

# Critical Materials: A Status Report

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# Elements Designated as Critical

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	57 La	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	
			†															
			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		

U.S. critical

E.U. critical

U.S. and E.U. critical

T. Graedel et al.,  
In review, 2020

# 2018 U.S. NET IMPORT RELIANCE

<u>Commodity</u>	<u>Percent</u>	<u>Major import sources (2018)</u>
ARSENIC (trioxide)	100	Morocco, China, Belgium
ASBESTOS	100	Brazil, Russia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, Vietnam, South Africa
GALLIUM	100	China, United Kingdom, Germany
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	China, Canada, Republic of Korea
MANGANESE	100	South Africa, Gabon, Australia
MICA (sheet, natural)	100	China, Brazil, Belgium, Australia
NEPHELINE SYENITE	100	Canada
NIOBIUM (columbium)	100	Brazil, Canada, Russia, Germany
RARE EARTHS (compounds and metals) <sup>3</sup>	100	China, Estonia, France, Japan
RUBIDIUM	100	Canada
SCANDIUM	100	Europe, China, Japan, Russia
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	Brazil, Rwanda, Australia, Canada
THORIUM	100	India, United Kingdom
VANADIUM	100	Austria, Canada, Republic of Korea
GEMSTONES	99	India, Israel, Belgium, South Africa
BISMUTH	96	China, Belgium, Mexico, France
YTTRIUM	>95	China, Estonia, Japan, Republic of Korea
POTASH	92	Canada, Russia, Belarus, Brazil
TITANIUM MINERAL CONCENTRATES	91	South Africa, Australia, Canada

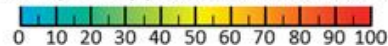
# Companionality: Metals present as minor constituents of the ores of host metals rather than in their own ore deposits

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57-71	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon

N. Nassar et al.,  
*Sci. Adv.* 1 (3),  
E1400180, 2015

<b>Lanthanide series</b>	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
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% of metal's global primary production obtained as companion

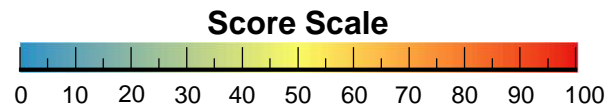


# The Substitute Performance of Metals

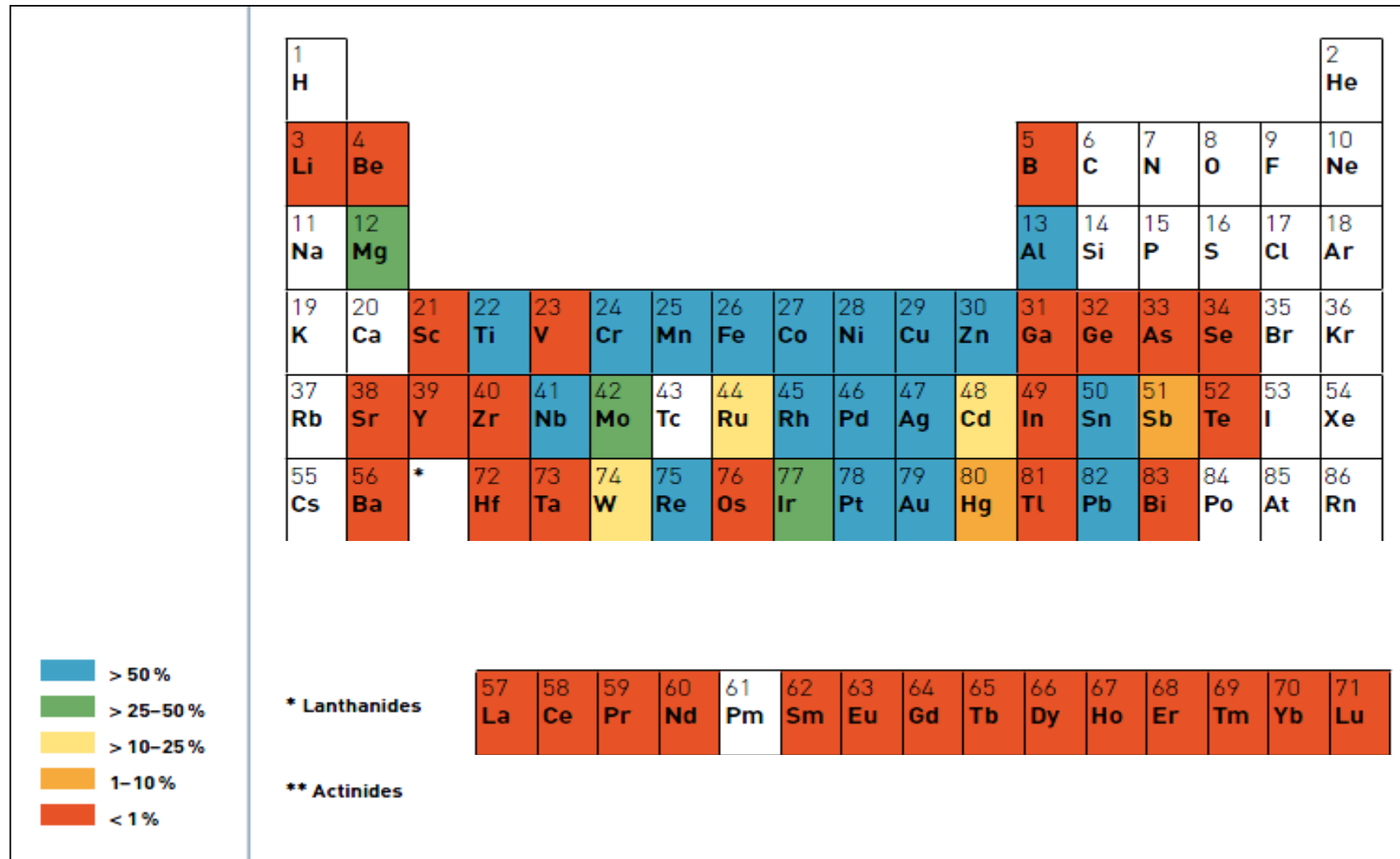
H																	He
Li 41	Be 63											B 41	C	N	O	F	Ne
Na	Mg 94											Al 44	Si	P	S	Cl	Ar
K	Ca	Sc 65	Ti 63	V 63	Cr 93	Mn 98	Fe 56	Co 54	Ni 62	Cu 70	Zn 38	Ga 38	Ge 44	As 38	Se 47	Br	Kr
Rb	Sr 78	Y 95	Zr 66	Nb 41	Mo 70	Tc	Ru 63	Rh 96	Pd 39	Ag 44	Cd 38	In 60	Sn 36	Sb 57	Te 38	I	Xe
Cs	Ba 63	*	Hf 38	Ta 41	W 53	Re 90	Os 38	Ir 66	Pt 66	Au 40	Hg 45	Tl 100	Pb 100	Bi 46	Po	At	Rn

* Lanthanides	La 75	Ce 60	Pr 41	Nd 41	Pm	Sm 63	Eu 100	Gd 66	Tb 63	Dy 100	Ho 63	Er 63	Tm 88	Yb 88	Lu 63
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T. Graedel et al.,  
*Pub. Natl. Acad. Sci.* 112 (14), 4257,  
 2015



# End of Life Recycling Rates of Metals

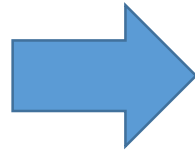


(UNEP, *Recycling Rates of Metals*, 2011)

# Rhenium (U.S. critical)

**U.S. is 82% dependent on imports:  
Chile, Germany, etc.**

**Global uses: 82% superalloys  
10% catalysts**

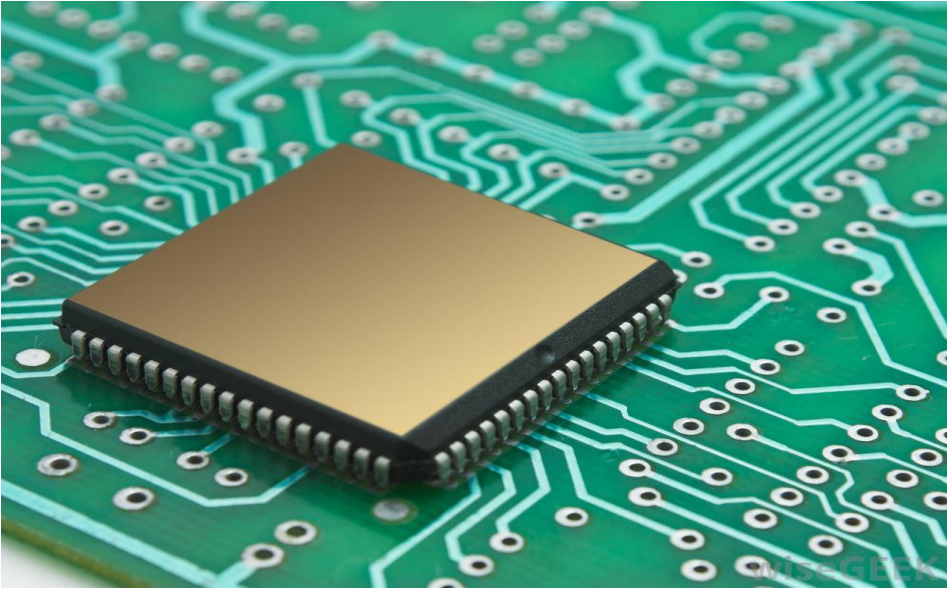
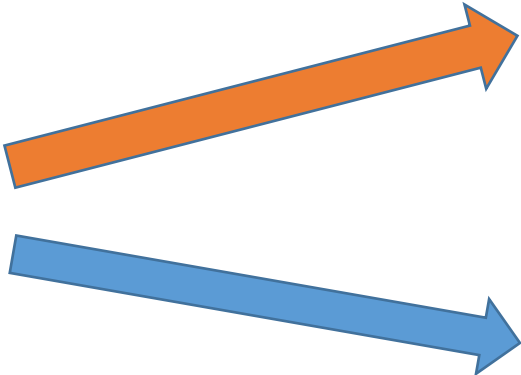




# Tantalum (U.S. critical)

**U.S. is 100% dependent on imports: Austria, Russia, etc.**

**Global uses: 33% electronics  
22% superalloys**





## Vanadium (U.S. critical)

**U.S. is 100% dependent on imports: Austria, Canada, etc.**



Industrial machining  
(1.5-2% V)



Long-haul trucks (0.02-0.1% V)



Aircraft fuselages (~2% V)

