LECTURE SCHEDULE

	Date		Topic
1.	Wed	28.10.	Course Introduction & Short Review of the Elements
2.	Fri	30.10.	Periodic Properties & Periodic Table & Main Group Elements (starts)
3.	Fri	06.11.	Short Survey of the Chemistry of Main Group Elements (continues)
4.	Wed	11.11.	Ag, Au, Pt, Pd & Catalysis (Antti Karttunen)
5.	Fri	13.11.	Redox Chemistry
6.	Mon	16.11.	Transition Metals: General Aspects & Crystal Field Theory
7.	Wed	18.11.	Zn, Ti, Zr, Hf & Atomic Layer Deposition (ALD)
8.	Fri	20.11.	V, Nb, Ta & Metal Complexes and MOFs
9.	Mon	23.11.	Cr, Mo, W & 2D materials
10	Wed	25.11.	Mn, Fe, Co, Ni, Cu & Magnetism and Superconductivity
11.	Fri	27.11.	Resources of Elements & Rare/Critical Elements & Element Substitutions
12.	Mon	30.11.	Lanthanoids + Actinoids & Pigments & Luminescence & Upconversion
13.	Wed	02.12.	Inorganic Materials Chemistry Research

EXAM: Thu Dec 10, 9:00-12:00 (IN ZOOM)

PRESENTATION TOPICS/SCHEDULE

Wed	18.11.	Ti: Ahonen & Ivanoff
Mon	23.11.	Mo: Kittilä & Kattelus
Wed	25.11.	Mn: Wang & Tran
		Ru: Mäki & Juopperi
Fri	27.11.	In: Suortti & Räsänen
		Te: Kuusivaara & Nasim
Mon	30.11.	Eu: Morina
		U: Musikka & Seppänen

QUESTIONS: Lecture 11

- Give three examples of seriously critical elements

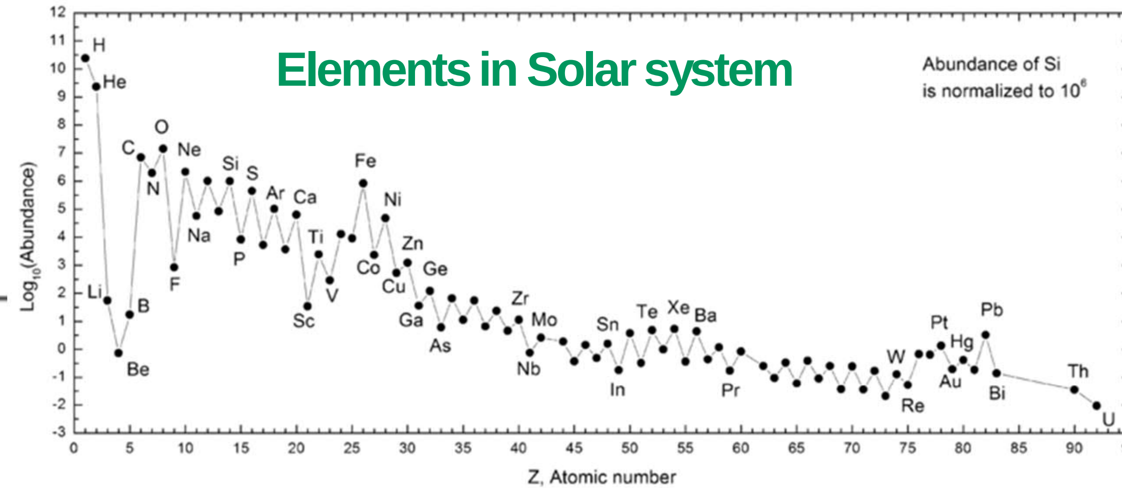
- Discuss shortly three chemistry approaches to solve the problems related to the CRMs

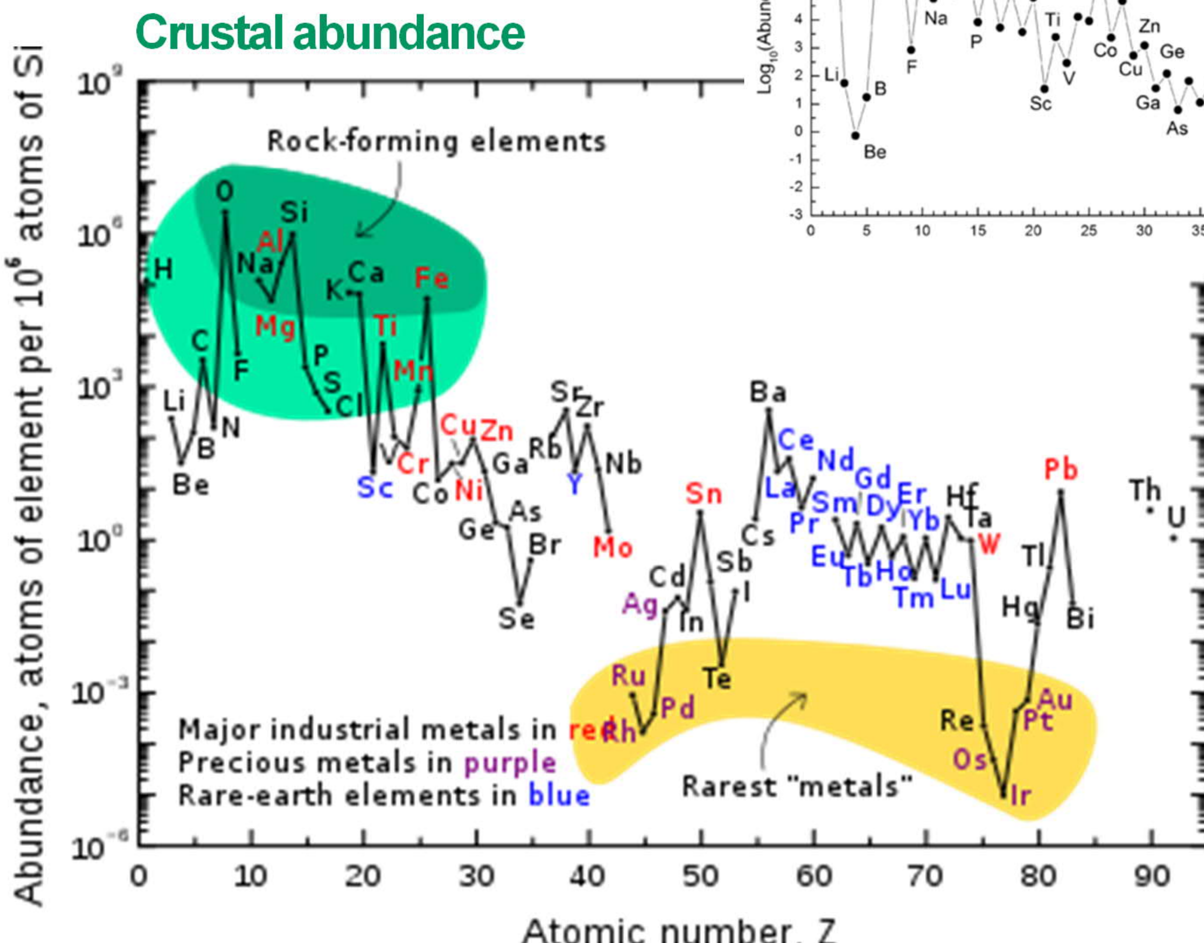
WHAT MAKES US CALL ELEMENTS RARE ?

- **Absolute abundance**
- **Accessable resources** (distribution, technical skills, etc.)
- **Availability** (politics, etc.)

WHAT MAKES US CALL ELEMENTS CRITICAL ?

- **Essential to human health**
- **Needed to make crucial/desired devices**
- **Needed to generate/store energy**
- **Needed but not readily available**

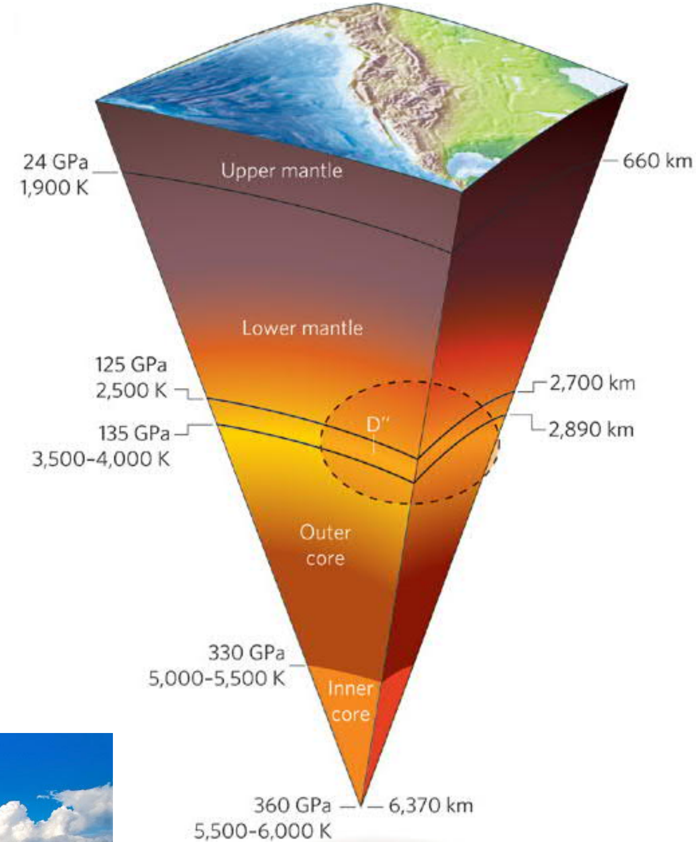




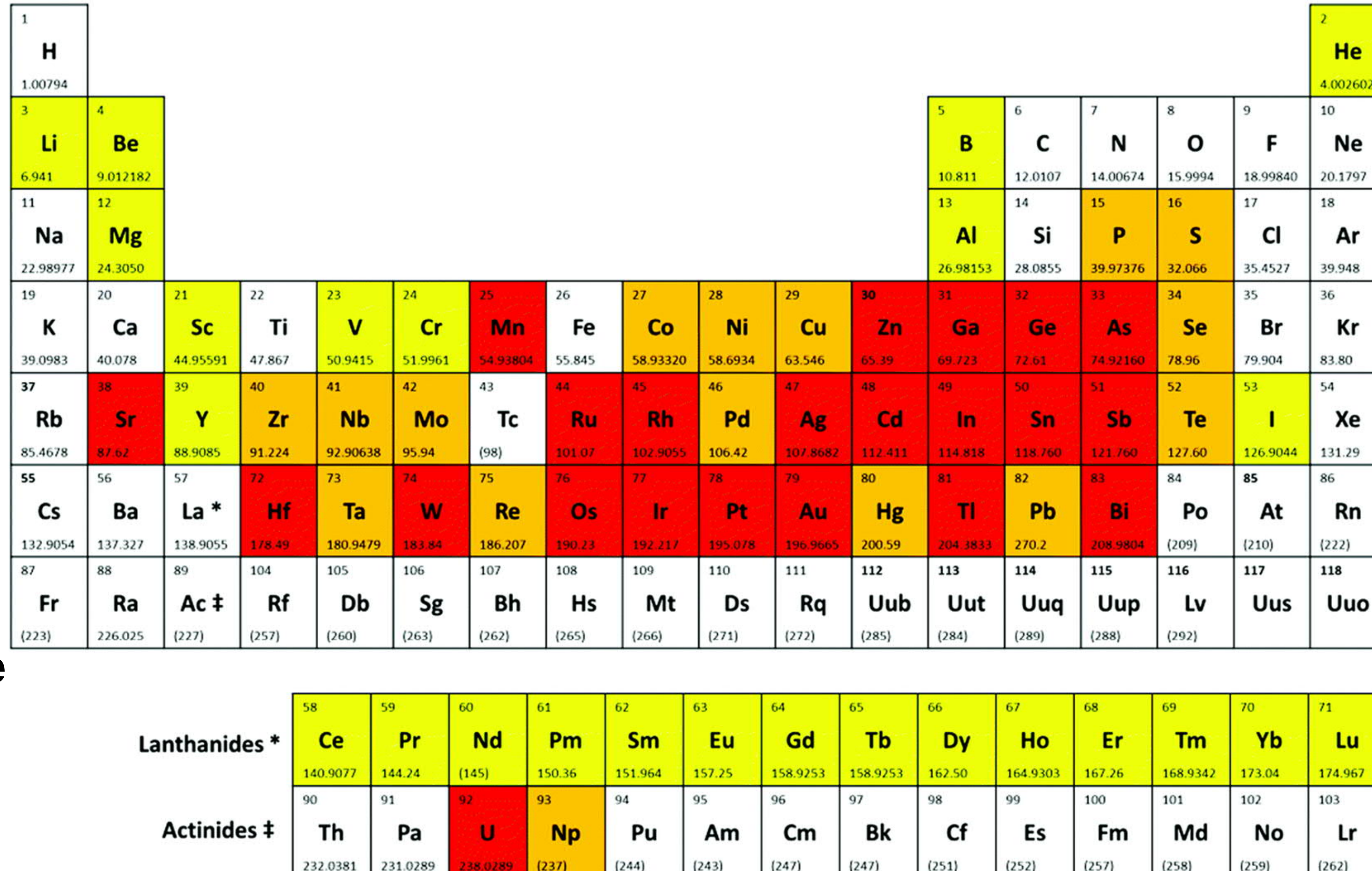
ABSOLUTE ABUNDANCE

ACCESSABLE RESOURCES

- **Distribution of the elements**
- **Mining technologies**
- ***Mponeng gold* mine in South Africa is the deepest mine in the world at a depth of ca. 4 km**



Remaining Known Usable Reserves of the Elements



Remaining years of availability based on the current rate of use

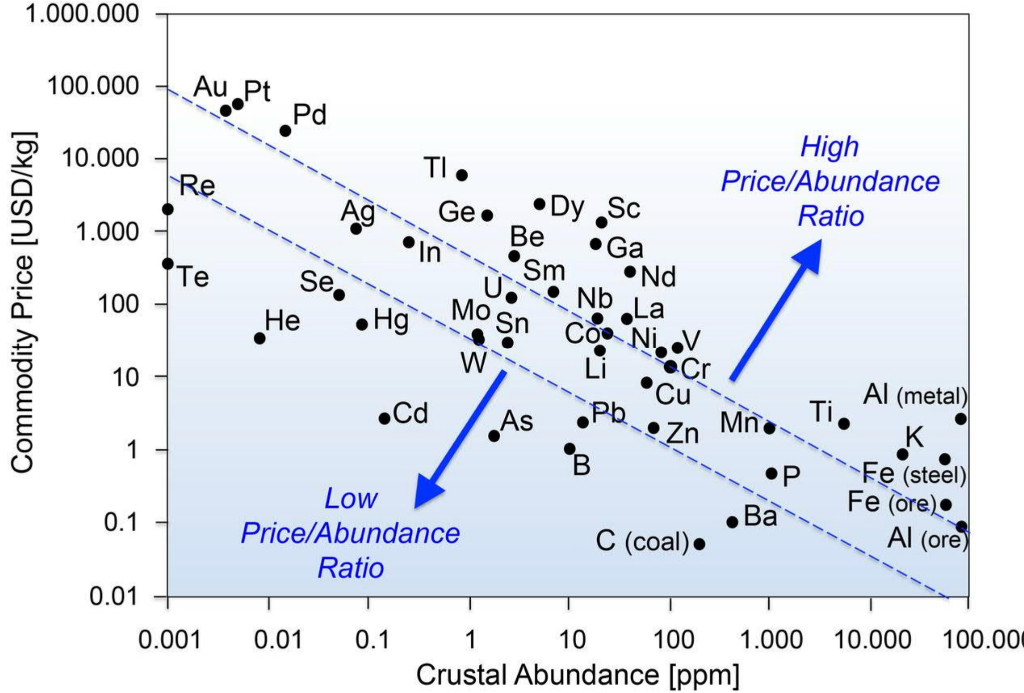
London metal exchange

	Official price
Aluminium	1,454.00
Aluminium Alloy	1,585.00
NASAAC	1,708.00
Copper	4,669.00
Lead	1,573.50
Nickel	8,955.00
Tin	14,660.00
Zinc	1,511.50
Cobalt	24,000.00
Molybdenum	10,800.00
Steel Billet	220.00

New York metal exchange

Top 10 Metals Products | Precious | Base | Ferrous | Other

Clearing	CME Globex	Floor	CME ClearPort	Product Name	Sub Group	Exchange	Volume	Open Interest
GC	GC	-	GC	Gold Futures	Precious	COMEX	187,052	428,212
SI	SI	-	SI	Silver Futures	Precious	COMEX	63,572	172,527
OG	OG	OG	OG	Gold Options	Precious	COMEX	25,194	1,515,879
PL	PL	-	PL	Platinum Futures	Precious	NYMEX	14,805	75,822
SO	SO	SO	SO	Silver Options	Precious	COMEX	6,498	165,506
PA	PA	-	PA	Palladium Futures	Precious	NYMEX	6,257	28,558
MGC	MGC	-	-	E-micro Gold Futures	Precious	COMEX	2,038	2,116
GCK	GCK	-	GCK	Gold Kilo Futures	Precious	COMEX	544	17
SIL	SIL	-	SIL	1,000-oz. Silver Futures	Precious	COMEX	206	2,003
QO	QO	-	-	miNY Gold Futures	Precious	COMEX	180	1,396



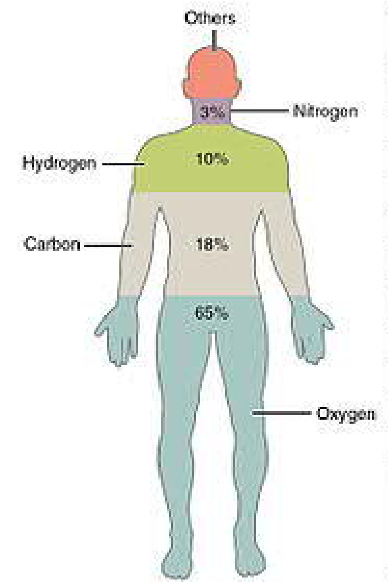
The Price

Price: often affected by fashion, speculation or politics besides the rarity

CRITICAL for Health & Wellbeing

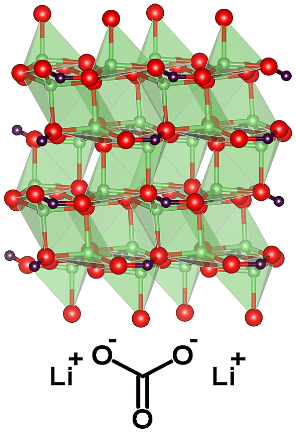
H																		He
Li	Be												B	C	N	O	F	Ne
Na	Mg												Al	Si	P	S	Cl	Ar
K	Ca		Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr		Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	**	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo
			*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	
			**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	

The four organic basic elements | Quantity elements | Essential trace elements | Possible structural or functional role in mammals

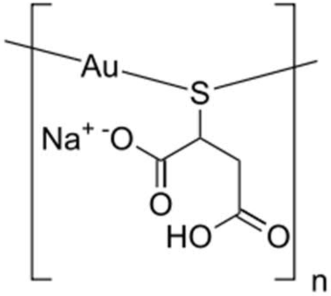


Supplement industry: $5 billion in sales

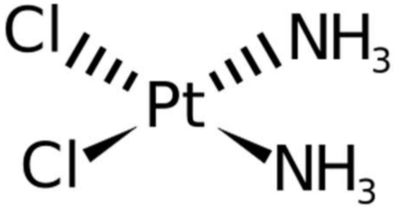
CRITICAL as MEDICINE



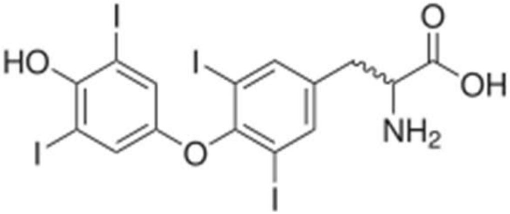
Li_2CO_3 for depression



Au for RA
(Rheumatoid Arthritis)

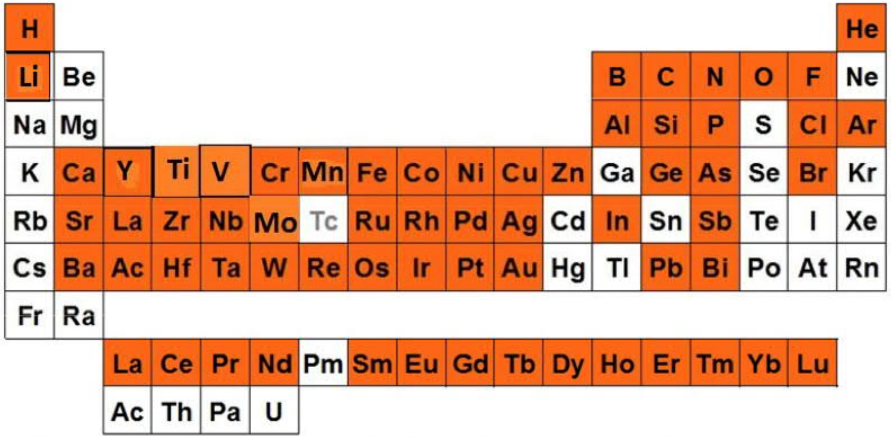


Cis-Pt complex for cancer



Iodine for thyroid hormones

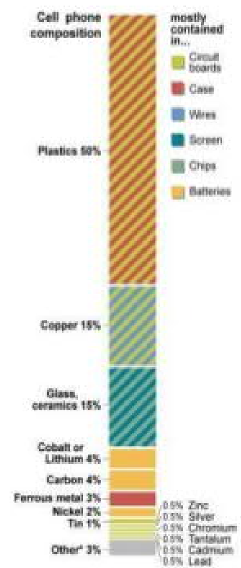
Modern medicine relies not just on organics but often a range of elements



Elements used in the production of components for computers

CRITICAL for Modern Devices

Elements in a Mobile Phone



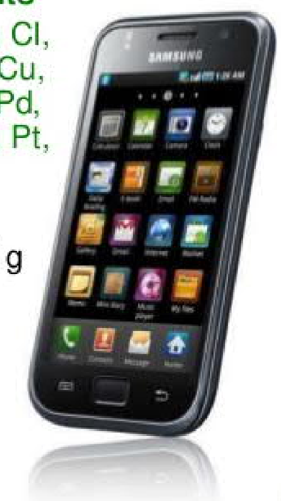
Source: Basel Convention, 2006; Lindholm (Nokia report), 2003

Roughly 40 different elements

H, Li, Be, C, N, O, F, Al, Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Br, Sr, Y, Zr, Ru, Pd, Ag, Cd, In, Sn, Sb, Ba, Ta, W, Pt, Au, Hg, Pb, Bi, Nd.

A mobile phone weighing 100 g contains:

- 13.7 g of copper
- 0.189 g of silver
- 0.028 g of gold
- 0.014 g of palladium

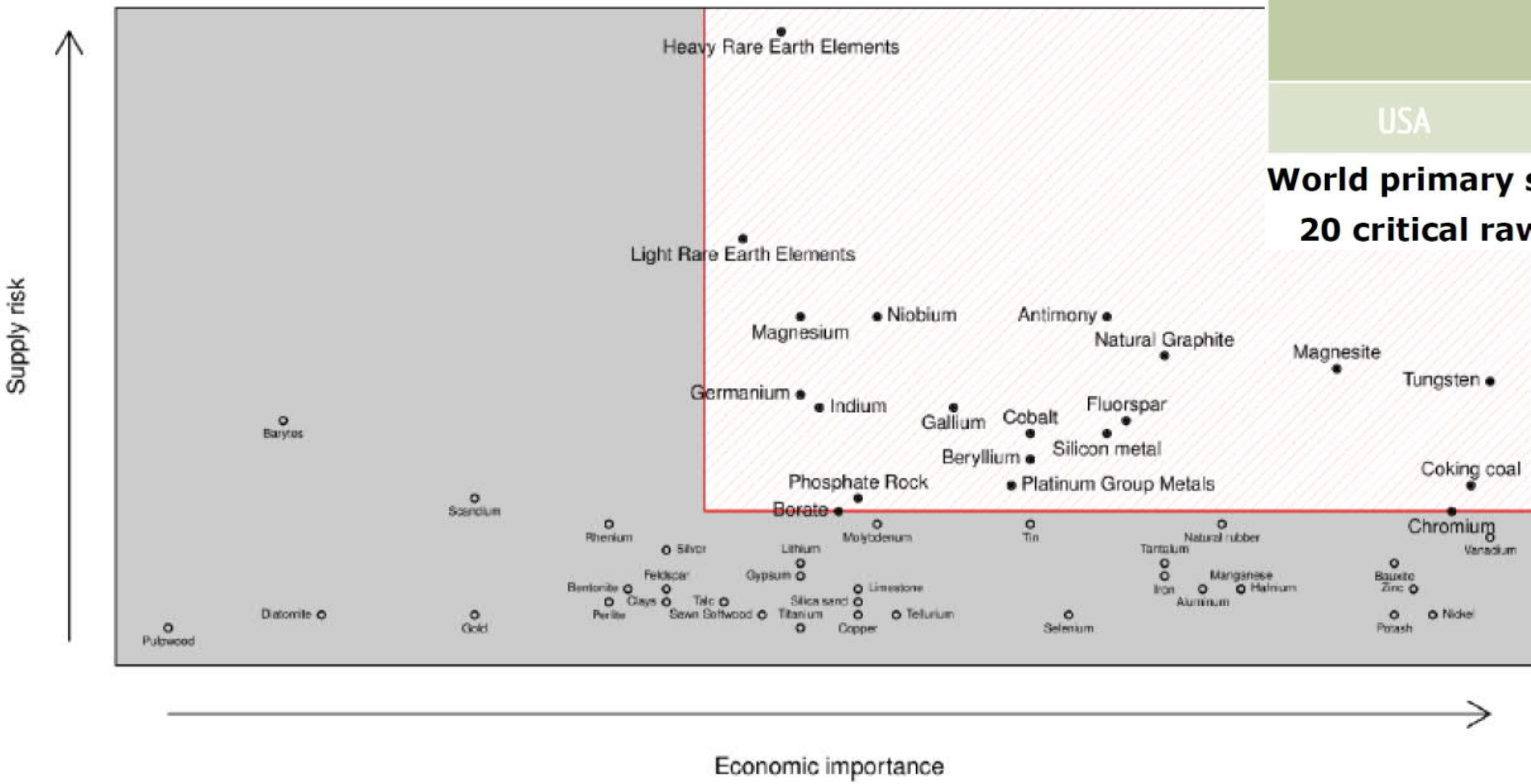


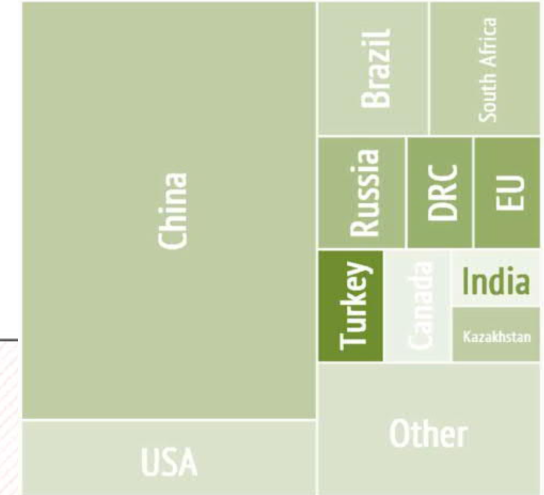
Courtesy of Dr Mike Pitts Sustainability Manager

CRITICAL RAW MATERIALS for EU

http://ec.europa.eu/DocsRoom/documents/10010/attachments/1/translations

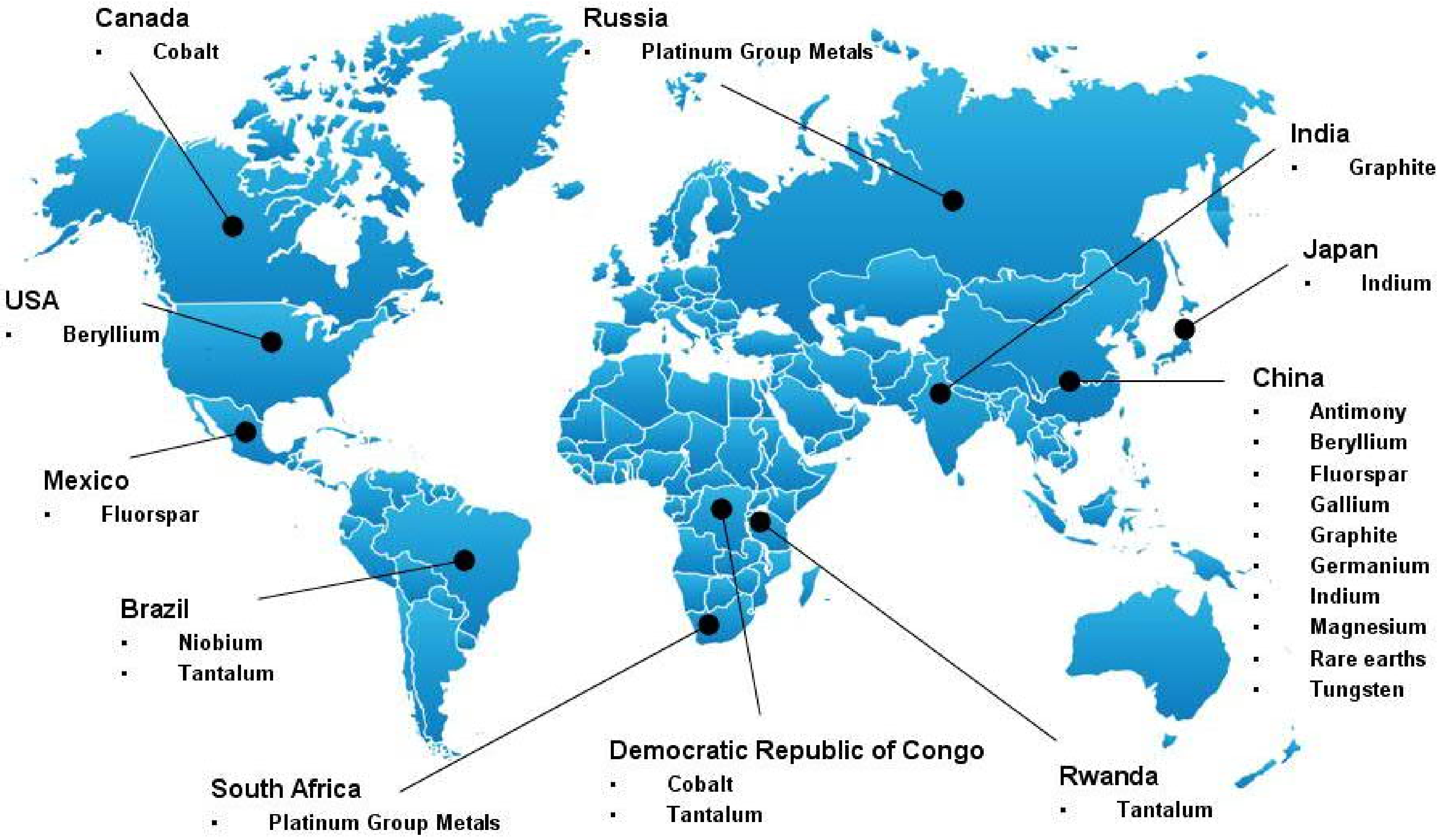
http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/pdf



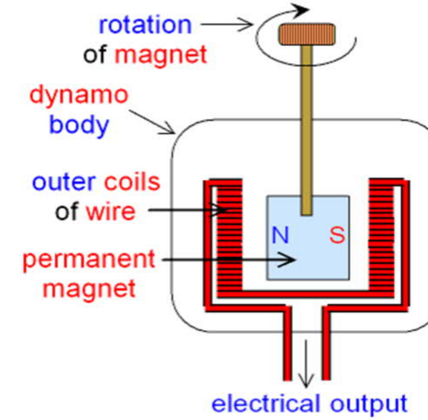


World primary supply of the 20 critical raw materials

Production concentration of critical raw mineral materials



MATERIALS for ENERGY

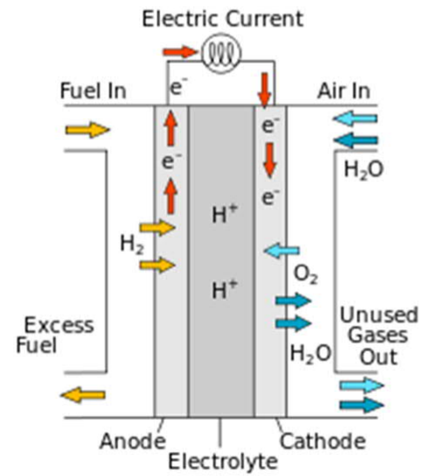


TURBINES: production of electricity from hydro, tidal, nuclear & fossil fuels

- REs (= Ln) for magnets
- (Cu), Ag, Au for wires

FUEL CELLS

- PEM: Pt, Pd; SOFC: Ni, Co, Ga, *Ln*

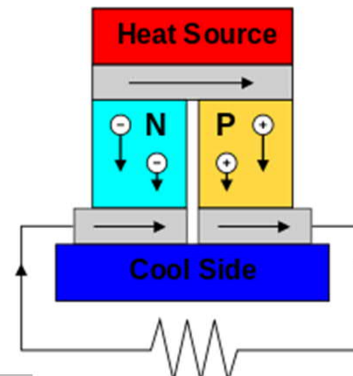


PHOTOVOLTAICS

- In, Ga, etc. …

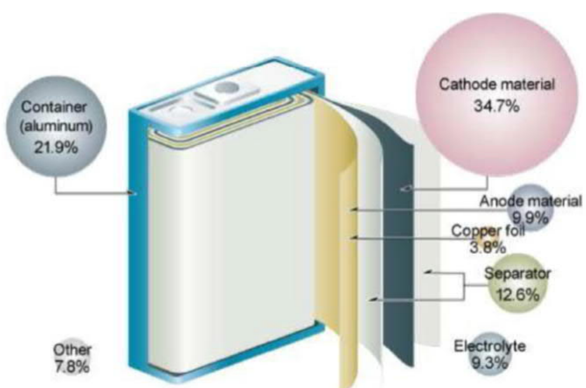
THERMOELECTRICS

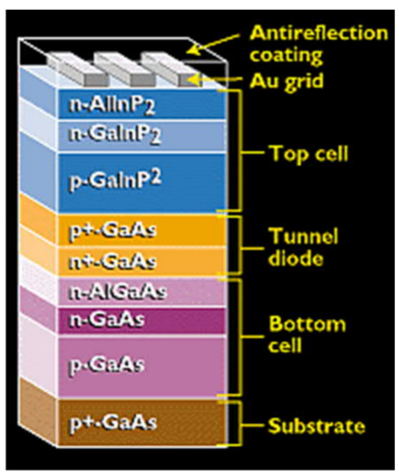
- Bi, Te, Se, Co, etc.

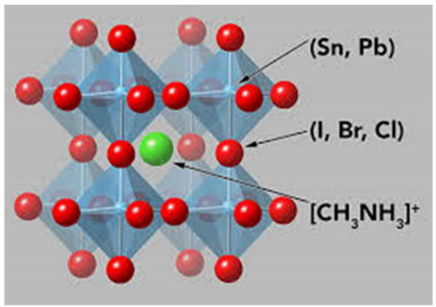


BATTERIES

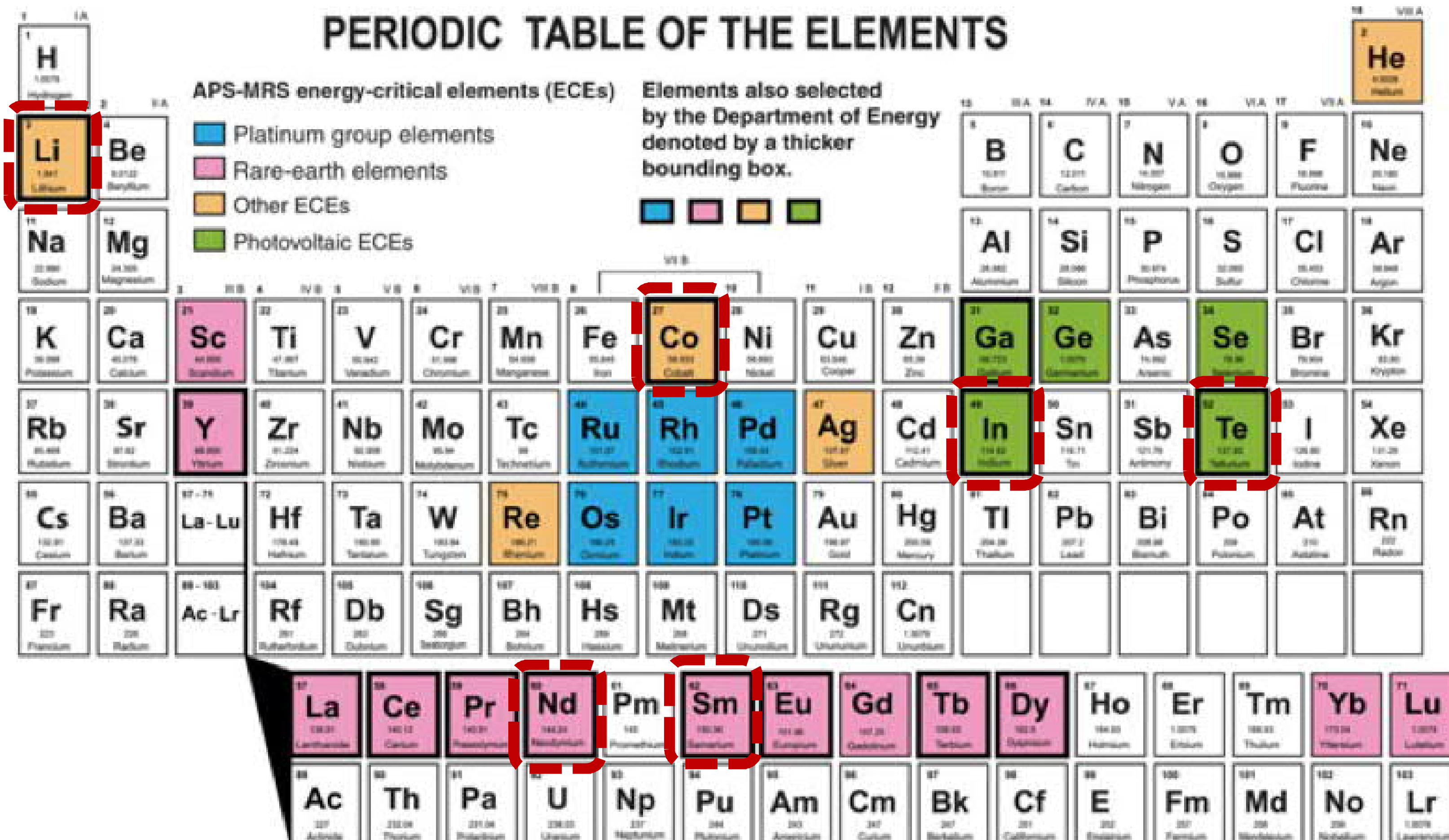
- Li, Co



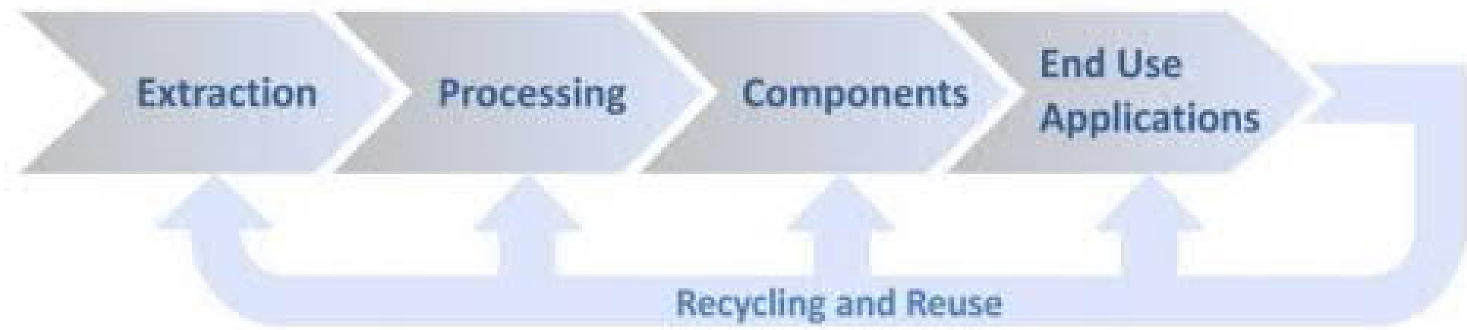




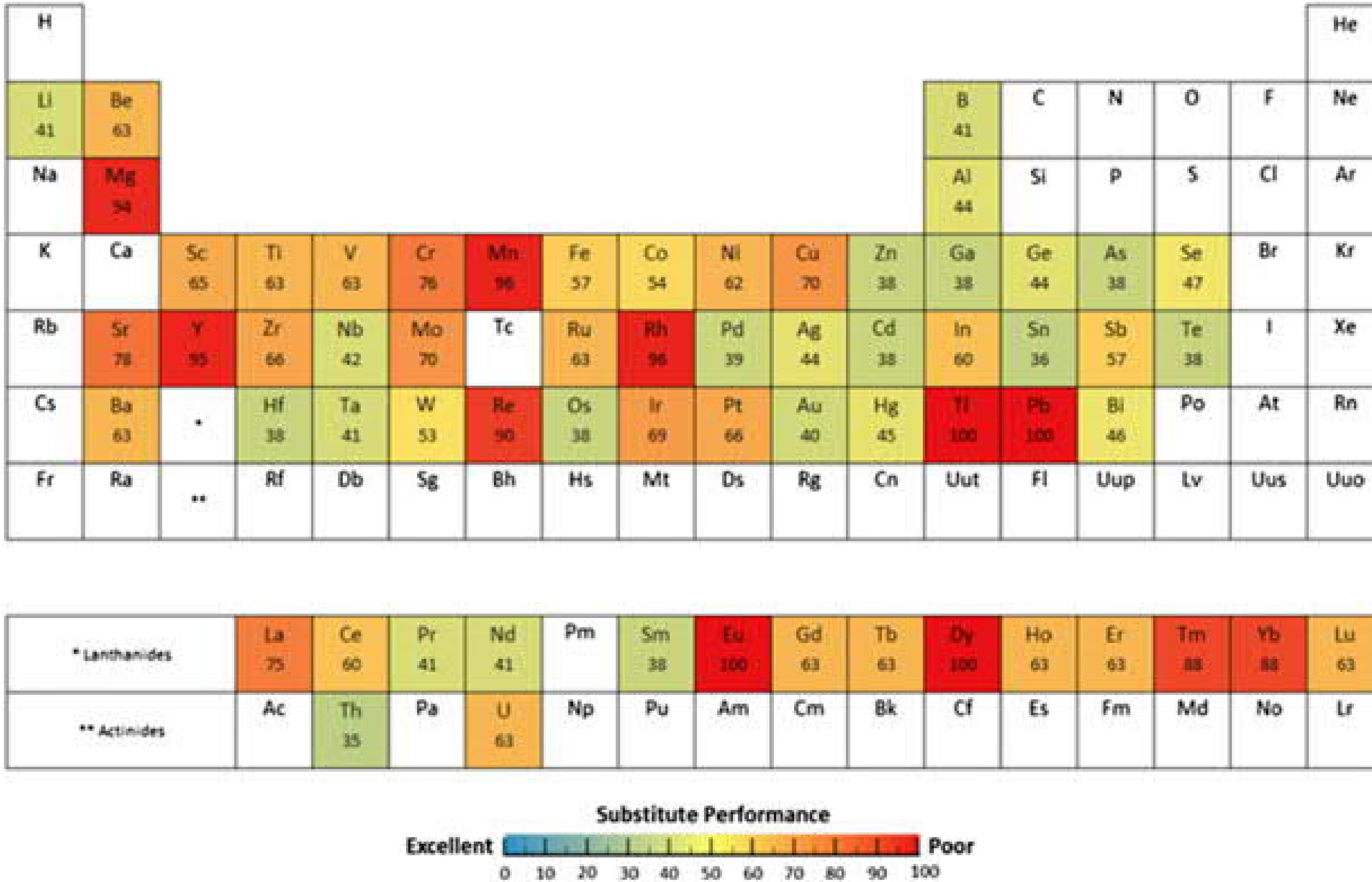
ECE: Energy Critical Elements (by APS & MRS)

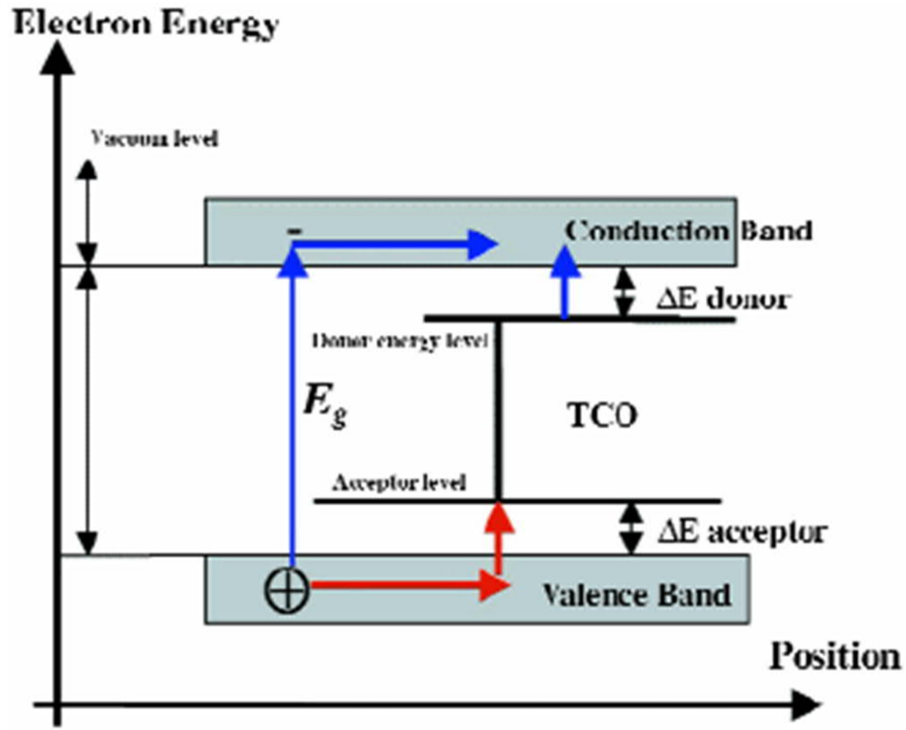


REUSE & RECYCLING



SUBSTITUTIONS: Can it be done?





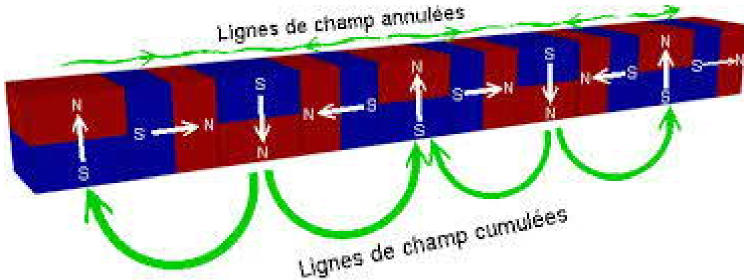
TRANSPARENT CONDUCTING OXIDES (TCOs)

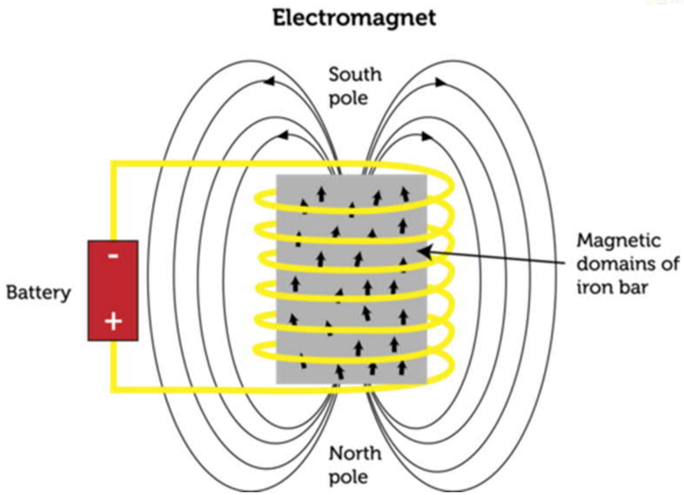
- ITO (In-Sn-O) is the current commercial leader, but the waste recovery is very much limited
- F-doped SnO_2 is a good candidate
- Al-doped ZnO would be a highly sustainable replacement

Strongest permanent magnet: $Nd_2Fe_{14}B$

"Non-Critical" ALTERNATIVES – Are there such ?

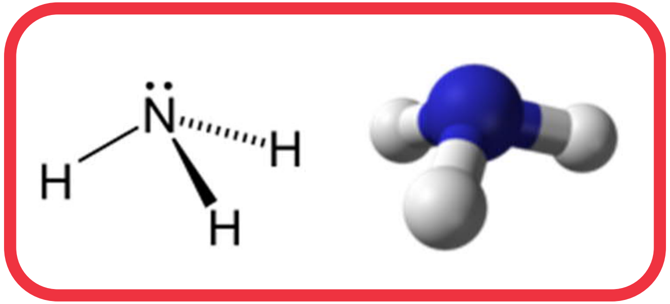
- **AlNiCo: "best of the rest"**
- **"Engineered" Fe_3O_4**
- **Electromagnets**

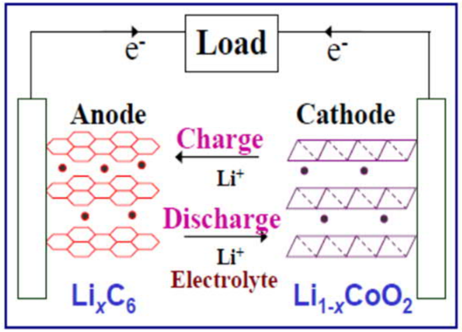




Elemental substitutions for toxicity

- $Ca^{2+} \rightarrow Cd^{2+}$: same size and charge
- K^{+} or $Ag^{+} \rightarrow Tl^{+}$: same size and charge
- $Bi^{3+} \rightarrow Pb^{2+}$: same stereo-active $6s^2$ electron pair





EC: ethylene carbonate

DEC: dimethyl carbonate

Li-ion battery

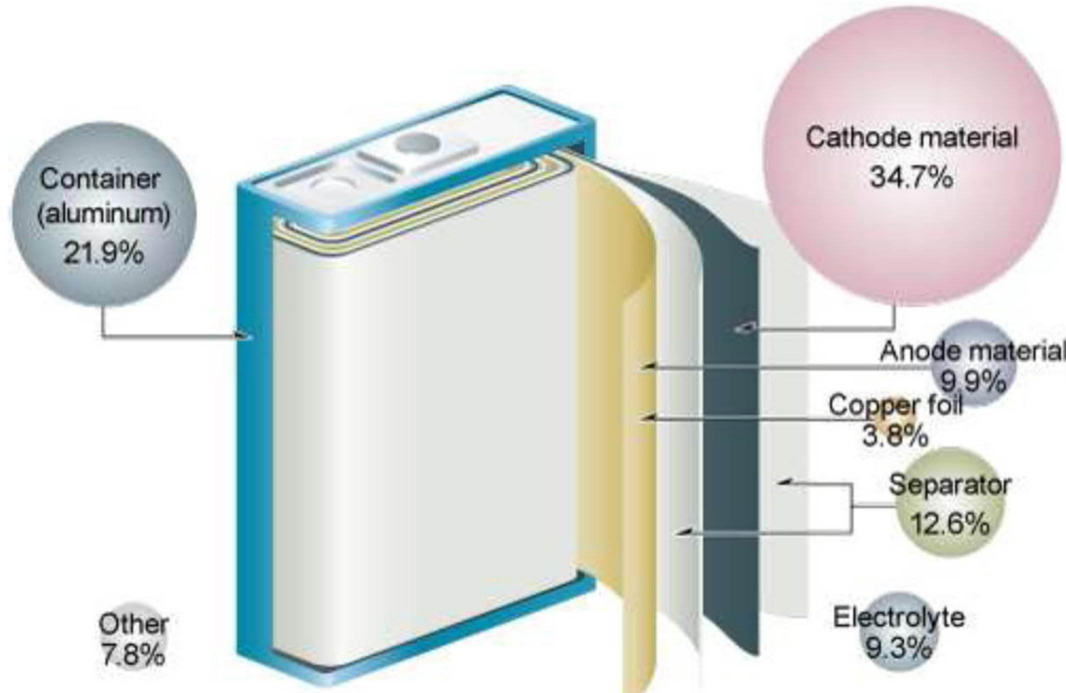
Cathode: $LiCoO_2$

Cell: $(-)\ C \mid LiPF_6\text{-}(EC{+}DEC) \mid LiCoO_2\ (+)$

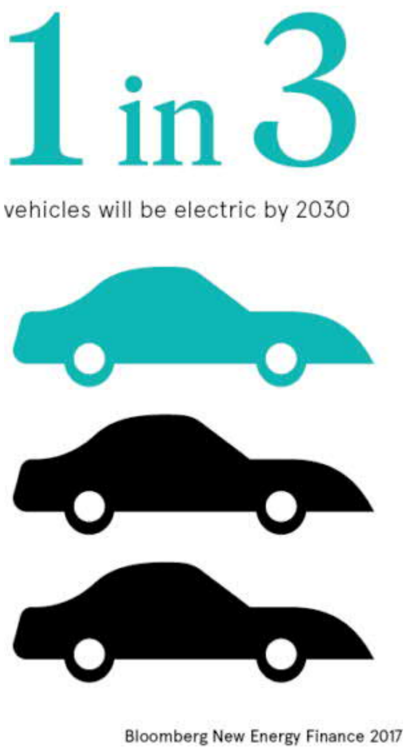
Cathode: $LiCoO_2 \underset{D}{\overset{C}{\rightleftarrows}} Li_{1-x}CoO_2 + xLi^+ + xe^-$

Anode: $6C + xLi^+ + xe^- \underset{D}{\overset{C}{\rightleftarrows}} Li_xC_6$

Total: $LiCoO_2 + 6C \underset{D}{\overset{C}{\rightleftarrows}} Li_{1-x}CoO_2 + Li_xC_6$



In 2030 one third of cars will be electric !



How much metals needed in 600 kg battery:

- 8 kg Li
- 7 kg Co
- 50 kg Ni

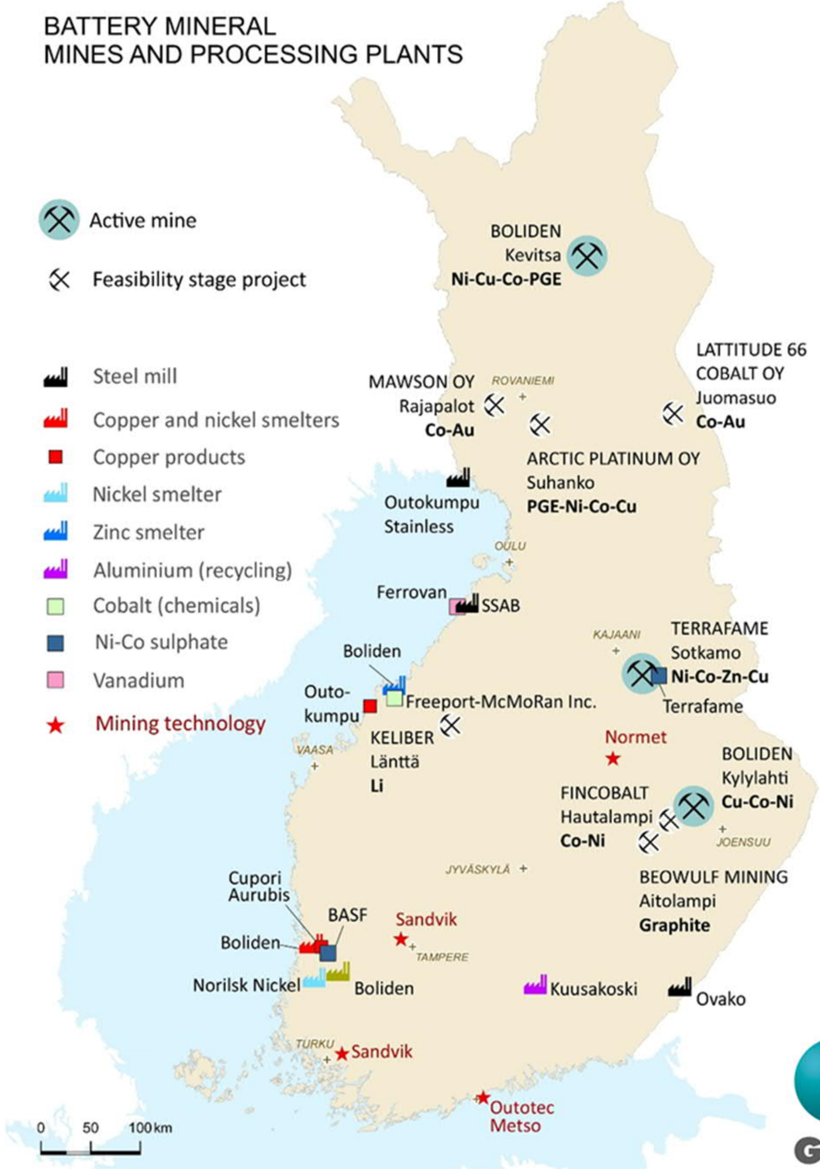
60 % of cobalt in the world is mined in Republic of Congo

Cobolt mining place in Congo close to Kasulo. Valokuvat: Siddharth Kara

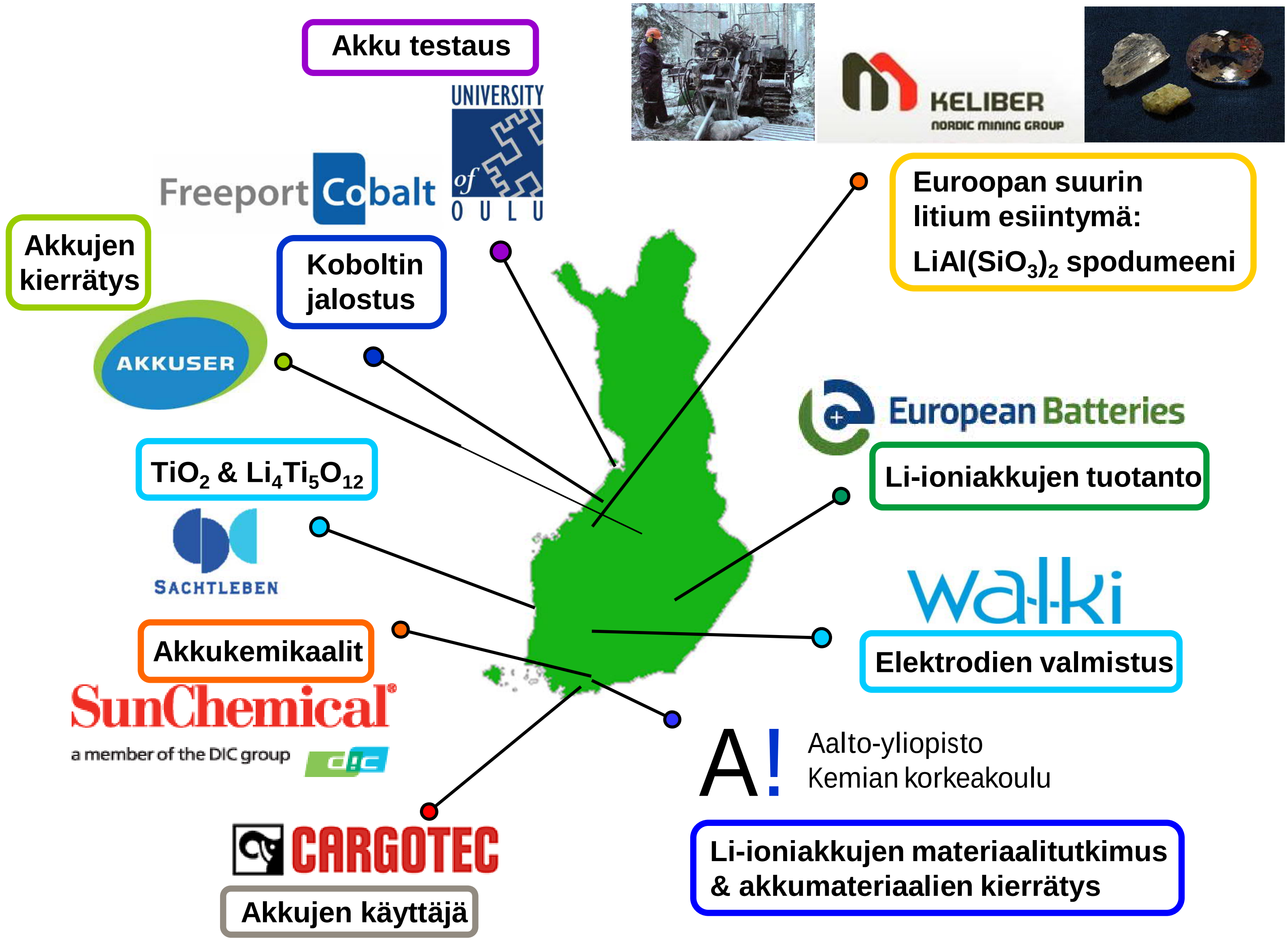
Battery Minerals in FINLAND

- **Mining: Ni, Cu, Co**
- **Refining: Co (13 %), Ni, Cu**
- **Planned mining/refining: Li, Co (→ 2-4 %)**

“Ethical Cobalt/Metals”



GTK



Akku testaus
UNIVERSITY of OULU
Freeport Cobalt
Akkujen kierrätys
AKKUSER
Koboltin jalostus
KELIBER
NORDIC MINING GROUP
Euroopan suurin litium esiintymä:
$LiAl(SiO_3)_2$ spodumeeni
European Batteries
Li-ioniakkujen tuotanto
TiO_2 & $Li_4Ti_5O_{12}$
SACHTLEBEN
walki
Elektrodien valmistus
Akkukemikaalit
SunChemical®
a member of the DIC group
DIC
A!
Aalto-yliopisto
Kemian korkeakoulu
CARGOTEC
Akkujen käyttäjä
Li-ioniakkujen materiaalitutkimus & akkumateriaalien kierrätys

Prof. Mari Lundström
Hydrometallurgy

Battery metals (Co, Li) from used batteries

Prof. Maarit Karppinen
Inorgaanic material chemistry

AALTO-CHEM COLLABORATION !

Electrode materials from recycled metals

Performance of batteries made from recycled metals

Prof. Tanja Kallio
Electrochemistry

C. Peng, K. Lahtinen, E. Medina, P. Kauranen, M. Karppinen, T. Kallio, B.P. Wilson & M. Lundström, Role of impurity copper in Li-ion battery recycling to $LiCoO_2$ cathode materials, *Journal of Power Sources* **450**, 227630 (2020).

CloseLoop (Closing the Loop for High-added-value Materials) supported by the STRATEGIC RESEARCH COUNCIL of FINLAND


Aalto University, School of Chemical Engineering:

- Maarit Karppinen, Jari Koskinen, Rodrigo Serna, Mari Lundström, Tanja Kallio, Antti Karttunen, Kari Laasonen, Pertti Kauranen

VTT Technical Research Centre of Finland

- Tarja Laitinen, Päivi Kivikytö-Reponen, Pertti Koukkari

Univ. Helsinki, Consumer Society Research Centre / Univ. Cambridge

- Minna Lammi

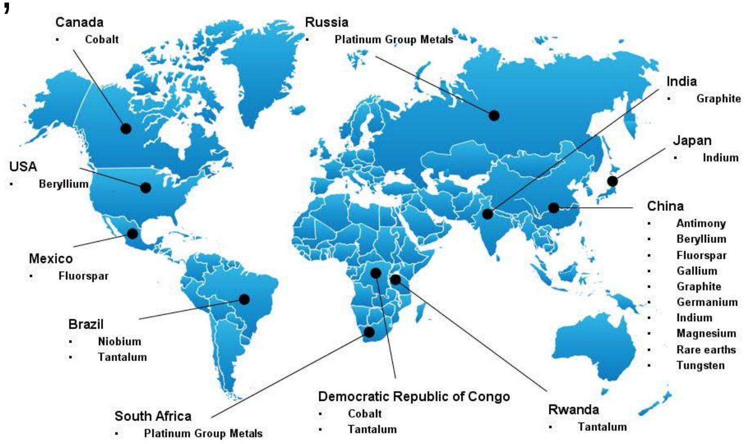
Outotec, Norilsk Nickel, Boliden, REC Alkaline, Picodeon, Espoo Esbo, Kokkolan Kaupunki Karleby Stad, YTP, Kuluttajaliitto Konsumentförbundet, Kuusakoski Recycling, Freeport Cobalt, elcogen, Suomen Autokierrätys, Pori, Harjavalta, Technology Industries, SATL

Aalto University School of Chemical Technology, Ministry of Economic Affairs and Employment of Finland, Ympäristöministeriö Miljöministeriet Ministry of the Environment, Puolustusministeriö Försvarsministeriet Ministry of Defence, mmm.fi Ministry of Agriculture and Forestry, SITRA, EIT RawMaterials

Background & Motivation for CloseLoop

- **High-added-value Materials** are crucially needed in the Modern Society (ICT, transportation, renewable energy, *etc*.)
- Current Materials & Products are **designed for high performance, NOT for easy reuse or recycling**
- EU has listed 20 **Critical Raw Materials (CRMs)** with a high impact on the society but a high risk of supply shortage
- Currently the **recycling rates** for CRMs are **very low**
- Material substituents are searched for the CRMs, **BUT recycling of the new materials** should be considered as well

Production concentration of critical raw mineral materials



CloseLoop Stakeholders

http://closeloop.fi/

Energy Live News

NEWS EVENTS VIDEOS INDUSTRY NEWS

Finance & Markets

Finland to lead EU battery recycling research

It will cover the whole process starting from their collection and processing

By **Priyanka Shrestha**

Outotec tackling battery recycling with Aalto University and Business Finland

Posted by Paul Moore on 1st November 2018

The European Commission has invited Finland to coordinate the research related to recycling in the battery industry. Outotec will lead the project together with Aalto University's Department of Chemical and Metallurgical Engineering. Business Finland, a public research funding agency, is also strongly involved in advancing the project.

Outotec and Aalto University to coordinate European research related to recycling in the battery industry

Published: 01.11.2018

Company: **Outotec** Recommendation: **Lisää** Target price: **3.90 EUR** Share price: **3.74 EUR**

EMAIL FACEBOOK LINKEDIN TWITTER

0 0

OUTOTEC OYJ PRESS RELEASE NOVEMBER 1, 2018 AT 1:00 PM

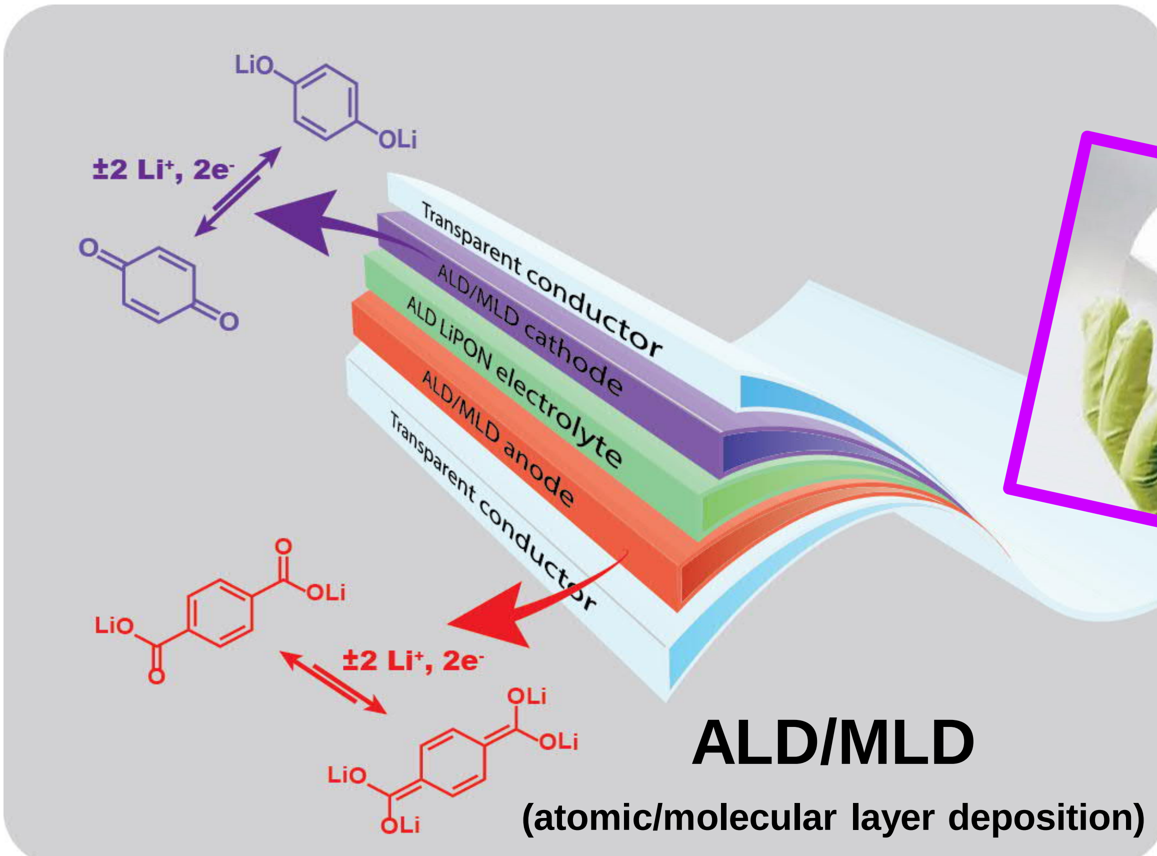
Outotec and Aalto University to coordinate European research related to recycling in the battery industry

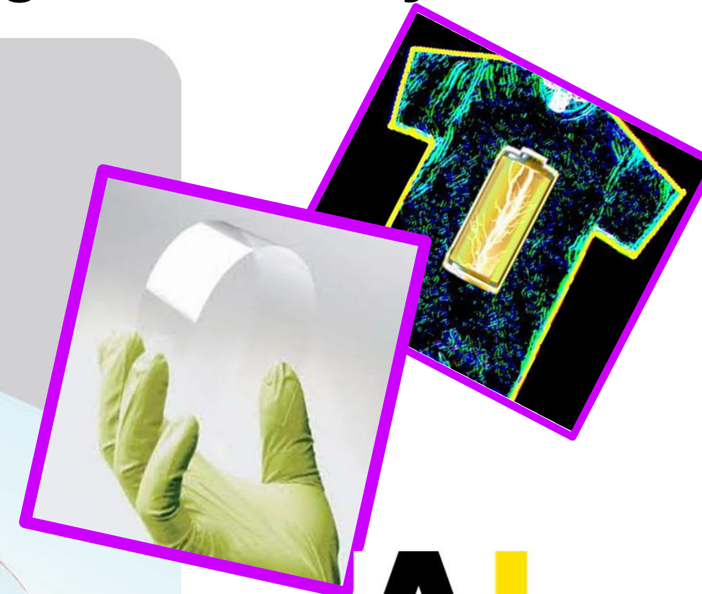
The European Commission has invited Finland to coordinate the research related to recycling in the battery industry. Outotec will lead the project together with Aalto University's Department of Chemical and Metallurgical Engineering. Business Finland, a public research funding agency, is also strongly involved in advancing the project.

Due to the rapidly growing demand for electric cars, the recycling of battery raw materials and equipment will become ever more important. The European Commission has compiled a

Key figures	2017	2018e	2019e
Turnover	1 143,8	1 335,4	1 430,4
Growth rate	8,1%	16,8%	7,1%
EBIT	26,0	-41,7	95,2
EBIT margin	2,3%	-3,1%	6,7%
Adjusted EPS	-0,03	0,19	0,30

Flexible safe "metal-sparing" Li-organic battery





Aalto University
School of Engineering

TOYOTA

M. Nisula, Y. Shindo, H. Koga & M. Karppinen, ***Chem. Mater.* 27**, 6987 (2015).
M. Nisula & M. Karppinen, ***Nano Lett.* 16**, 1276 (2016).
M. Nisula & M. Karppinen, ***J. Mater. Chem. A* 6**, 7027 (2018).