

Chapitre 3 – Métaux et Alliages – 1: Al & Cu

Chapitre 3 – Métaux et Alliages – 1: Al & Cu

Que lire ?

Polycopié Métaux et Alliages Chapitres I, II & III (va au-delà de ce cours)

Ashby & Jones, vol. 2, Chapitres 1, 2, 15, 16, 11 (ainsi que les chapitres 3 à 10 selon besoin/intérêt).

Chapitre 3 – Métaux et Alliages – 1

Héphaïstos remet à [Thétis](#) les armes d'Achille, médaillon d'un [kylix](#) du [Peintre de la Fonderie \(en\)](#), 490-480 av. J.-C., [Altes Museum](#) de Berlin.

By/par Peintre de la Fonderie (vase éponyme) — User:Bibi Saint-Pol, own work, Domaine public,
<https://commons.wikimedia.org/w/index.php?curid=3957273>
(via
<https://fr.wikipedia.org/wiki/H%C3%A9pha%C3%AFstos>)



I – Les métaux et alliages: panorama

Tableau périodique des éléments chimiques

Groupe → I A II A 1 2

Période ↓

1 Hydrogène 1 H 1,007975

2 Lithium 3 Li 6,9395 Béryllium 4 Be 9,0121831

3 Sodium 11 Na 22,98976928 Magnésium 12 Mg 24,3055

4 Potassium 19 K 39,0983 (1) Calcium 20 Ca 40,078 (4)

5 Rubidium 37 Rb 85,4678 (3) Strontium 38 Sr 87,62 (1)

6 Césium 55 Cs 132,905452 Baryum 56 Ba 137,327 (7)

7 Francium 87 Fr [223] Radium 88 Ra [226]

nom de l'élément (gaz, liquide ou solide à 0°C et 101,3 kPa)
numéro atomique
symbole chimique
masse atomique relative [ou celle de l'isotope le plus stable]
[CIAAW "Atomic Weights 2013" + rev. 2015]

III A IV A V A VI A VII A VIII I B II B

3 4 5 6 7 8 9 10 11 12

Aluminium 13 Al 26,9815385

Silicium 14 Si 28,085 (1)

Phosphore 15 P 30,97376200

Soufre 16 S 32,0675

Chlore 17 Cl 35,4515

Argon 18 Ar 39,948 (1)

Bore 5 B 10,8135

Carbone 6 C 12,0106

Azote 7 N 14,006432

Oxygène 8 O 15,9994

Fluor 9 F 18,99840316

Néon 10 Ne 20,1797 (6)

Scandium 21 Sc 44,955908 (5)

Titane 22 Ti 47,867 (1)

Vanadium 23 V 50,9415 (1)

Chrome 24 Cr 51,9961 (6)

Manganèse 25 Mn 54,938044

Fer 26 Fe 55,845 (2)

Cobalt 27 Co 58,933194

Nickel 28 Ni 58,6934 (4)

Cuivre 29 Cu 63,546 (3)

Zinc 30 Zn 65,38 (2)

Gallium 31 Ga 69,723 (1)

Germanium 32 Ge 72,630 (8)

Arsenic 33 As 74,921595

Sélénium 34 Se 78,971 (8)

Brome 35 Br 79,904

Krypton 36 Kr 83,798 (2)

Yttrium 39 Y 88,90584

Zirconium 40 Zr 91,224 (2)

Niobium 41 Nb 92,90637

Molybdène 42 Mo 95,95 (1)

Technétium 43 Tc [98]

Ruthénium 44 Ru 101,07 (2)

Rhodium 45 Rh 102,90550

Palladium 46 Pd 106,42 (1)

Argent 47 Ag 107,8682 (2)

Cadmium 48 Cd 112,414 (4)

Indium 49 In 114,818 (1)

Étain 50 Sn 118,710 (7)

Antimoine 51 Sb 121,760 (1)

Tellure 52 Te 127,60 (3)

Iode 53 I 126,90447

Xénon 54 Xe 131,293 (6)

Lanthanides 57-71

Hafnium 72 Hf 178,49 (2)

Tantale 73 Ta 180,94788

Tungstène 74 W 183,84 (1)

Rhénium 75 Re 186,207 (1)

Osmium 76 Os 190,23 (3)

Iridium 77 Ir 192,217 (3)

Platine 78 Pt 195,084 (9)

Or 79 Au 196,966569

Mercur 80 Hg 200,592 (3)

Thallium 81 Tl 204,3835

Plomb 82 Pb 207,2 (1)

Bismuth 83 Bi 208,98040

Polonium 84 Po [209]

Astato 85 At [210]

Radon 86 Rn [222]

Actinides 89-103

Rutherfordium 104 Rf [267]

Dubnium 105 Db [268]

Seaborgium 106 Sg [269]

Bohrium 107 Bh [270]

Hassium 108 Hs [277]

Meitnérium 109 Mt [278]

Darmstadtium 110 Ds [281]

Roentgenium 111 Rg [282]

Copernicium 112 Cn [285]

Nihonium 113 Nh [286]

Flérovium 114 Fl [289]

Moscovium 115 Mc [289]

Livermorium 116 Lv [293]

Tennessee 117 Ts [294]

Oganesson 118 Og [294]

Lanthane 57 La 138,90547

Cérium 58 Ce 140,116 (1)

Praséodyme 59 Pr 140,90766

Néodyme 60 Nd 144,242 (3)

Prométhium 61 Pm [145]

Samarium 62 Sm 150,36 (2)

Europium 63 Eu 151,964 (1)

Gadolinium 64 Gd 157,25 (3)

Terbium 65 Tb 158,92535

Dysprosium 66 Dy 162,500 (1)

Holmium 67 Ho 164,93033

Erbium 68 Er 167,259 (3)

Thulium 69 Tm 168,93422

Ytterbium 70 Yb 173,045

Lutécium 71 Lu 174,9668

Actinium 89 Ac [227]

Thorium 90 Th 232,0377

Protactinium 91 Pa 231,03588

Uranium 92 U 238,02891

Neptunium 93 Np [237]

Plutonium 94 Pu [244]

Américium 95 Am [243]

Curium 96 Cm [247]

Berkélium 97 Bk [247]

Californium 98 Cf [251]

Einsteinium 99 Es [252]

Fermium 100 Fm [257]

Mendélévium 101 Md [258]

Nobélium 102 No [259]

Lawrencium 103 Lr [266]

Métaux

Alcalins Alcalino-terreux Lanthanides Actinides Métaux de transition Métaux pauvres Métalloïdes

Non métaux

Autres non-métaux Halogènes Gaz nobles Non classés

primordial désintégration d'autres éléments synthétique

Tableau périodique des éléments chimiques

Groupe → I A II A 1 2

Période ↓

1 Hydrogène 1 H 1,007975

2 Lithium 3 Li 6,941 Béryllium 4 Be 9,0121831

3 Sodium 11 Na 22,98976928 Magnésium 12 Mg 24,304

4 Potassium 19 K 39,0983 (1) Calcium 20 Ca 40,078 (4)

5 Rubidium 37 Rb 85,4678 (3) Strontium 38 Sr 87,62 (1)

6 Césium 55 Cs 132,905452 Baryum 56 Ba 137,327 (7)

7 Francium 87 Fr [223] Radium 88 Ra [226]

nom de l'élément (gaz, liquide ou solide à 0°C et 101,3 kPa)
numéro atomique
symbole chimique
masse atomique relative [ou celle de l'isotope le plus stable]
[CIAAW "Atomic Weights 2013" + rev. 2015]

III A IV A V A VI A VII A VIII I B II B 3 4 5 6 7 8 9 10 11 12

Scandium 21 Sc 44,955908 (5) Titane 22 Ti 47,067 (1) Vanadium 23 V 50,9415 (1) Chrome 24 Cr 51,9961 (6) Manganèse 25 Mn 54,938044 Fer 26 Fe 55,845 (2) Cobalt 27 Co 58,933194 Nickel 28 Ni 58,6934 (4) Cuivre 29 Cu 63,546 (3) Zinc 30 Zn 65,38 (2)

Gallium 31 Ga 69,723 (1) Germanium 32 Ge 72,630 (8) Arsenic 33 As 74,921595 Sélénium 34 Se 78,971 (8) Brome 35 Br 79,904 Krypton 36 Kr 83,798 (2)

Yttrium 39 Y 88,90584 Zirconium 40 Zr 91,224 (2) Niobium 41 Nb 92,90637 Molybdène 42 Mo 95,94 (1) Technétium 43 Tc [98] Ruthénium 44 Ru 101,07 (2) Rhodium 45 Rh 102,90550 Palladium 46 Pd 106,42 (1) Argent 47 Ag 107,8682 (2) Cadmium 48 Cd 112,414 (4) Indium 49 In 114,818 (1) Étain 50 Sn 118,710 (7) Antimoine 51 Sb 121,760 (1) Tellure 52 Te 127,60 (3) Iode 53 I 126,90447 Xénon 54 Xe 131,293 (6)

Lanthanides 57–71 Actinides 89–103

Hafnium 72 Hf 178,49 (2) Tantalum 73 Ta 180,94788 Tungstène 74 W 183,84 (1) Rhénium 75 Re 186,207 (1) Osmium 76 Os 190,23 (3) Iridium 77 Ir 192,217 (3) Platine 78 Pt 195,084 (9) Or 79 Au 196,966569 Mercure 80 Hg 200,597 (3) Thallium 81 Tl 204,3835 Plomb 82 Pb 207,2 (1) Bismuth 83 Bi 208,98040 Polonium 84 Po [209] Astatine 85 At [210] Radon 86 Rn [222]

Rutherfordium 104 Rf [267] Dubnium 105 Db [268] Seaborgium 106 Sg [269] Bohrium 107 Bh [270] Hassium 108 Hs [277] Meitnérium 109 Mt [278] Darmstadtium 110 Ds [281] Roentgenium 111 Rg [282] Copernicium 112 Cn [285] Nihonium 113 Nh [286] Flérovium 114 Fl [289] Moscovium 115 Mc [289] Livermorium 116 Lv [293] Tennessé 117 Ts [294] Oganesson 118 Og [294]

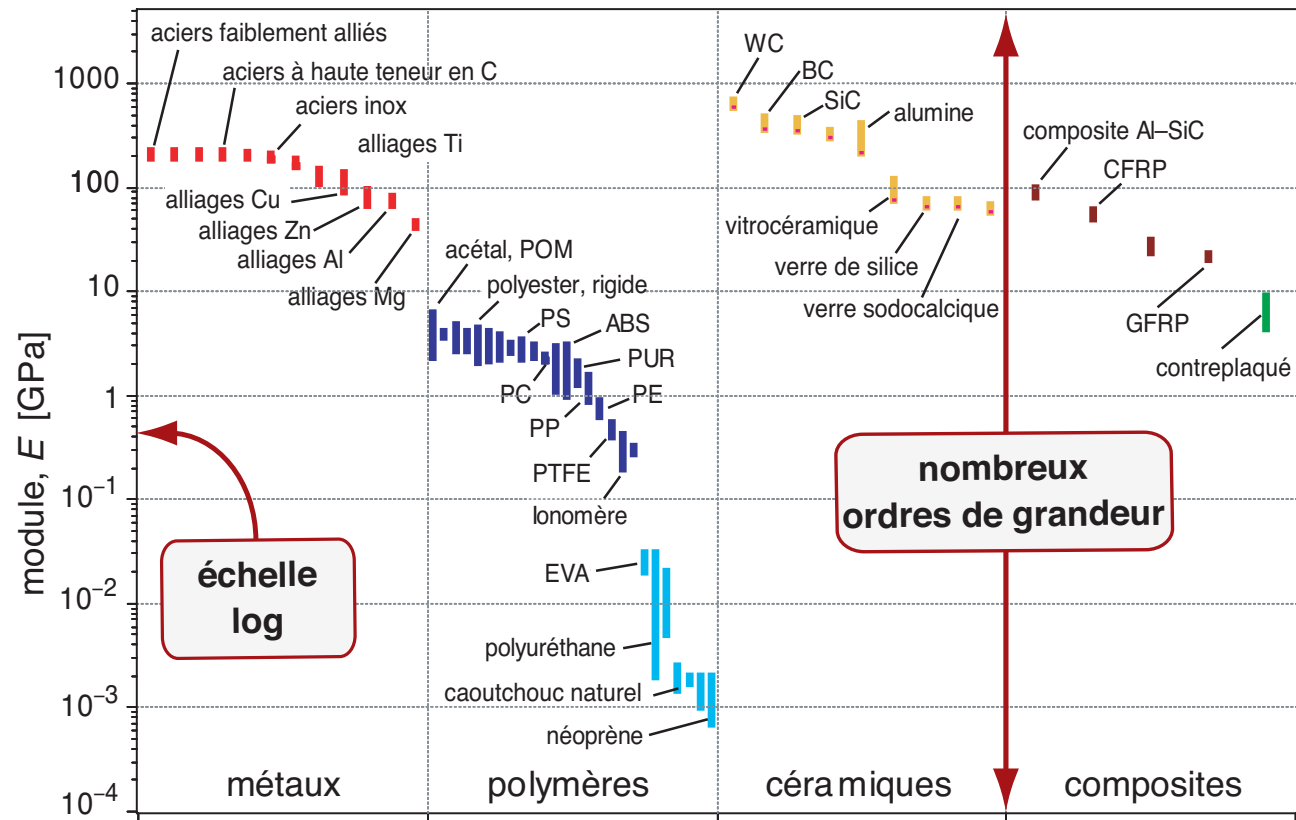
Lanthane 57 La 138,90547 Cérium 58 Ce 140,116 (1) Praseodyme 59 Pr 140,90766 Néodyme 60 Nd 144,242 (3) Prométhium 61 Pm [145] Samarium 62 Sm 150,36 (2) Europium 63 Eu 151,964 (1) Gadolinium 64 Gd 157,25 (3) Terbium 65 Tb 158,92535 Dysprosium 66 Dy 162,500 (1) Holmium 67 Ho 164,93033 Erbium 68 Er 167,259 (3) Thulium 69 Tm 168,93422 Ytterbium 70 Yb 173,045 Lutécium 71 Lu 174,9668

Actinium 89 Ac [227] Thorium 90 Th 232,0377 Protactinium 91 Pa 231,03588 Uranium 92 U 238,02891 Neptunium 93 Np [237] Plutonium 94 Pu [244] Américium 95 Am [243] Curium 96 Cm [247] Berkélium 97 Bk [247] Californium 98 Cf [251] Einsteinium 99 Es [252] Fermium 100 Fm [257] Mendélévium 101 Md [258] Nobélium 102 No [259] Lawrencium 103 Lr [266]

Métaux Non métaux

Alcalins Alcalino-terreux Lanthanides Actinides Métaux de transition Métaux pauvres Métalloïdes Autres non-métaux Halogènes Gaz nobles Non classés

primordial désintégration d'autres éléments synthétique



Source: M.F. Ashby, H. Shercliff
et D. Cebon, Matériaux, PPUR,
traduction de Materials:
engineering, science, processing
and design, 3rd Ed. Elsevier, 2014

Source: M.F. Ashby & D.R.H. Jones,
Engineering Materials Vol. 2, 3rd Ed.,
2006, Elsevier Butterworth.

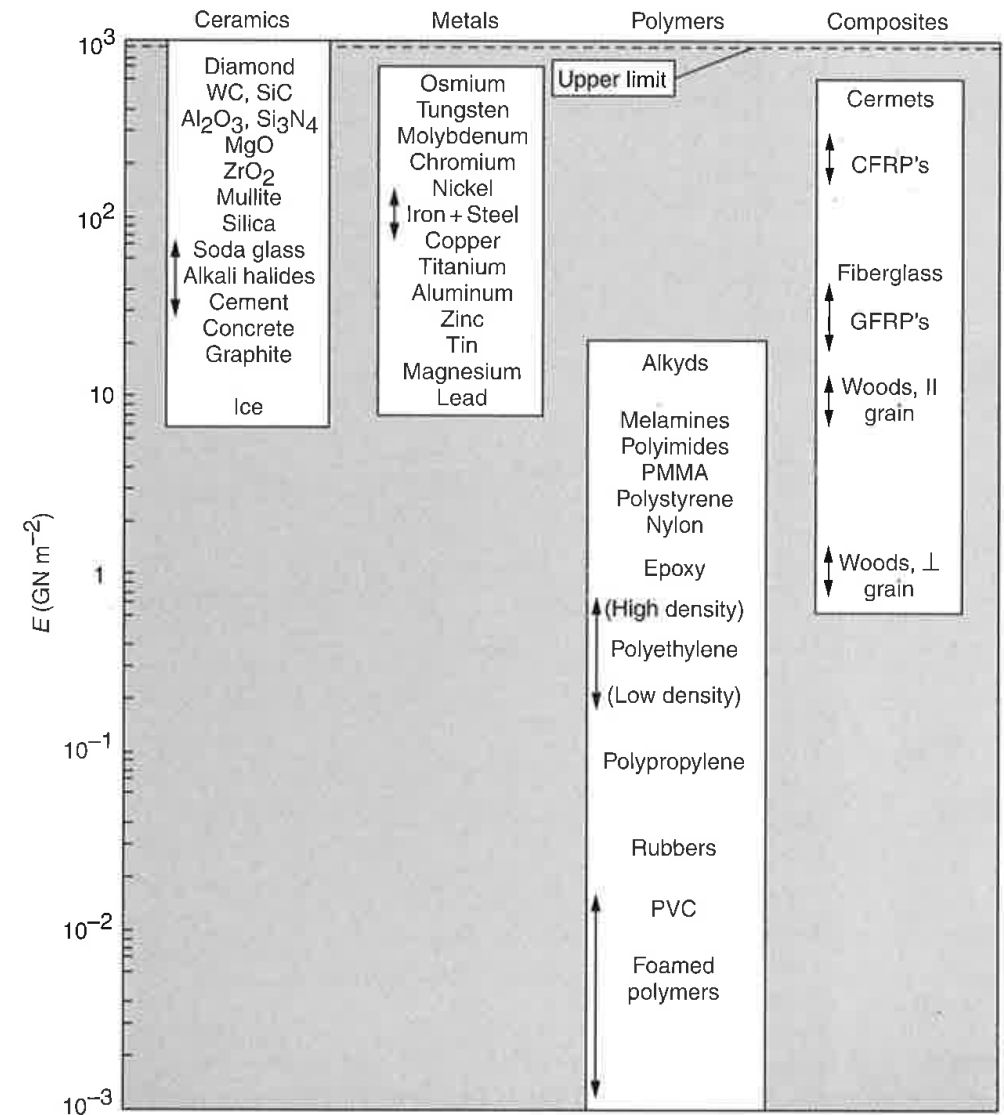
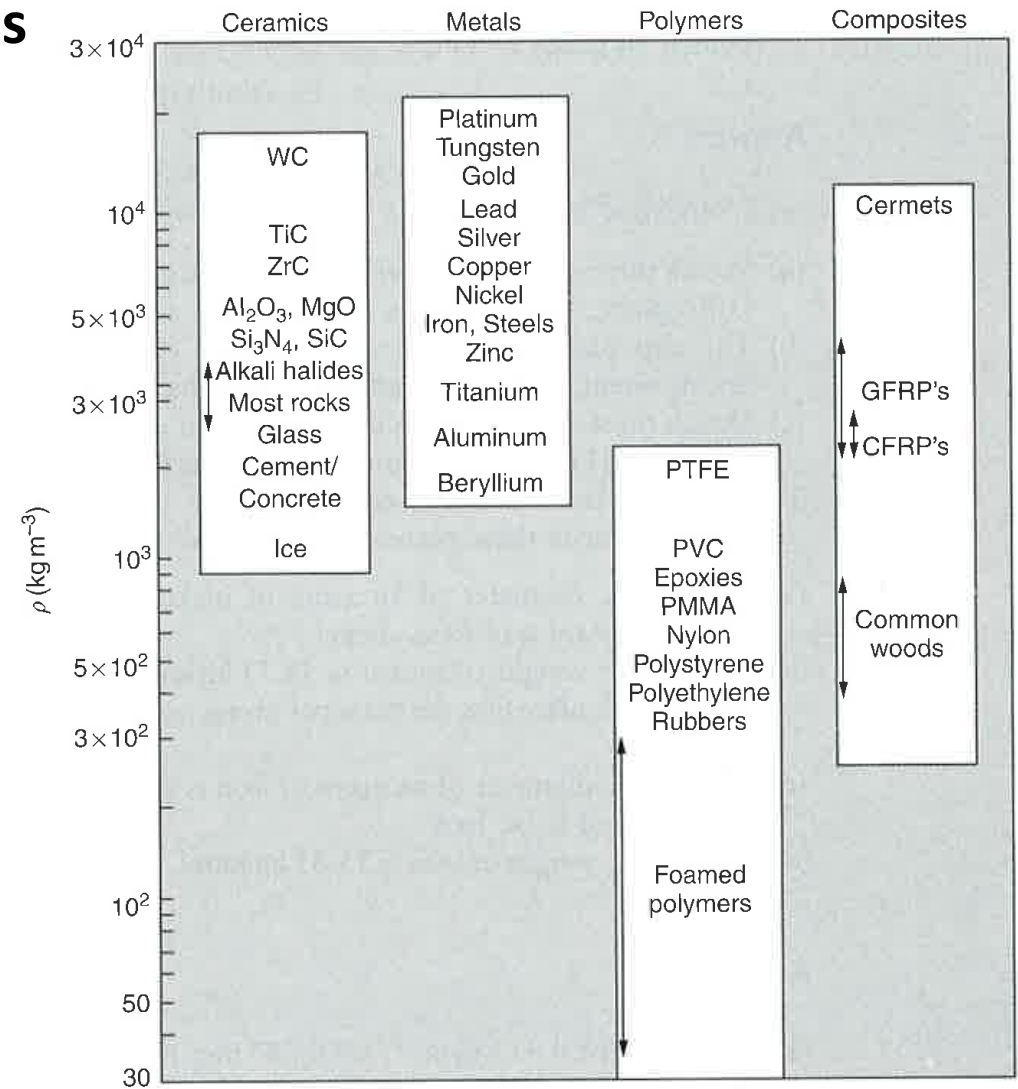
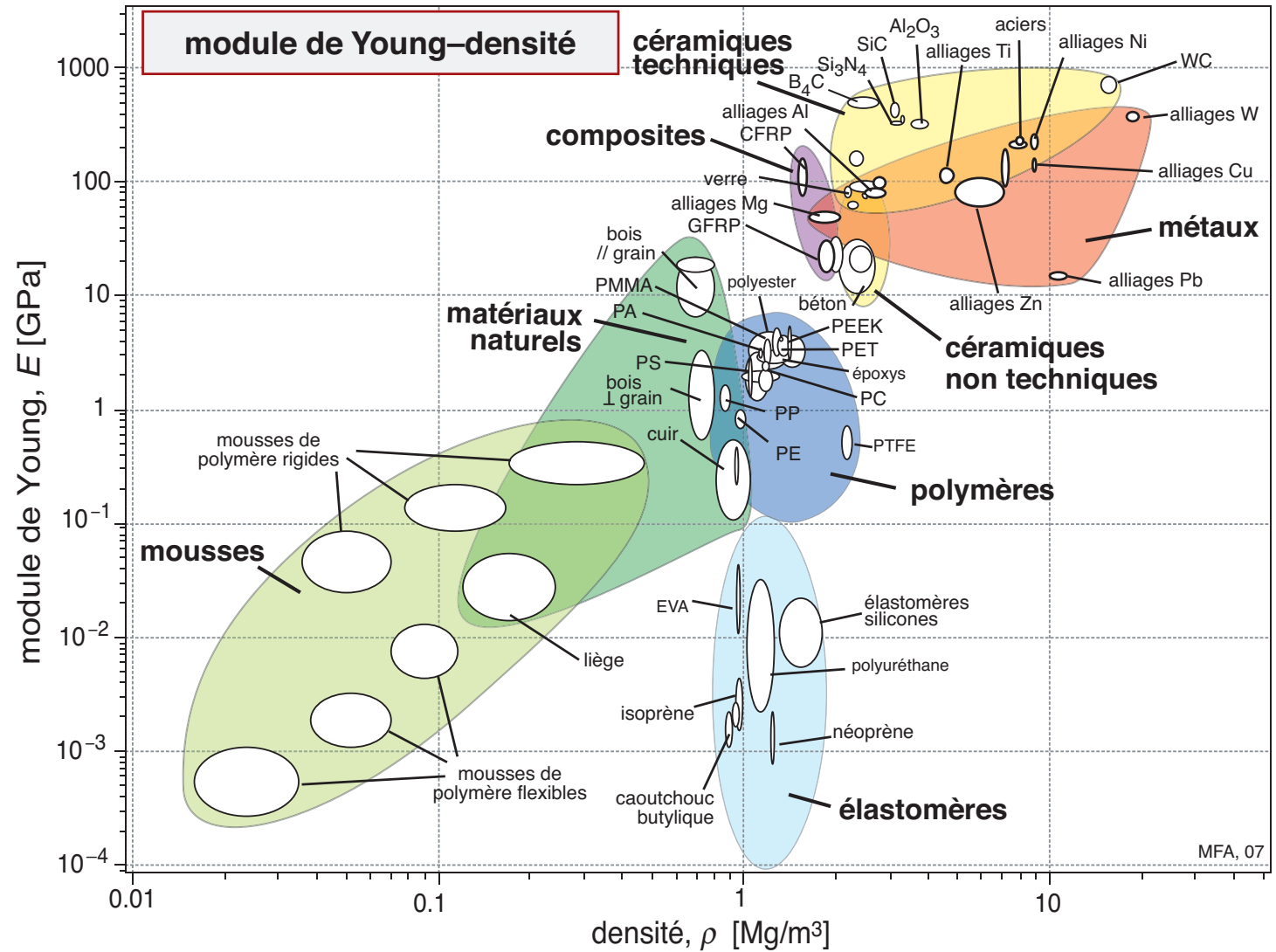


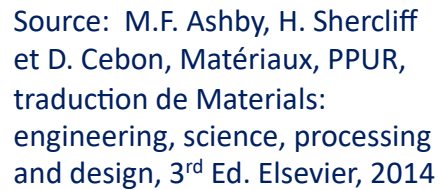
Figure 3.5 Bar chart of data for Young's modulus, E .



Source: M.F. Ashby & D.R.H. Jones,
Engineering Materials Vol. 2, 3rd Ed.,
2006, Elsevier Butterworth.

Figure 5.12 Bar chart of data for density, ρ .



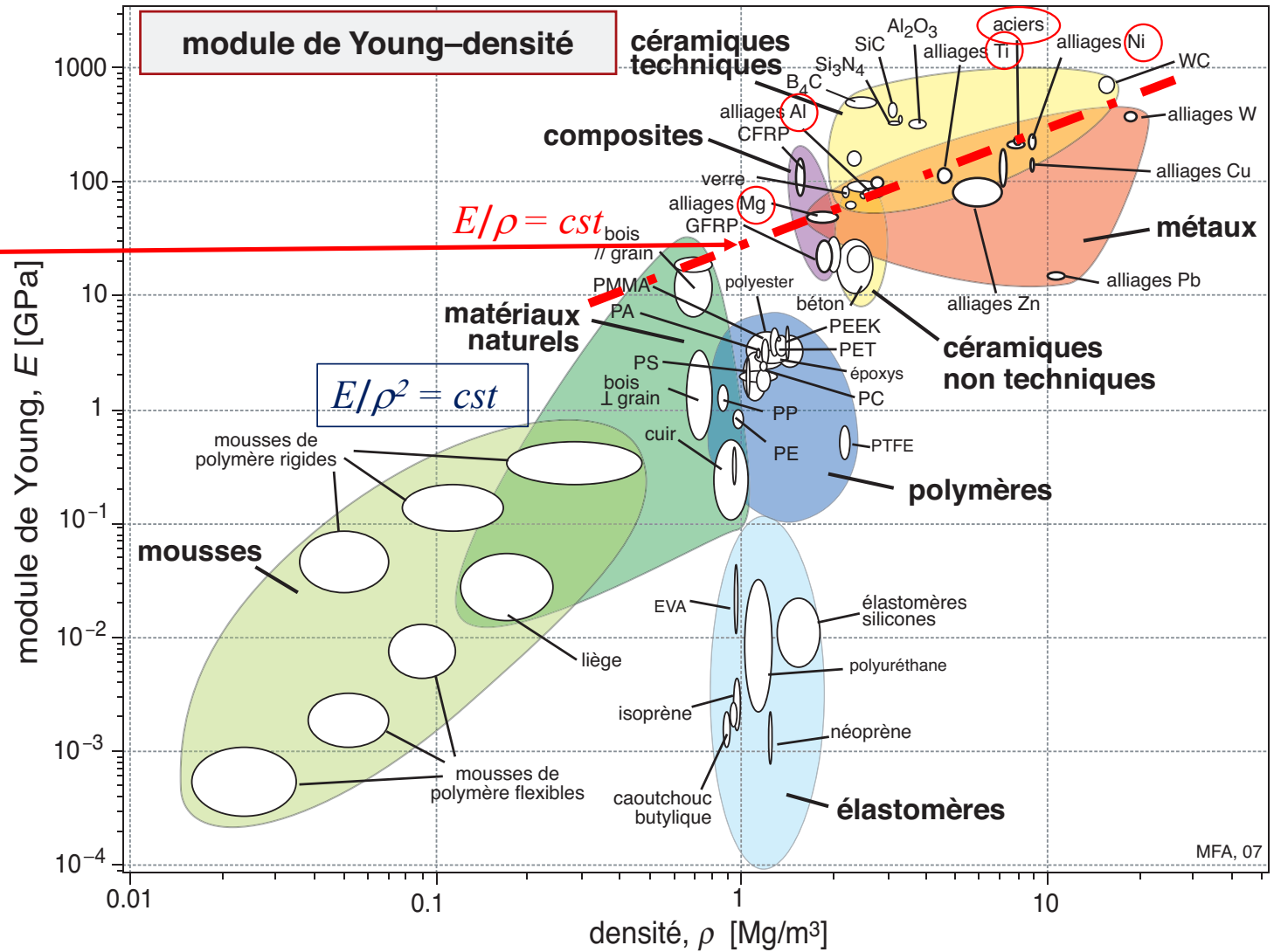




Chapitre 2 – Les Céramiques12

EPFL Propriétés des Métaux et Alliages

Notez que plusieurs des métaux les plus usuels ont la même valeur de E/ρ (Fe, Al, Ti, Mg, Ni)



Source: M.F. Ashby, H. Shercliff et D. Cebon, Matériaux, PPUR, traduction de Materials: engineering, science, processing and design, 3rd Ed. Elsevier, 2014

Source: M.F. Ashby & D.R.H. Jones,
Engineering Materials Vol. 2, 3rd Ed.,
2006, Elsevier Butterworth.

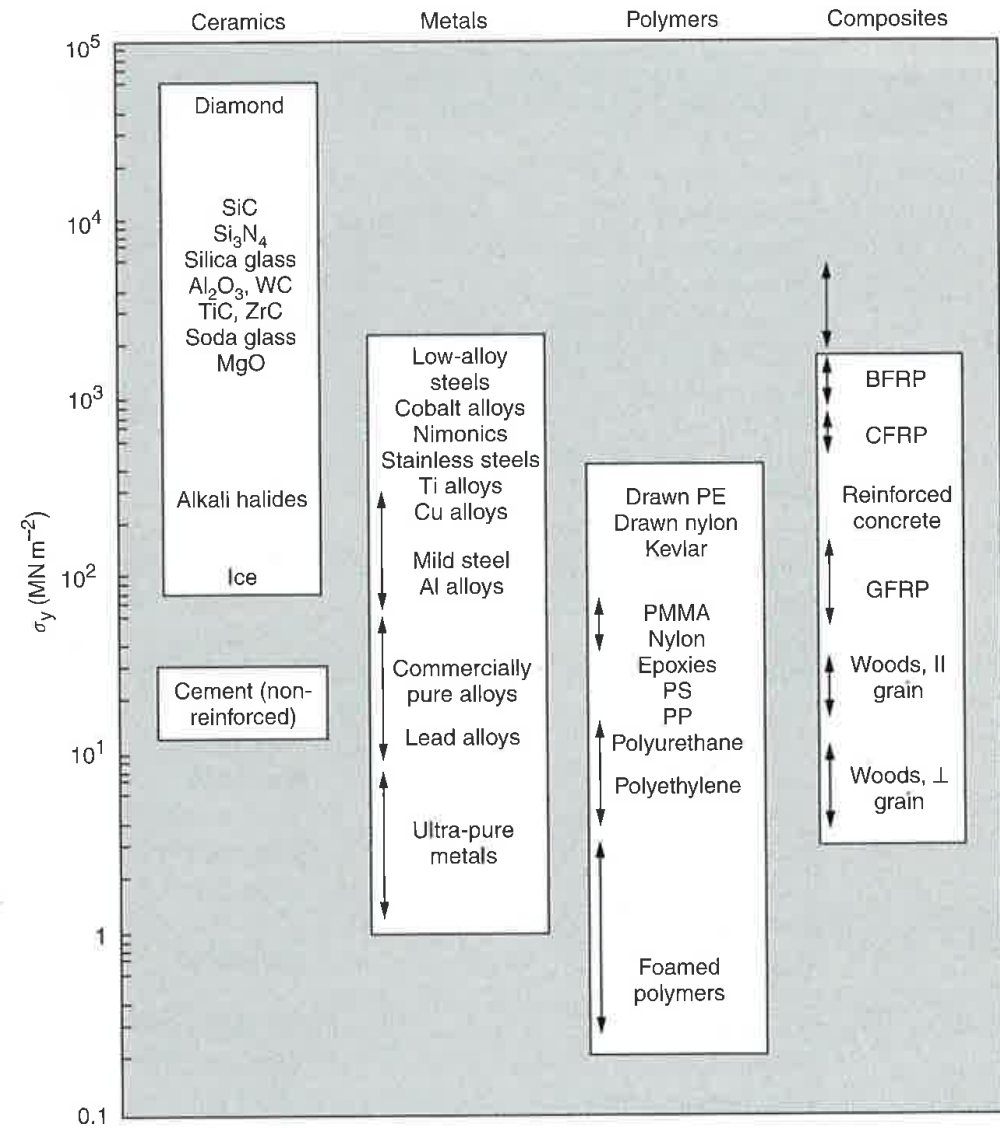
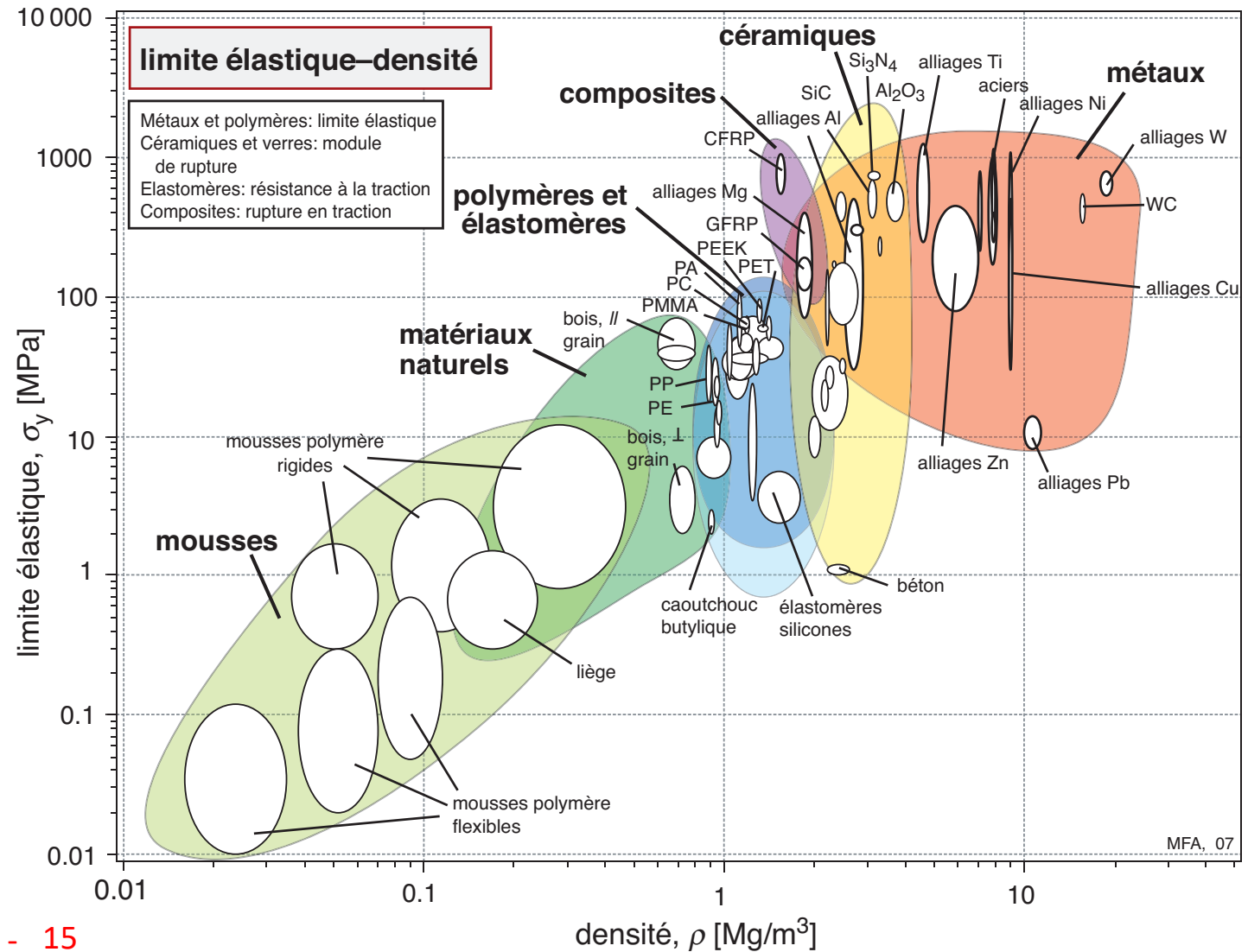
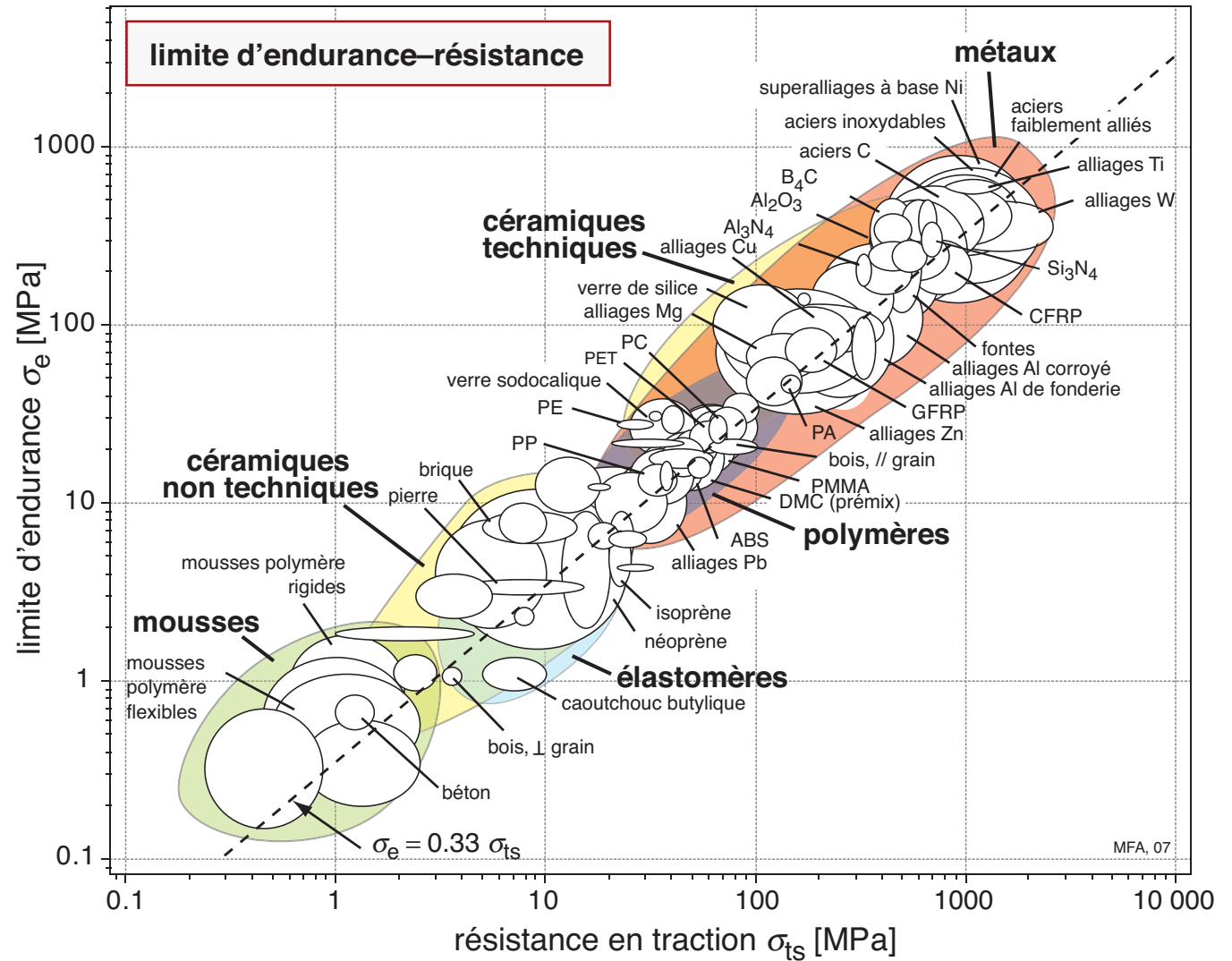


Figure 8.12 Bar chart of data for yield strength, σ_y .



Source: M.F. Ashby, H. Shercliff et D. Cebon, Matériaux, PPUR, traduction de Materials: engineering, science, processing and design, 3rd Ed. Elsevier, 2014

$$\sigma_e \approx \sigma_t$$



Source: M.F. Ashby, H. Shercliff et D. Cebon, Matériaux, PPUR, traduction de Materials: engineering, science, processing and design, 3rd Ed. Elsevier, 2014

Source: M.F. Ashby & D.R.H. Jones,
Engineering Materials Vol. 2, 3rd Ed.,
2006, Elsevier Butterworth.

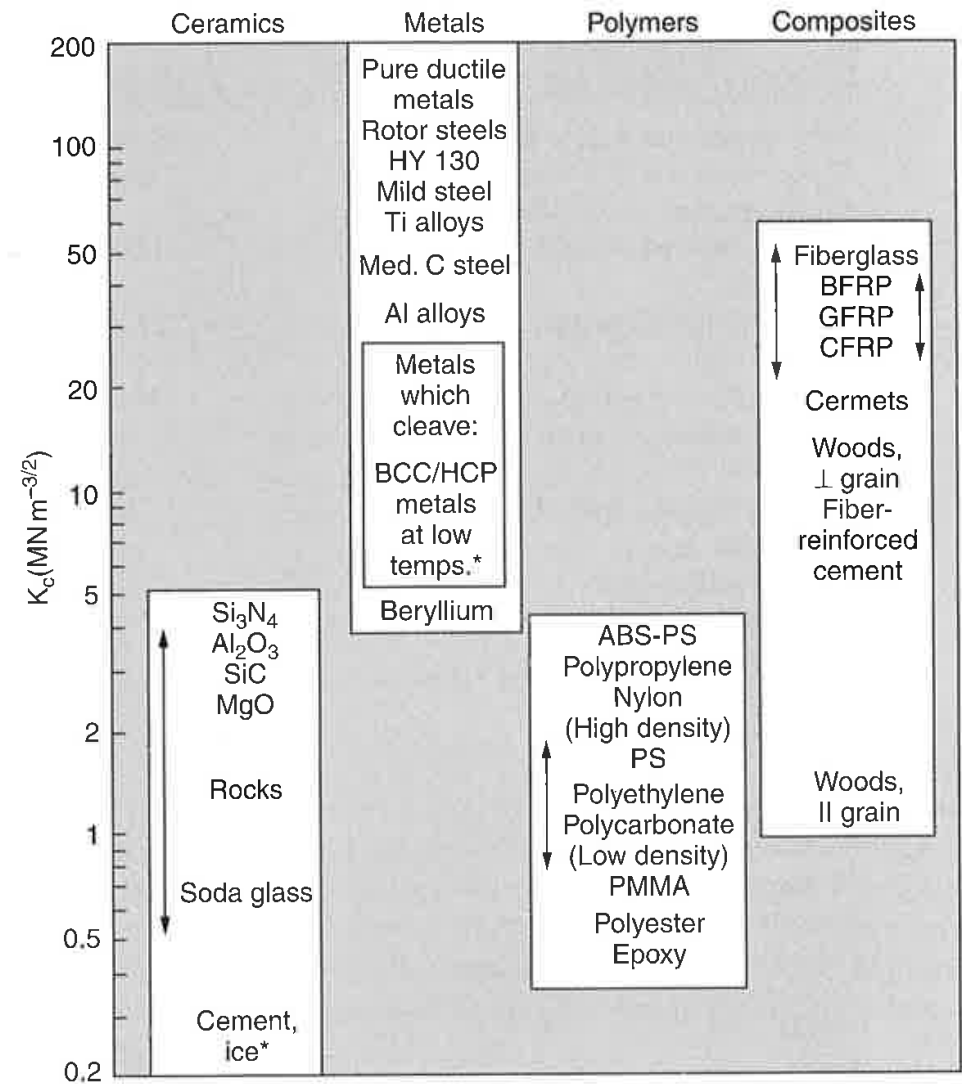
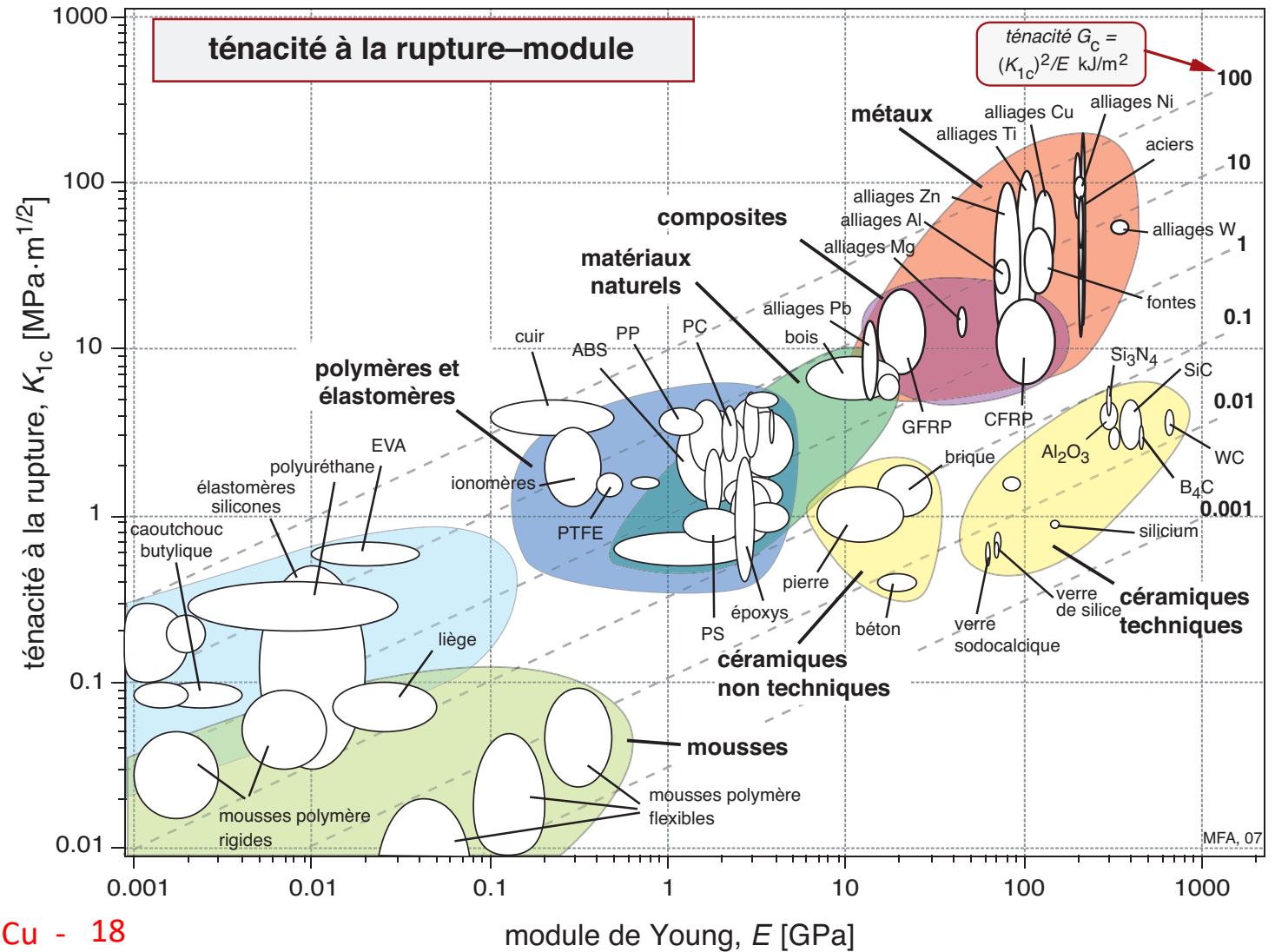
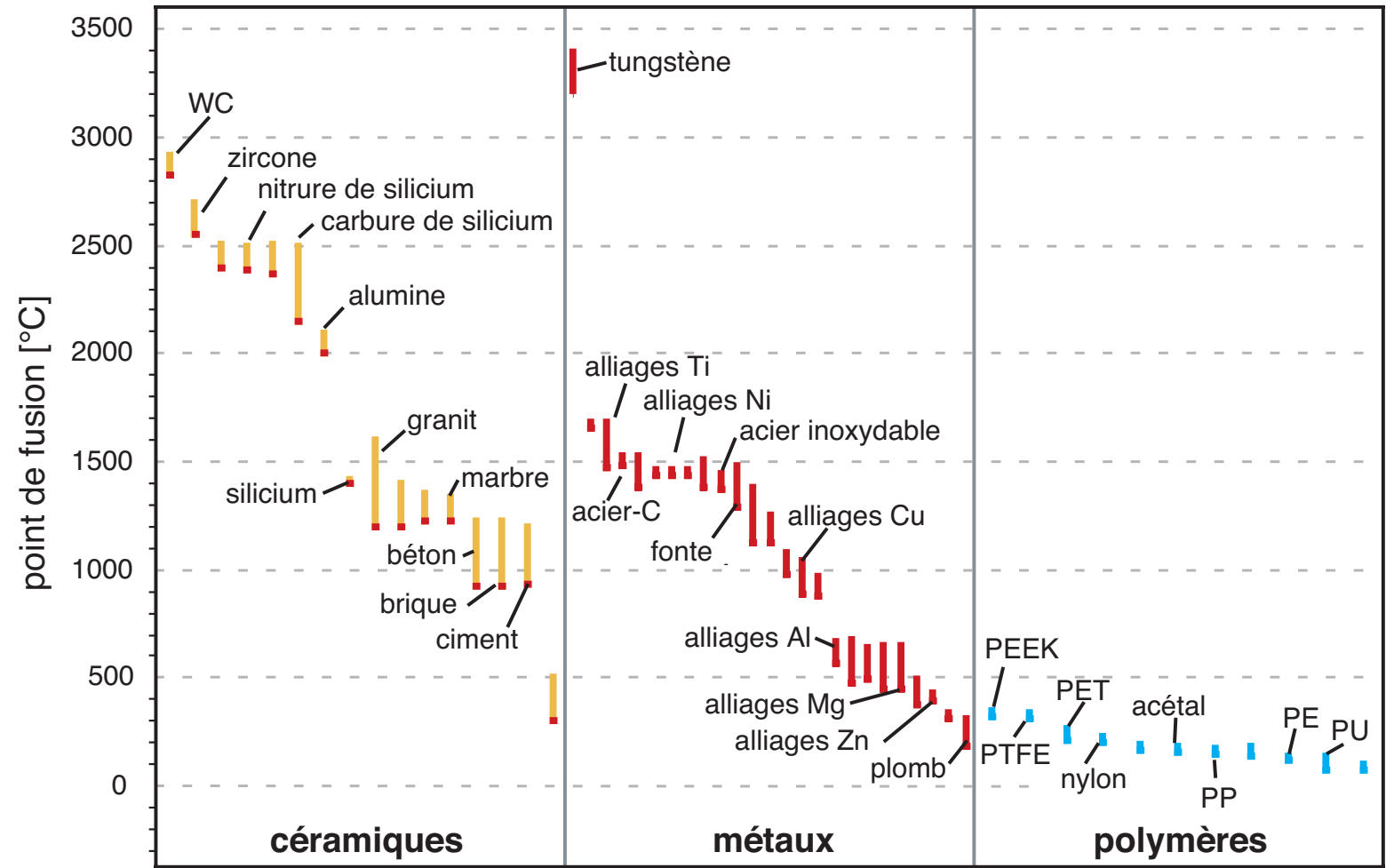
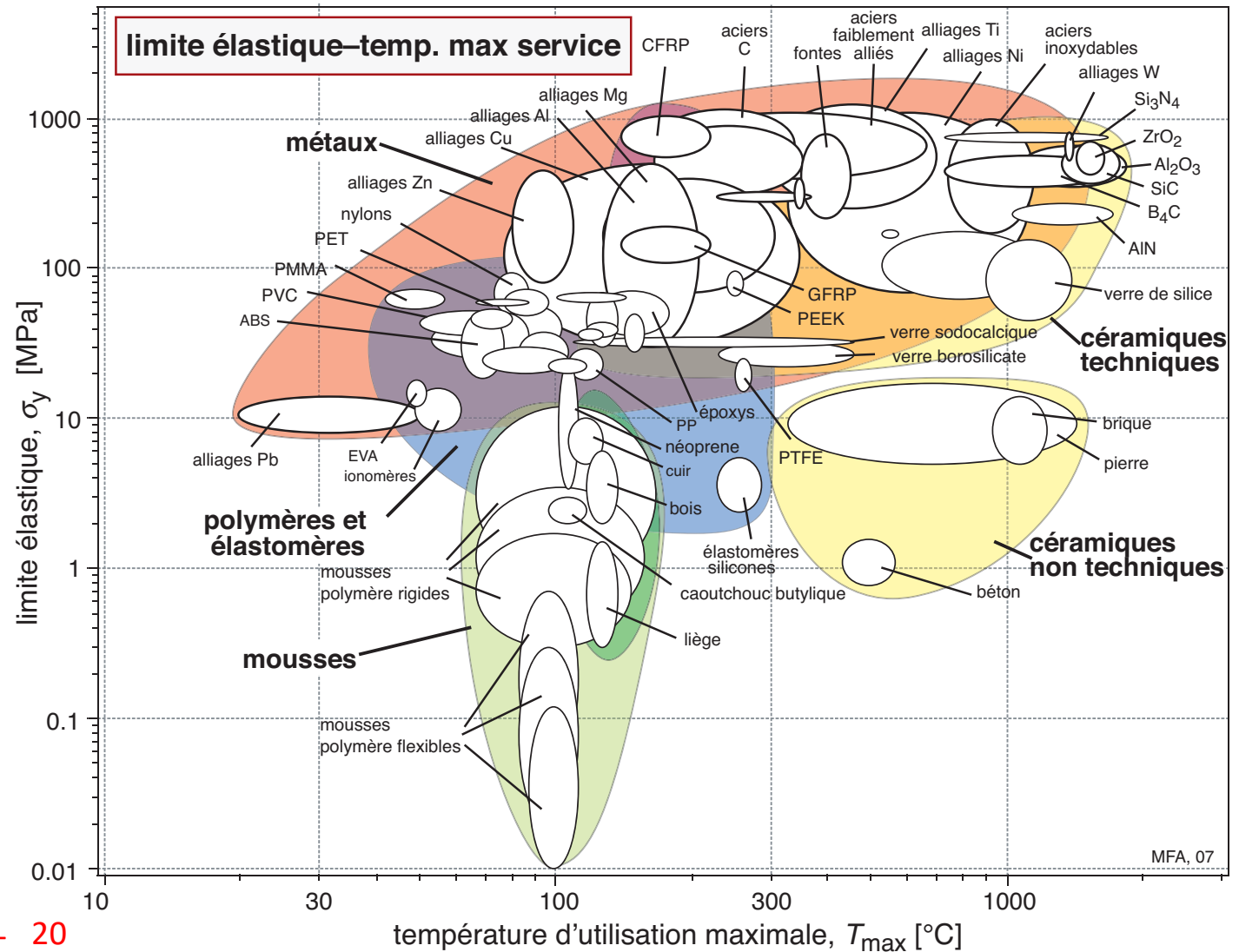


Figure I3.6 Fracture toughness, K_c (values at room temperature unless starred).





Source: M.F. Ashby, H. Shercliff
et D. Cebon, Matériaux, PPUR,
traduction de Materials:
engineering, science, processing
and design, 3rd Ed. Elsevier, 2014



Source: M.F. Ashby, H. Shercliff
et D. Cebon, Matériaux, PPUR,
traduction de Materials:
engineering, science, processing
and design, 3rd Ed. Elsevier, 2014

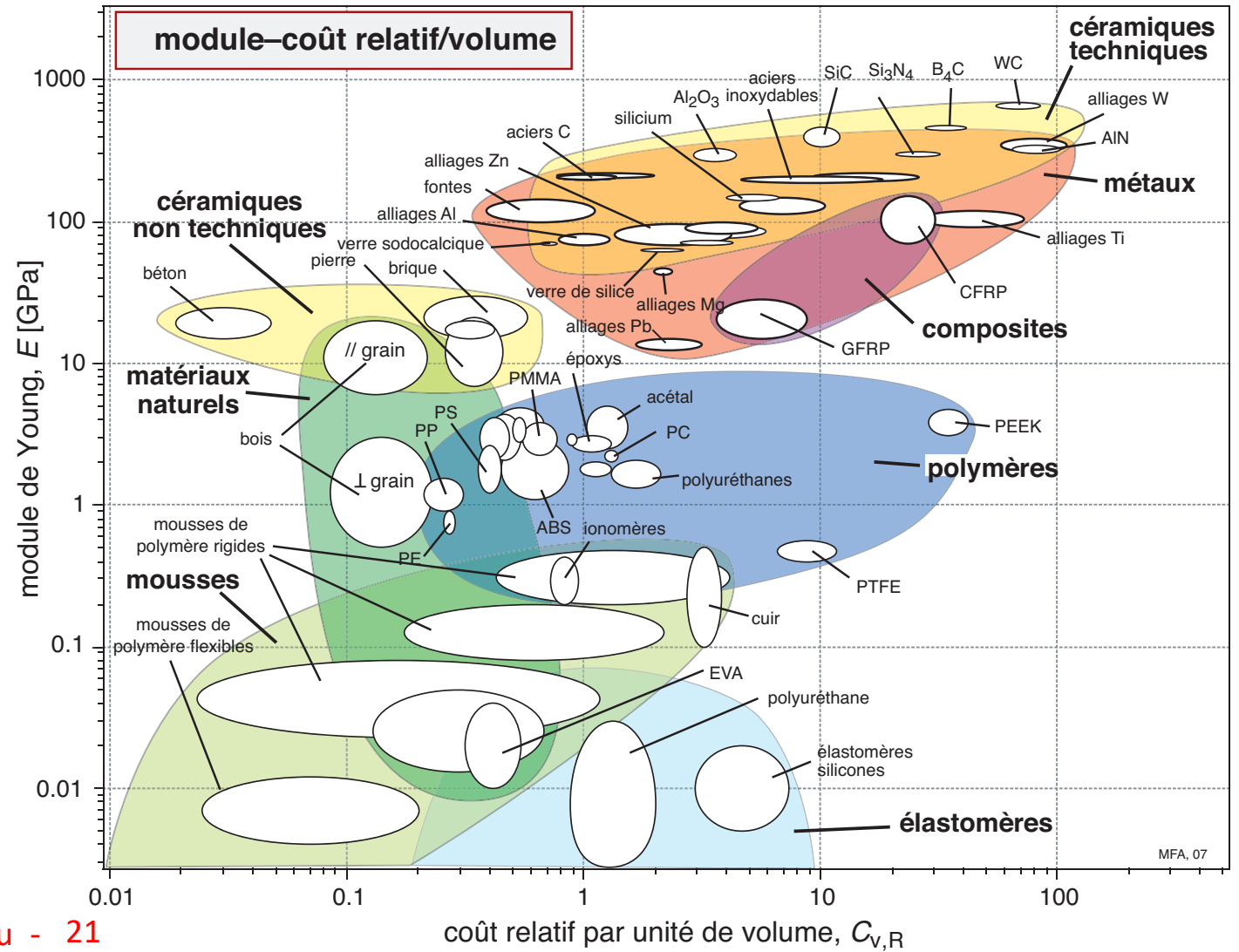


Table 2.3 Abundance of Elements

Crust		Oceans		Atmosphere	
Element	Weight %	Element	Weight %	Element	Weight %
Oxygen	47	Oxygen	85	Nitrogen	79
Silicon	27	Hydrogen	10	Oxygen	19
Aluminum	8	Chlorine	2	Argon	2
Iron	5	Sodium	1	Carbon as carbon dioxide	0.04
Calcium	4	Magnesium	0.1		
Sodium	3	Sulphur	0.1		
Potassium	3	Calcium	0.04		
Magnesium	2	Potassium	0.04		
Titanium	0.4	Bromine	0.007		
Hydrogen	0.1	Carbon	0.002		
Phosphorus	0.1				
Manganese	0.1				
Fluorine	0.06				
Barium	0.04				
Strontium	0.04				
Sulphur	0.03				
Carbon	0.02				

Note: The total mass of the crust to a depth of 1 km is 3×10^{21} kg; the mass of the oceans is 10^{20} kg; that of the atmosphere is 5×10^{18} kg.

Les **réserves** mondiales d'un métal donné sont l'ensemble des dépôts miniers connus à partir desquels le métal peut être extrait, à profit, au jour considéré, avec les techniques du jour.

L'ensemble total de tout ce dont on peut envisager l'extraction d'un métal donné en constitue les **ressources**; c'est là l'autre extrême mesurant l'abondance d'un métal.

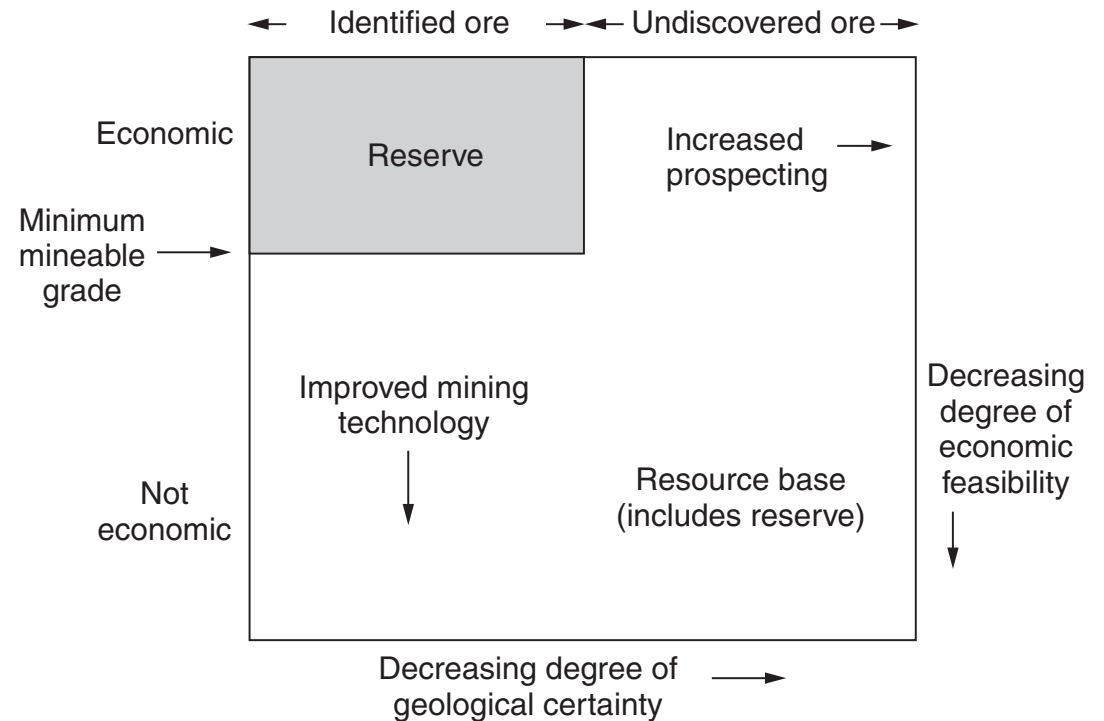


FIGURE 2.3

The distinction between the reserve and the resource base, illustrated by the McElvey diagram.

TABLE I-5 – Concentration de métal dans la croûte terrestre et la composition des minerais utiles.

Source: W.J. Rankin, *Minerals, Metals and Sustainability: Meeting Future Material Needs*, CSIRO, Australia, 2011.

Metal	Abondance	Concentration utile	
	[ppm]	[ppm]	[%pds]
Aluminium	80'000	320'000	32
Fer	50'000	250'000	25
Magnésium	25'000	150'000	15
Titane	5'000	100'000	10
Manganèse	1'500	300'000	30
Nickel	100	10'000	1
Zinc	80	40'000	4
Cuivre	50	5'000	0.5
Plomb	10	40'000	4
Étain	2	50'000	5
Argent	0.1	100	0.01
Platine	0.004	4	0.0004
Or	0.0	4	0.0004

TABLE I-6 – Production, réserves et ressources mondiales des métaux en 2007.

Source: W.J. Rankin, *Minerals, Metals and Sustainability: Meeting Future Material Needs*, CSIRO, Australia, 2011.

Métal ou minéral	Production [milliers de tonnes]	Prix [\$/tonne]	Réserves [milliers de tonnes]	Ressources [milliers de tonnes]
Fer (minéral)	1'900'000	63	150'000'000	340'000'000
Acier	1'320'000	600-860		
Bauxite (minéral d'Al)	190'000	27	25'000'000	65'000'000
Aluminium	38'000	2700		
Manganèse	11'600		460'000	5'200'000
Zinc	10'500	3'500	180'000	1'900'000
Plomb	3'550	2'400	79'000	> 1'500'000
Nickel	1'660	37'700	67'000	150'000
Étain	302	13'800	6'100	11'000
Cobalt	62.3	66'600	7'000	15'000
Argent	20.5	431'000	270	570
Or	2.5	21'700'000	42	90
Palladium	0.232	11'600'000	71	100
Platine	0.230	40'500'000		

TABLE I-7 – Principales réserves de métaux de base, en 1977 et en 2010.

Source: D.G. Altenpohl, *Materials in World Perspective*, Springer-Verlag, Berlin, 1980; U.S. Geological Survey, *Mineral Commodity Summaries* 2010.

Minerai	1977		2010	
	Pays	Réserves mondiales	Pays	Réserves mondiales
Aluminium	Guinée	33.9%	Guinée	26.8%
	Australie	18.6%	Australie	19.3%
	Brésil	10.3%	Brésil	12.1%
	Jamaïque	6.2%	Vietnam	7.5%
	Inde	5.8%	Jamaïque	7.1%
Cuivre	U.S.A.	18.5%	Chili	23.8%
	Chili	18.5%	Pérou	14.3%
	U.R.S.S.	7.9%	Australie	12.7%
	Pérou	7.0%	Mexique	6.0%
	Canada	6.8%	U.S.A.	5.6%

	1977		2010	
Étain	Indonésie	23.6%	Chine	28.8%
	Chine	14.8%	Indonésie	15.4%
	Thaïlande	11.8%	Pérou	13.7%
	Bolivie	9.7%	Brésil	11.3%
	Malaisie	8.2%	Bolivie	7.7%
Fer	U.R.S.S.	3.0%	Ukraine	16.7%
	Brésil	17.5%	Brésil	16.1%
	Canada	11.7%	Russie	13.9%
	Australie	11.5%	Australie	13.3%
	Inde	5.8%	Chine	12.8%
Plomb	U.S.A.	20.8%	Australie	33.8%
	Australie	13.8%	Chine	16.3%
	U.R.S.S.	13.2%	Russie	11.5%
	Canada	9.5%	U.S.A.	8.8%
	Afrique du Sud	4.1%	Pérou	7.5%
Zinc	Canada	18.7%	Australie	21.2%
	U.S.A.	14.5%	Chine	16.8%
	Australie	12.6%	Pérou	9.2%
	U.R.S.S.	7.3%	Kazakhstan	6.4%
	Irlande	5.5%	Mexique	6.0%

Resources et Réserves

TABLE I-8 – Principales réserves des autres métaux importants, en 1977 et en 2010.

Source: D.G. Altenpohl, *Materials in World Perspective*, Springer-Verlag, Berlin, 1980 ; U.S. Geological Survey, *Mineral Commodity Summaries* 2010.

Minerai	1977		2010	
	Pays	Réserves mondiales	Pays	Réserves mondiales
Chrome	Afrique du Sud	74.1%	Kazakhstan	51.4%
	Zimbabwe	22.2%	Afrique du Sud	37.1%
	U.R.S.S.	0.6%	Inde	12.6%
	Finlande	0.6%		
	Inde	0.4%		
Cobalt	Zaïre (Congo)	30.3%	Congo	46.6%
	Nouvelle-Calédonie	18.8%	Australie	19.2%
	U.R.S.S.	13.9%	Cuba	6.8%
	Philippines	12.8%	Nouvelle-Calédonie	5.1%
	Zambie	7.7%	Zambie	3.7%
Manganèse	Afrique du Sud	45.0%	Ukraine	22.2%
	U.R.S.S.	37.5%	Afrique du Sud	19.0%
	Australie	8.0%	Brésil	17.5%
	Gabon	5.0%	Australie	14.8%
	Brésil	2.2%	Gabon	8.9%

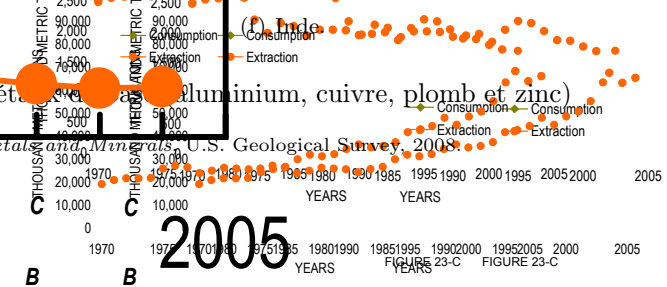
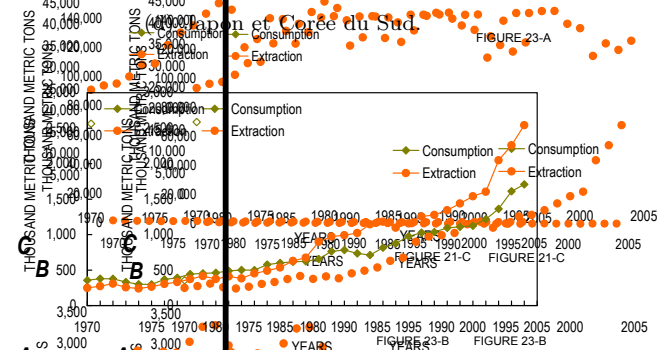
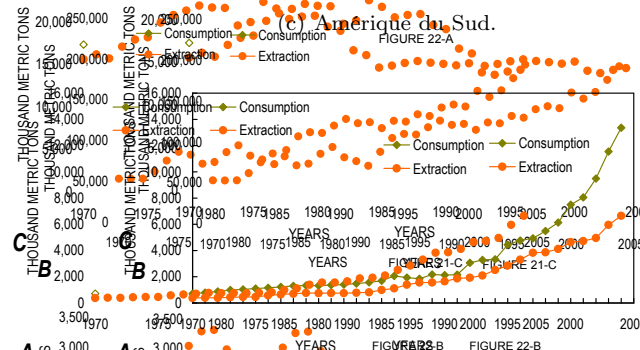
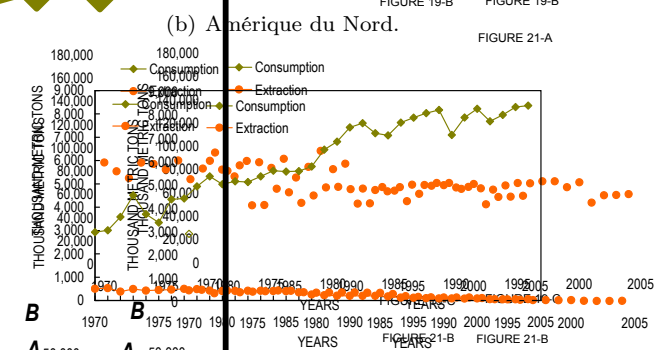
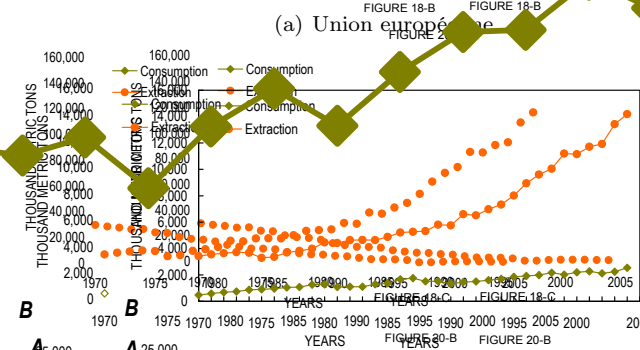
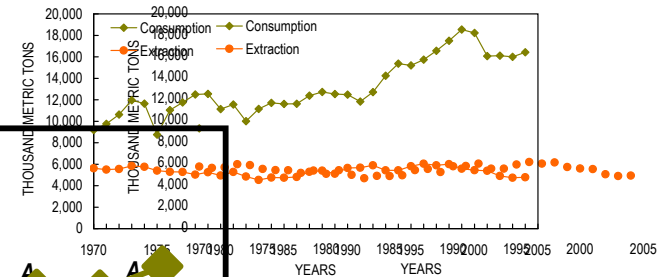
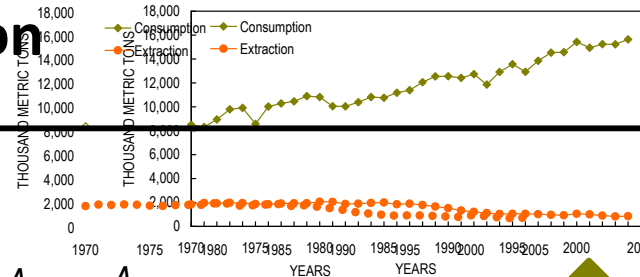
1977			2010	
Molybdène	U.S.A.	38.4%	Chine	43.9%
	Chili	27.8%	U.S.A.	27.6%
	Canada	8.1%	Chili	11.2%
	U.R.S.S.	6.6%	Pérou	4.6%
	Chine	6.0%	Russie	2.6%
Nickel	Nouvelle-Calédonie	25.0%	Australie	31.6%
	Canada	16.0%	Brésil	11.4%
	U.R.S.S.	13.5%	Nouvelle-Calédonie	9.3%
	Indonésie	13.0%	Russie	7.9%
	Australie	9.3%	Cuba	7.2%
Titane	Brésil	26.3%	Chine	30.8%
	Inde	17.5%	Australie	15.4%
	Canada	15.2%	Inde	13.1%
	Afrique du Sud	8.6%	Afrique du Sud	9.7%
	Australie	6.6%	Brésil	6.6%
Vanadium	U.R.S.S.	74.8%	Chine	37.5%
	Afrique du Sud	18.7%	Russie	36.8%
	Chili	1.4%	Afrique du Sud	25.7%
	Australie	1.4%	U.S.A.	0.3%

FIGURE 18-A

EPFL

Production & Utilisation

Consumption —◆—
Extraction —●—



Chapitre 3 – Métaux et Alliages – Al & Cu – 30

Source: D.G. Rogich et G.R. Matos, *The Global Flows of Metals and Minerals*, U.S. Geological Survey, 2008.

1980

1985

1990

1995

2000

2005

YEARS

Production & Utilisation

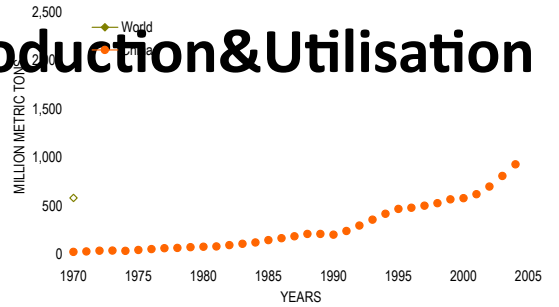


FIGURE 9

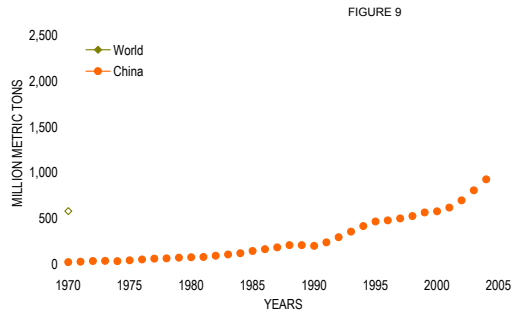
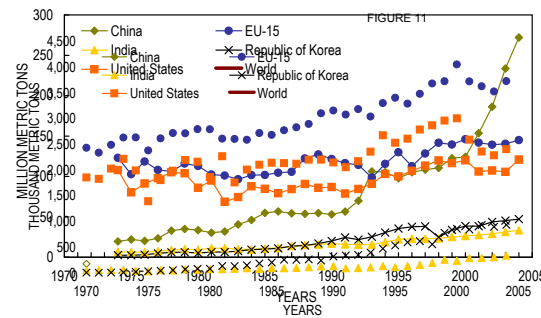
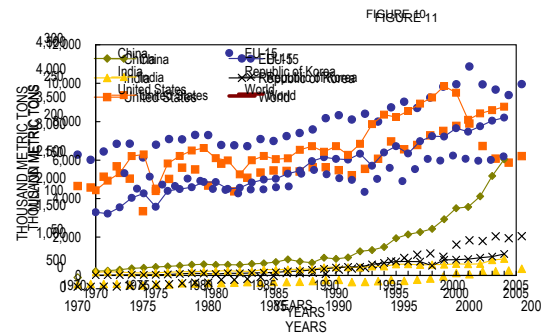


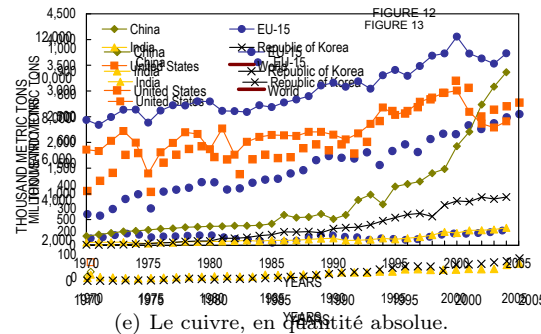
FIGURE 9



(a) L'acier, en quantité absolue.



(c) L'aluminium, en quantité absolue.



(e) Le cuivre, en quantité absolue.

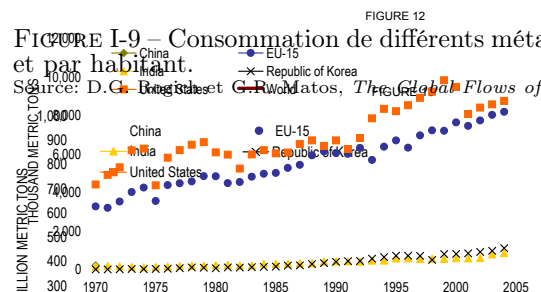


FIGURE 12

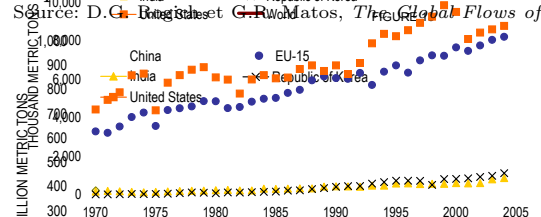
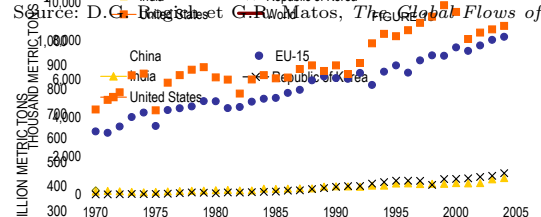
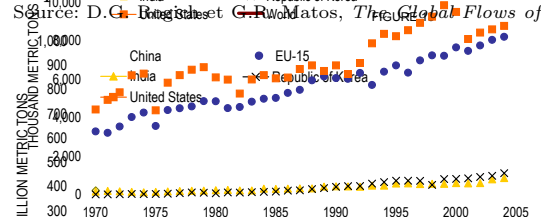
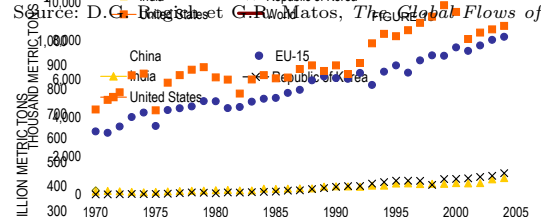
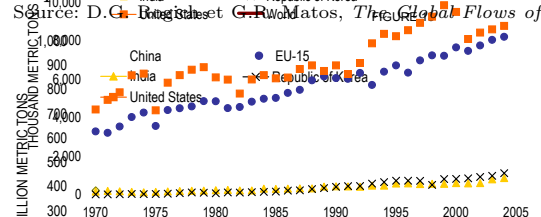
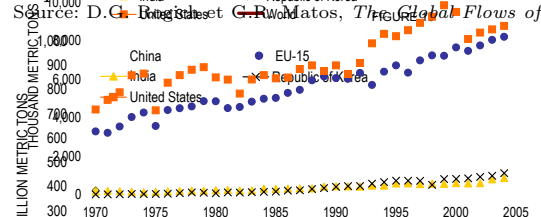
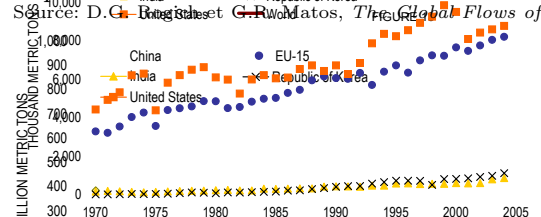
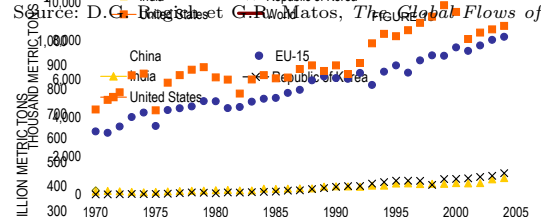
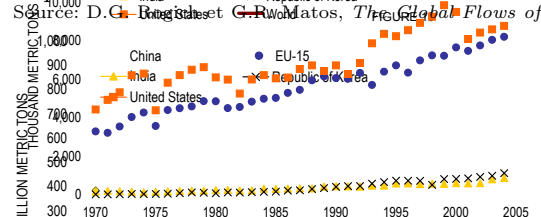
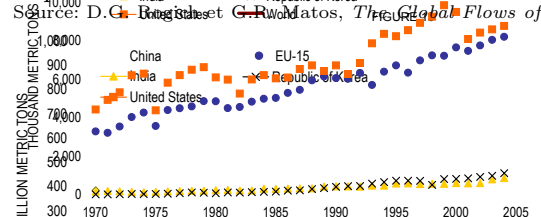
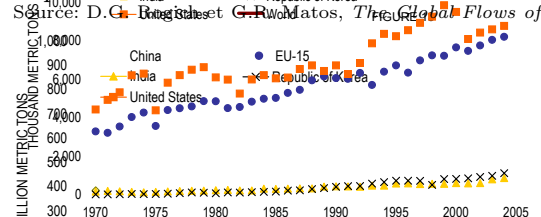
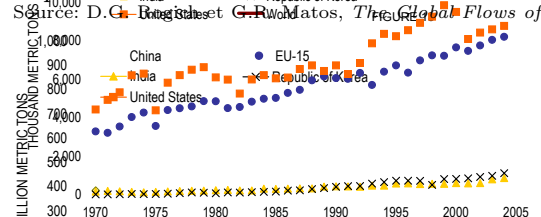
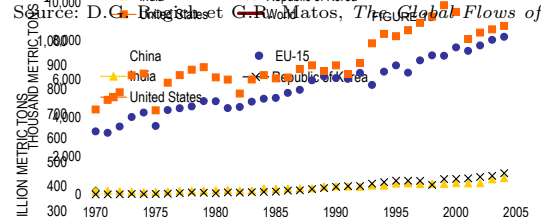
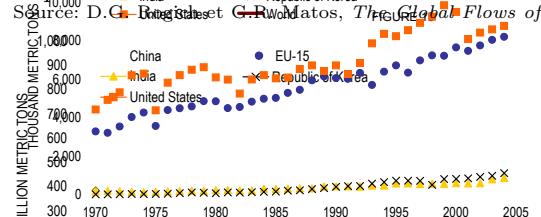
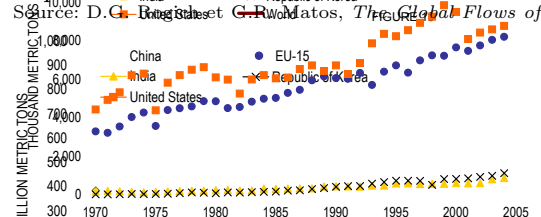
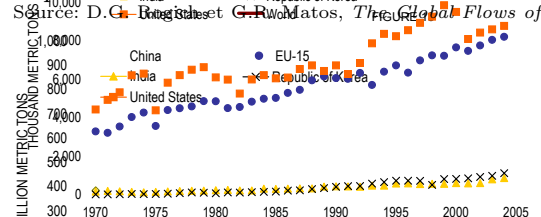
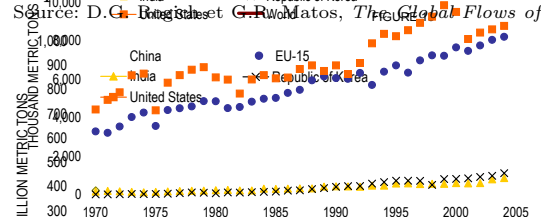
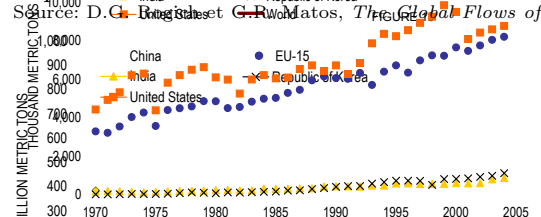
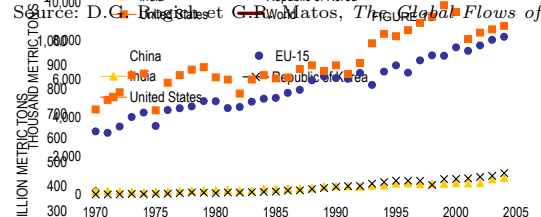
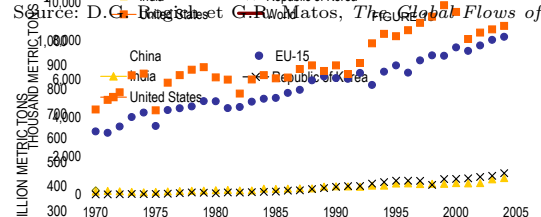
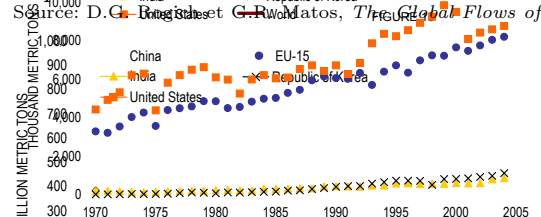
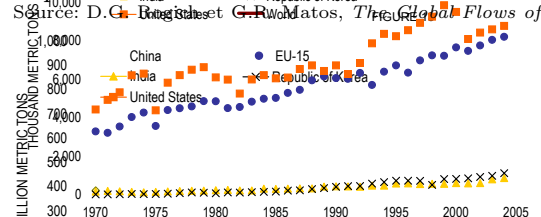
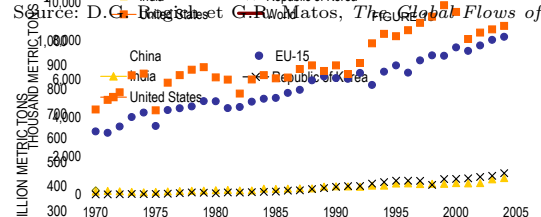
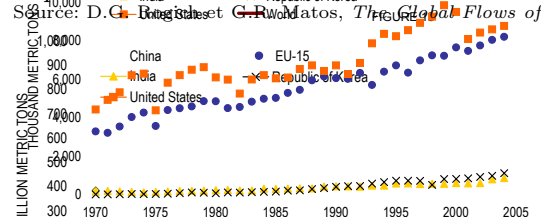
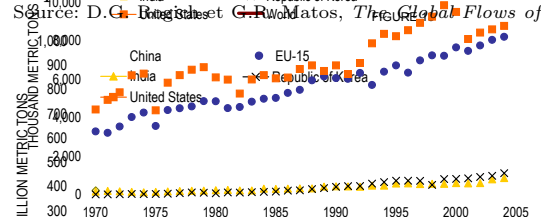
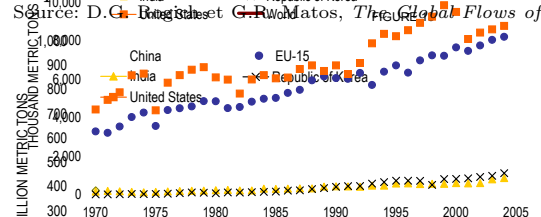
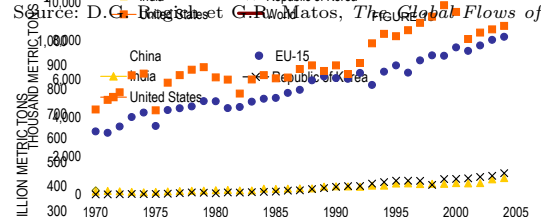
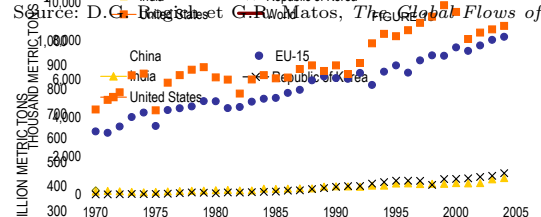
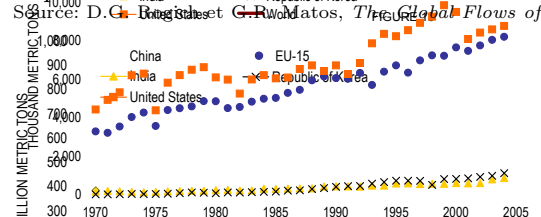
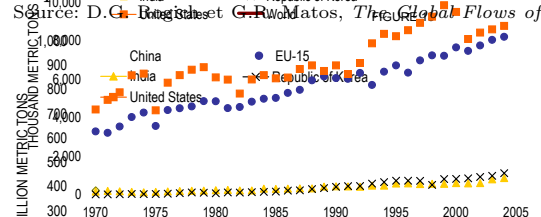
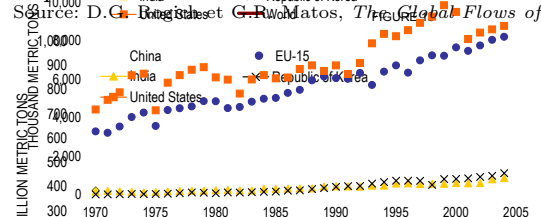
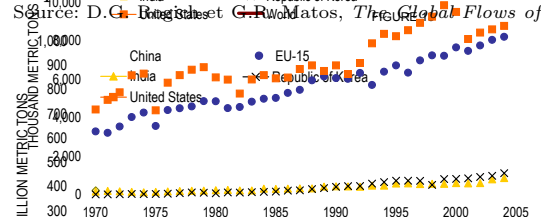
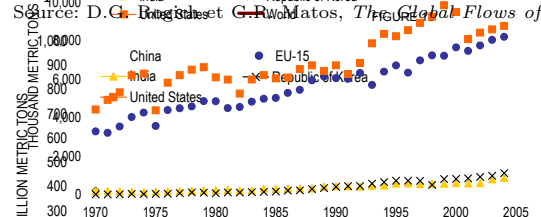
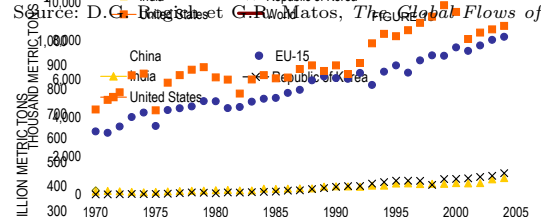
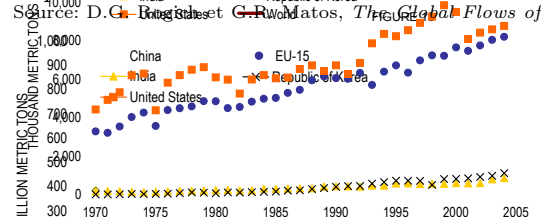
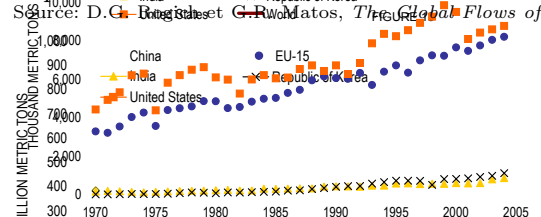
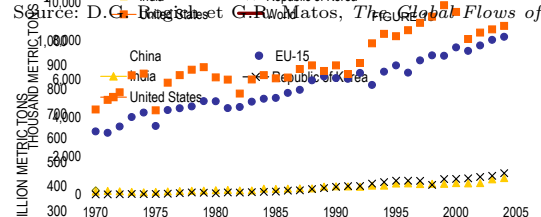
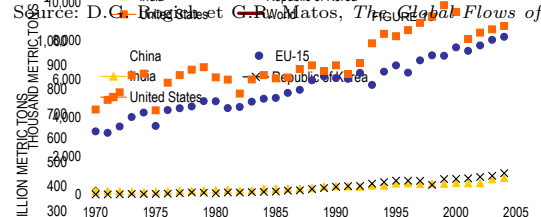
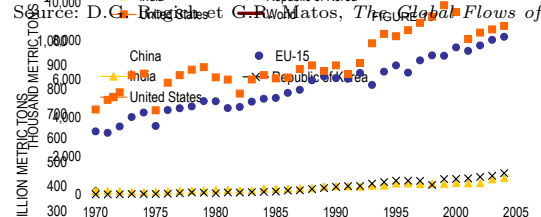
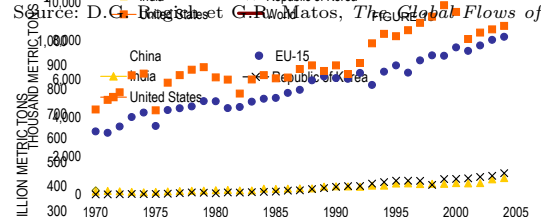
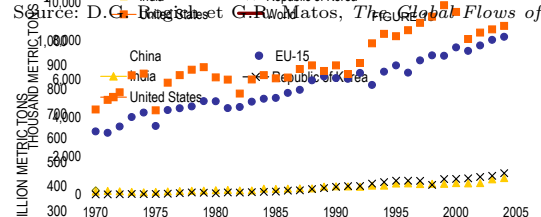
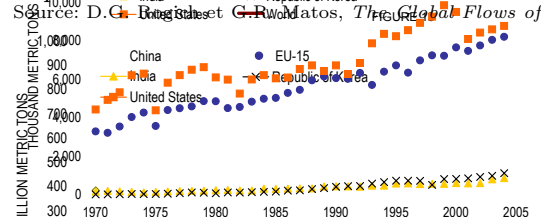
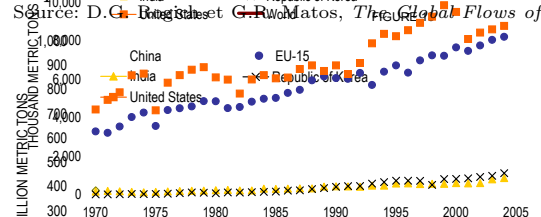
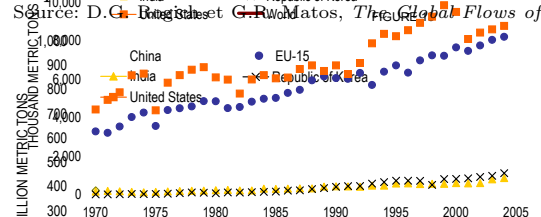
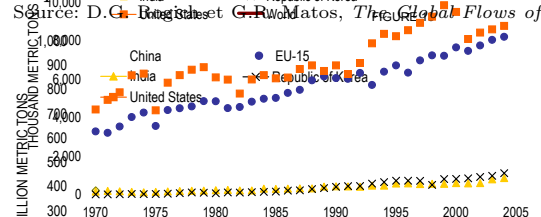
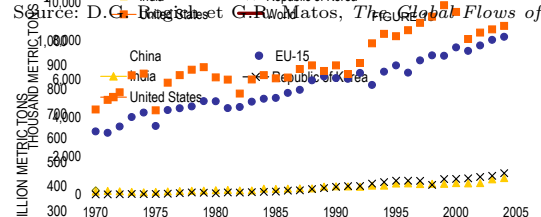
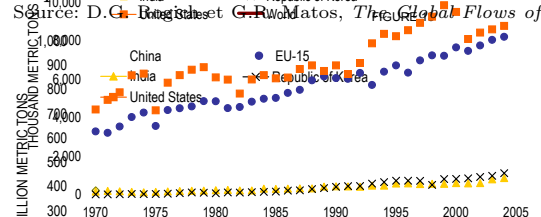
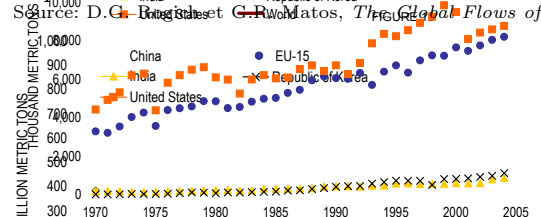
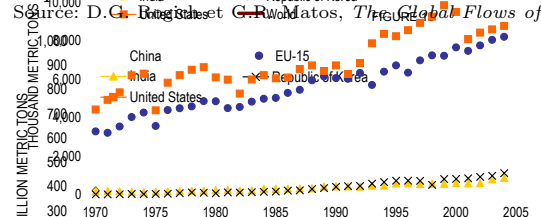
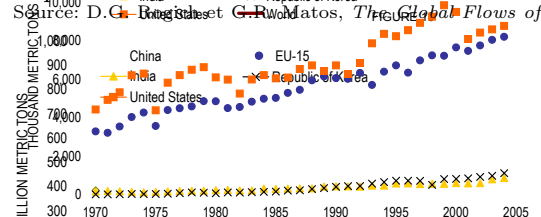
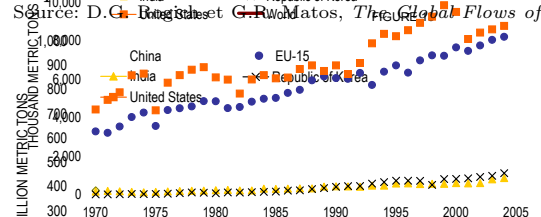
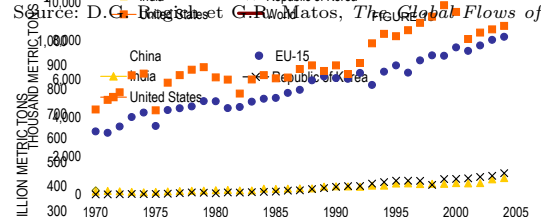
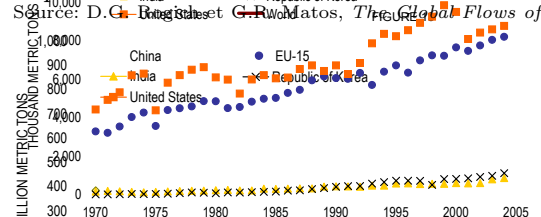
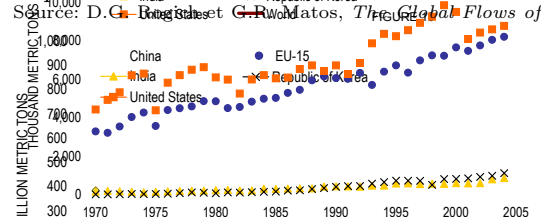
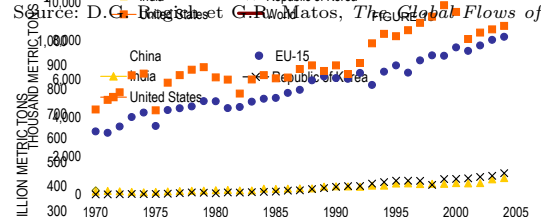
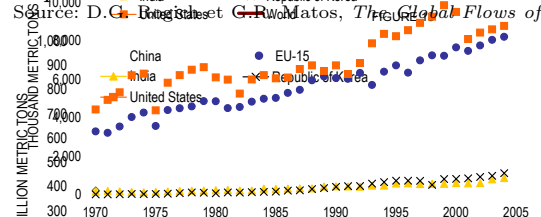
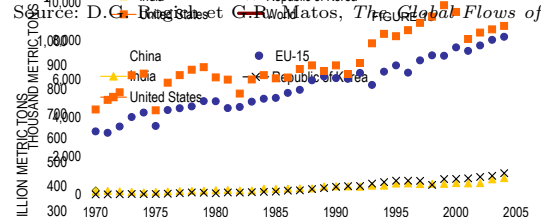
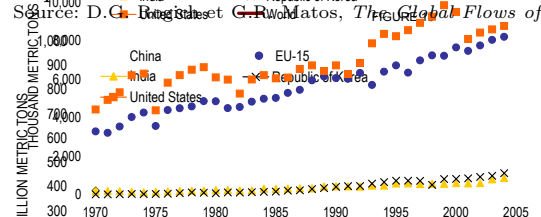
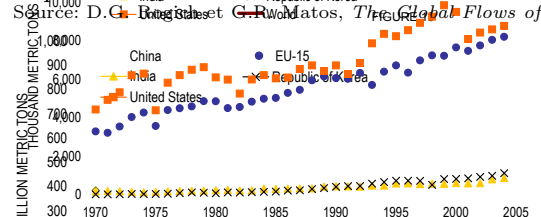
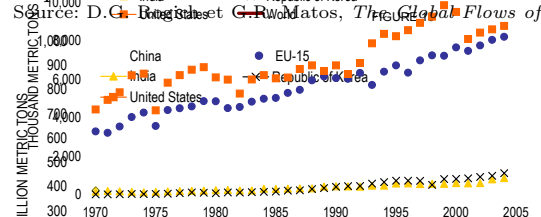
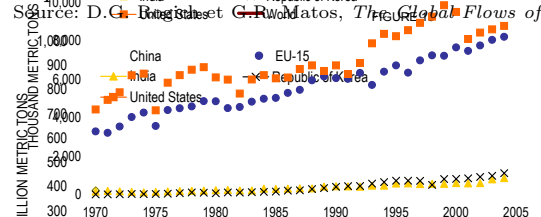
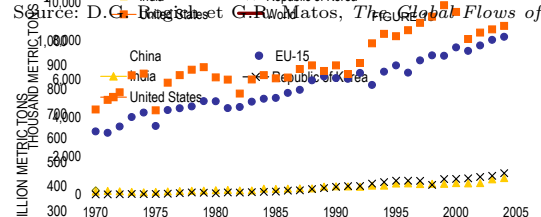
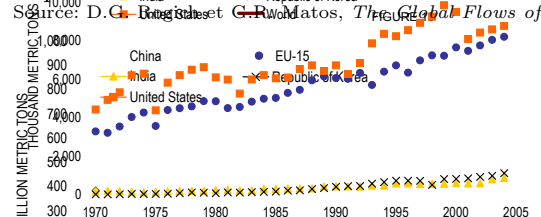
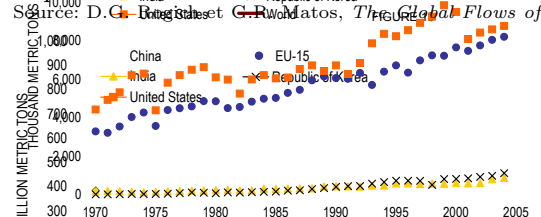
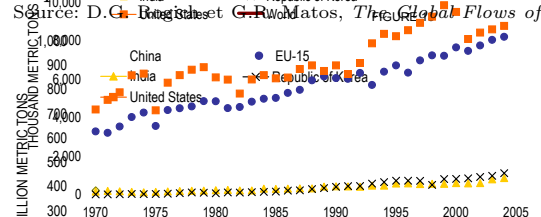
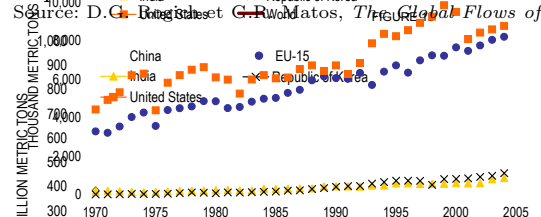
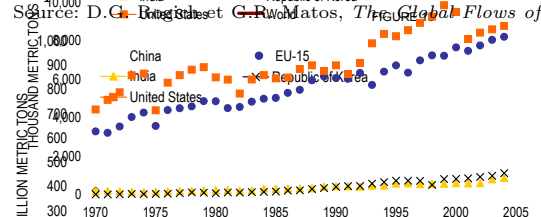
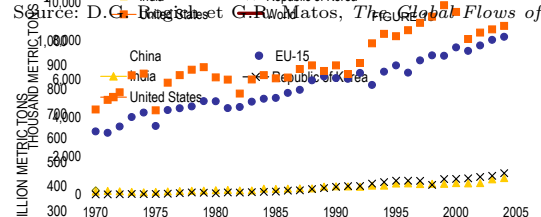
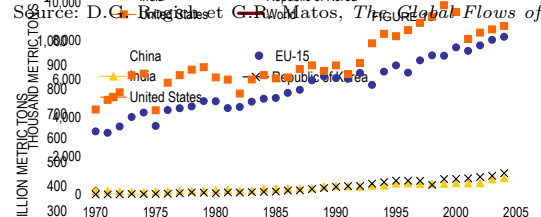
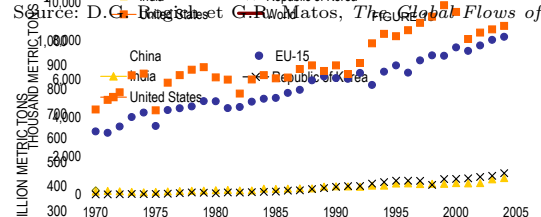
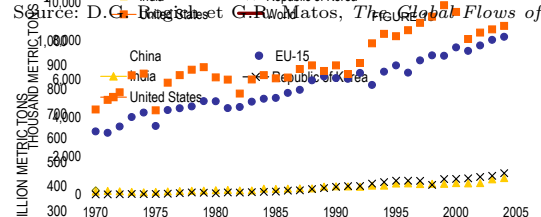
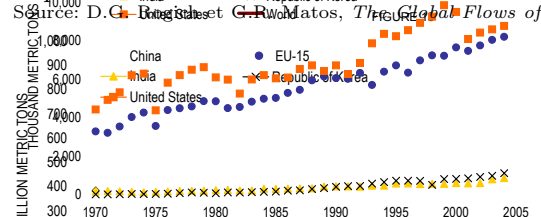
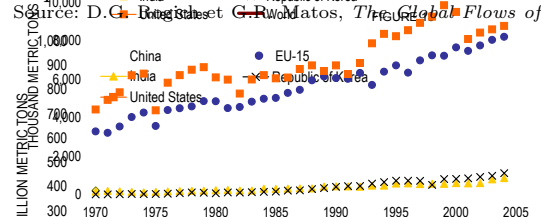
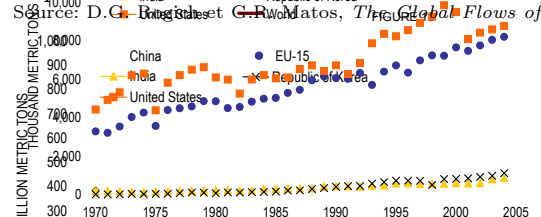
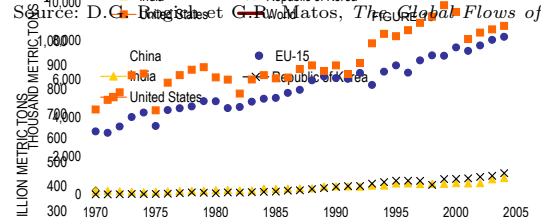
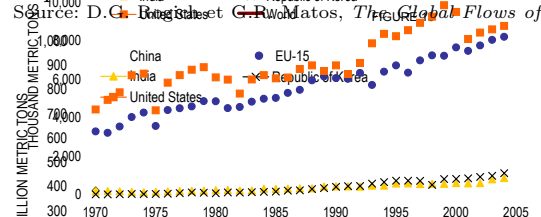
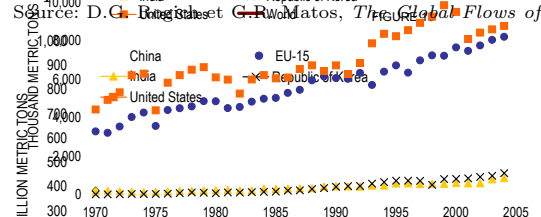
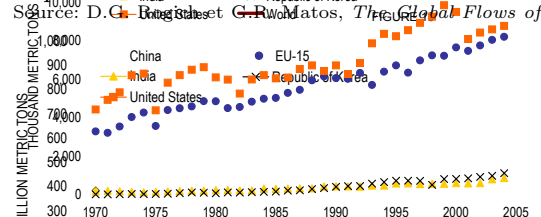
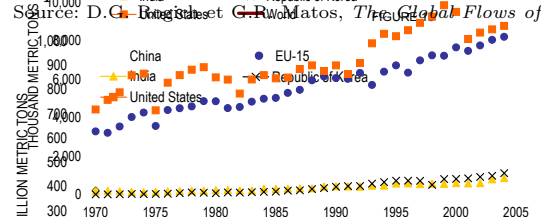
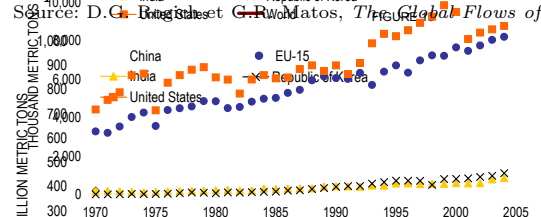
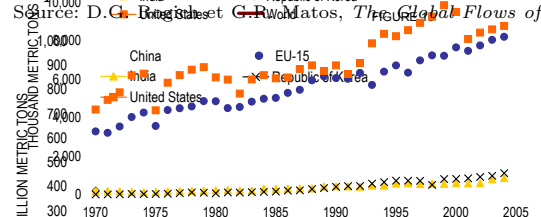
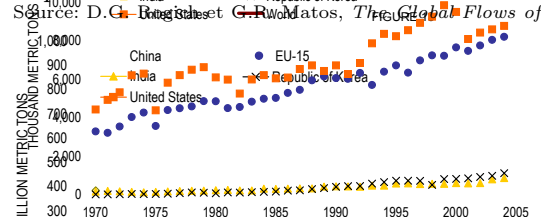
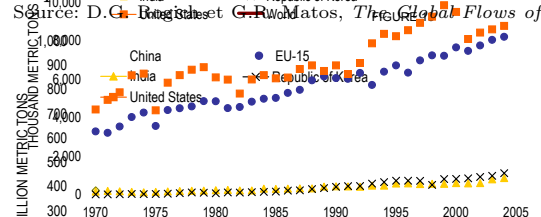
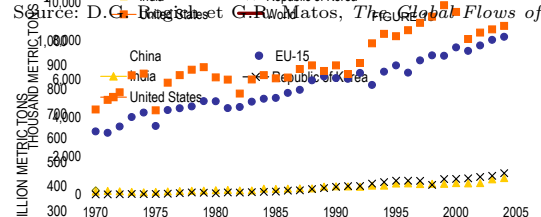
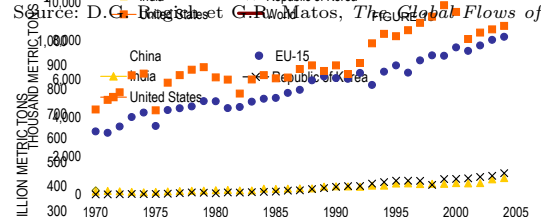
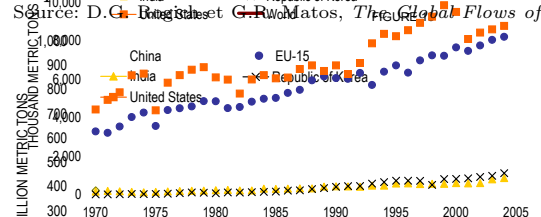
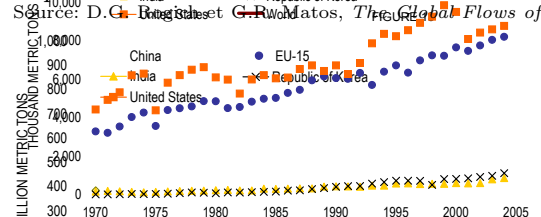
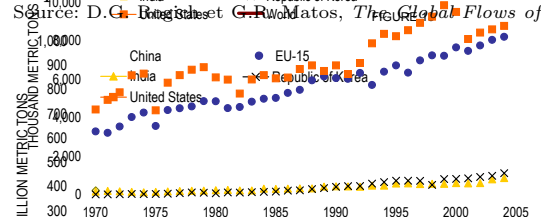
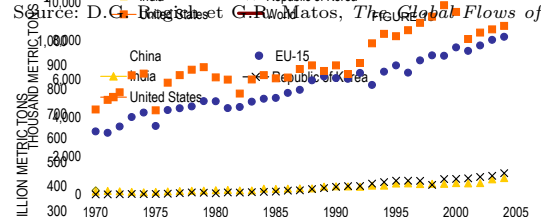
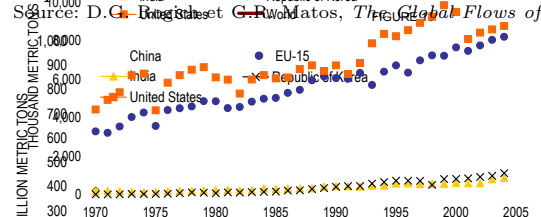


Table 2.4 Approximate Energy Content of Materials (GJ ton⁻¹)

Material	Energy
Aluminum	280
Plastics	85–180
Copper	140, rising to 300
Zinc	68
Steel	55
Glass	20
Cement	7
Brick	4
Timber	2.5–7
Gravel	0.2
Oil	44
Coal	29

Source: M.F. Ashby & D.R.H. Jones, Engineering Materials Vol. 1, 4th Ed., 2012, Elsevier Butterworth.

Cite this article: Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Phil Trans R Soc A 371: 20120003.
<http://dx.doi.org/10.1098/rsta.2012.0003>

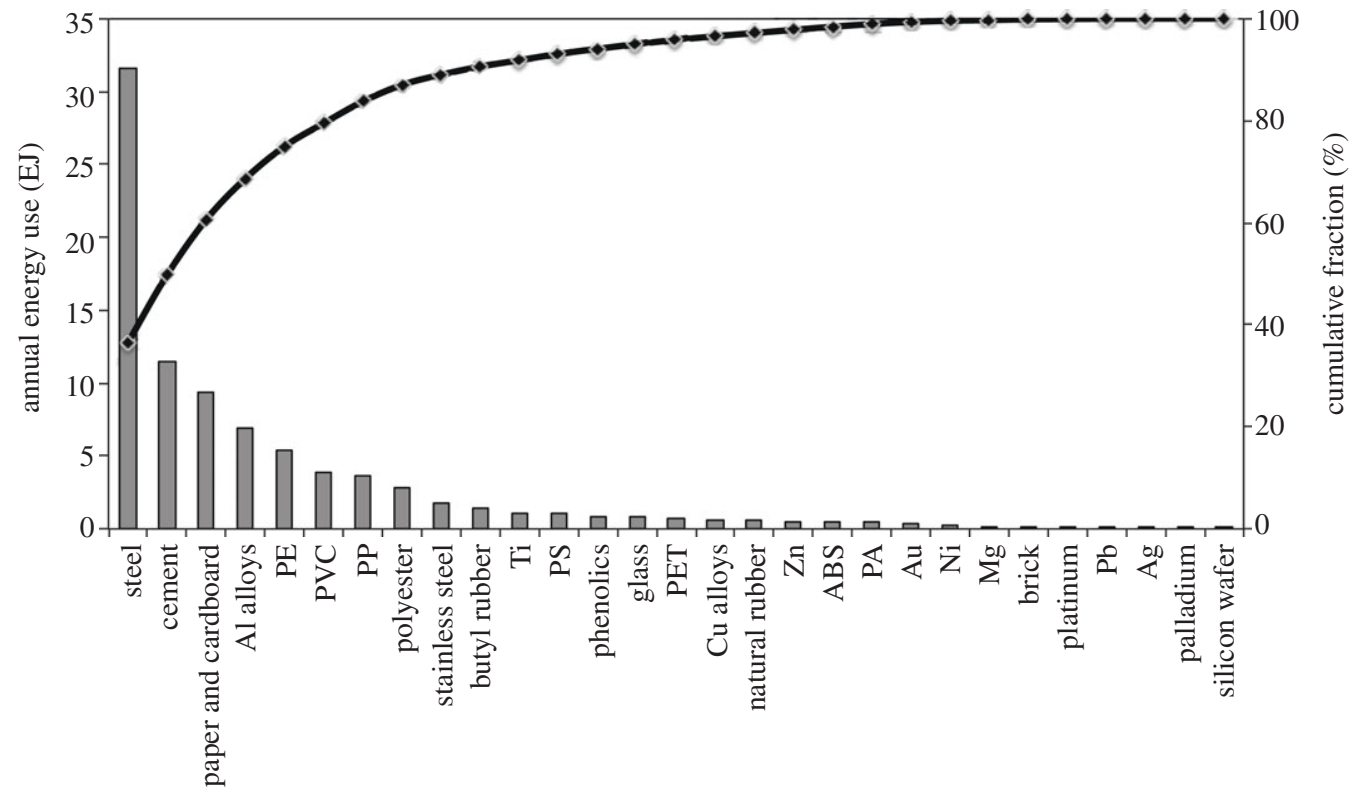


Figure 1. Annual primary energy used for the production of 29 materials worldwide, cumulative scale on the right. PE, polyethylene; PVC, polyvinyl chloride; PP, polypropylene; PS, polystyrene; PET, polyethylene terephthalate; ABS, acrylonitrile butadiene styrene; PA, polyamides. Adapted from Ashby [10].

Cite this article: Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. *Phil Trans R Soc A* 371: 20120003. <http://dx.doi.org/10.1098/rsta.2012.0003>

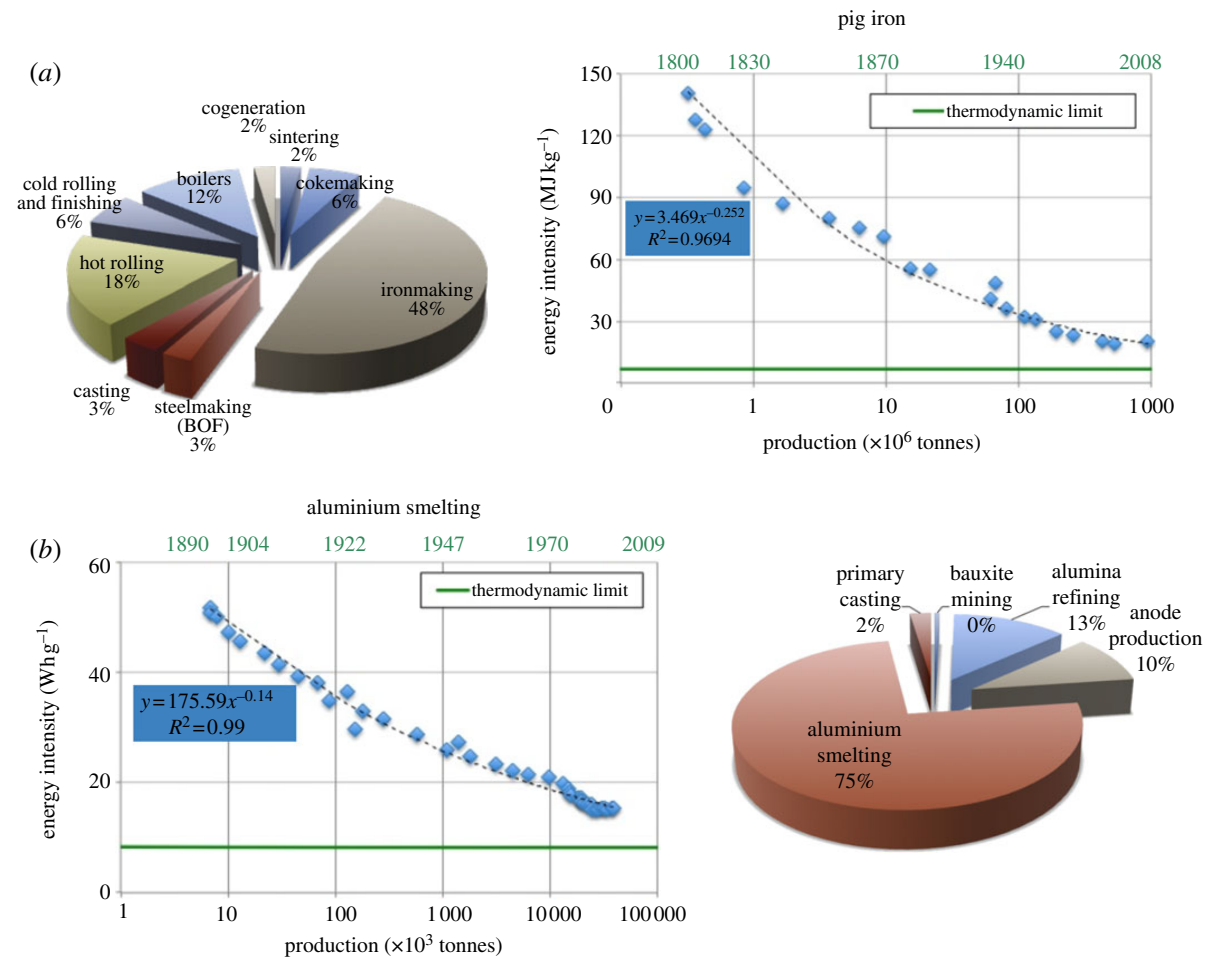


Figure 4. (a) Historic trends in global average energy requirements for production of pig iron from ore (coke use), and (b) for aluminium smelting (electricity use), versus the respective global production volumes (mass). The corresponding years are labelled above the chart. Also included are the theoretical minimum values for the two processes. Data for iron energy intensity are adapted from Smil [15] and that for aluminium are adapted from Choate & Green [16]. Production data are adapted from the *Mineral yearbooks* [17]. Pie chart data are adapted from Choate & Green [16], Worrell *et al.* [18] and de Beer *et al.* [19]. BOF, basic oxygen furnace.

Cite this article: Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Phil Trans R Soc A 371: 20120003. <http://dx.doi.org/10.1098/rsta.2012.0003>

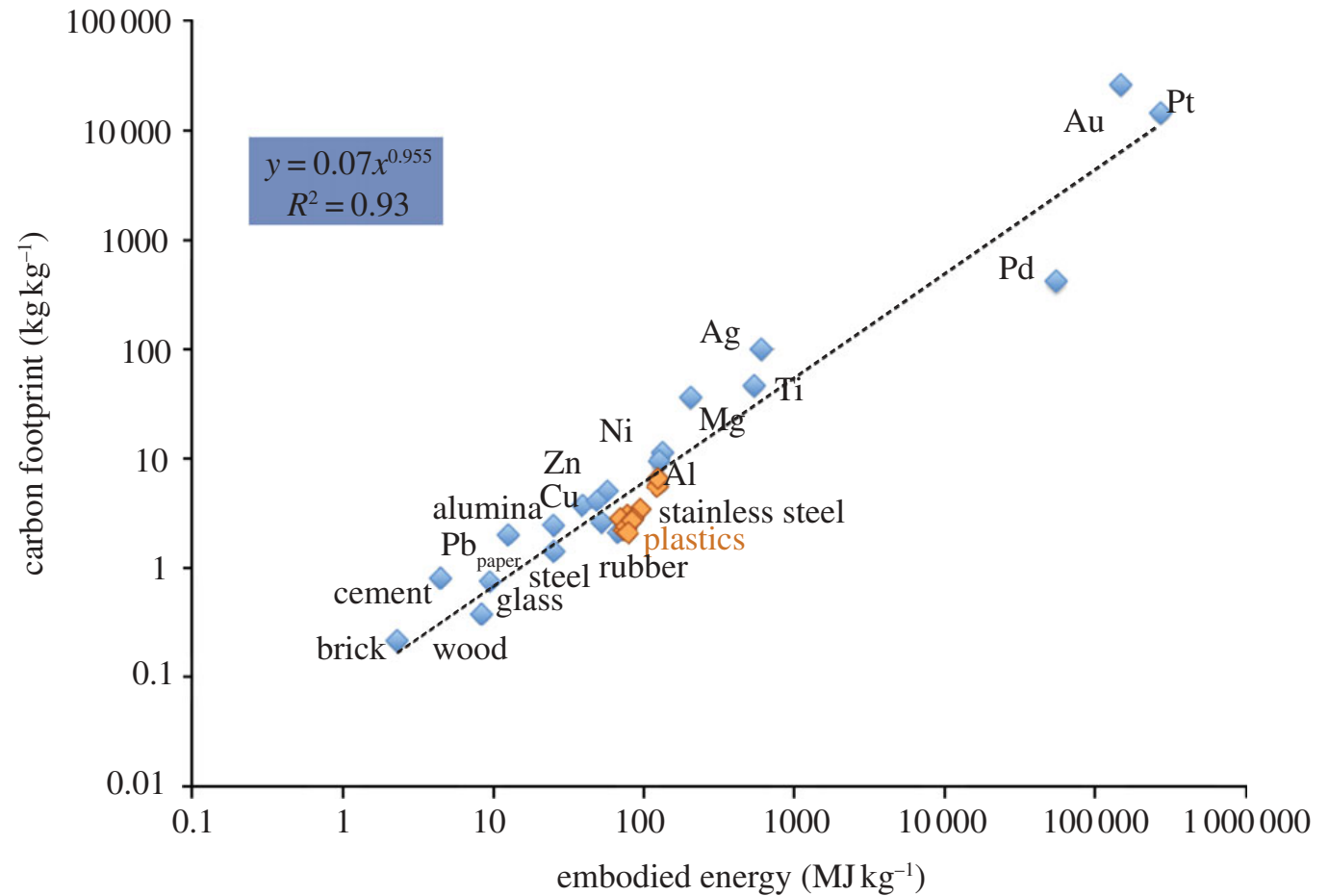


Figure 2. The carbon emission in kilograms of CO_2 per kilogram of material produced versus the embodied primary energy. Data adapted from Ashby [10].

Contenu énergétique et rareté ("dilution" au sein de la croûte terrestre)

Cite this article: Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Phil Trans R Soc A 371: 20120003. <http://dx.doi.org/10.1098/rsta.2012.0003>

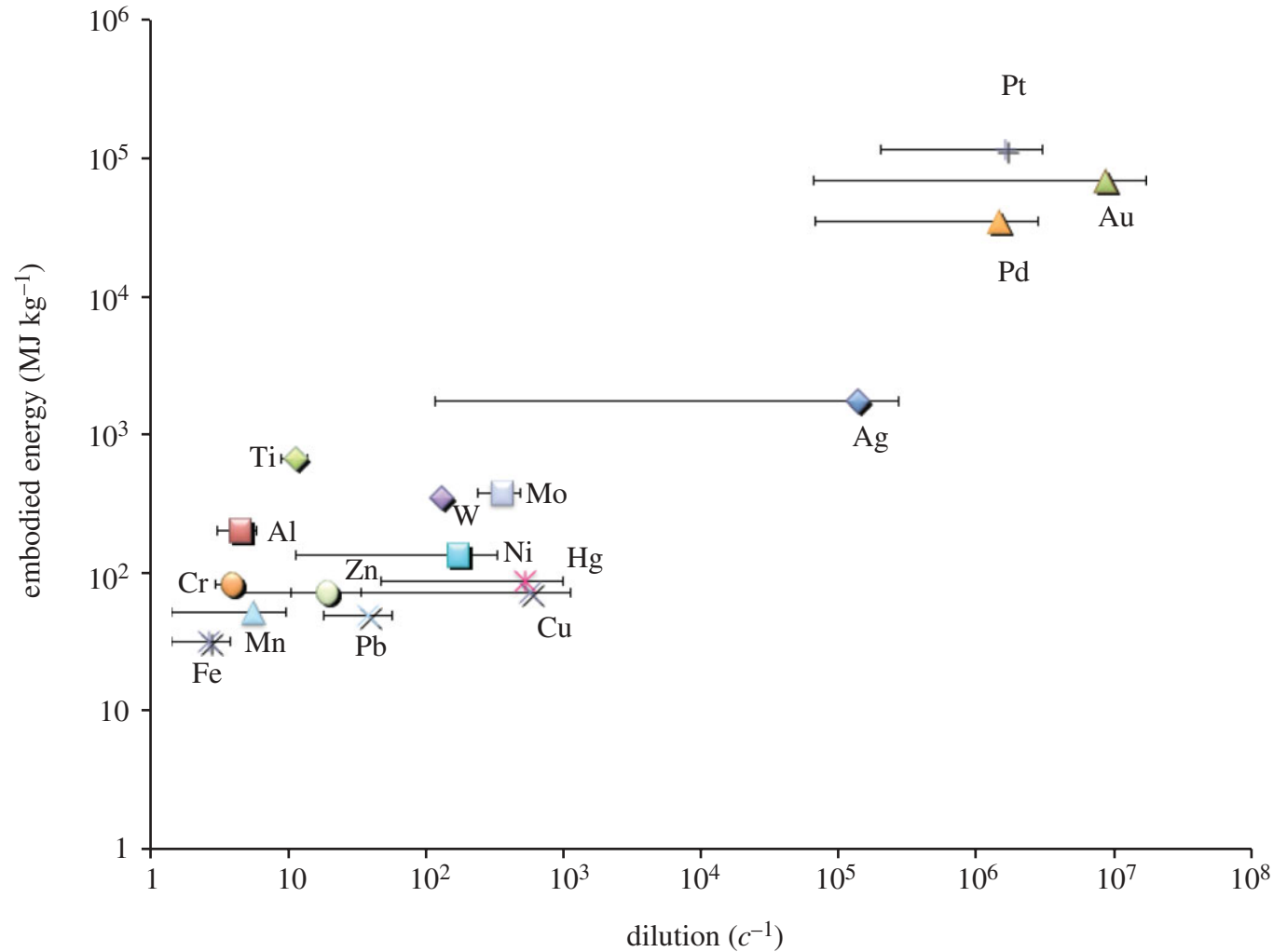


Figure 3. Embodied primary energy of 16 metals [10] plotted against the dilution, or inverse of concentration, of the common ores used to produce the metals [12].

Contenu énergétique: évolution dans le temps

Cite this article: Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Phil Trans R Soc A 371: 20120003. <http://dx.doi.org/10.1098/rsta.2012.0003>

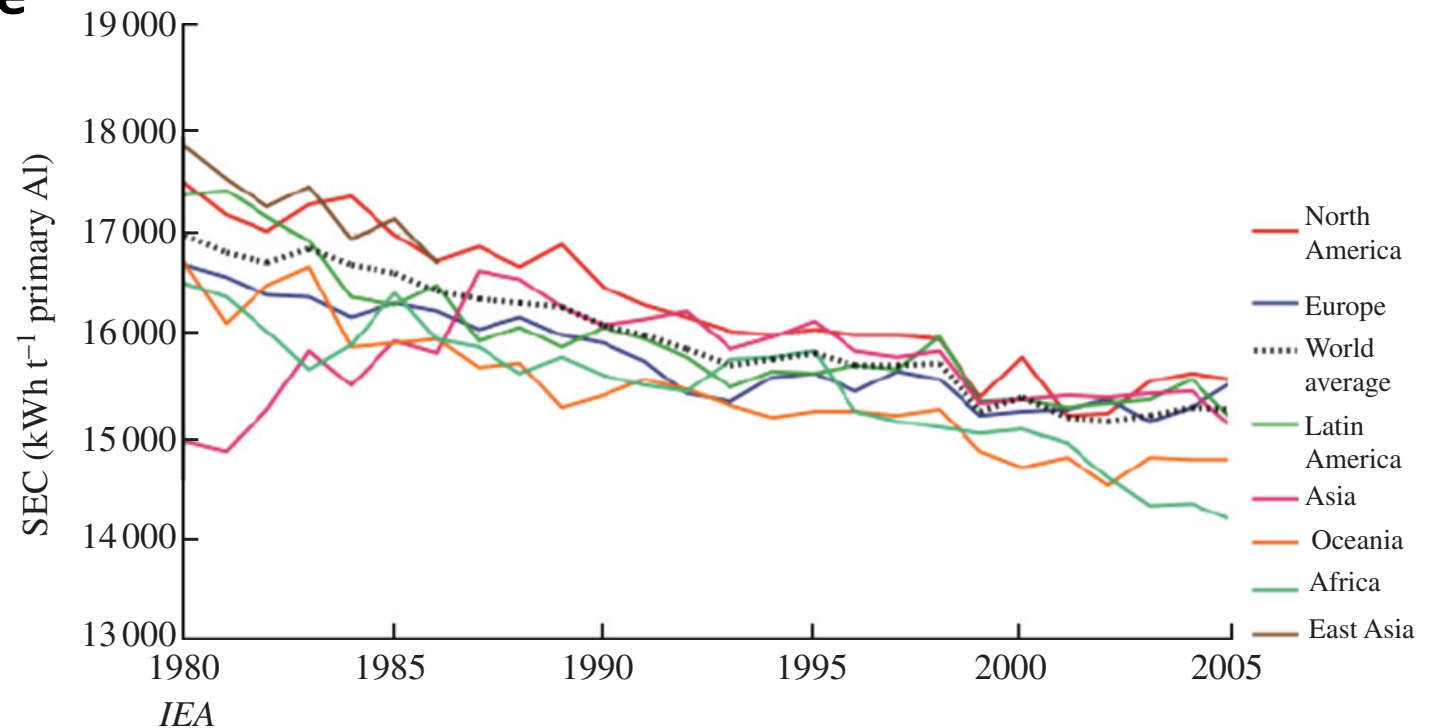


Figure 5. Historical regional data for the energy (electricity) intensity of aluminium smelting. SEC, specific energy consumption. Reproduced with permission from IEA [7]. Tracking industrial energy efficiency and CO₂ emissions © OECD/IEA 2007, figure 8.1, page 211.

Contenu énergétique et prix

Cite this article: Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Phil Trans R Soc A 371: 20120003.
<http://dx.doi.org/10.1098/rsta.2012.0003>

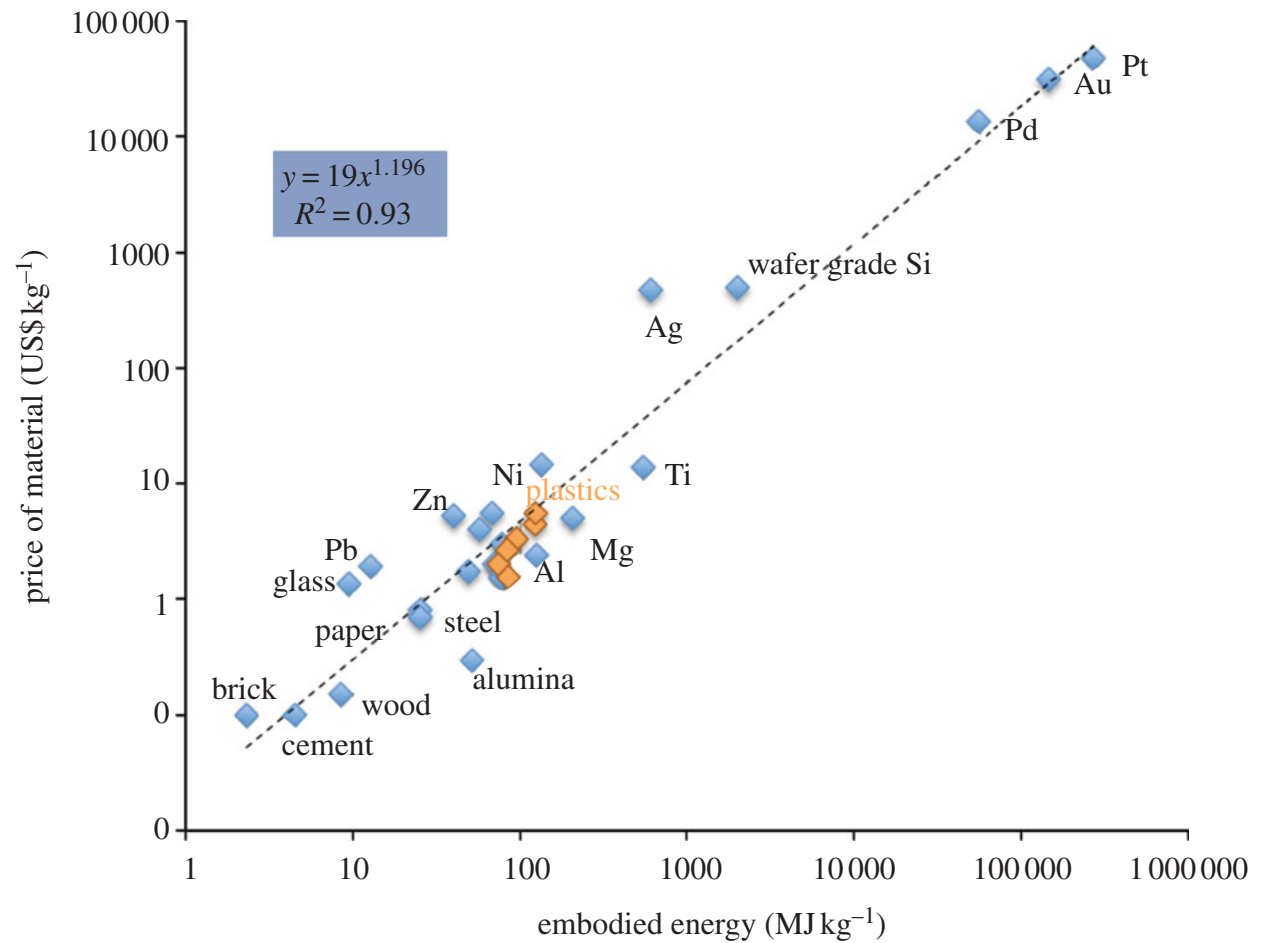


Figure 6. Price of various materials plotted against the embodied energy of the materials. The data for embodied energy comes from Ashby [10], for material prices for metals from the *Mineral yearbooks* [17], plastics from IDES [28] and brick, wood and glass from Ashby [10]. Plastic prices are for year 2011, and all others are for 2009.

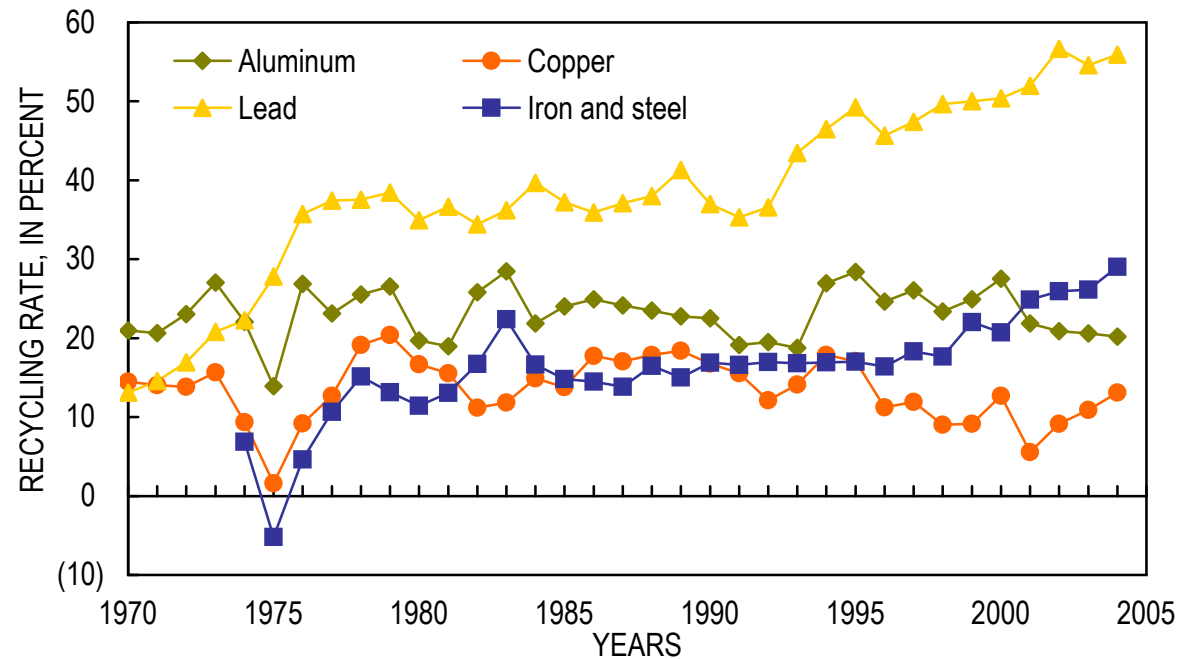


FIGURE I-11 – Recyclage des métaux principaux dans le monde.

Source: D.G. Rogich et G.R. Matos, *The Global Flows of Metals and Minerals*, U.S. Geological Survey, 2008.

Source: Poly M&A

Chapitre 3 – Métaux et Alliages – Al & Cu - 39

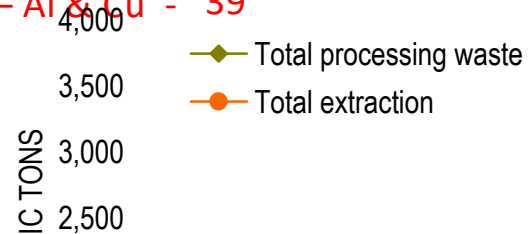
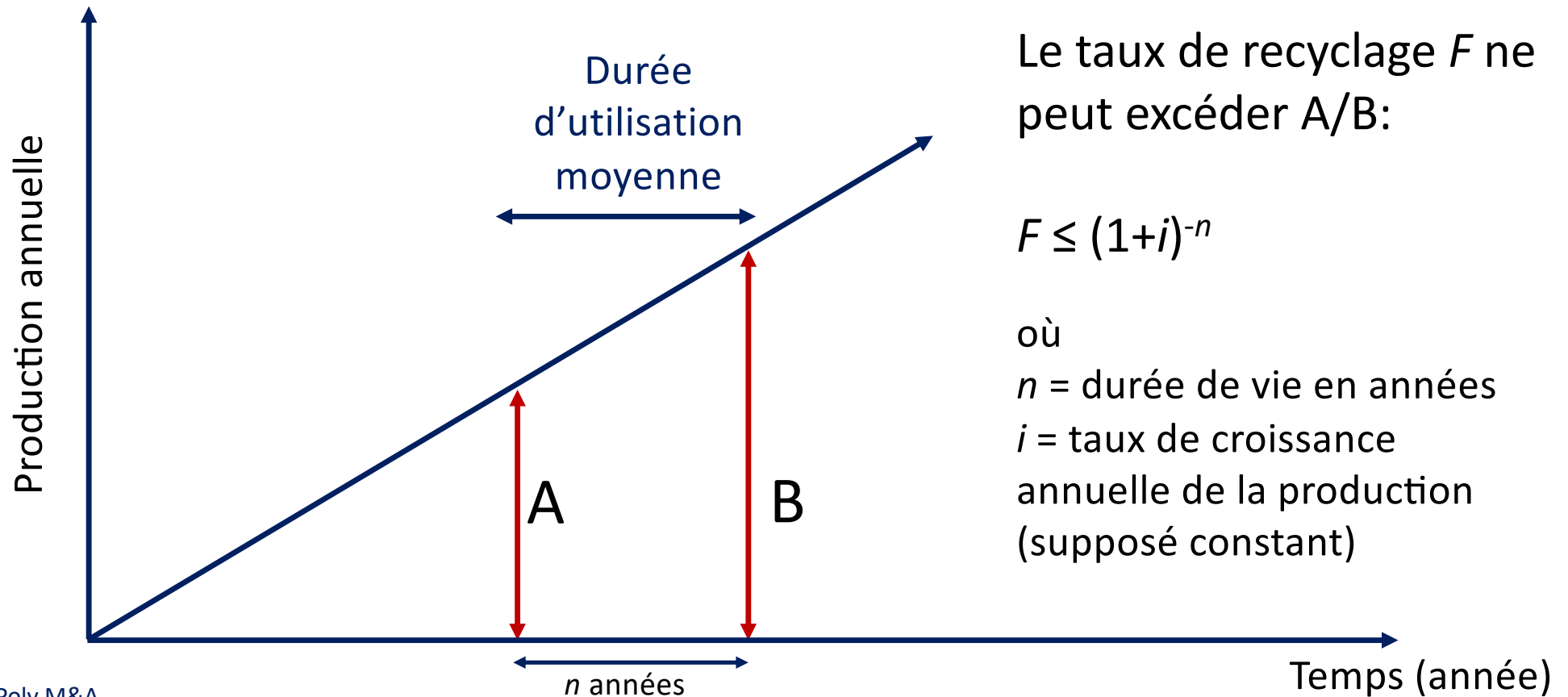


FIGURE 25

Recyclage:

le taux de recyclage est limité par la croissance globale de la demande et donc de la production (schéma simplifié)



Source: Poly M&A

Table 1. Recycling parameters for top five materials. Cur, current average; CE, cutting edge; r , recycling rate as a fraction of supply. Details are provided in the electronic supplementary material.

material	n (years)	r_{2005} (%)	r_{2050} (%)
steel	19	37	69
aluminium	15	30	65
cement	50	0	0
paper	1	45	80
plastic	5	4	28

↑
(estimé)

Cite this article: Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Phil Trans R Soc A 371: 20120003.
<http://dx.doi.org/10.1098/rsta.2012.0003>

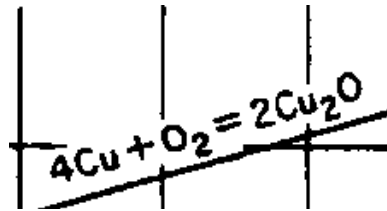
EPFL Récapitulatif du panorama:

Les métaux et alliages :

- forment une vaste famille de matériaux;
- sur le plan chimique sont généralement constitués d'un élément principal (Cu, Fe, Al, Mg, Zn, Ni, Ti, Ag, Au, ...) auquel on ajoute des *éléments d'alliage* (alloying elements; exception: les *intermétalliques* constitués de parts égales de métaux différents);
- sont moins rigides ou durs et souvent plus lourds que les céramiques,
- sont ductiles et capables de déformation plastique,
- sont tenaces,
- peuvent être réfractaires (càd résistants aux températures élevées),
- peuvent être résistants à l'attaque chimique
- peuvent se dégrader par oxidation,
- peuvent être composés d'éléments abondants et donc peuvent être de faible prix,
- ont une empreinte énergie/carbone non négligeable,
- sont assez facilement recyclés.

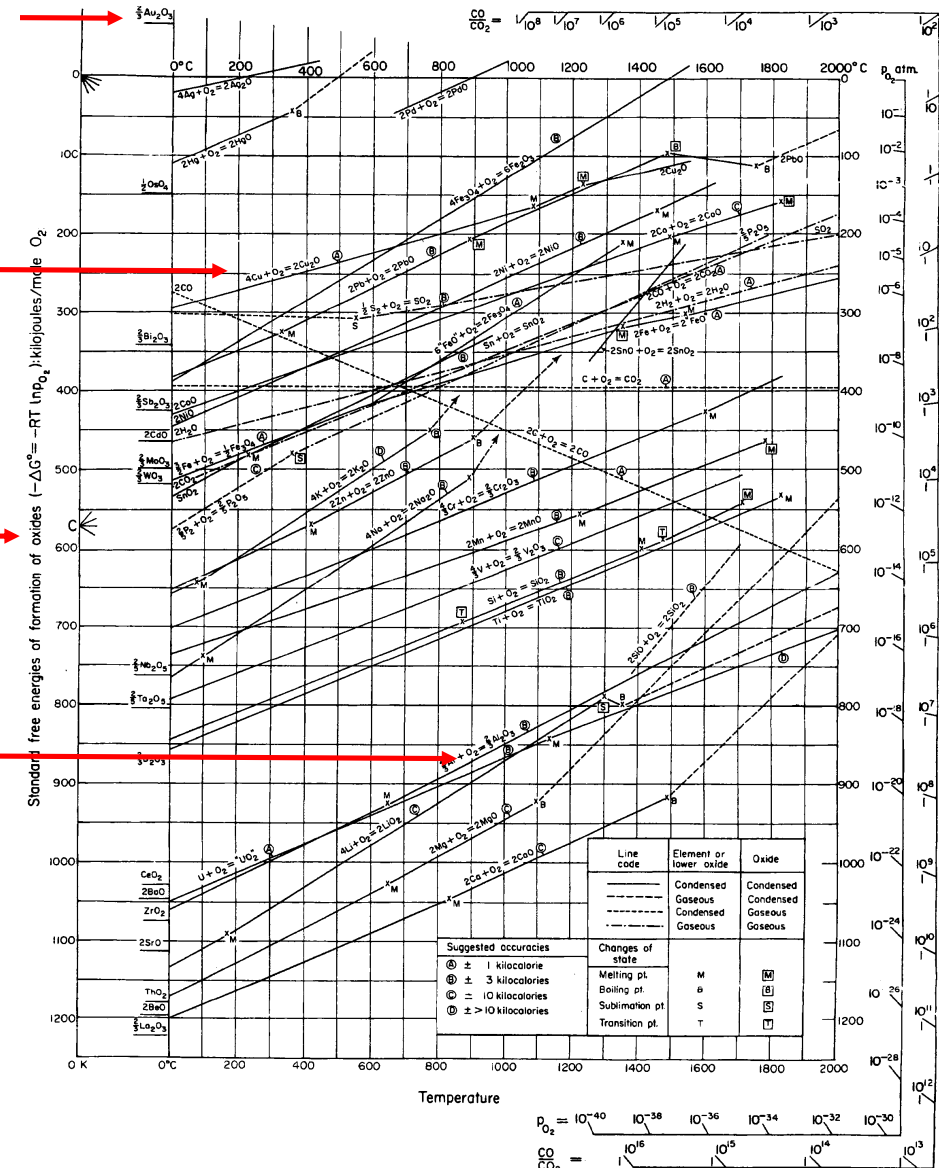
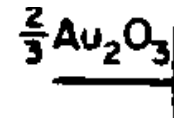
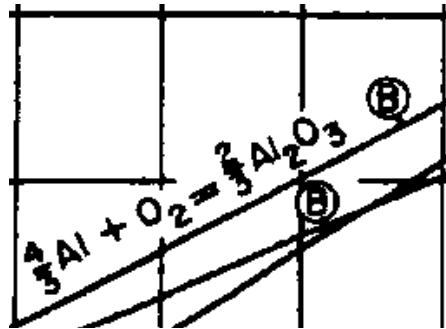
II – Production de l'aluminium et du cuivre

Notion de base: le diagramme d'Ellingham



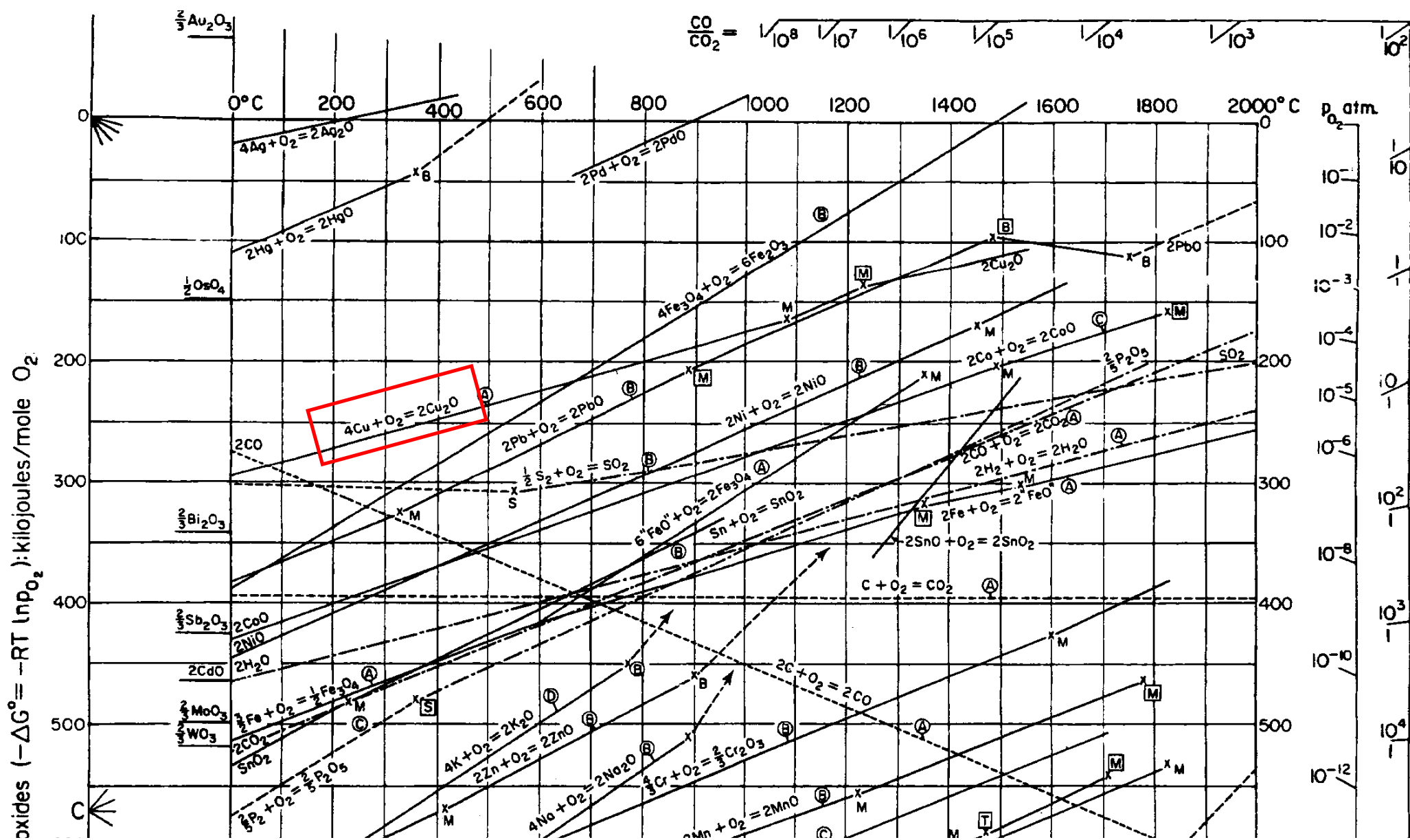
Standard free energies of formation of oxides

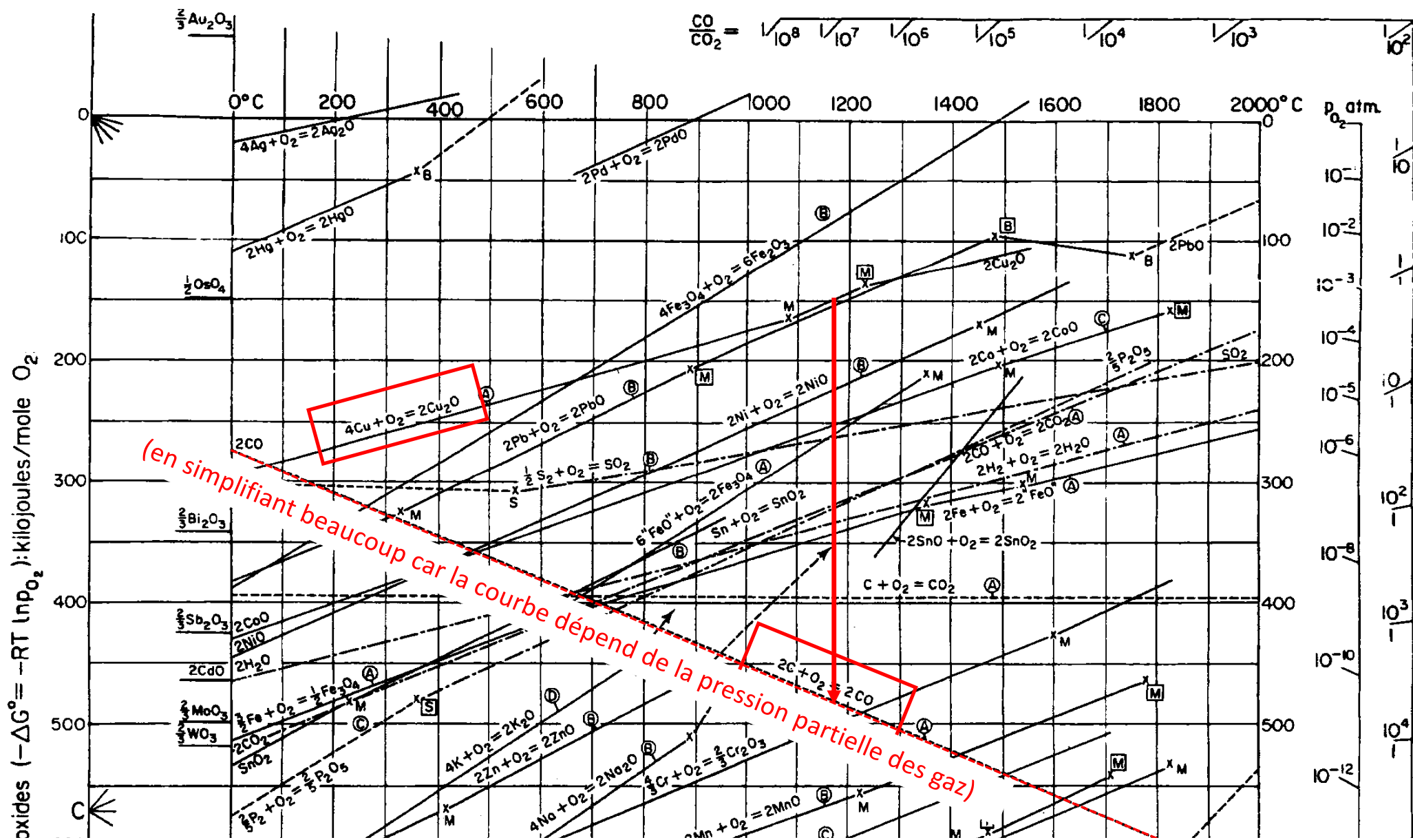
$(-\Delta G^\circ = -RT \ln p_{\text{O}_2})$: kilojoules/mole O_2

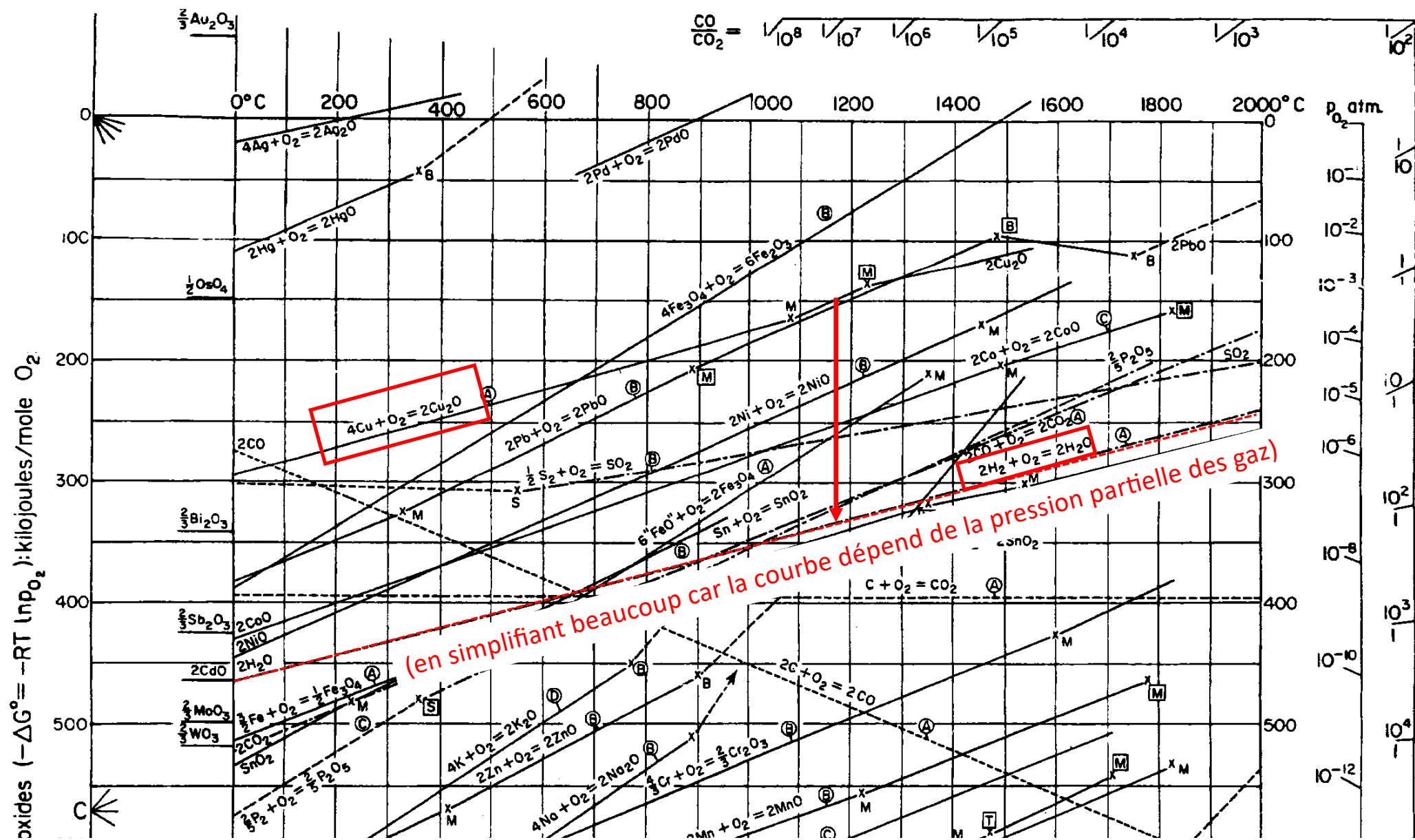


(voir page 170 du polycopié Métaux et Alliages)

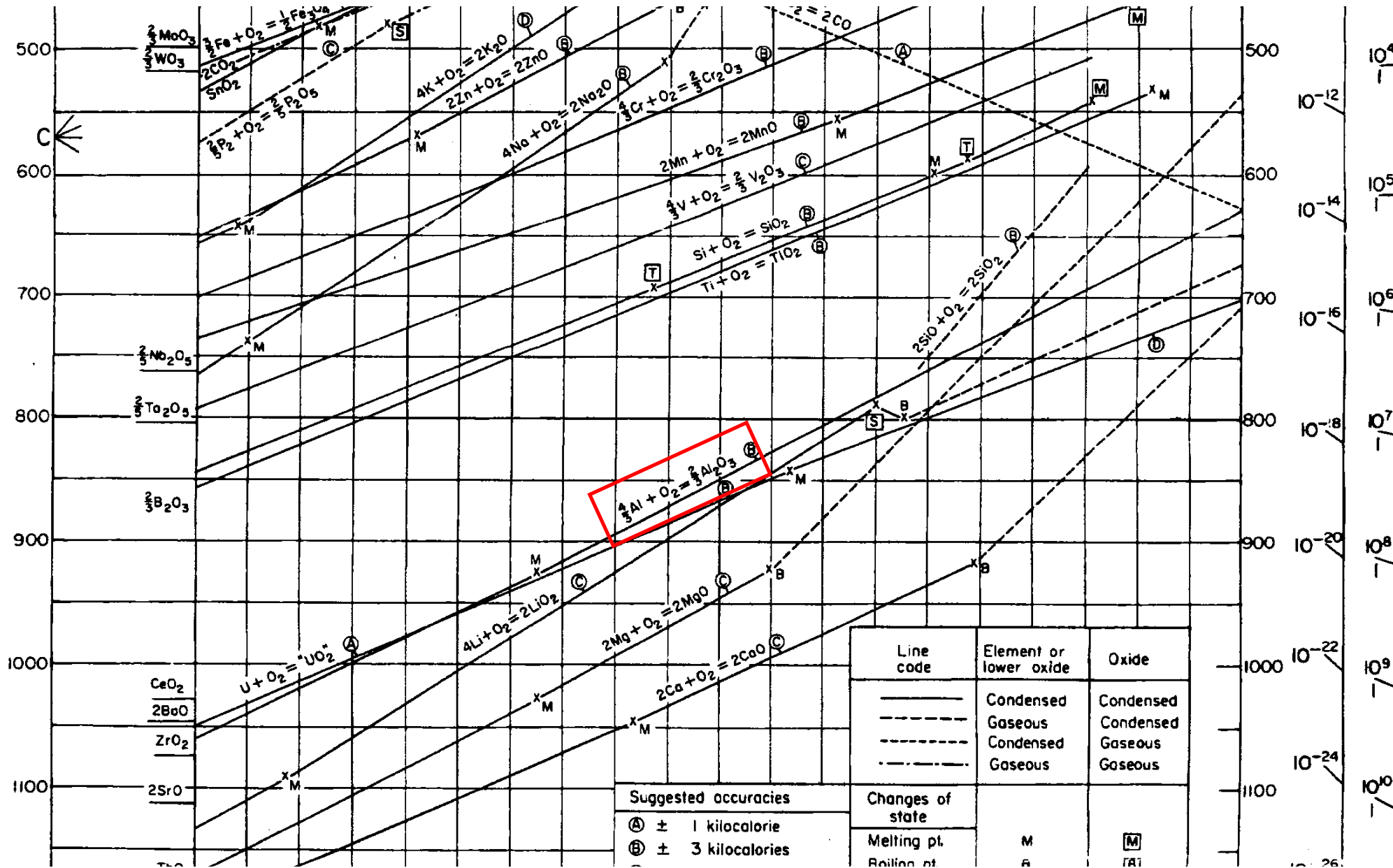
FIGURE IV-7 – Diagramme d'Ellingham.



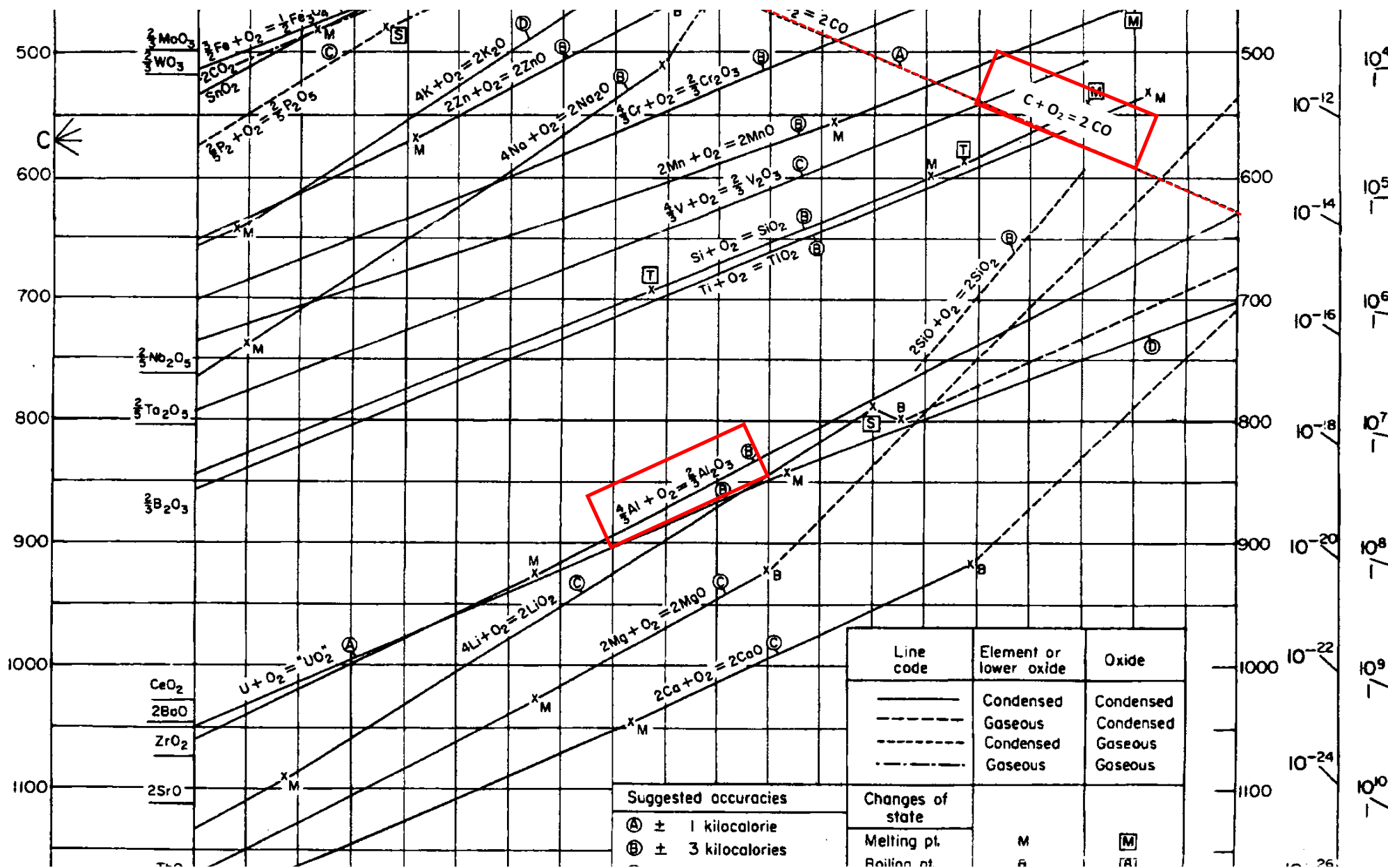




Standard free energies of formation of oxides ($-\Delta G^\circ$)



Standard free energies of formation of oxides ($-\Delta G^\circ$)



Extraction du cuivre

Âge du Bronze: env. 3'300 -1'200 AC

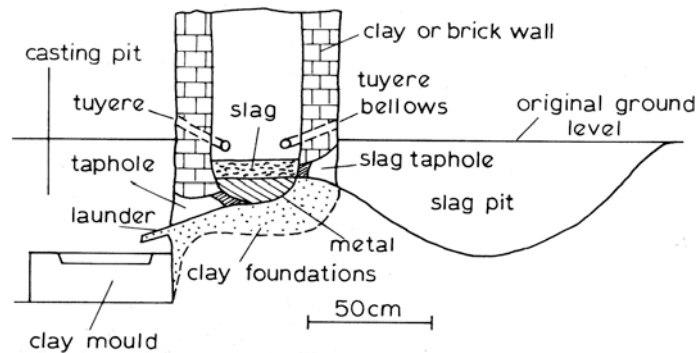


FIGURE I-1 – Four à charbon primitif.

Source: R.F. Tylecote, *A History of Metallurgy*, 2nd Edition, The Institute of Materials, London, 1992.

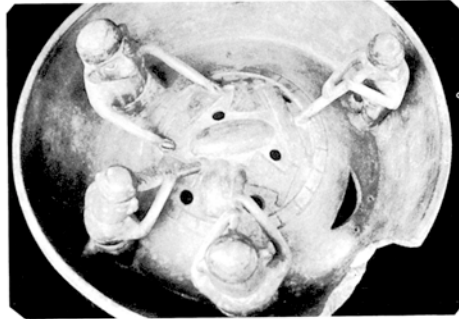


FIGURE I-2 – Bol décoratif de Batan Grande au Pérou, illustrant l'utilisation de tuyères dans l'extraction du cuivre.

Source: R.F. Tylecote, *A History of Metallurgy*, 2nd Edition, The Institute of Materials, London, 1992.



Lingots de cuivre, Crète et Chypre, env. 1'500 AC

Source: Musée d'Héraklion, Crète

Extraction du cuivre

Le cuivre représente seulement 50 ppm de l'écorce Terrestre.

Par contre l'énergie requise pour sa réduction (au sens oxydo-réduction) est comparativement faible (métal quasi noble)

Source: Poly M&A

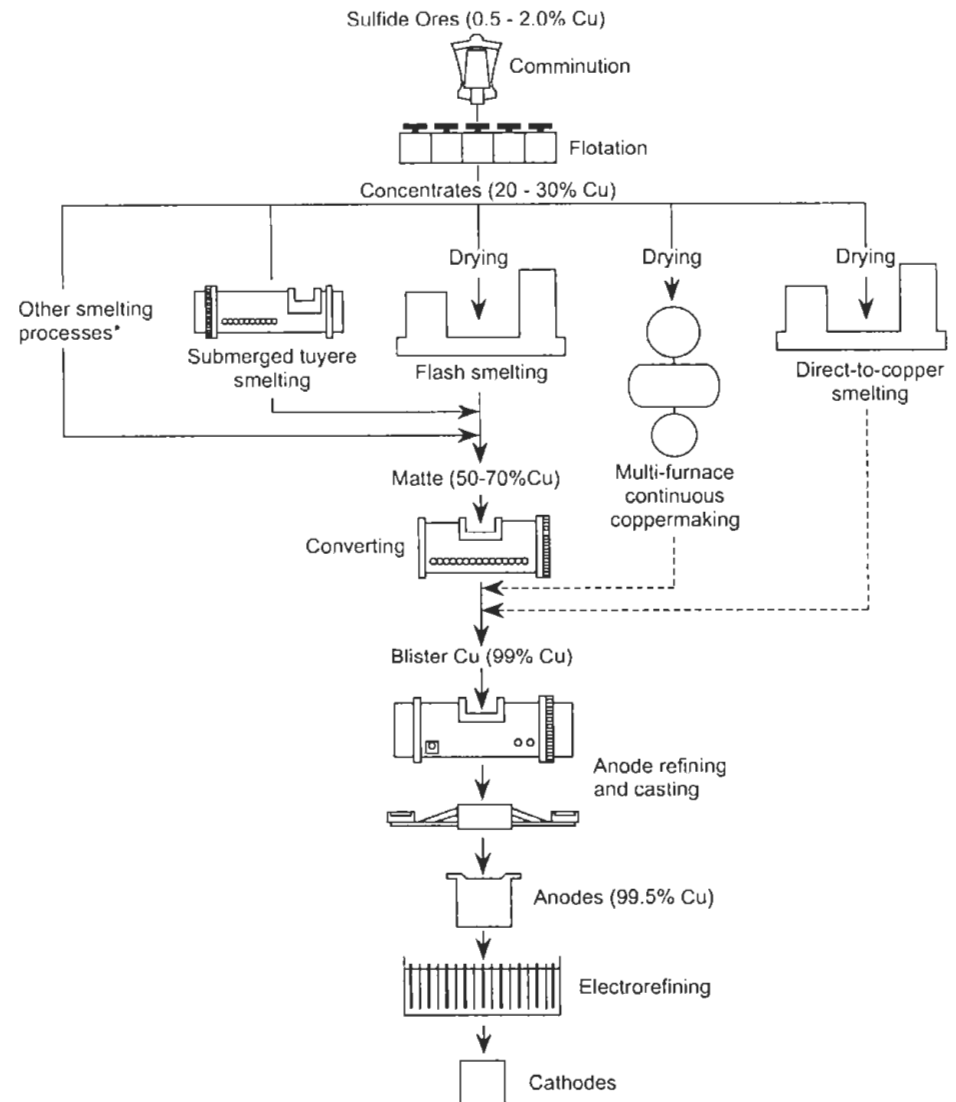


FIGURE III-3 – Extraction pyrométallurgique du cuivre.

Source: W.G. Davenport, M. King, M. Schlesinger, A.K. Biswas, *Extractive Metallurgy of Copper*, 4th Edition, Pergamon, Oxford, 2002.

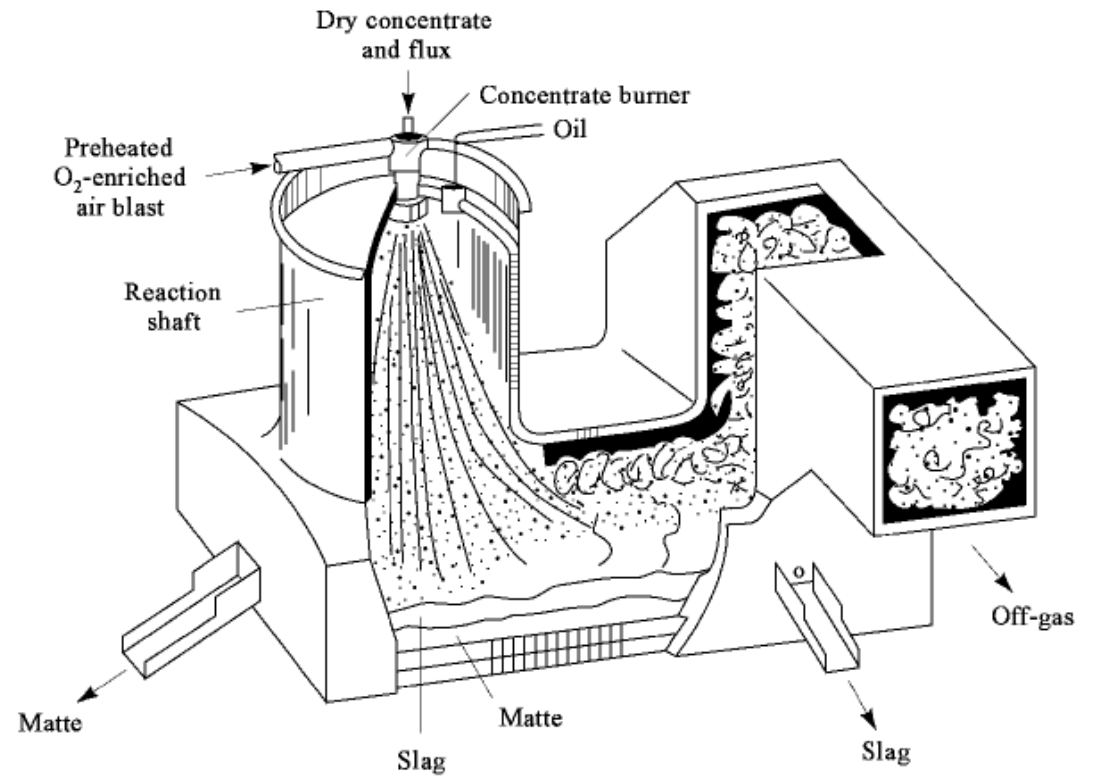
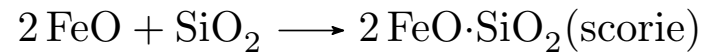
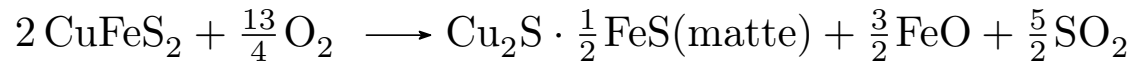
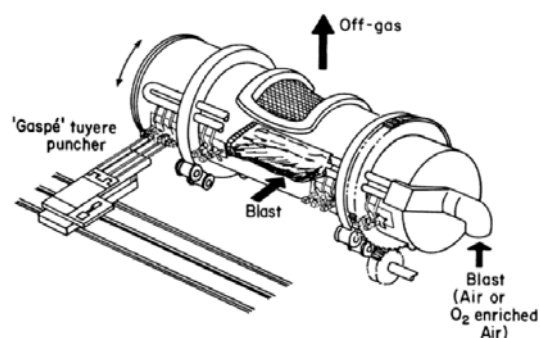
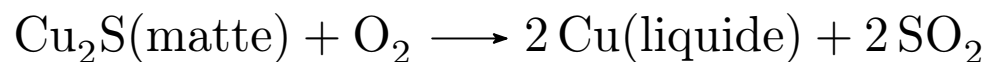
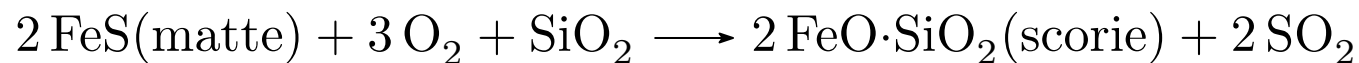


FIGURE III-4 – Four flash.

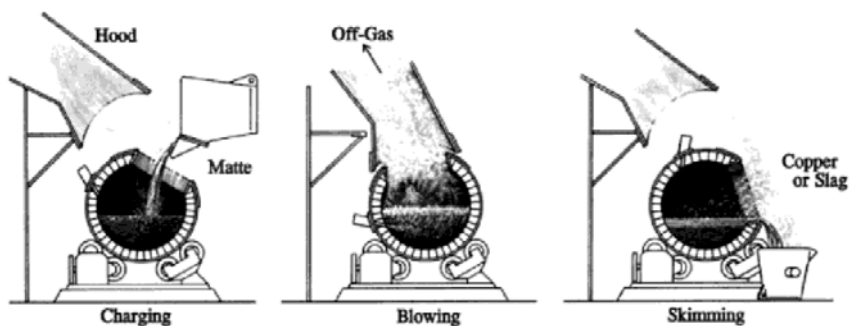
Source: R.E. Kirk, *Encyclopedia of Chemical Technology* Vol. 7, 4th Edition, Wiley Interscience, New York, 1991.

Source: Poly M&A

EPFL Extraction du cuivre



(a) Convertisseur



(b) Différentes positions.

Source: Poly M&A

FIGURE III-5 – Convertisseur Pierce-Smith.

Source: W.G. Davenport, M. King, M. Schlesinger, A.K. Biswas, *Extractive Metallurgy of Copper*, 4th Edition, Pergamon, Oxford, 2002.



Picture 7. Blister copper being taken from the converter.



Picture 8. This huge wheel is used to cast the anodes. Molten copper is poured into a mould and the wheel is turned for the next mold. Meanwhile, the molten copper cools and solidifies into anodes over a metre tall.

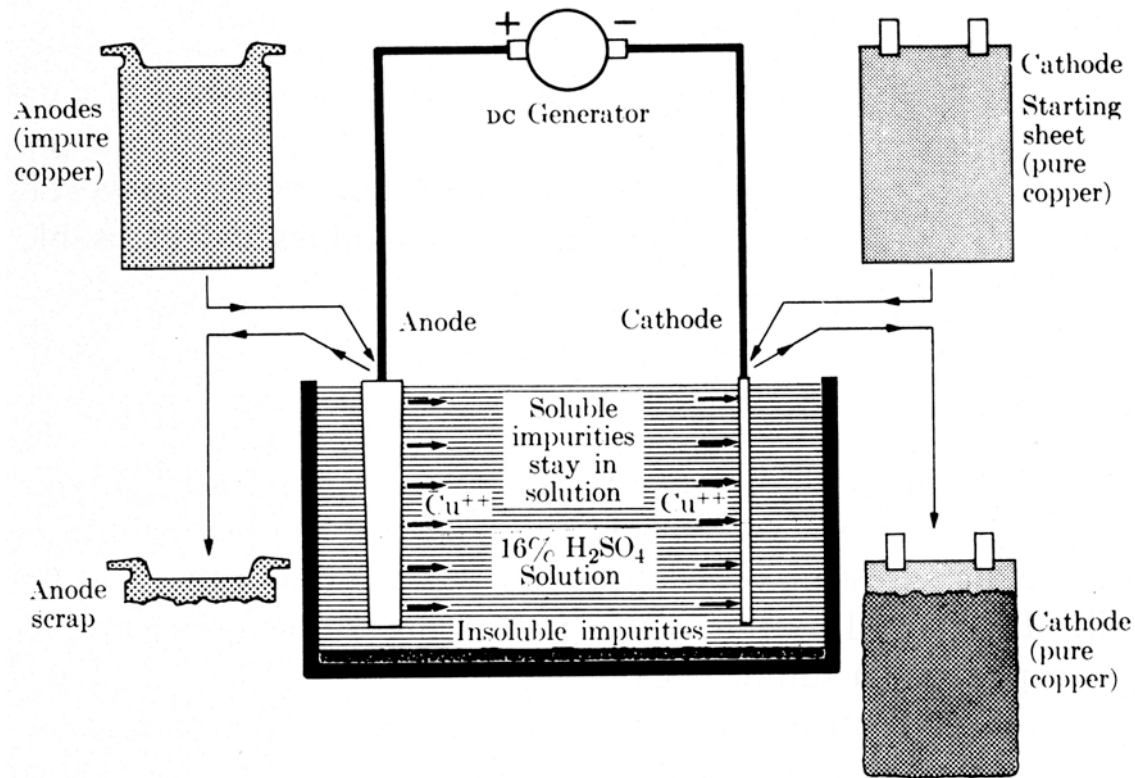


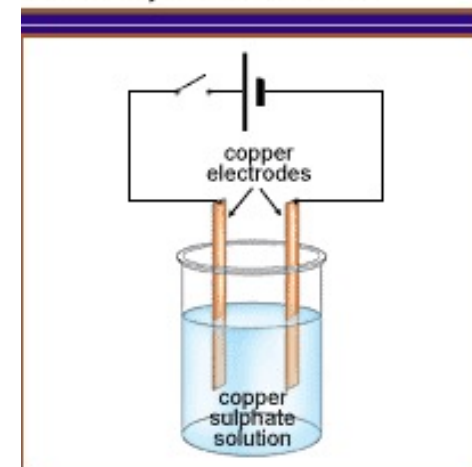
FIGURE III-6 – Raffinage électrolytique du cuivre.

Source: W.F. Smith, *Structure and Properties of Engineering Alloys*, McGraw-Hill, USA, 1993.

Source: Poly M&A

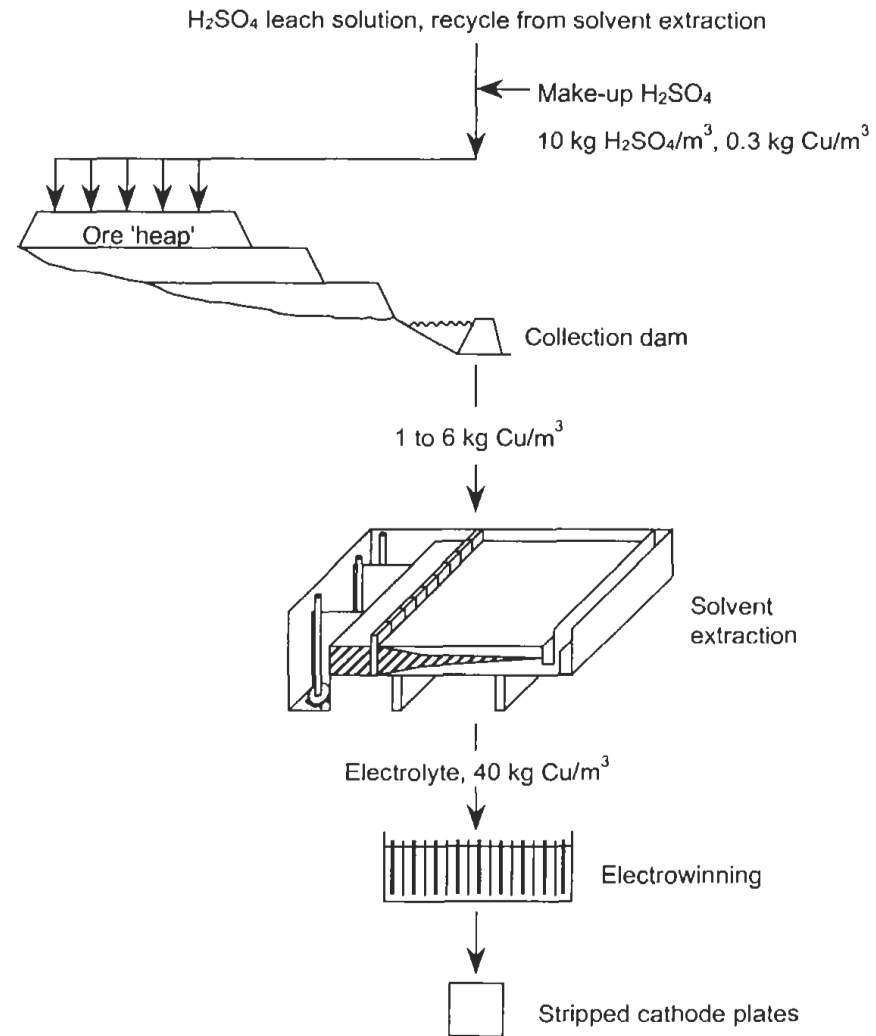


Picture 9. The giant copper *cathodes* being lifted out of the solution. Notice all the electrolytic cells underneath.



Picture 10. Laboratory electrolysis apparatus.

Extraction du cuivre: voie hydrométallurgique



Source: Poly M&A

FIGURE III-7 – Extraction hydrométallurgique du cuivre.

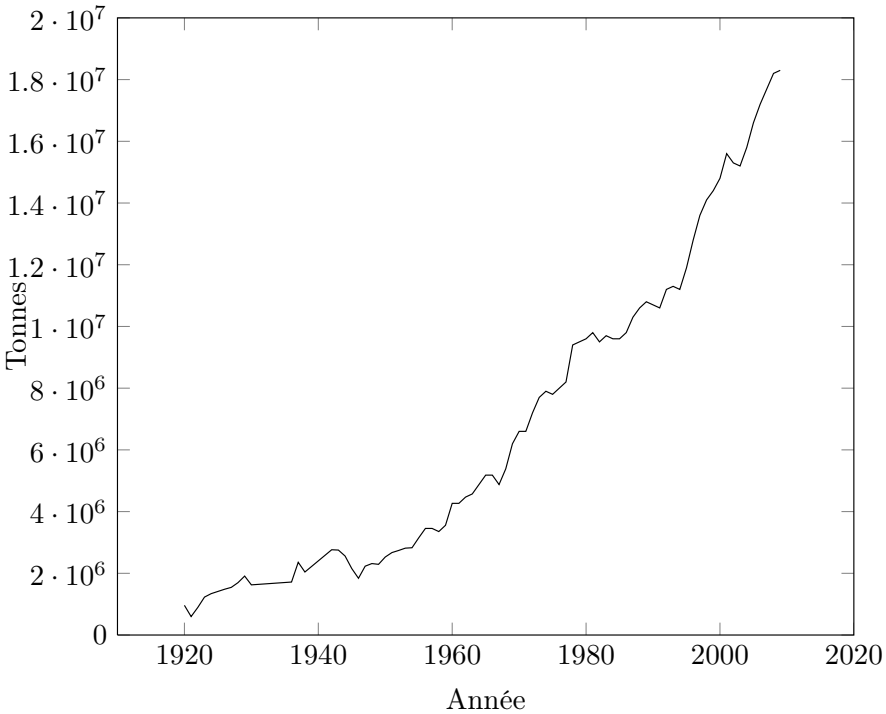
Source: W.G. Davenport, M. King, M. Schlesinger, A.K. Biswas, *Extractive Metallurgy of Copper*, 4th Edition, Pergamon, Oxford, 2002.

EPFL

Production et utilisation du cuivre

TABLE III-2 – Consommation de cuivre aux États-Unis en 2003 par type d'utilisation .
Source: U.S. Geological Survey, 2005, Copper statistics, in T.D. Kelly and G.R. Matos, *Historical statistics for mineral and material commodities in the United States : U.S. Geological Survey Data Series 140*

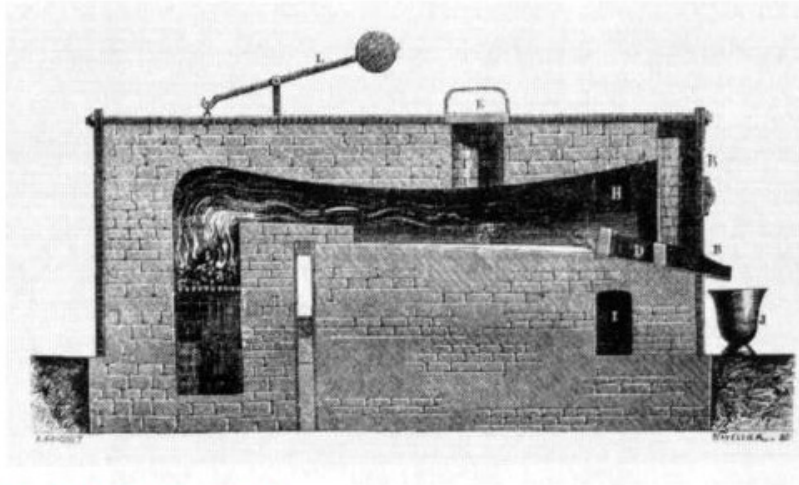
Catégorie	Tonnes	Proportion
Construction	1'170'000	48%
Produits électriques et électroniques	510'000	21%
Machines et équipement	240'000	10%
Transports	240'000	10%
Produits de consommation	270'000	11%
Total	2'430'000	



Source: Poly M&A

FIGURE III-2 – Production mondiale de cuivre raffiné.
Source: British Geological Survey.

Extraction de l'aluminium



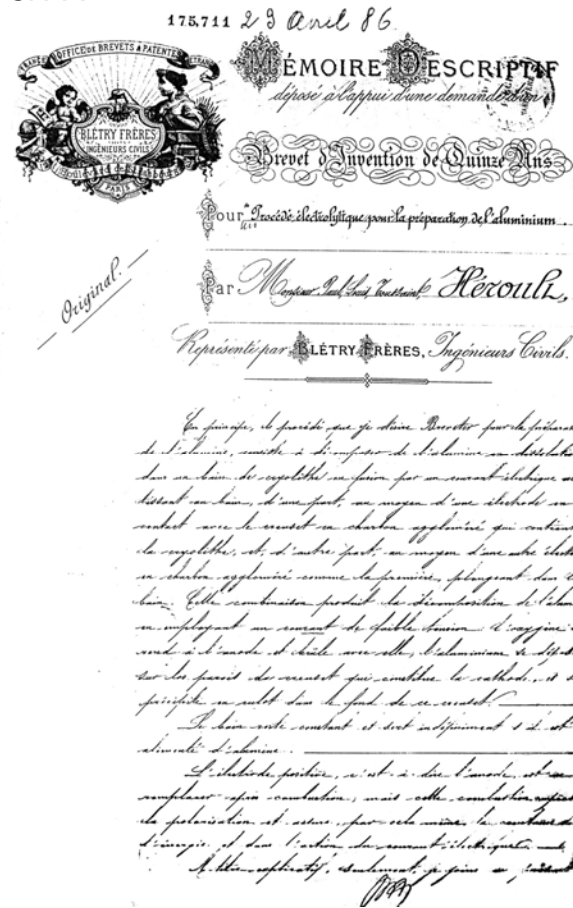
Agrandir Original (jpeg, 220k) ↓

Four à sole pour la fabrication d'aluminium, 1860. On projette par leur regard (E) les produits de la réaction : chlorure double d'aluminium et de sodium, sodium, fluorure de calcium. L'aluminium liquide et la scorie coulent vers le bas de la sole et sont recueillis en (J). Une charge permettait d'obtenir environ 9 kg d'aluminium (longueur env. 5 m, extrait de Figuier, vers 1867-1869).

<https://journals.openedition.org/archeosciences/560>

Source: Poly M&A

Chapitre 3 – Métaux et Alliages – Al & Cu - 57



(a) Document original.

En principe, le procédé que je désire breveter pour la préparation de l'aluminium consiste à décomposer de l'alumine en dissolution dans un bain de cryolithe en fusion par un courant électrique aboutissant au bain, d'une part, au moyen d'une électrode en contact avec le creuset en charbon aggloméré qui contient la cryolithe et, d'autre part, au moyen d'une autre électrode en charbon aggloméré comme la première, plongeant dans le bain. Cette combinaison produit la décomposition de l'alumine en employant un courant de faible tension : l'oxygène se rend à l'anode et brûle avec elle, l'aluminium se dépose sur les parois du creuset qui constitue la cathode, et se précipite en culot dans le fond du creuset.

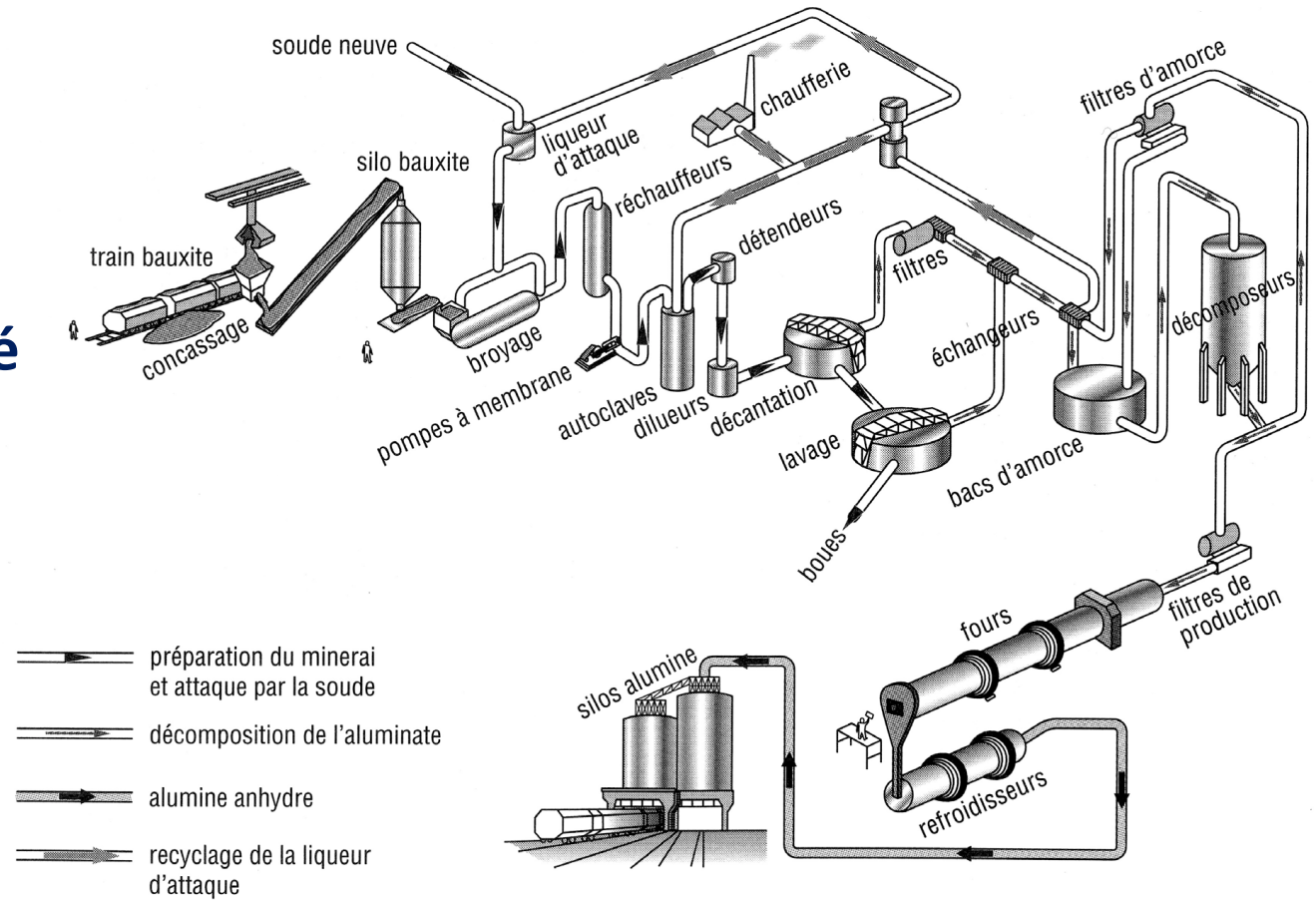
Le bain reste constant et sert indéfiniment s'il est alimenté en alumine.

L'électrode positive, c'est-à-dire l'anode, est à remplacer après combustion, mais cette combustion empêche la polarisation et assure par cela même la constance dans l'énergie et dans l'action du courant électrique.

(b) Texte du brevet.

FIGURE II-3 – Brevet numéro 175711 de P.L.T. Hérault, déposé le 23 avril 1886, Paris.
Source: www.bibnum.education.fr/files/HEROULT_BREVET.pdf (accédé le 2 novembre 2011)

Première étape: procédé Bayer de production de l'alumine



D'après doc. Aluminium Pechiney

FIGURE II-2 – Fabrication d'alumine.

Source: J. Barralis, G. Maeder, *Précis de métallurgie: Élaboration, structure-propriétés, normalisation*, 7^e Édition, Nathan-AFNOR, Paris, 1997.

Source: Poly M&A

Seconde étape: réduction de l'alumine



Source: Poly M&A

FIGURE II-6 – Photo d'une usine d'électrolyse d'aluminium au Kazakhstan, ouverte en 2007.
Source: Kazakhstan electrolysis plant. <http://gelio-nsk.livejournal.com/138008.html> (accédé le 2 novembre 2011).

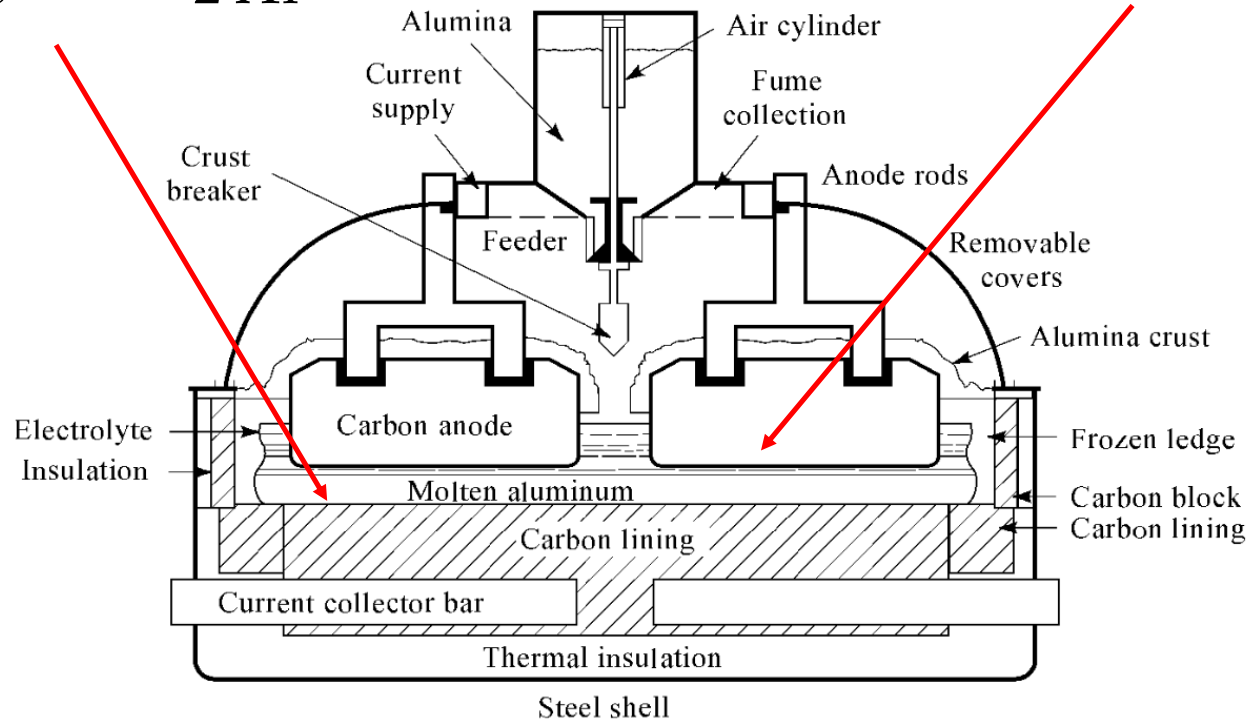
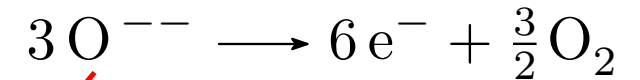
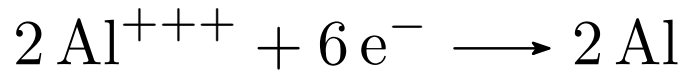


FIGURE II-4 – Anode préchauffées schématisées.

Source: R.E. Kirk, *Encyclopedia of Chemical Technology* Vol. 2, 4th Edition, Wiley Interscience, New York, 1991.

Source: Poly M&A

Extraction de l'aluminium : bilan matière

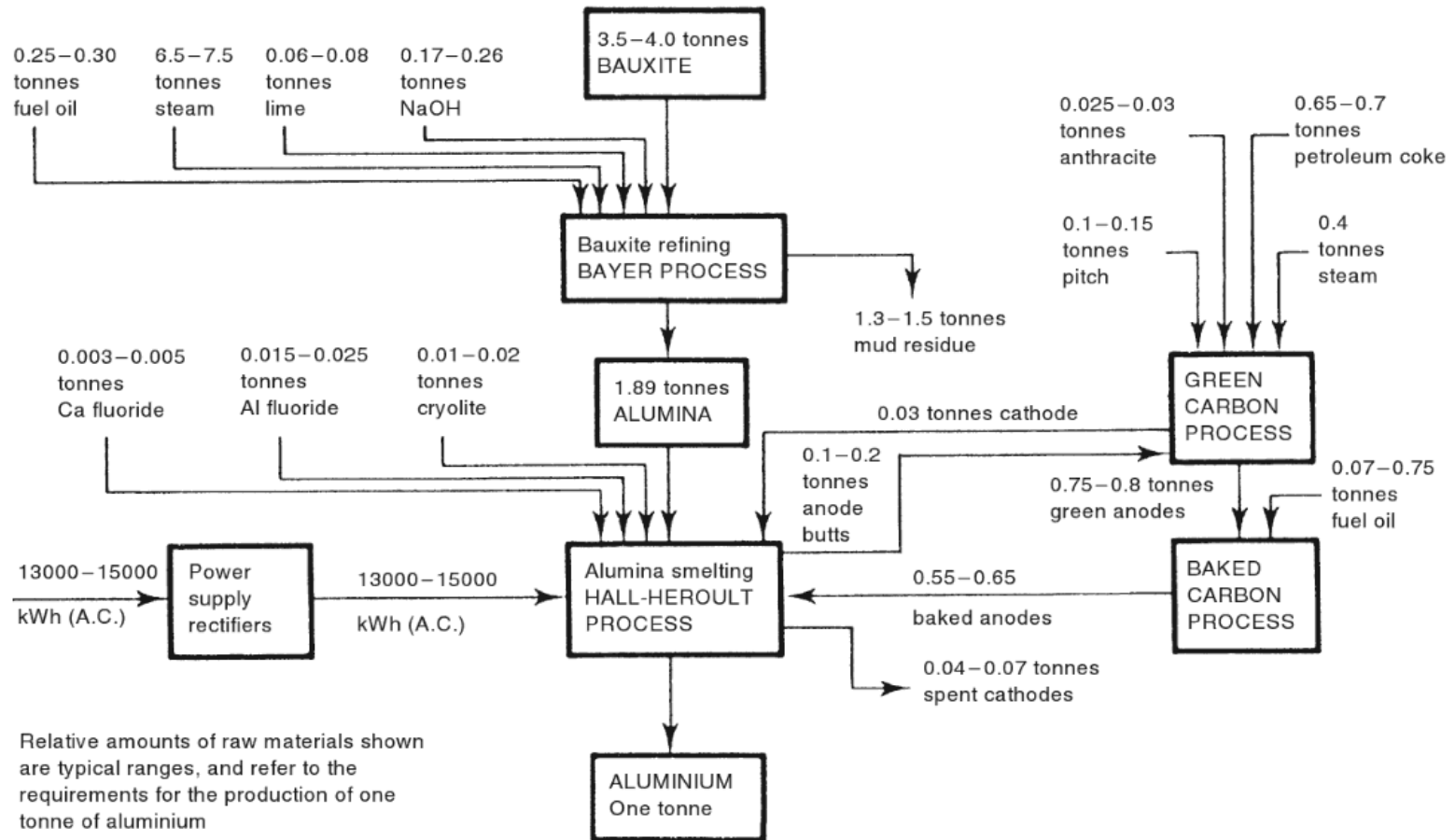


FIGURE II-7 – Bilan global d'extraction de l'aluminium.

Source: I.J. Polmear, *Light Alloys: from traditional alloys to nanocrystals*, Butterworth-Heinemann, 2006 ; courtesy Australian Aluminium Council

Source: Poly M&A

La production mondiale est actuellement de 100 Mtonnes environ; dont 30% environ vient du recyclage.

Il faut de nos jours environ 12 ± 2 kWh/kg d'énergie pour produire l'aluminium à partir de son minerai. La limite théorique est de 6.5 kWh/kg.

Recycler l'aluminium coûte environ 10% de cette valeur (≈ 1 kWh/kg). Mais il y a des limites aux gains possibles (voir diapo 41)

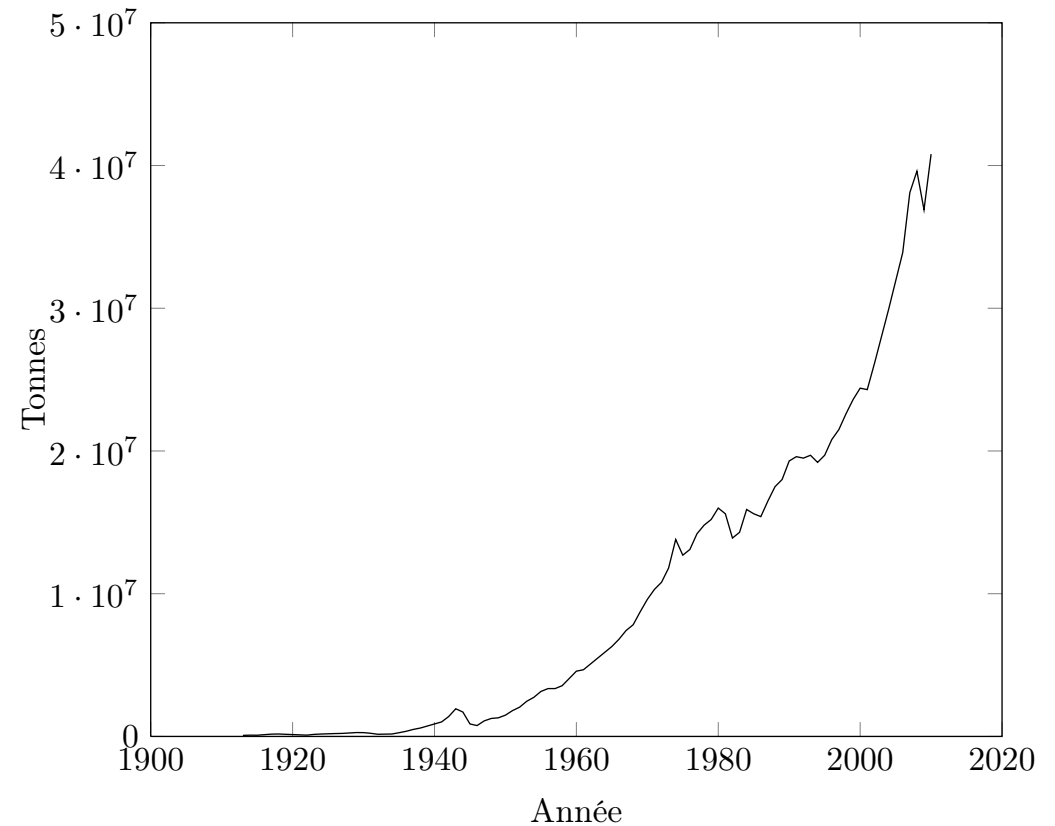


FIGURE II-1 – Production mondiale d'aluminium.
Source: U.S. Geological Survey, British Geological Survey.

Petit exercice: à combien d'accélération de 0 à 100 km/h ces 12 kWh/kg correspondent-ils ?

EPFL Extraction de l'aluminium

Petit exercice: à combien d'accélération de 0 à 100 km/h ces 12 kWh/kg correspondent-ils ?

Réponse: l'énergie cinétique correspondant à une accélération est, par kilogramme

$$\frac{1}{2} m v^2 = (10^5/3'600)^2 / 2 = 386 \text{ Joules/kg}$$

$$12 \text{ kWh/kg} = 43'200 \text{ kJ/kg}$$

$$N = 43'200'000 / 386 = 112'000 \text{ accélération.}$$

Sur 10 ans cela fait $112'000 / 3'650 = 31$ accélération par jour.

...ce qui n'est pas hors de proportion avec la vie courante de bien des personnes. L'utilisation d'un métal léger comme l'aluminium pour économiser du poids dans les transports peut donc mener à des économies d'énergie (à évaluer au cas par cas; notez qu'on n'a par exemple pas regardé les alternatives, voulant dire ce que l'aluminium remplacerait).

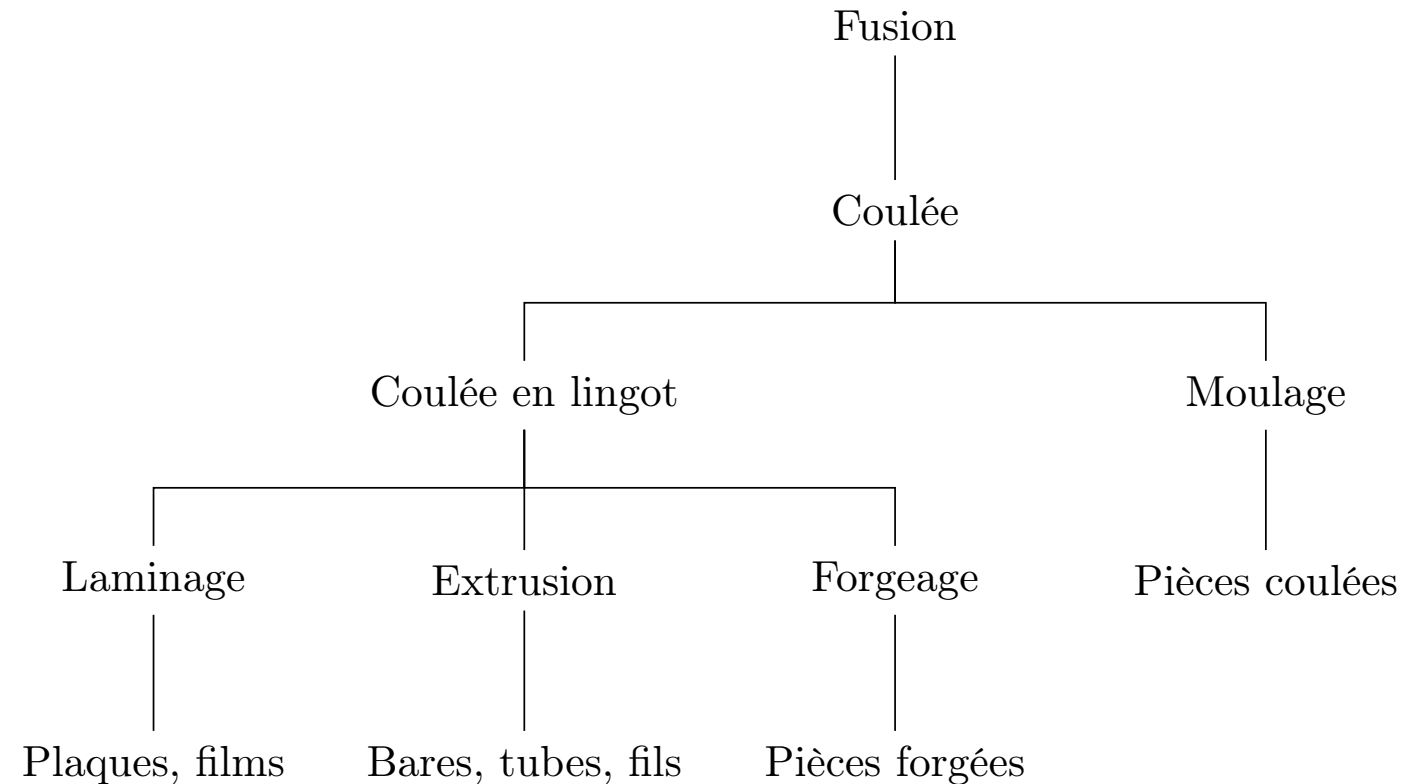
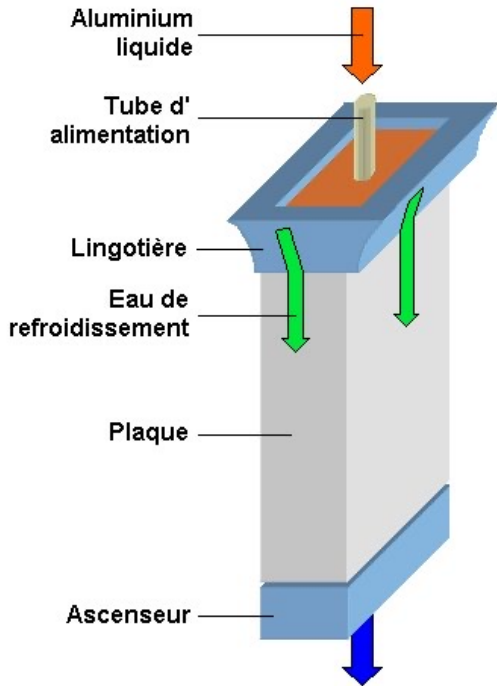
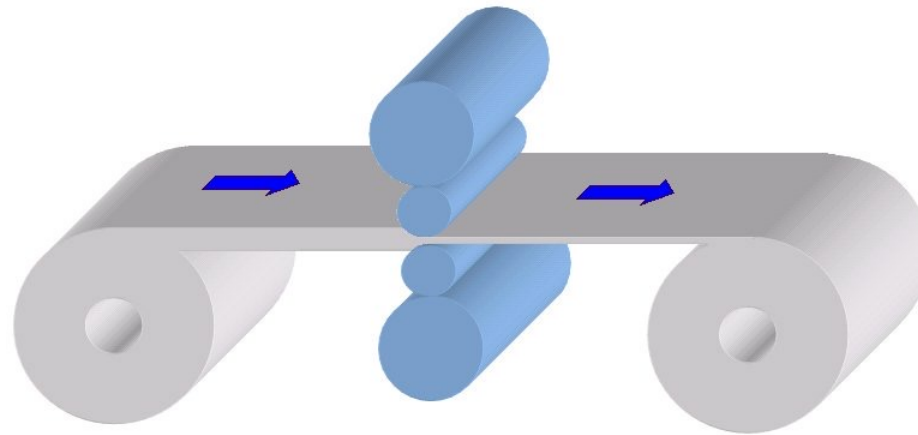


FIGURE II-9 – Opérations et procédés de mise en forme de l'aluminium.

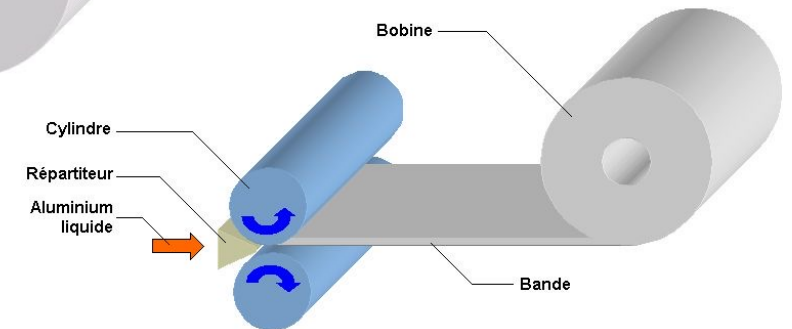
EPFL Mise en forme de l'aluminium: les produits plats et le laminage



Coulée continue



Laminage



Coulée directe en bande

Sources:

Par Original uploader was Wikifab at fr.wikipedia — Transferred from fr.wikipedia; transferred to Commons by User:Bloody-libu using CommonsHelper, Domaine public, <https://commons.wikimedia.org/w/index.php?curid=17946212>

Par Wikifab sur Wikipédia français — Transféré de fr.wikipedia à Commons par Bloody-libu utilisant CommonsHelper, Domaine public, <https://commons.wikimedia.org/w/index.php?curid=17946211>

Par wikifab — Travail personnel, Domaine public, <https://commons.wikimedia.org/w/index.php?curid=3187051>

à https://fr.wikipedia.org/wiki/Fabrication_des_feuilles_et_bandes_d%27aluminium

Chapitre 3 – Métaux et Alliages – Al & Cu - 66

EPFL Mise en forme de l'aluminium: l'extrusion

Un site web avec une bonne description du procédé

<https://www.gabrian.com/what-is-aluminum-extrusion-process/>

Site industriel montrant le procédé à grande échelle et de façon assez complète tant l'extrusion que la coulée continue de l'aluminium:

<https://www.youtube.com/watch?v=baM5hNnBcT8>



Mise en forme de l'aluminium: le forgeage

Exemple d'entreprise suisse

<https://www.imbach.com/fr/procede-de-production/forgeage-libre.html>

<https://www.imbach.com/fr/procede-de-production/matricage-a-chaud.html>

Nota: sur ces films on voit surtout le forgeage de l'acier.

Autre site web industriel assez complet sur le forgeage:

<https://www.farinia.com/fr/blog/forge-froid-vs-forge-chaud-explications-avantages-et-inconvenients#Le%20proc%C3%A9d%C3%A9%20de%20fabrication%20de%20forge%20%C3%A0%20froid>

Source image: <https://www.prodiu.fr/Sous-Traitance/metallurgie/forgeage-i247.html>

Chapitre 3 – Métaux et Alliages – Al & Cu - 68

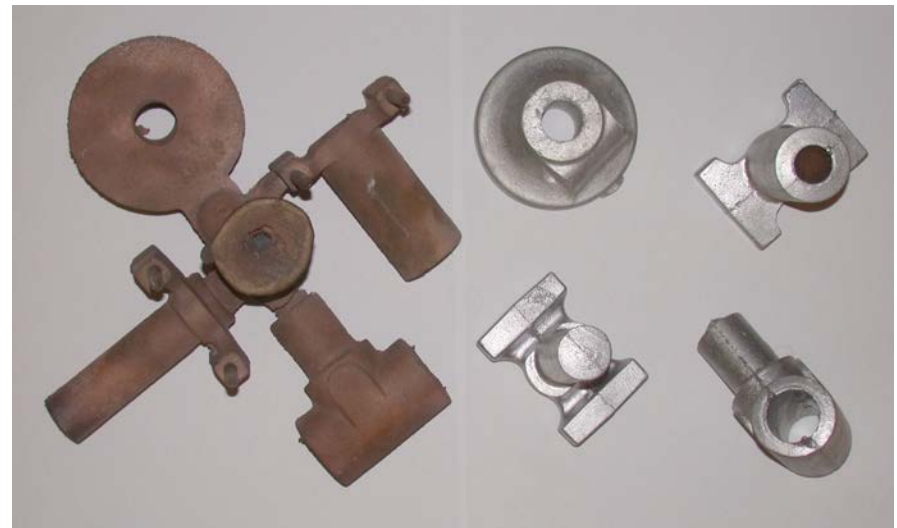
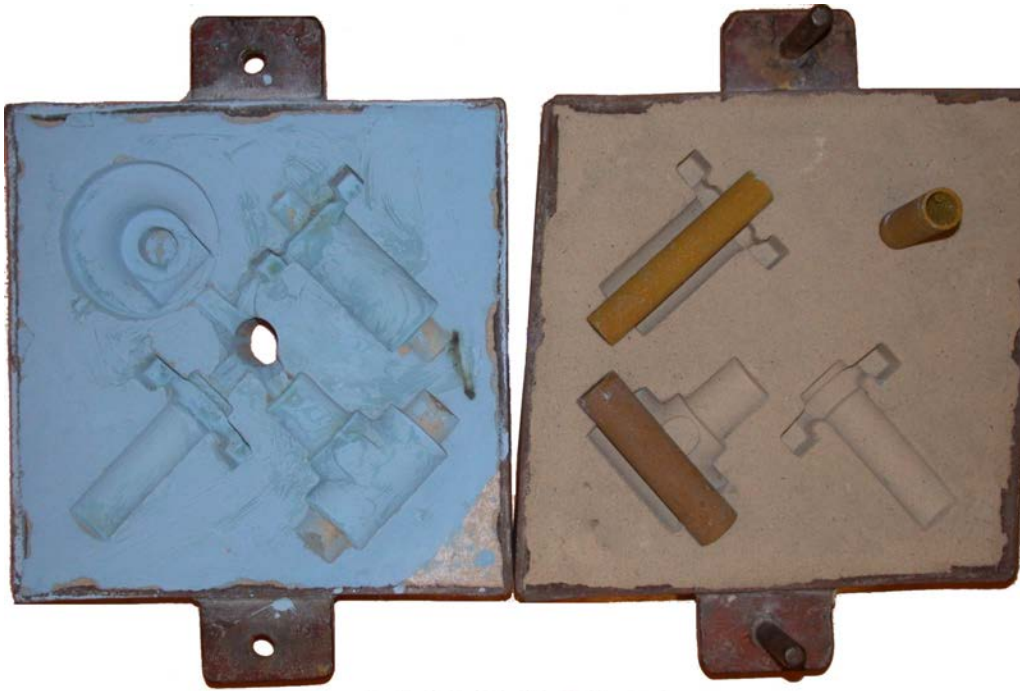


Forgeage alu à chaud



Mise en forme de l'aluminium: la coulée et les procédés de fonderie (casting and foundry processes)

Coulée en moule de sable (sand casting)



Images: By Photograph taken by Glenn McKechnie - Own work, CC BY-SA 2.0, <https://commons.wikimedia.org/w/index.php?curid=109984>
By Photograph taken by Glenn McKechnie - Own work, CC BY-SA 2.0, <https://commons.wikimedia.org/w/index.php?curid=109988>
à https://en.wikipedia.org/wiki/Sand_casting

Mise en forme de l'aluminium: la coulée et les procédés de fonderie (casting and foundry processes)

Coulée à la cire perdue
(lost wax casting)

images de

<https://www.cnstatue.com/what-is-lost-wax-casting-process.html>

reproduites et
commentées sur

https://en.wikipedia.org/wiki/Lost-wax_casting

(nota: ici il s'agit de
bronze)



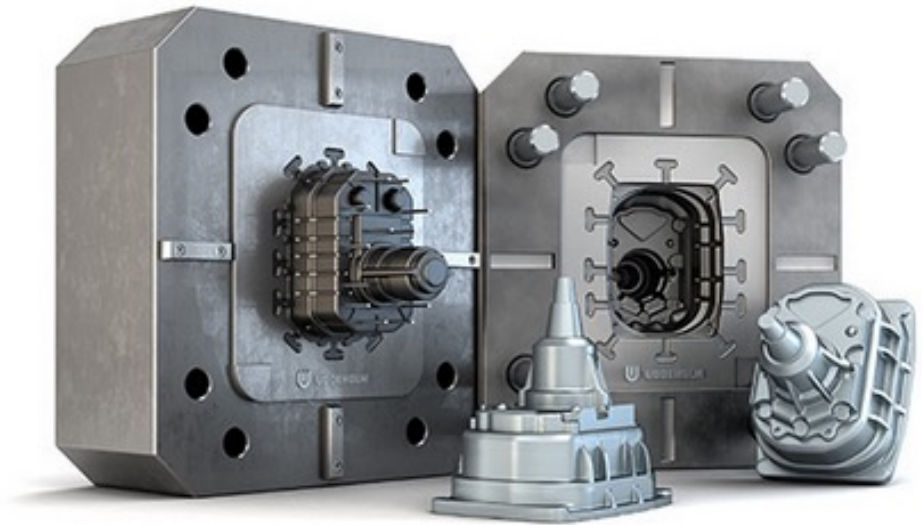
Mise en forme de l'aluminium: la coulée et les procédés de fonderie (casting and foundry processes)

Site industriel décrivant assez bien le
procédé de coulée en moule permanent
(permanent mold casting)

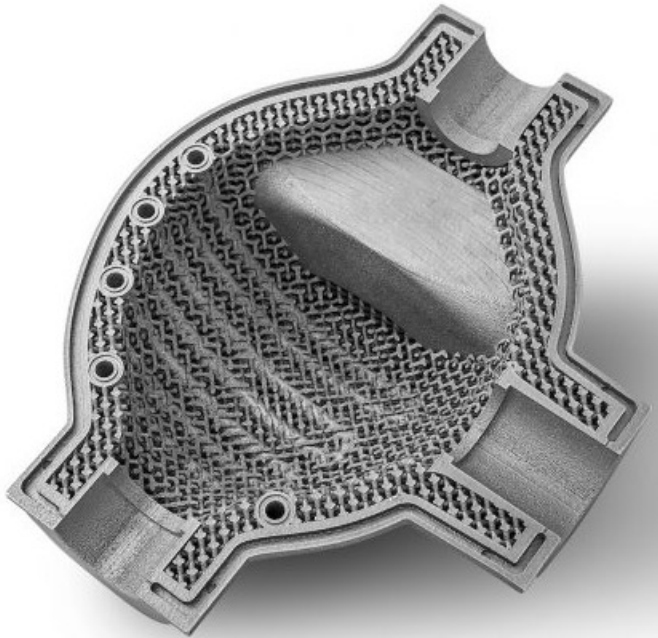
<https://www.youtube.com/watch?v=lsITWA9o7Lg>

Fabricant (majeur) suisse de machines de
coulée à haute pression (pressure die
casting machines)

<https://www.buhlergroup.com/content/buhlergroup/global/fr/product-families/die-casting-machines.html>



Mise en forme de l'aluminium: L'impression 3D (3D printing = freeform manufacturing)



images: <https://www.lightmetalage.com/news/industry-news/3d-printing/article-additive-manufacturing-of-aluminum-alloys/>

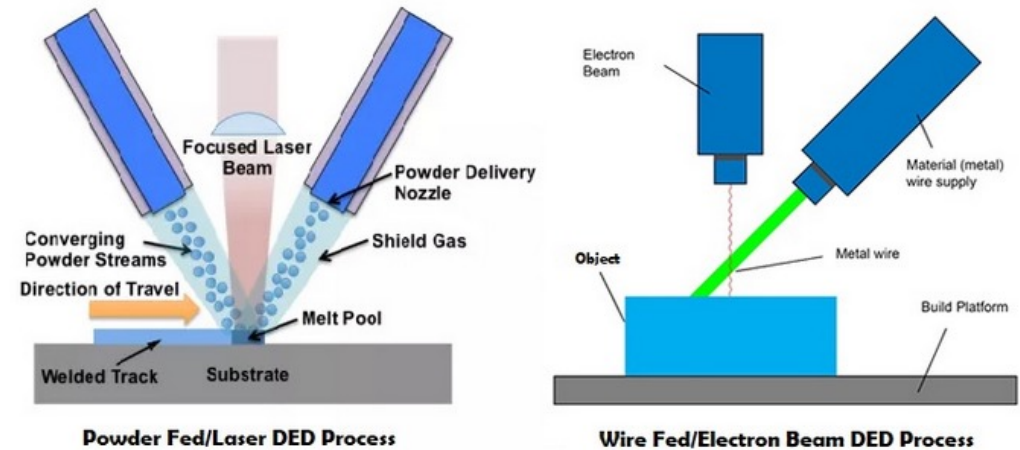


Figure 2. Schematic diagram of DED processes to produce AM metal parts utilizing either metallic powder or wire, although several variations exist for energy source and material requirements.

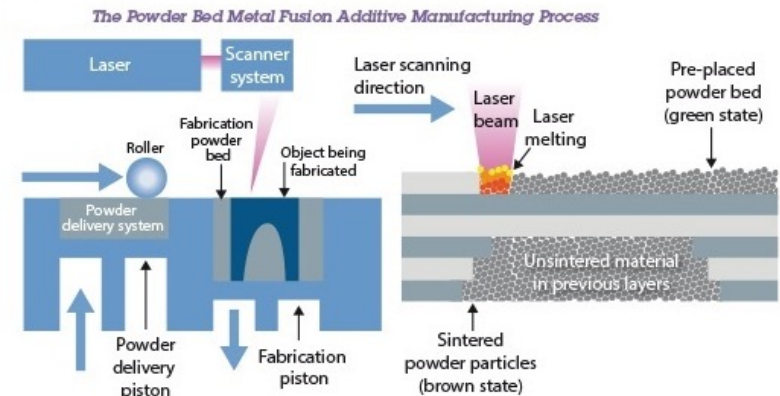


Figure 3. Schematic diagram of PBF processes to produce AM metal parts utilizing metallic powder, although several variations exist for energy source and material requirements.

Mise en forme de l'aluminium: L'impression 3D (3D printing = freeform manufacturing)

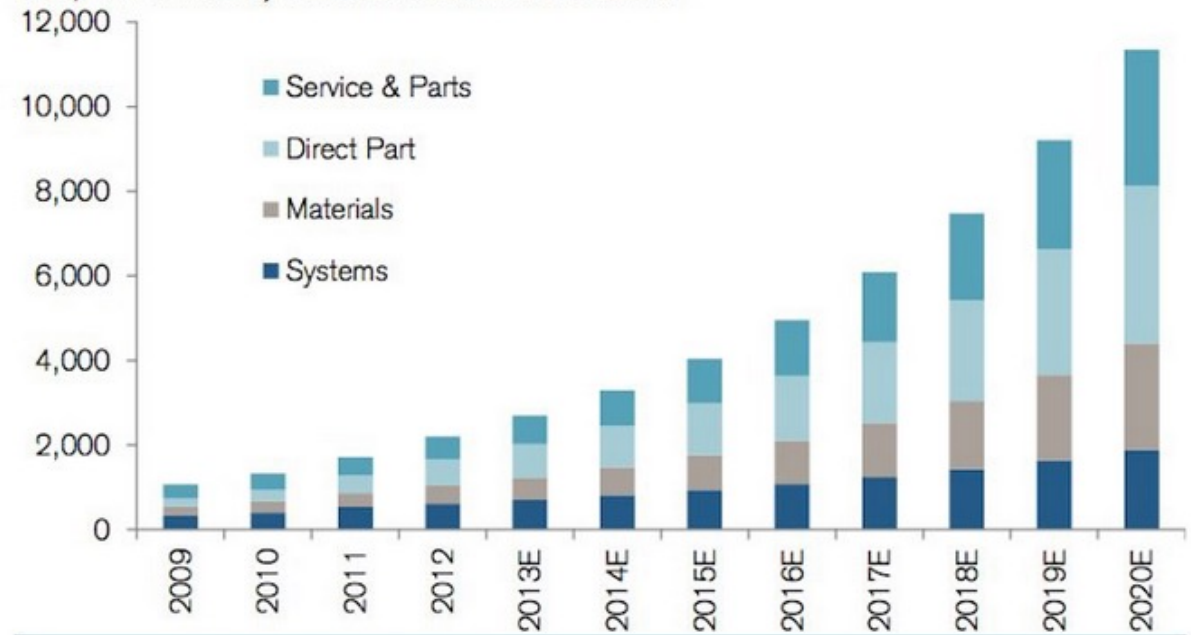
Sites décrivant assez bien le procédé et un appareil (commercial) de fusion de poudre par laser (SLM = Selective Laser Melting); notez que ce ne sont pas les seuls fabricants de tels appareils:

<https://www.youtube.com/watch?v=VqjtuFxGio4>

<https://www.youtube.com/watch?v=IUp3oCGZOzk>

Primary Global AM Market

US\$ in millions, unless otherwise stated



Source: Credit Suisse estimates.

Figure 1. Summary of Credit Suisse business report issued in the fall of 2013 on the AM/3D printing market growth estimating that opportunities in aerospace, automotive, health care, and consumer markets will sustain a growth rate of 20-30% in the future.[2]

Image: <https://www.lightmetalage.com/news/industry-news/3d-printing/article-additive-manufacturing-of-aluminum-alloys/>

The Pilling–Bedworth ratio (P–B ratio), in corrosion of metals, is the ratio of the volume of the elementary cell of a metal oxide to the volume of the elementary cell of the corresponding metal (from which the oxide is created).

On the basis of the P–B ratio, it can be judged if the metal is likely to passivate in dry air by creation of a protective oxide layer.



Un attribut important de l'aluminium

Contents

[Definition](#)

[History](#)

[Application](#)

[Values](#)

[References](#)

l'aluminium est comme on l'a vu très stable (voir diagramme d'Ellingham). Il a un attribut qui fait qu'il protège le métal très efficacement contre la corrosion: l'alumine et sa faible réactivité avec l'environnement, l'alumine forme une couche d'oxyde compatible avec l'aluminium dont elle est issue. Ceci est mesuré par le rapport de Pilling et Bedworth, qui s'il est près de l'unité laisse attendre un oxyde qui se forme sans fissures ni recouvrement, et donc protège le métal sur la surface duquel il s'est formé. On dit que son oxyde passif (passivates) l'aluminium.

The P–B ratio is defined as:^[1]

$$R_{PB} = \frac{V_{\text{oxide}}}{n \cdot V_{\text{metal}}} = \frac{M_{\text{oxide}} \cdot \rho_{\text{metal}}}{n \cdot M_{\text{metal}} \cdot \rho_{\text{oxide}}}$$

where:

- R_{PB} – Pilling–Bedworth ratio
- M – atomic or molecular mass
- n – number of atoms of metal per molecule of the oxide
- ρ – density
- V – molar volume



https://en.wikipedia.org/wiki/Pilling%E2%80%93Bedworth_ratio

By DerSilberspiegel - Own work, CC BY-SA 4.0,

<https://commons.wikimedia.org/w/index.php?curid=67158237>

N.B. Pilling and R.E. Bedworth^[2] suggested in 1923 that metals can be classed into two categories: those that form protective oxides, and those that cannot. They ascribed the protectiveness of the oxide to the volume the oxide takes in comparison to the volume of the metal used to produce this oxide in a corrosion process in dry air. The oxide layer would be

TABLE II-1 – Consommation d'aluminium aux États-Unis et au Canada en 2009.
Source: U.S. Geological Survey, *Aluminum statistics*, 2010.

Catégorie	Tonnes	Proportion
Consommables et emballages	2'150'000	32%
Construction	964'000	14%
Transports	1'190'000	28%
Electricité	593'000	9%
Biens durables	458'000	7%
Machines et équipement	475'000	7%
Autres	254'000	4%
Total	6'810'000	