Deutsches Kupferinstitut
Copper Alliance

Possibilities and Limits of Lead Substitution in Copper Alloys

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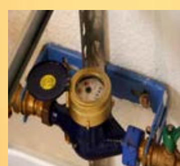
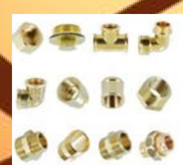








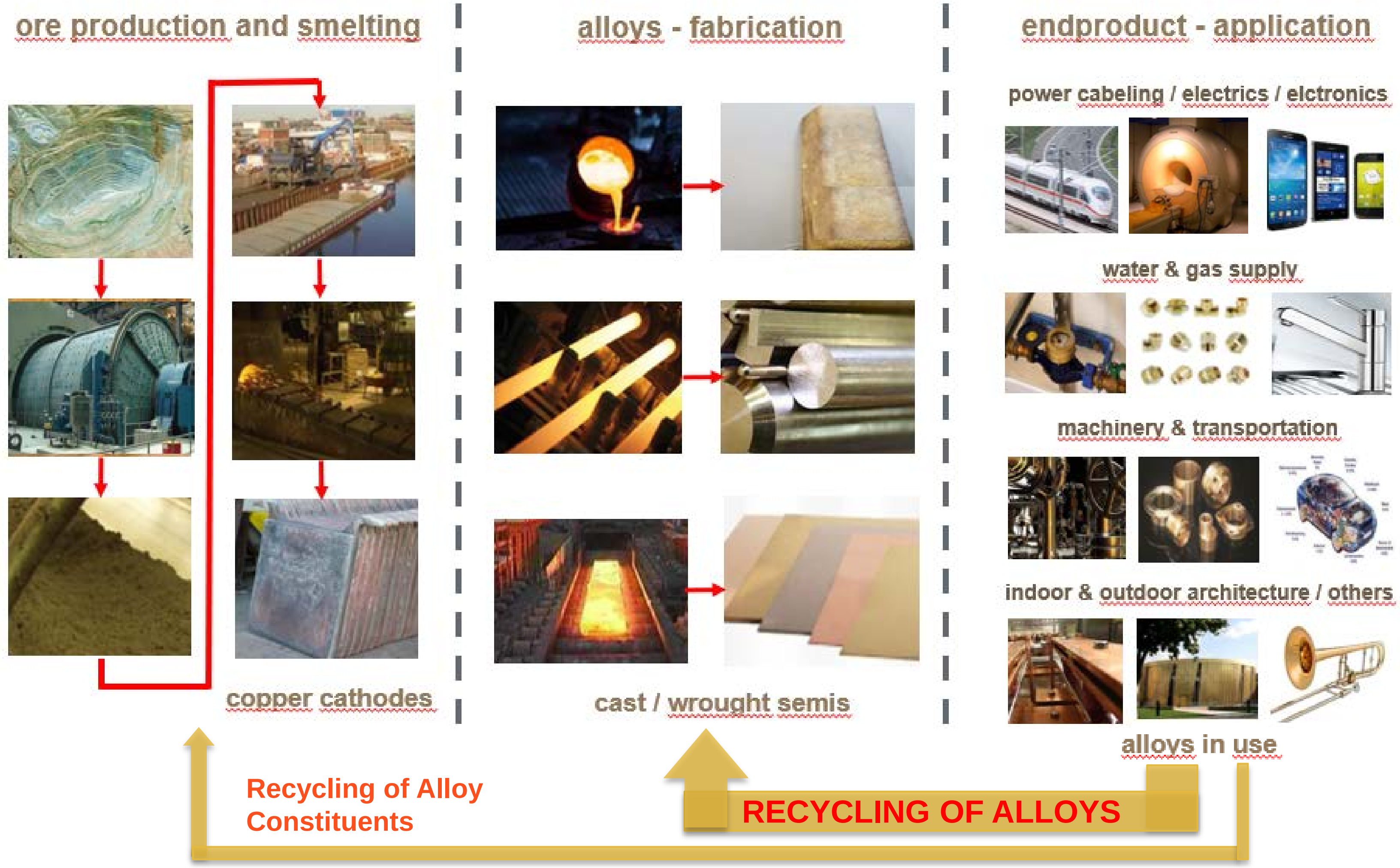


AGENDA

- ***briefing:*** copper alloys – from source to application
- ***briefing:*** why alloying?
- ***industry efforts for substitution:*** example from the past
- ***search for lead alternatives:*** R & D and challenges
- ***take home***

copper alloys - overview

from source to application – a long way



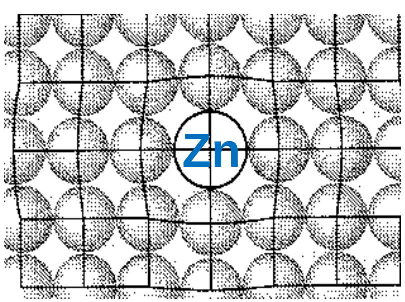
alloying copper – what for?

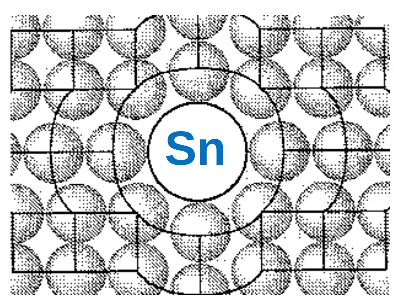
(1) adopt properties to meet technical requirements

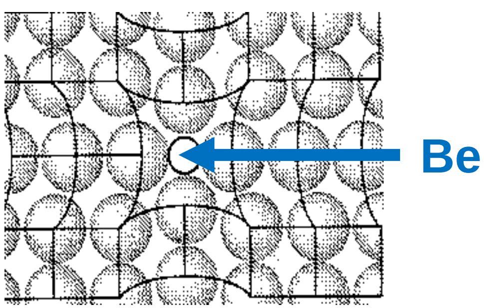
- masse ↗
- atoms radius ↗
- electronegativity ↘
- ionization energy ↘
- metallic character ↗

	main													groups					
	I	II												III	IV	V	VI	VII	VIII
1	H																		He
2	Li	Be												B	C	N	O	F	Ne
3	Na	Mg		subgroups										Al	Si	P	S	Cl	Ar
4	K	Ca		Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr		Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	La …	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
	Fr	Ra	Ac …	Lr	Rf	Db	Sg	Bh	Hs	Mt									

- masse ↗
- atoms radius ↘
- electronegativity ↗
- ionization energy ↗
- metallic character ↘

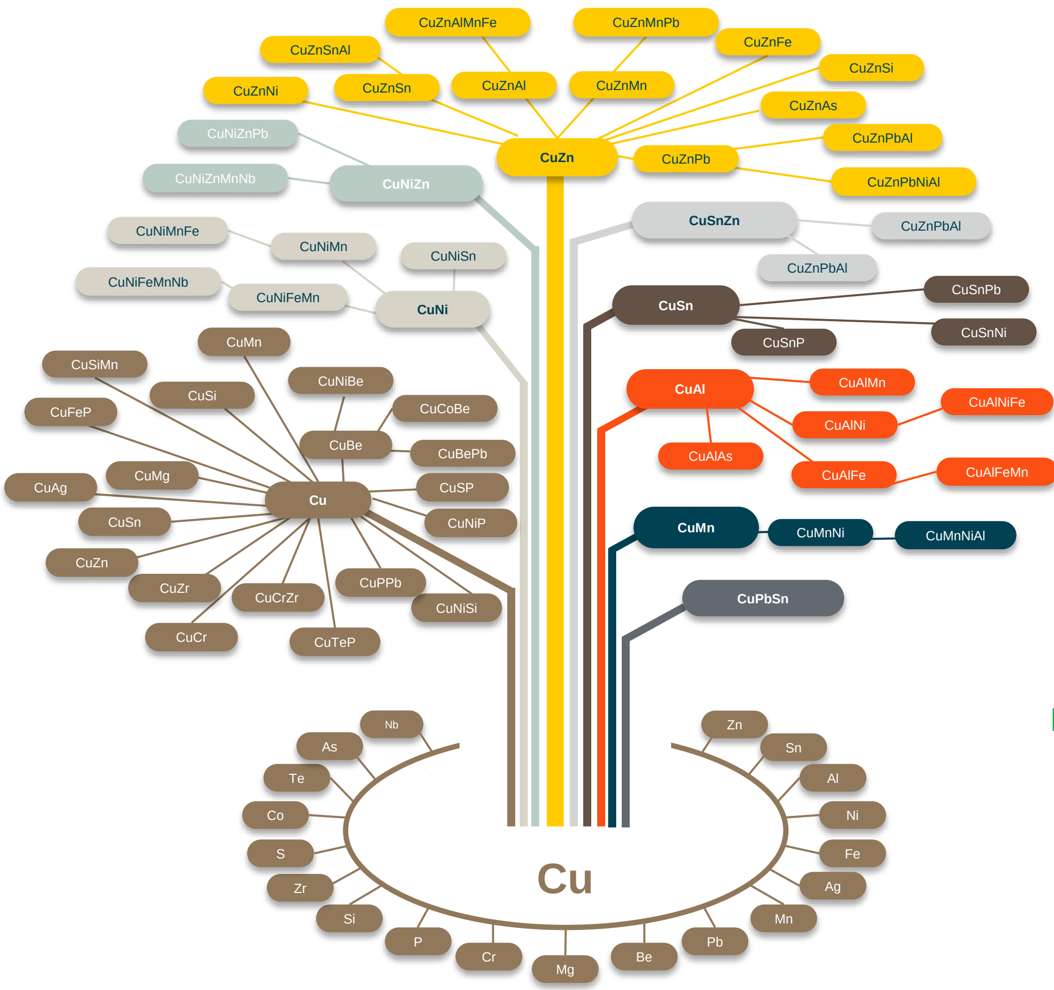


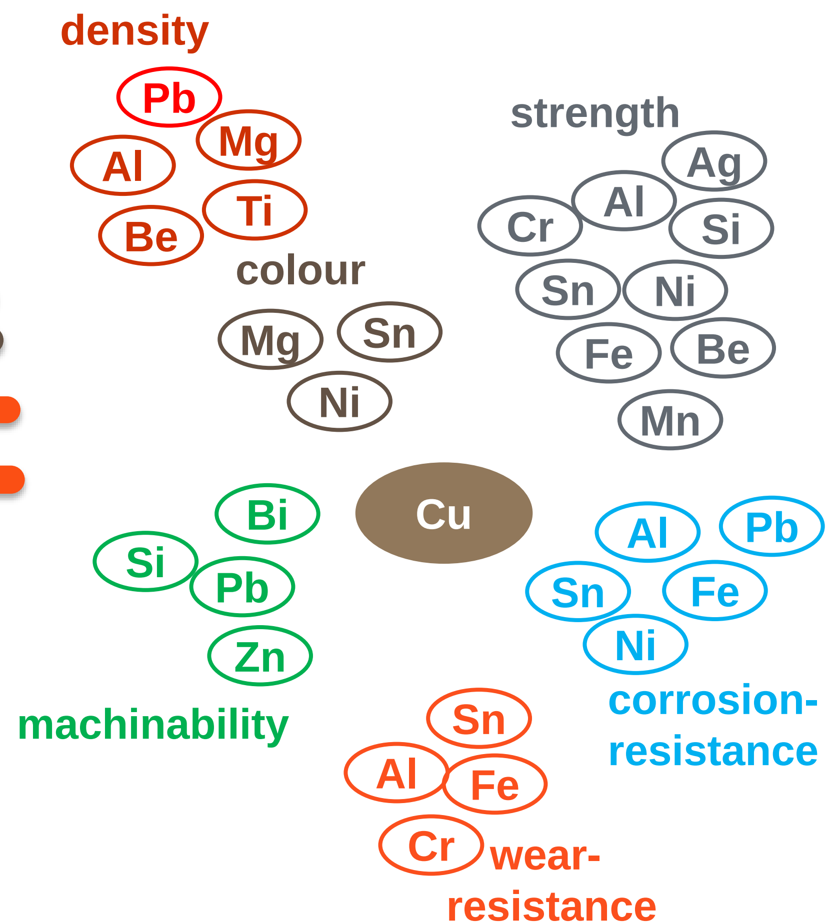




alloying copper – what for?

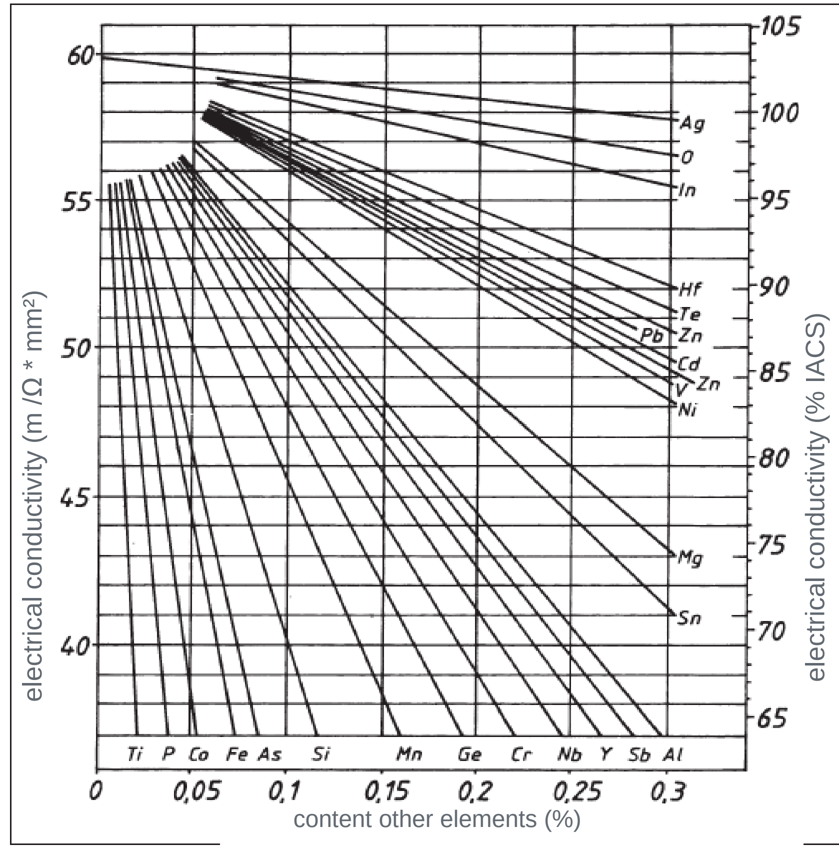
(2): alloying elements





alloying copper – what for?

(3): e. g. steering (just) 2 properties for a specific application – challenging enough



power cables - demands:

- high strength under mech. stress conditions
- keep high elect. conductivity

technical solutions: Cu-Mg or ~~Cu-Cd Alloys~~

market solution: Cu-Mg

substitution of lead

(1) screening the periodic system

Periodic Table of the Elements

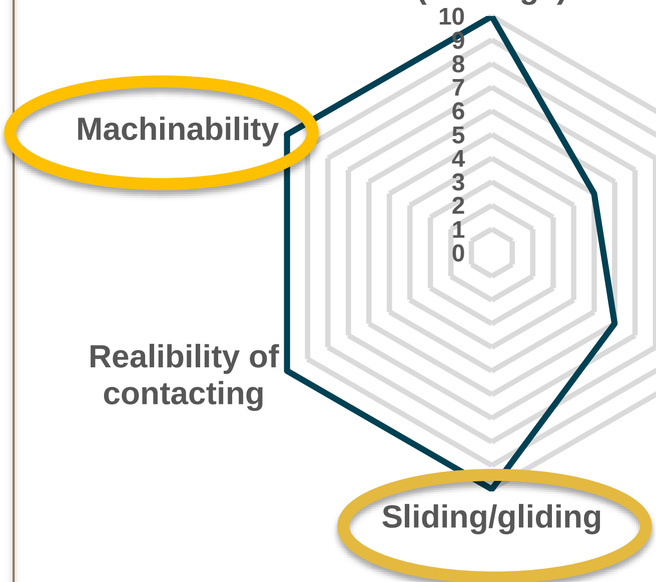
IA 1	IIA 2	IIIB 3	IVB 4	VB 5	VIB 6	VIIB 7	8	VIII 9	10	IB 11	IIB 12	IIIA 13	IVA 14	VA 15	VIA 16	VIIA 17	VIIIA 18
1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.98	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.409	31 Ga 69.723	32 Ge 72.64	33 As 74.921	34 Se 78.96	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.904	54 Xe 131.293
55 Cs 132.905	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	103 Lr (262)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)	111 Rg (272)	112 Cn (285)	113 Nh (284)	114 Fl (289)	115 Mc (288)	116 Lv (293)	117 Ts (294)	118 Og (294)

57 La 138.906	58 Ce 140.116	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.925	66 Dy 162.500	67 Ho 164.930	68 Er 167.259	69 Tm 168.934	70 Yb 173.04
89 Ac 227.028	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)

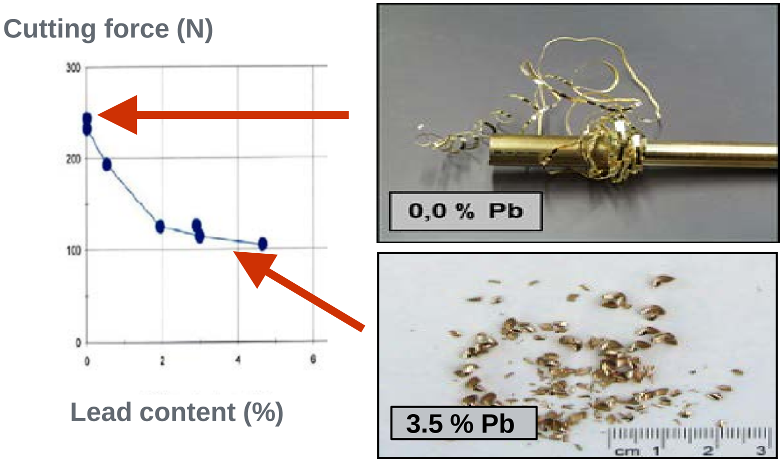
substitution of lead

(2) properties of lead

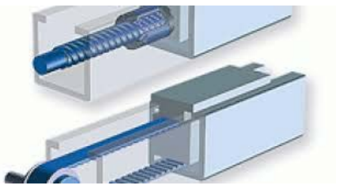
MANY technical properties of Pb



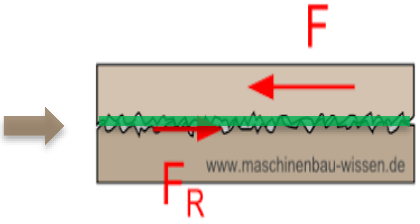
e. g. machinability: cutting forces & chip braking



e. g. sliding / gliding



dry-running:
low coefficient of friction…

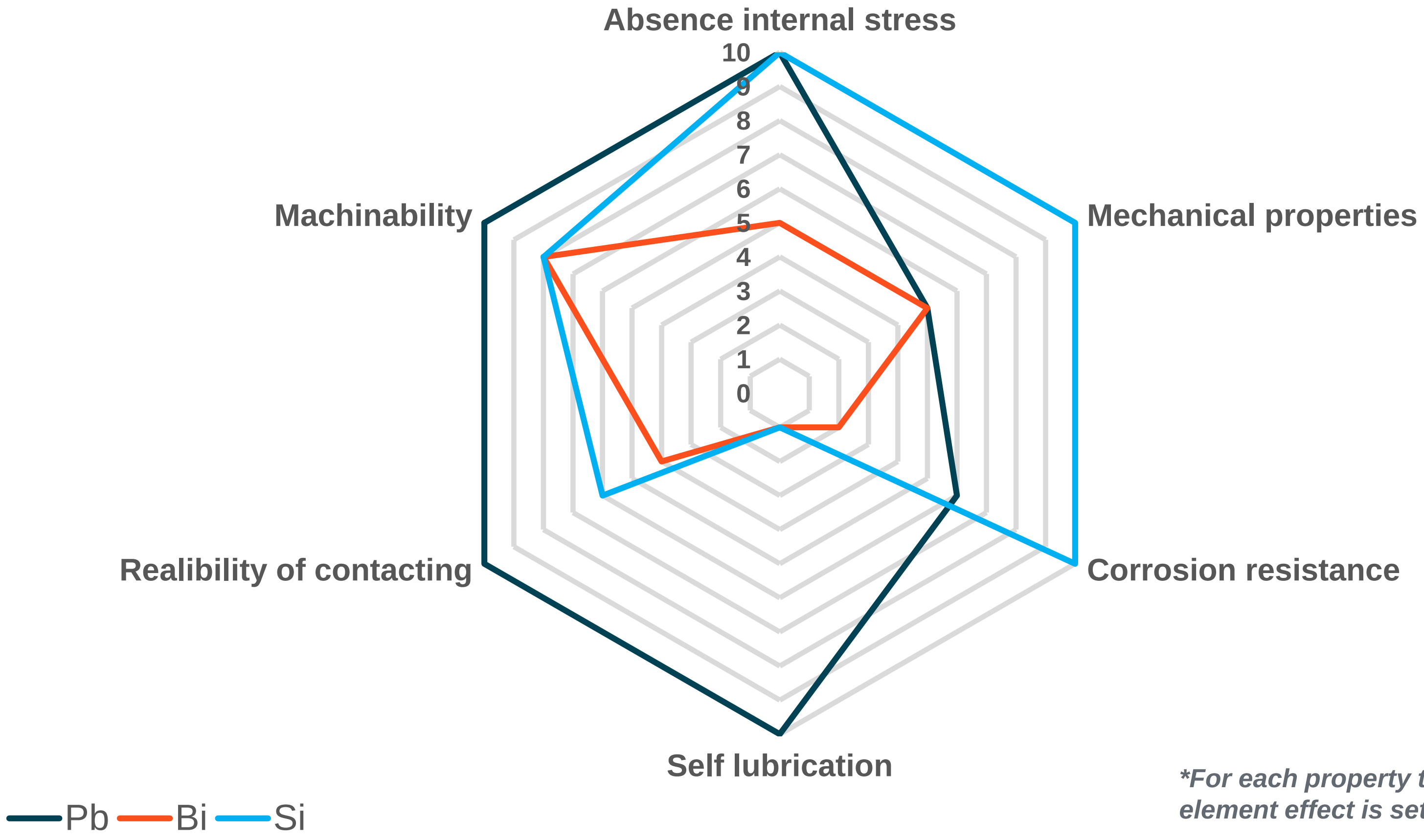


dry-running:
due to the low friction layer

Pb technically not easy to replace → the „*one size fits all*“ problem

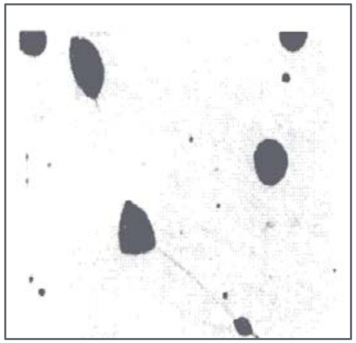
substitution of lead

(3) comparison with the 2 substitution favourites

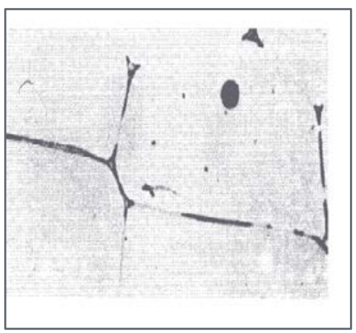


**For each property the best element effect is set to „10“*

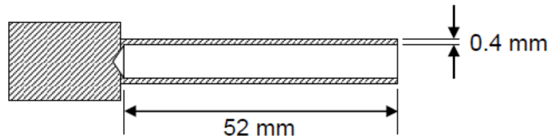
substitution of lead
(4) results on Bi research (a)



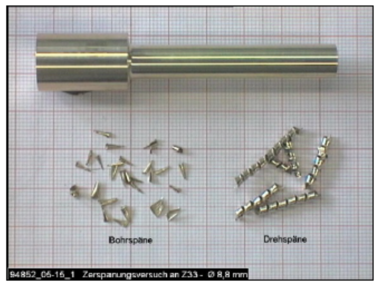
Lead



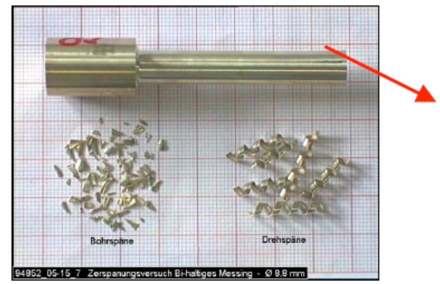
Bismuth



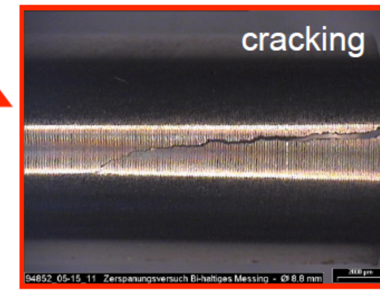
Turning: vc = 111 m/min, f = 0,1 mm
Drilling: vc = 80 m/min, f = 0.2 mm
no lubricants



wrought CuZn39Pb3 (150 HB)



wrought CuZn40Bi1.5 (104 HB)



wrought CuZn40Bi1.5 (104 HB)

Source: Wieland

- **Bi particles expand during solidification**

  → high susceptibility for stress corrosion cracking

- **Bi containing alloys cannot match wrought leaded alloys in terms of reliability of machined parts**

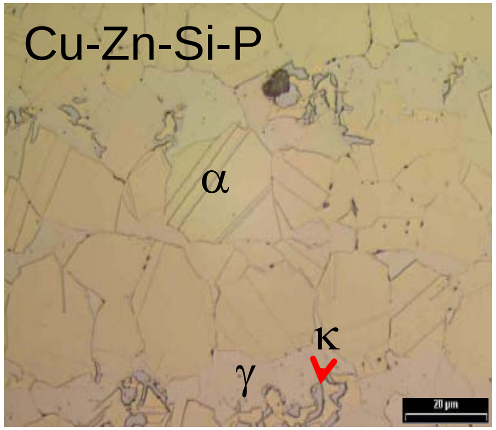
  → complex machining operations cannot be realized with Bi containing alloys

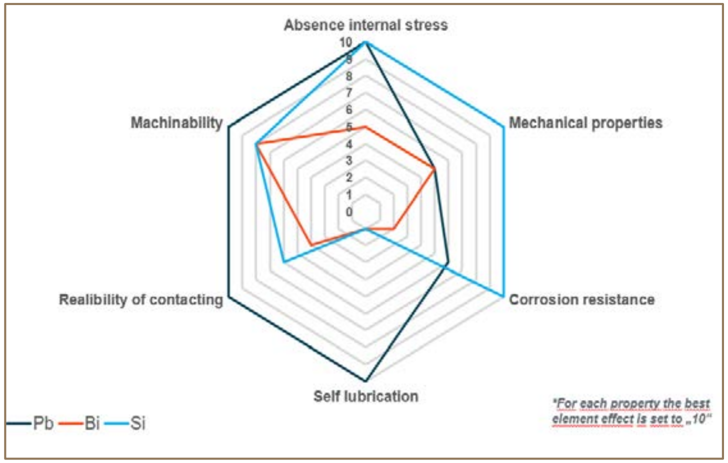
substitution of lead

(4) results on Bi research (b)

substitution of lead

(5) results on Si research





- ➢Silicon confers free cutting ability and high strength
- ➢But a new phase appears → no lubrificating behaviour and changes in the forming ability

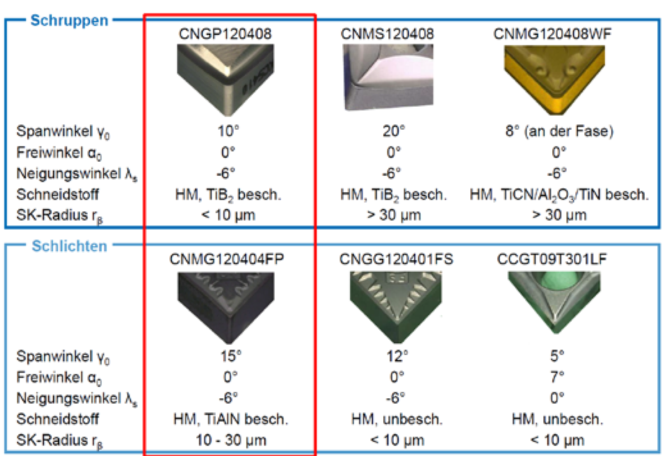
challenges to be solved -
further down stream (1): technical needs

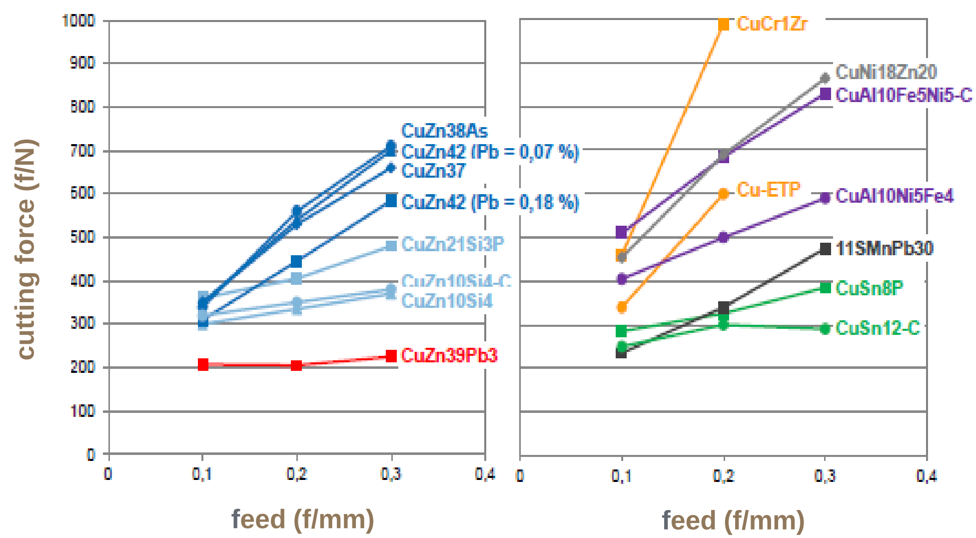
just to mention: * it took > 1 decade to adopt down stream world to use of Si brasses
* still: many technical applications and needs NOT covered by actual solutions

domino effects of a new alloy on R & D downstream:

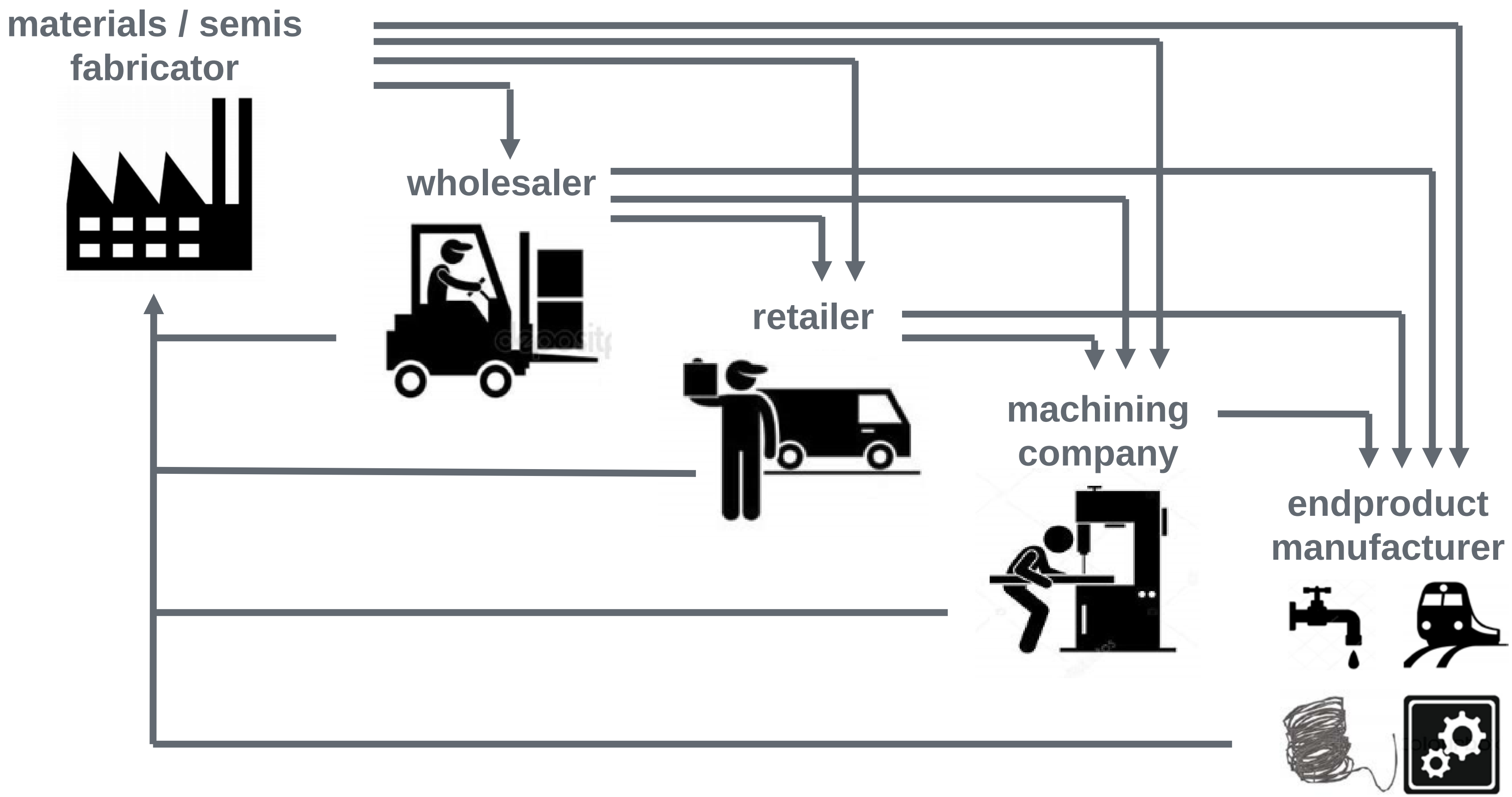
- development / adoption lubricants
- development processes
- development machining tools

R & D cutting tools:





challenges to be solved -
further down stream (2): communication



TAKE HOME

- *Leaded copper alloys in use / needed for ALL AREAS of TECHNOSPHERE*
- *Cu-industry CONTINUOUSLY driving Cu alloys R & D (incl. search for critical elements substitution)*
- *Pb OUTSTANDING as ENABLER for MANY technical alloy properties*

→ ***Technical properties of Pb in alloys can PARTLY be taken over by other elements but <u>NO SOLUTION „ONE FITS ALL“</u>***

→ ***Proposed alternatives show limits:***

- ***Cu-Zn-Si-alloys: approved „good material“ but LIMITED in application spectrum***
- ***Cu-Zn-Bi-alloys: limited in application spectrum and to suffer from damages & non-recyclability***

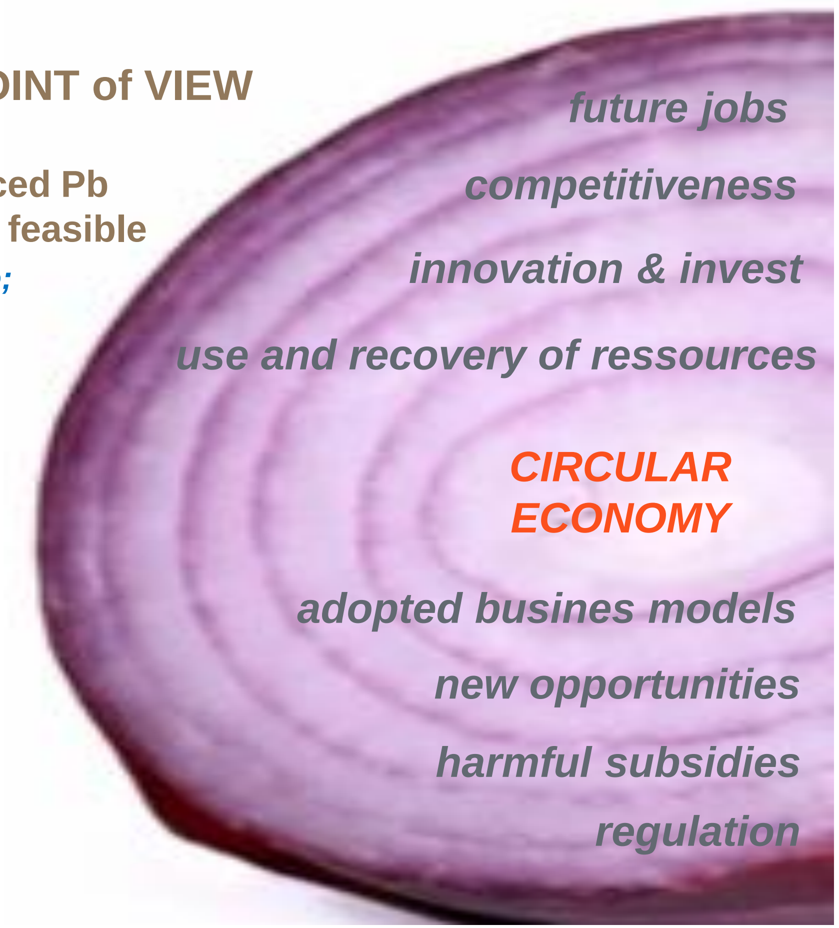
RESOURCE EFFICIENT EUROPE

- an ONION with many shells, challenges and demands

Cu

Pb containing Cu alloys:
necessities & questions from a TECHNICAL POINT of VIEW

- ***technical limits:*** Cu-industry has significantly reduced Pb use in Cu-alloys over time and as far as technically feasible
  - → ***no restrictions unless sustainable alternatives available; support R & D on alternatives***
  - → ***no restriction on use of Pb containing alloys where safe use is given***
- ***products in use (urban stock):***
  lasts for decades or even centuries. Pb-delution?
  - → ***keep functioning recycling loops (existing standards)***
  - → ***secure future use of scrap***
  - → ***avoid regrettable substitution***
- ***conflicting interests:***
  - → ***resource efficiency policy vs. chemicals policy***
  - → ***chemicals policy vs. resource efficiency policy***



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Thank you for listening

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