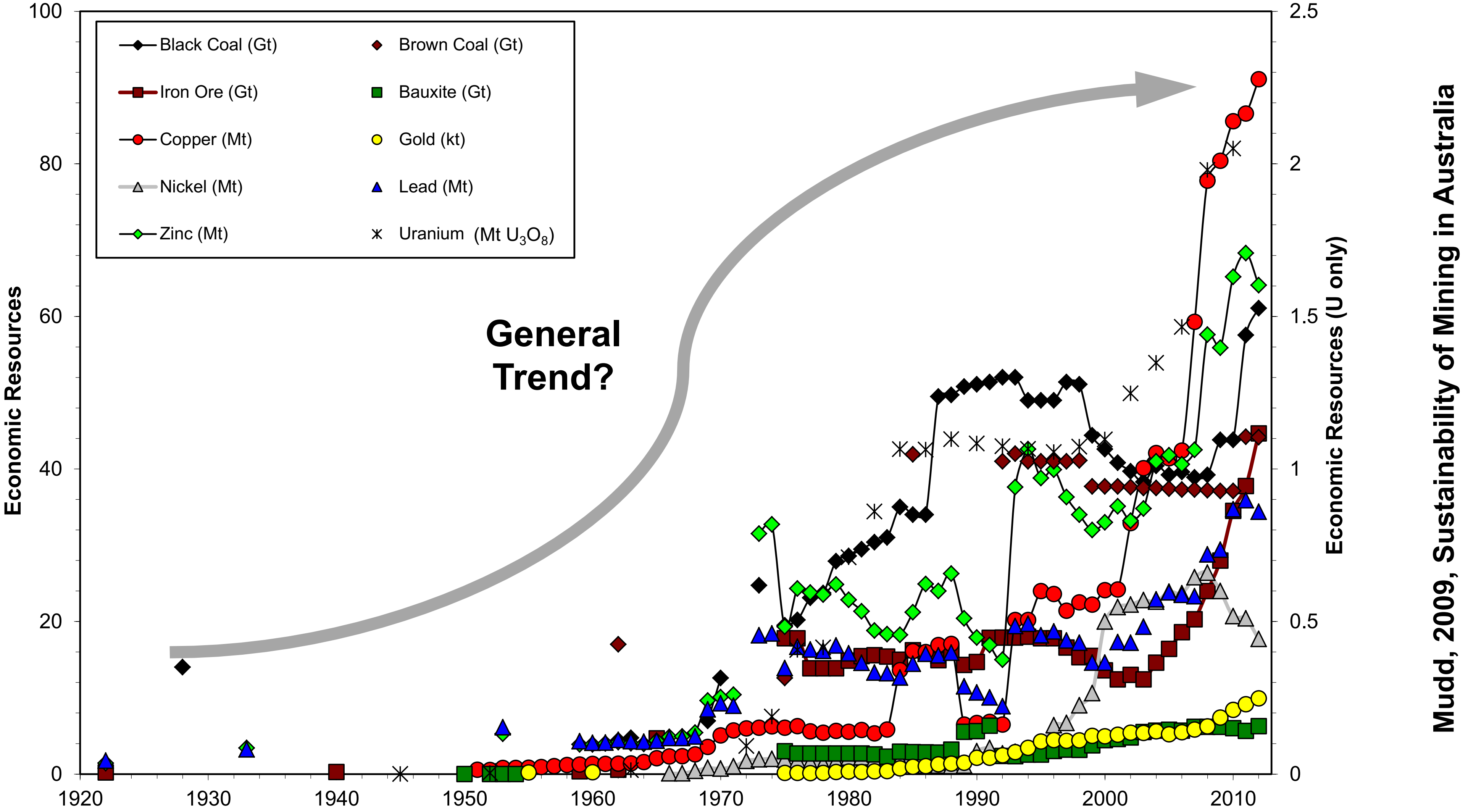


Mudd-Jowitt, 2018

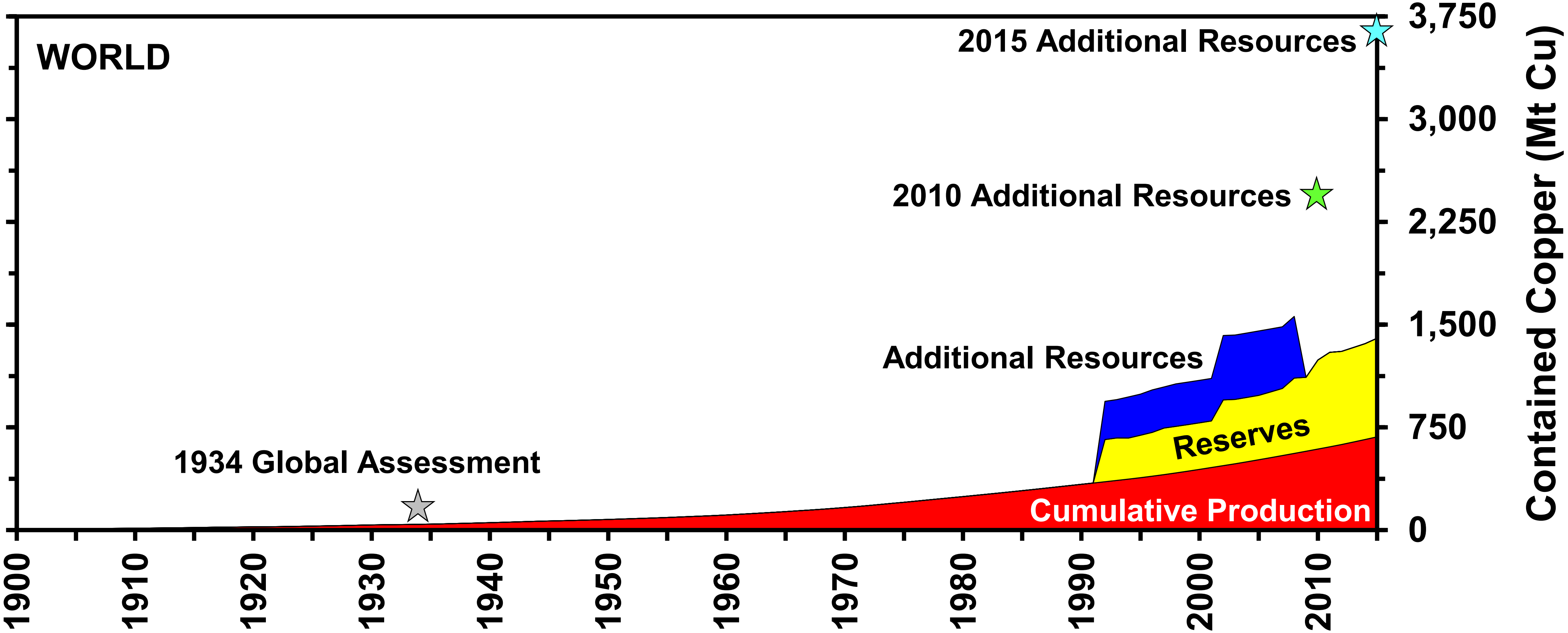
Skinner's 1976 "Mineralogical Barrier" for geochemically scarce metals



Australia's Economic Resources

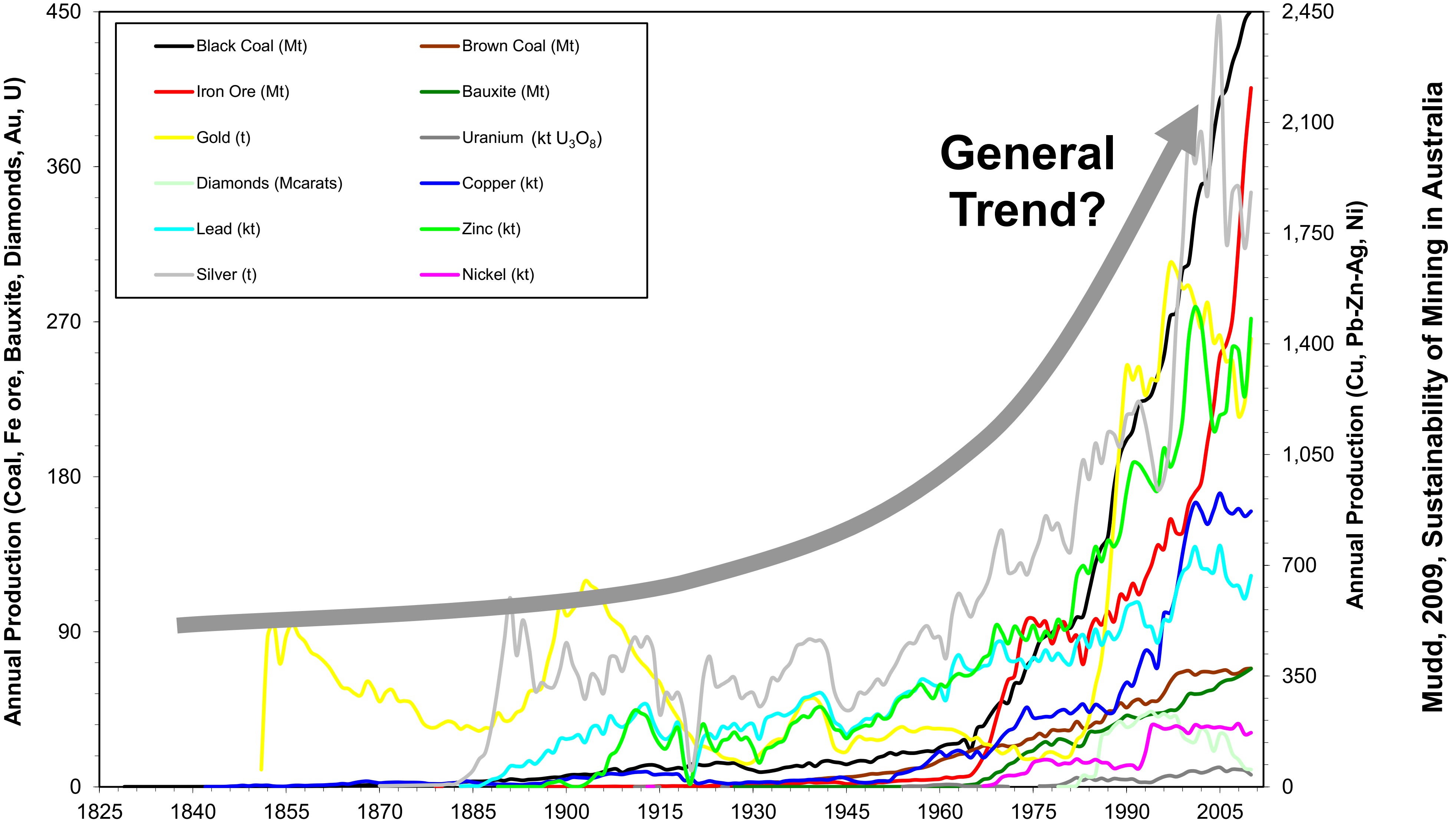


Global Copper's Growing Endowment



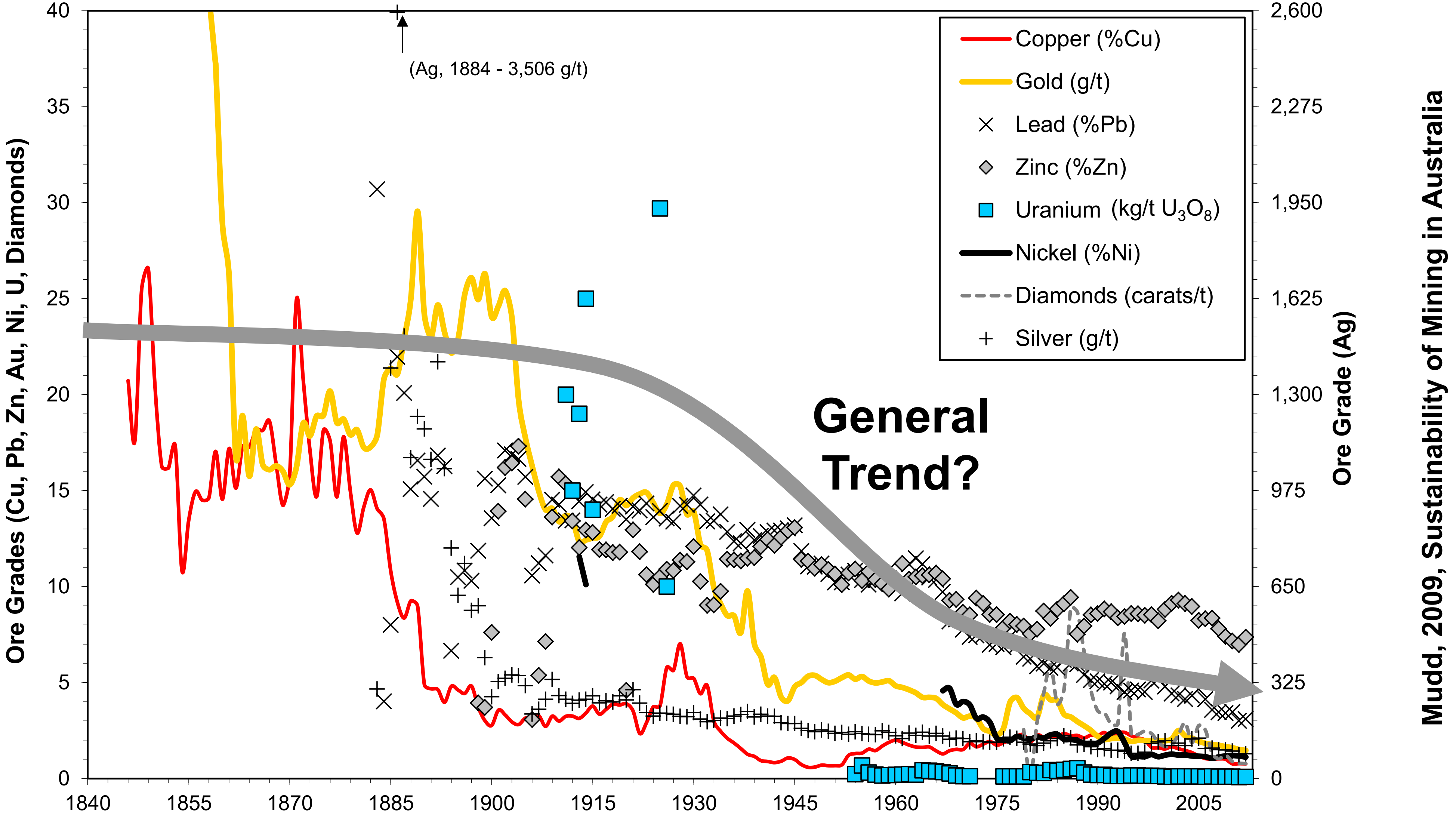
Mudd-Jowitt (2018b)

Australian Mining Production

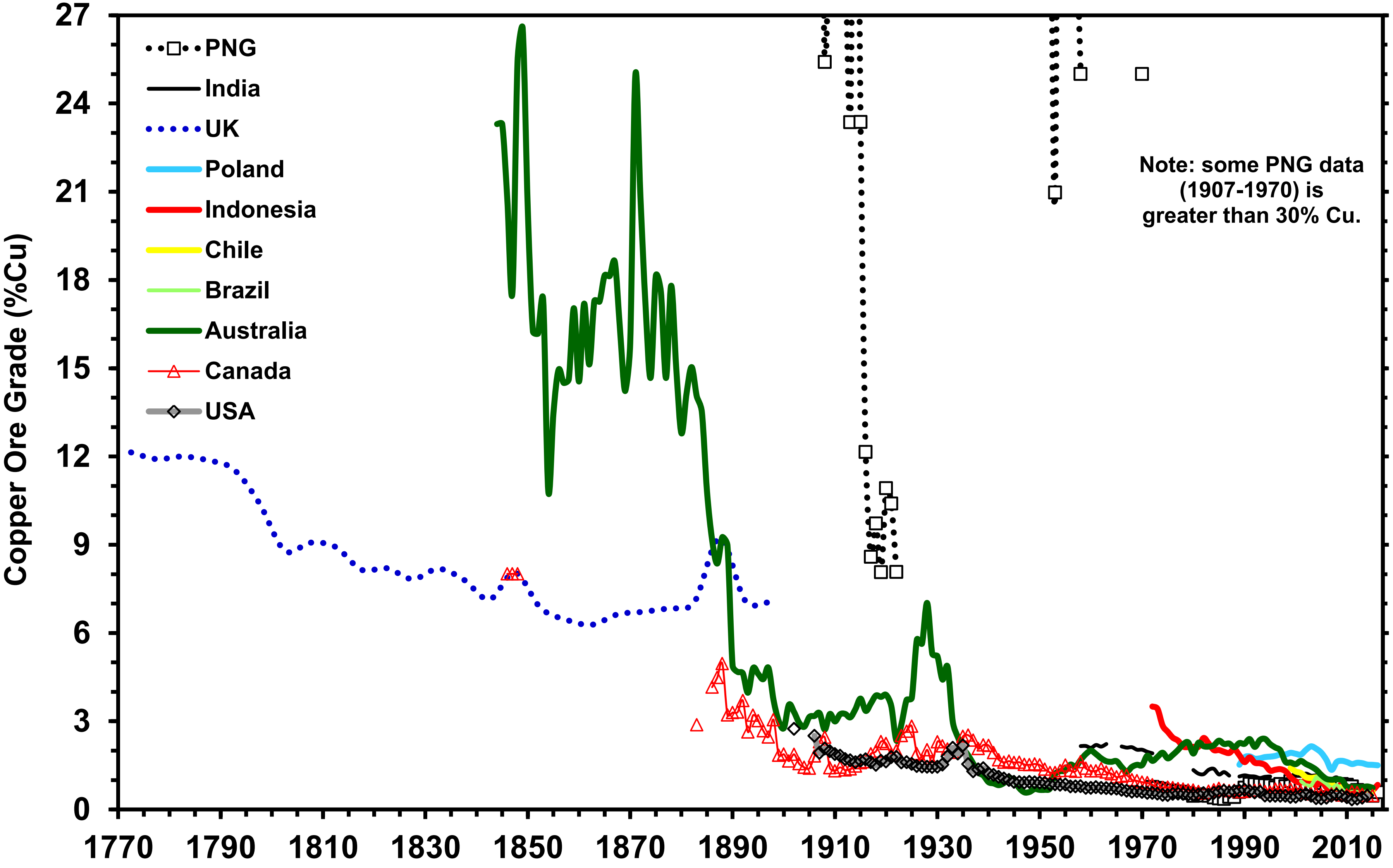


Mudd, 2009, Sustainability of Mining in Australia

Ore Grades – Australia

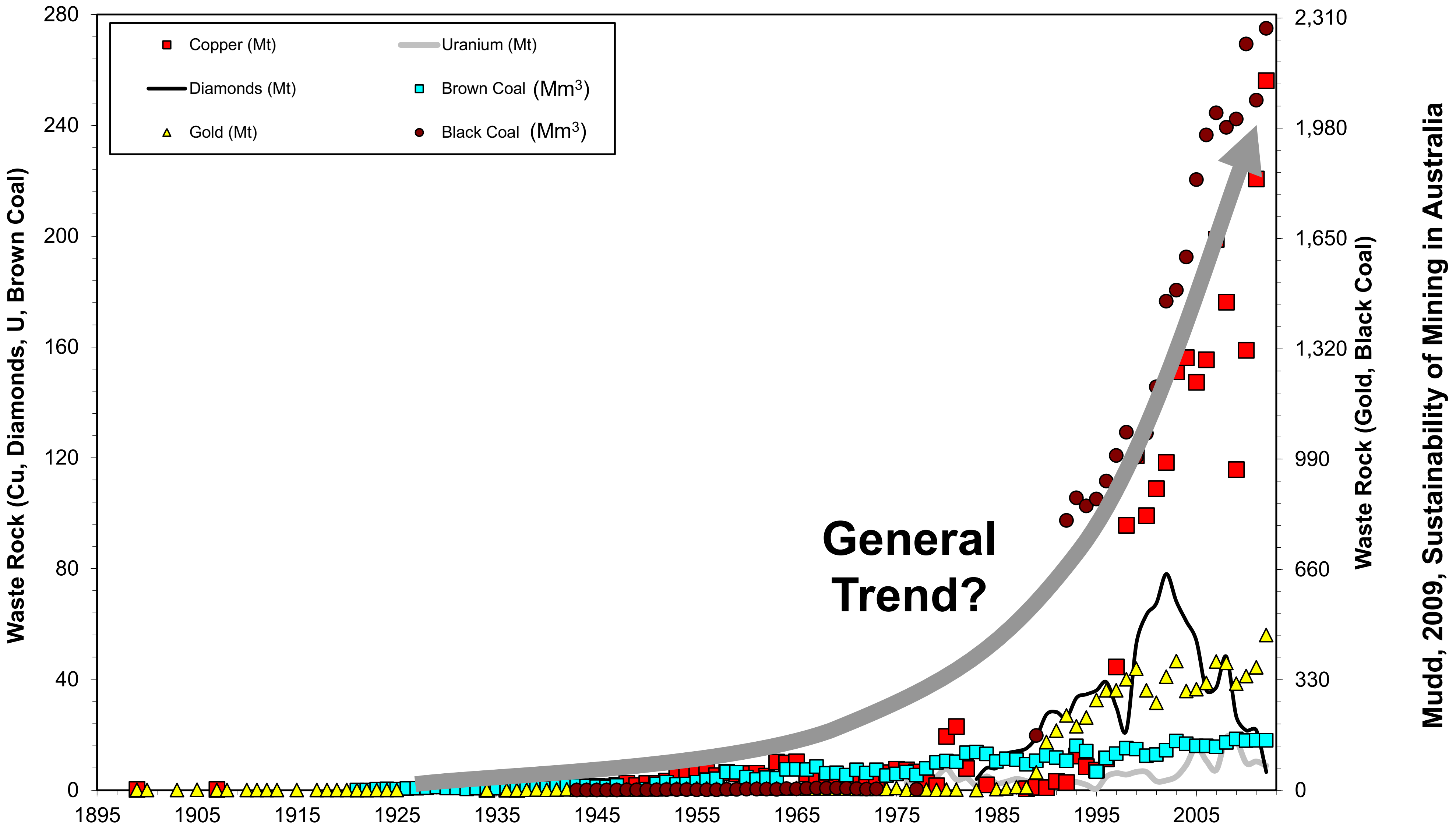


Global Copper Ore Grades

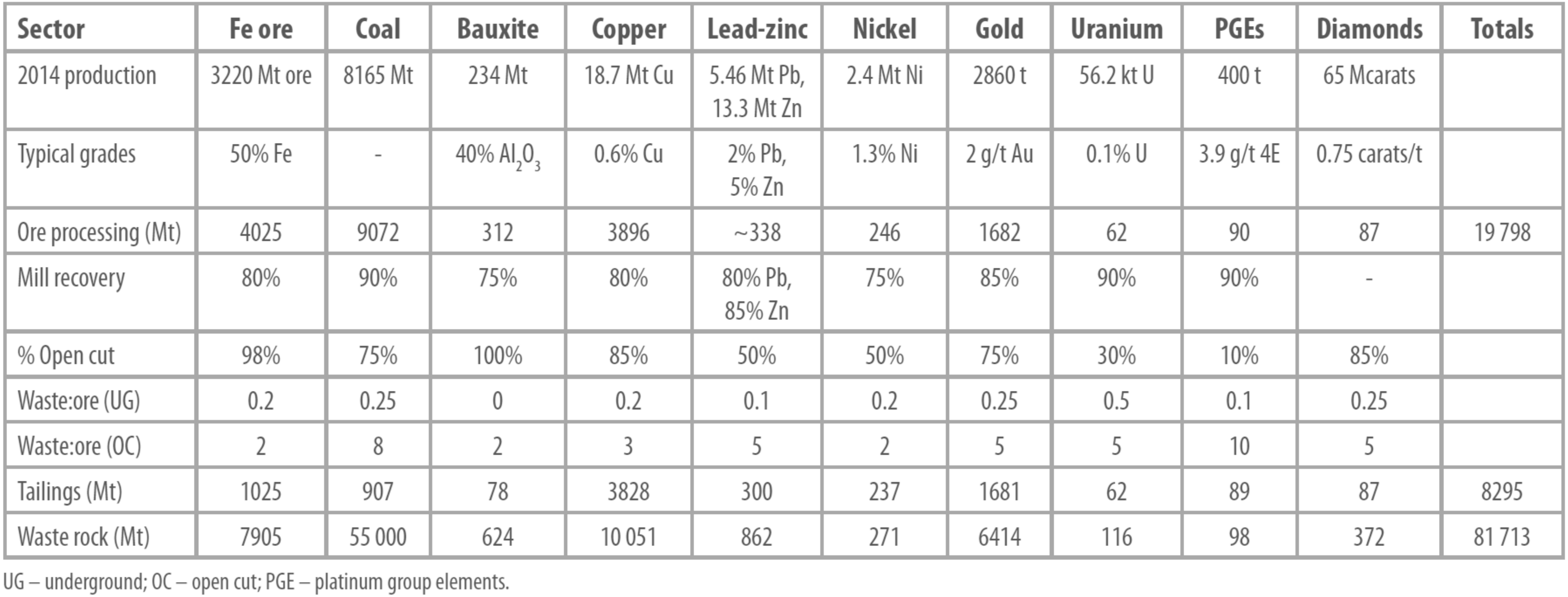


Note: some PNG data (1907-1970) is greater than 30% Cu.

Waste Rock – Australia



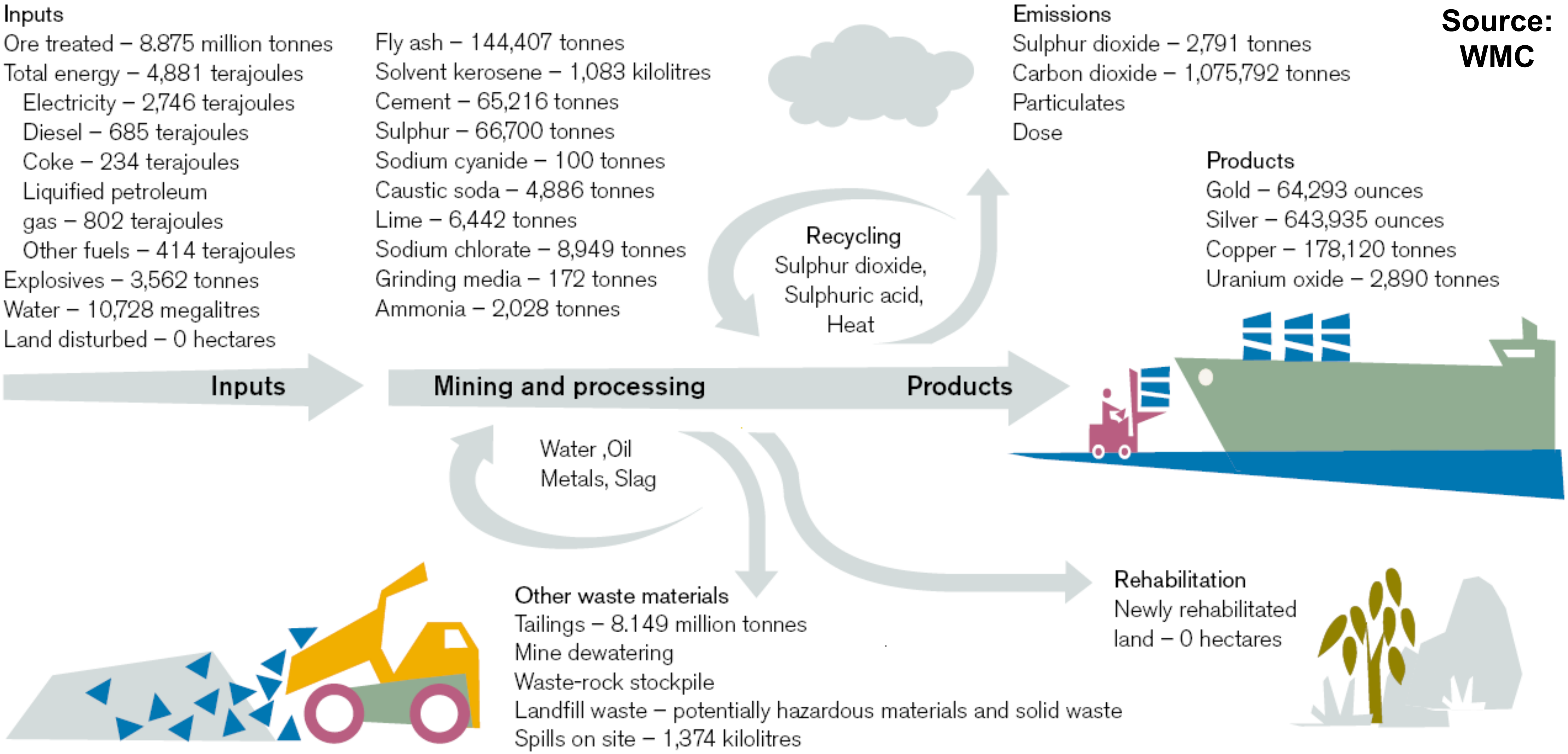
Global Mine Waste Estimate (2014)



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_2O_3	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	8	2	3	5	2	5	5	10	5	
Tailings (Mt)	1025	907	78	3828	300	237	1681	62	89	87	8295
Waste rock (Mt)	7905	55 000	624	10 051	862	271	6414	116	98	372	81 713

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

Sustainability Reporting: Good Example?



Source: WMC

Inputs
Ore treated – 8.875 million tonnes
Total energy – 4,881 terajoules
  Electricity – 2,746 terajoules
  Diesel – 685 terajoules
  Coke – 234 terajoules
  Liquified petroleum gas – 802 terajoules
  Other fuels – 414 terajoules
Explosives – 3,562 tonnes
Water – 10,728 megalitres
Land disturbed – 0 hectares

Fly ash – 144,407 tonnes
Solvent kerosene – 1,083 kilolitres
Cement – 65,216 tonnes
Sulphur – 66,700 tonnes
Sodium cyanide – 100 tonnes
Caustic soda – 4,886 tonnes
Lime – 6,442 tonnes
Sodium chlorate – 8,949 tonnes
Grinding media – 172 tonnes
Ammonia – 2,028 tonnes

Emissions
Sulphur dioxide – 2,791 tonnes
Carbon dioxide – 1,075,792 tonnes
Particulates
Dose

Products
Gold – 64,293 ounces
Silver – 643,935 ounces
Copper – 178,120 tonnes
Uranium oxide – 2,890 tonnes

Recycling
Sulphur dioxide,
Sulphuric acid,
Heat

Inputs

Mining and processing

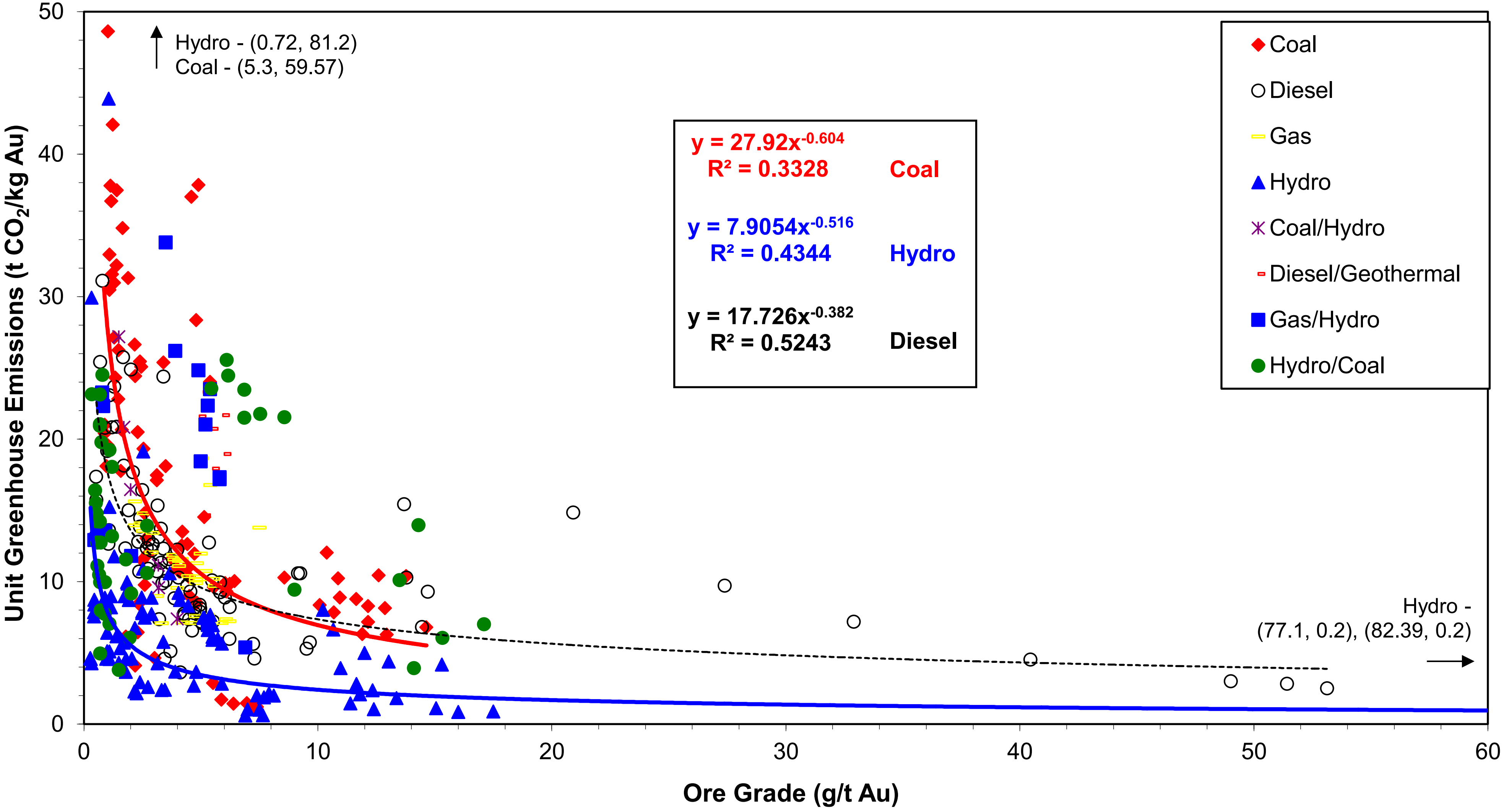
Products

Water ,Oil
Metals, Slag

Other waste materials
Tailings – 8.149 million tonnes
Mine dewatering
Waste-rock stockpile
Landfill waste – potentially hazardous materials and solid waste
Spills on site – 1,374 kilolitres

Rehabilitation
Newly rehabilitated land – 0 hectares

Using Sustainability Rep. v Life Cycle Assessment



AMD: Acid & Metalliferous Drainage

- Wherever iron sulfide minerals are exposed to water and oxygen, there is a high risk of AMD (often greatly accelerated by microorganisms):

Primary oxidation	$2\,FeS_{2(s)} + 7\,O_2 + 2\,H_2O \rightarrow 2\,Fe^{2+} + 4\,SO_4^{2-} + 4H^+$
Ferrous oxidation	$4\,Fe^{2+} + O_2 + 4\,H^+ \rightarrow 4\,Fe^{3+} + 2\,H_2O$
Ferrihydrite formation	$Fe^{3+} + 3\,H_2O \rightarrow 4\,Fe(OH)_3 + 3\,H^+$
Ferric/sulfide oxidation	$FeS_2 + 14\,Fe^{3+} + 8\,H_2O \rightarrow 15\,Fe^{2+} + 2\,SO_4^{2-} + 16\,H^+ + \text{energy}$

$$\boxed{4\,FeS_{2(s)} + 15\,O_2 + 14\,H_2O \rightarrow 4\,Fe(OH)_{3(s)} + 8\,H_2SO_4 + \text{energy}}$$

Redbank Cu mine, NT

WRD Seepage: pH 3.3

Aussie Mine ‘Rehabilitation’ Examples #1

Aussie Mine 'Rehabilitation' Examples #2

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**

Gold: Need vs Greed?

- Gold is almost exclusively jewellery & financial uses
- Small amount is for technological uses, mainly electronics

Data (Mine - kinda 'unpublished')

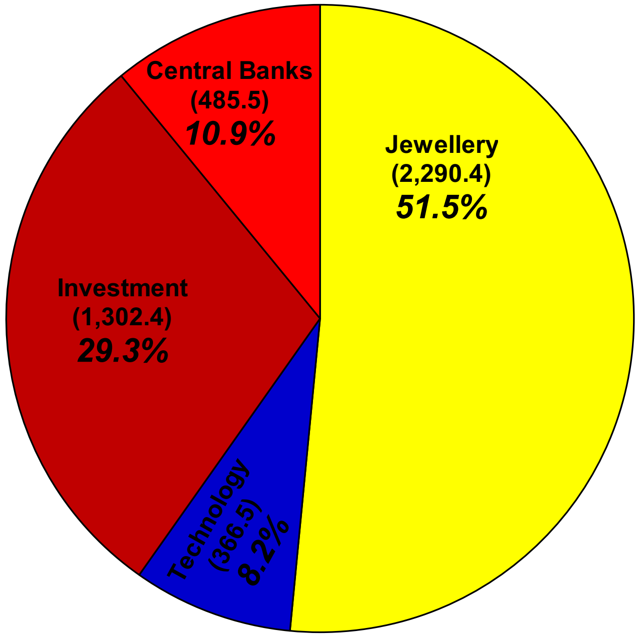
Resources (2011 data)

Fractional Value	Count	t Au	%	g/t Au
Au only	1,428	87,947	**44.9**	1.47
Au 75-100%	61	15,413	7.9	2.66
Au 40-75%	426	44,911	22.9	0.72
Au 20-40%	200	24,858	12.7	0.31
Au <20%	494	22,777	11.6	0.08

Reserves (2011 data)

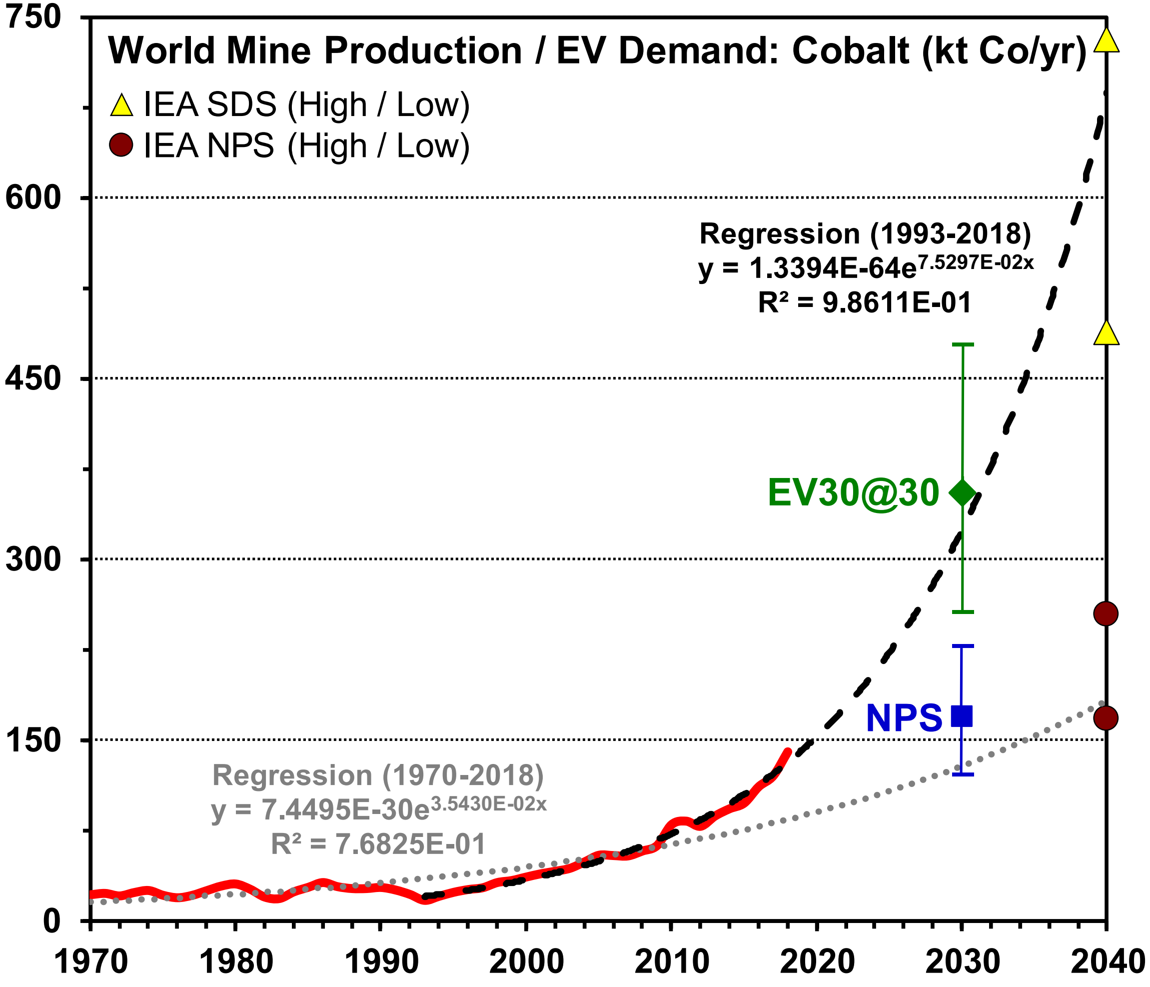
Fractional Value	Count	t Au	%	g/t Au
Au only	433	28,342	**52.6**	1.53
Au 75-100%	78	6,623	12.3	1.35
Au 40-75%	82	9,175	17.0	0.57
Au 20-40%	50	4,879	9.0	0.45
Au <20%	143	4,903	9.1	0.09

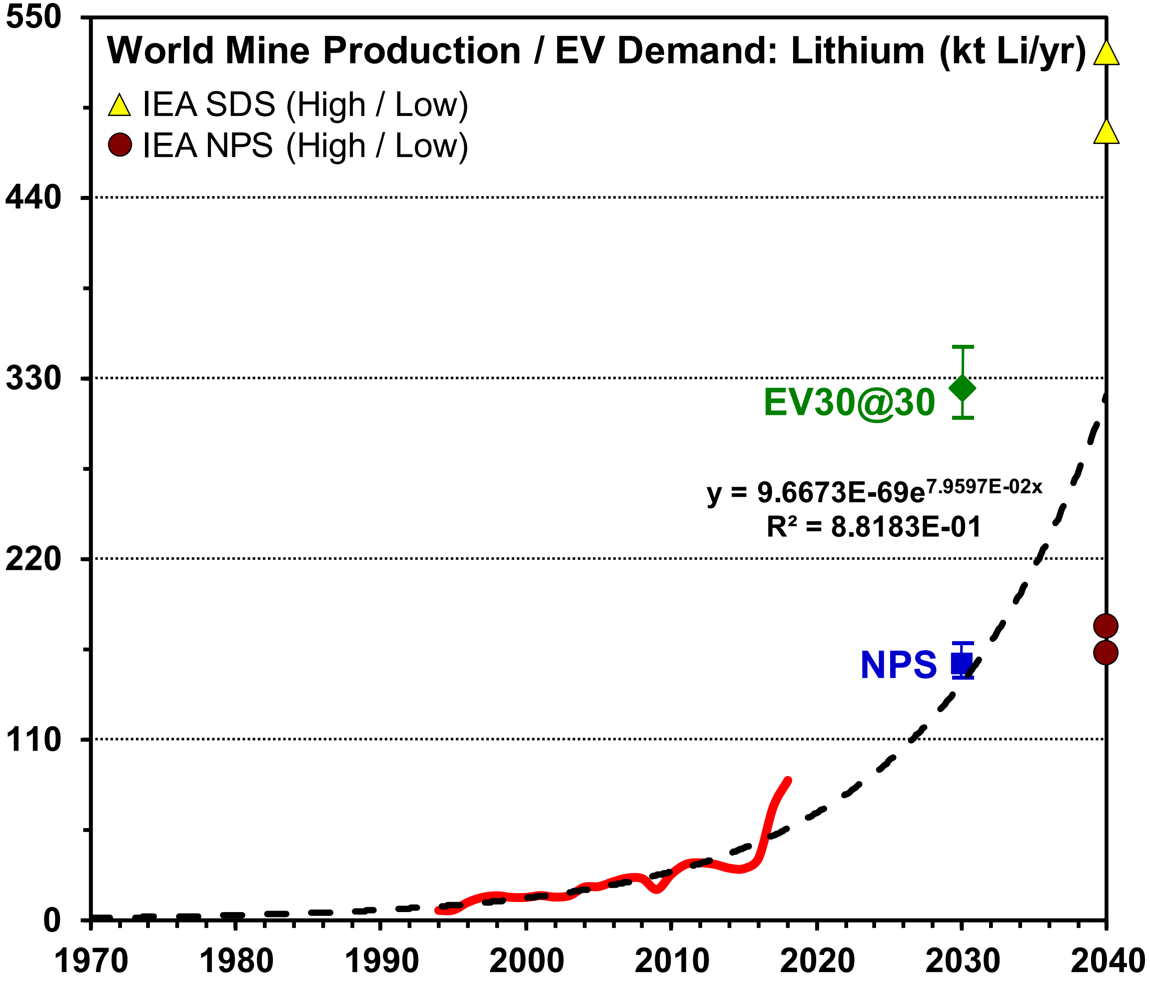
Average Gold Demand:



Data World Gold Council

Rise of the (EV) Machines





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:

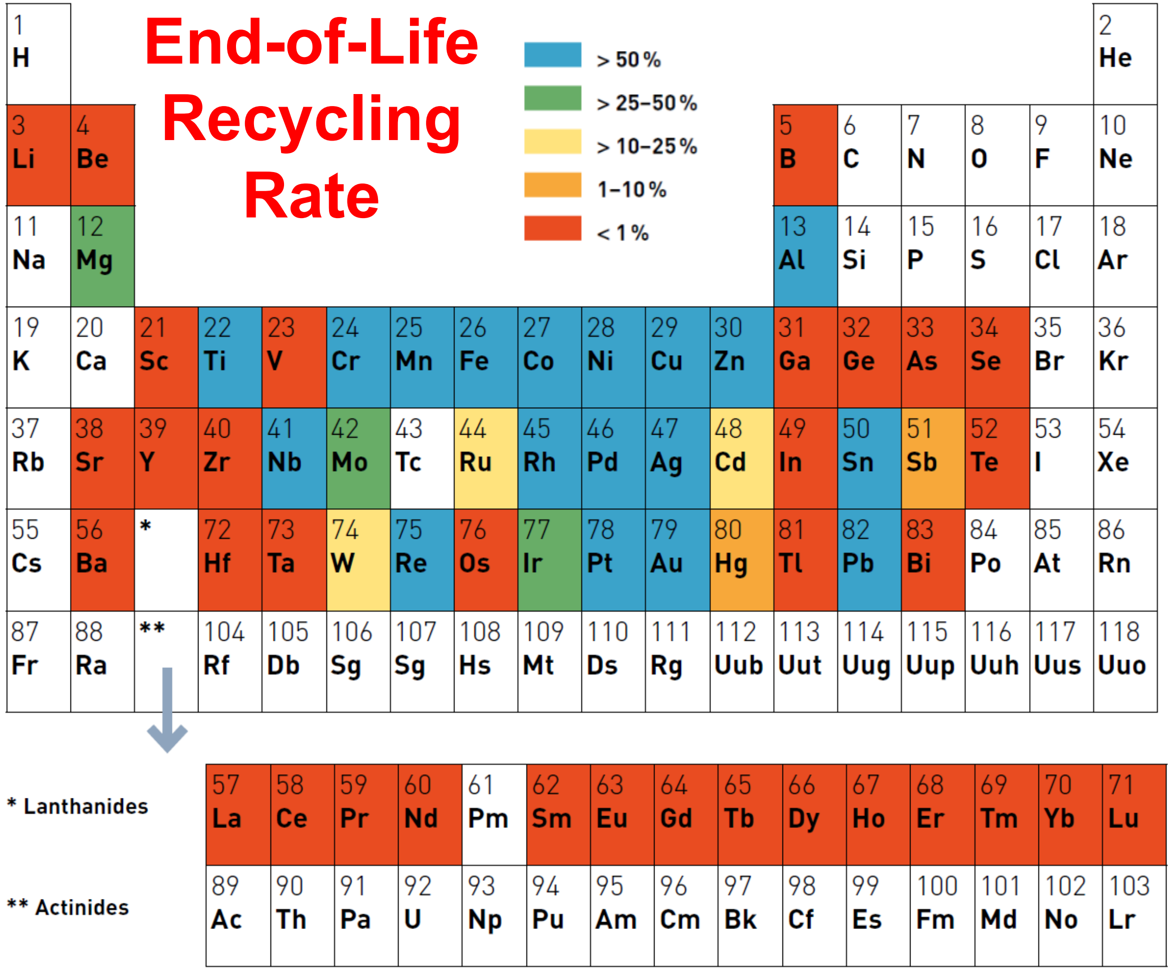
50–150 kg copper
500–700 g silver
150–400 g gold

1 TONNE OF ORE YIELDS:

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

Boliden, 2007, Sustainability Report.

Extent of Metals Recycling …

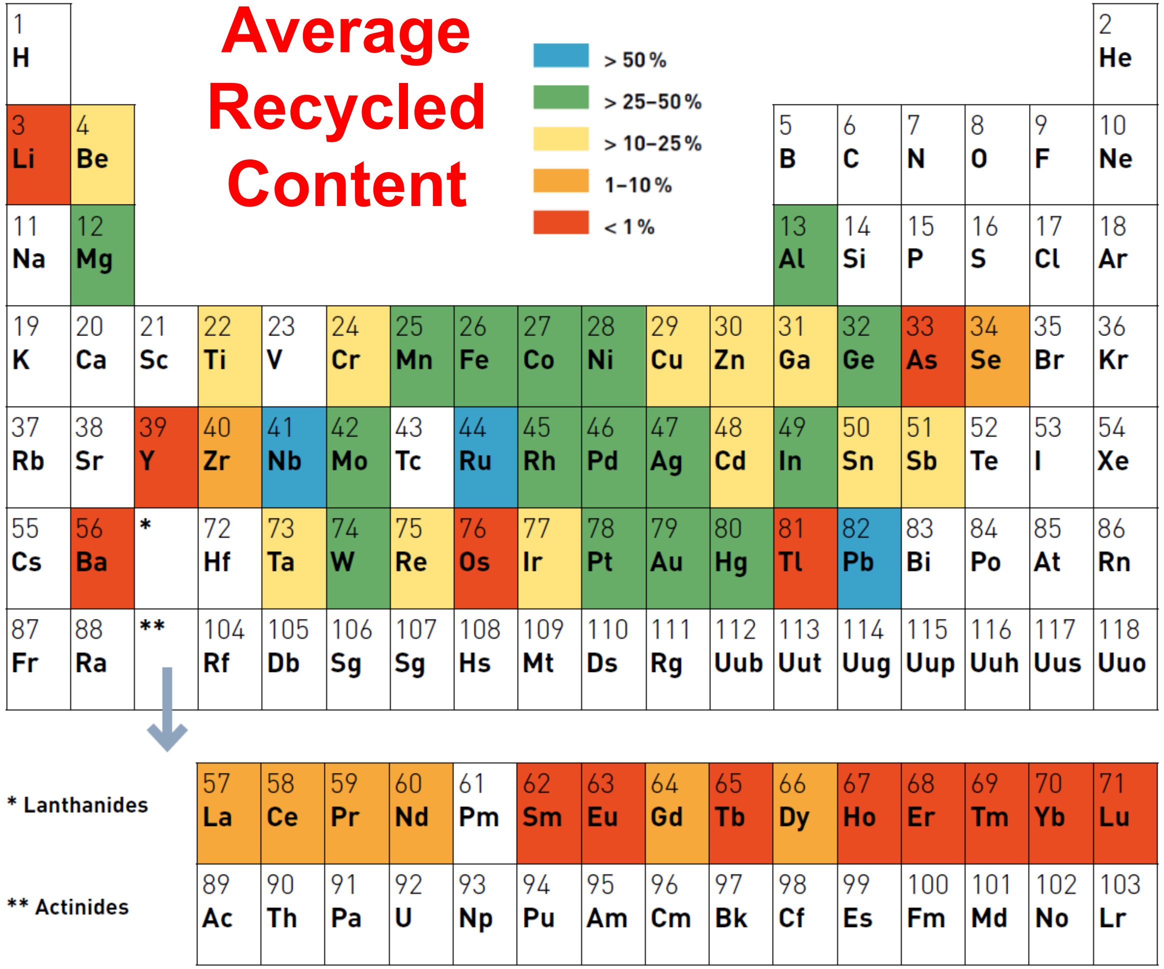


End-of-Life Recycling Rate

- 🟦 > 50 %
- 🟩 > 25–50 %
- 🟨 > 10–25 %
- 🟧 1–10 %
- 🟥 < 1 %

1 H																	2 He
🟥 3 Li	🟥 4 Be											🟥 5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	🟩 12 Mg											🟦 13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	🟥 21 Sc	🟦 22 Ti	🟥 23 V	🟦 24 Cr	🟦 25 Mn	🟦 26 Fe	🟦 27 Co	🟦 28 Ni	🟦 29 Cu	🟦 30 Zn	🟥 31 Ga	🟥 32 Ge	🟥 33 As	🟥 34 Se	35 Br	36 Kr
37 Rb	🟥 38 Sr	🟥 39 Y	🟥 40 Zr	🟦 41 Nb	🟩 42 Mo	43 Tc	🟨 44 Ru	🟩 45 Rh	🟦 46 Pd	🟦 47 Ag	🟨 48 Cd	🟥 49 In	🟦 50 Sn	🟧 51 Sb	🟥 52 Te	53 I	54 Xe
55 Cs	🟥 56 Ba	*	🟥 72 Hf	🟥 73 Ta	🟨 74 W	🟦 75 Re	🟥 76 Os	🟩 77 Ir	🟦 78 Pt	🟦 79 Au	🟧 80 Hg	🟥 81 Tl	🟦 82 Pb	🟥 83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Sg	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uug	115 Uup	116 Uuh	117 Uus	118 Uuo

* 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
** 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



Average Recycled Content

- 🟦 > 50 %
- 🟩 > 25–50 %
- 🟨 > 10–25 %
- 🟧 1–10 %
- 🟥 < 1 %

1 H																	2 He
🟥 3 Li	🟨 4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	🟩 12 Mg											🟩 13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	🟨 22 Ti	23 V	🟨 24 Cr	🟩 25 Mn	🟩 26 Fe	🟩 27 Co	🟩 28 Ni	🟨 29 Cu	🟨 30 Zn	🟩 31 Ga	🟩 32 Ge	🟥 33 As	🟧 34 Se	35 Br	36 Kr
37 Rb	38 Sr	🟥 39 Y	🟧 40 Zr	🟦 41 Nb	🟩 42 Mo	43 Tc	🟦 44 Ru	🟩 45 Rh	🟩 46 Pd	🟩 47 Ag	🟨 48 Cd	🟩 49 In	🟨 50 Sn	🟨 51 Sb	52 Te	53 I	54 Xe
55 Cs	🟥 56 Ba	*	72 Hf	🟨 73 Ta	🟩 74 W	🟨 75 Re	🟥 76 Os	🟨 77 Ir	🟩 78 Pt	🟩 79 Au	🟩 80 Hg	🟥 81 Tl	🟦 82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Sg	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uug	115 Uup	116 Uuh	117 Uus	118 Uuo

* 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
** 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

UNEP, 2013

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

Some Key References:

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Email me if interested in the numerous papers !!