scale

SCANDIUM ALUMINIUM EUROPE

what is scandium?

RARE EARTH

scandium

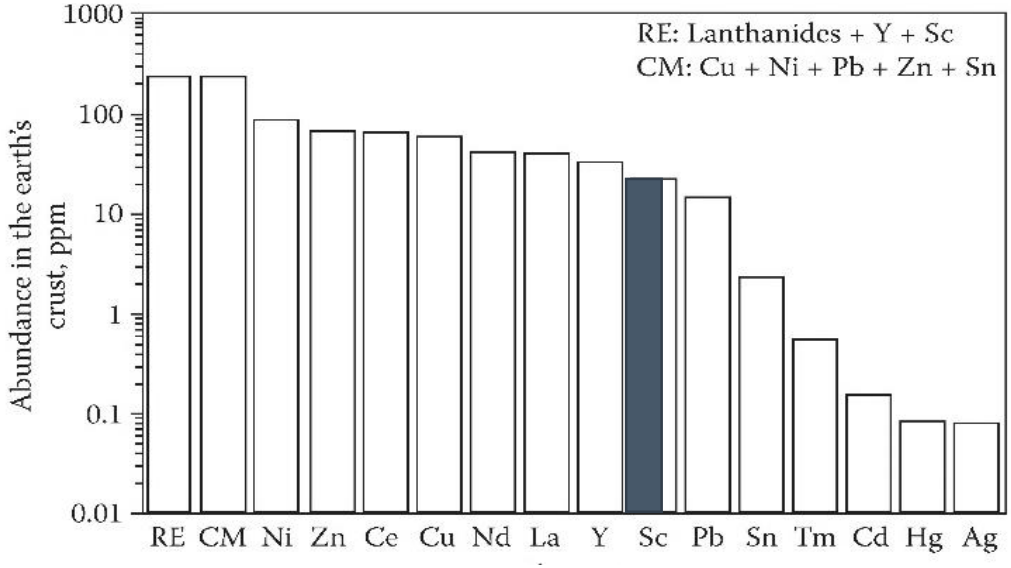
21

Sc

44.956

SCALE project has received funding from the European Union's Horizon 2020 Research and Innovation program under Grant Agreement No 730105

Occurrence of Scandium



- Sc is the 36th most abudent element in the crust
- Earth's crust abundance of 22 mg/kg, the occurrence of scandium is comparable with that of lead (14 mg/kg) and cobalt (25 mg/kg)
- However, scandium is rarely concentrated in nature and remains widely dispersed in the lithosphere as **it lacks affinity to combine with the common ore-forming anions**

Sc is 'more rare' than all other REEs

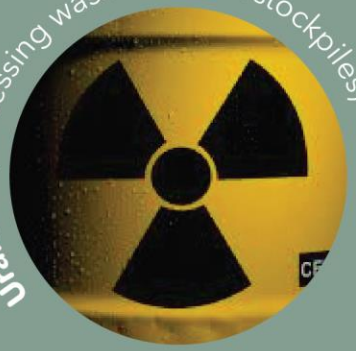
scandium 21 Sc 44.956														
yttrium 39 Y 88.906														
lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.05	lutetium 71 Lu 174.97

WHERE IS **Sc** FOUND?

Viable sources of **Sc** today

TiO2 pigment product acid wastes streams

Uranium processing wastes (Soviet stockpiles)



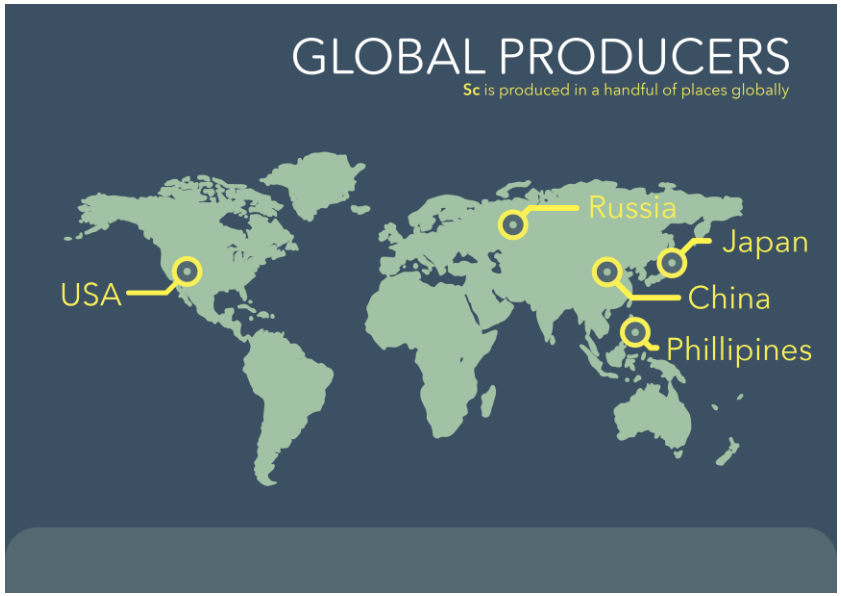
Nickel-Cobalt Laterites (Australia/Turkey/USA)

Bauxite Residues (RUSAL, AoG)

Bauxides and nickel laterite ores are proposed as the most promising **Sc** resources for future large scale production; **Parnassos/Greece could well be a worldwide resource for Sc!**

Supply of Scandium today

- A major source for scandium deposits was the now flooded Ashurst mine in Zhovti Vody outside Kiev, Ukraine, that was once a major harvesting ground for iron ore and uranium for the Soviet military.
- Today there is an active mine for Sc is in Kazahkstan
- Other Sc sources include REE byproducts in Kola Peninsula in Russia and Bayan Obo in China and there are several Acid Waste facilities (TiO_2 production) in China, USA, Philippines and Japan

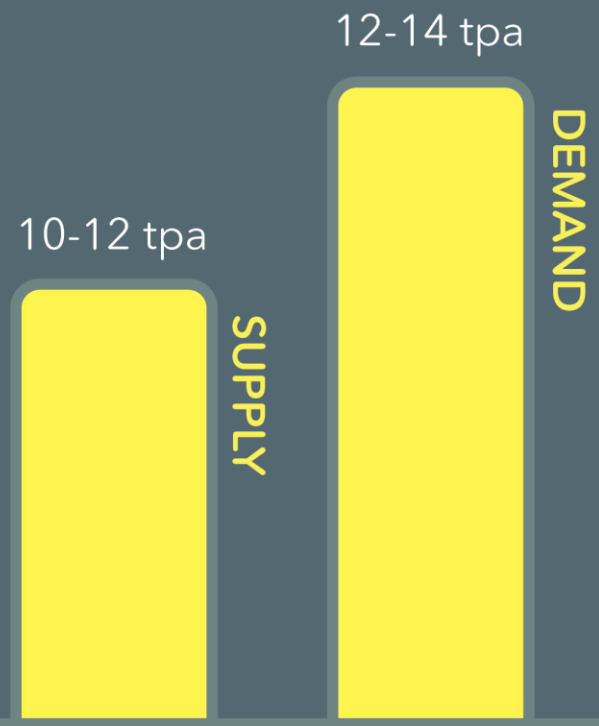


The current Sc world production is estimated at 10 – 12 tpy of scandium oxide

Main producers

- **China (66%)**
- **Russia (26%)**
- **Ukraine (7%)**

THE ECONOMY OF Sc



Al - Sc 2%

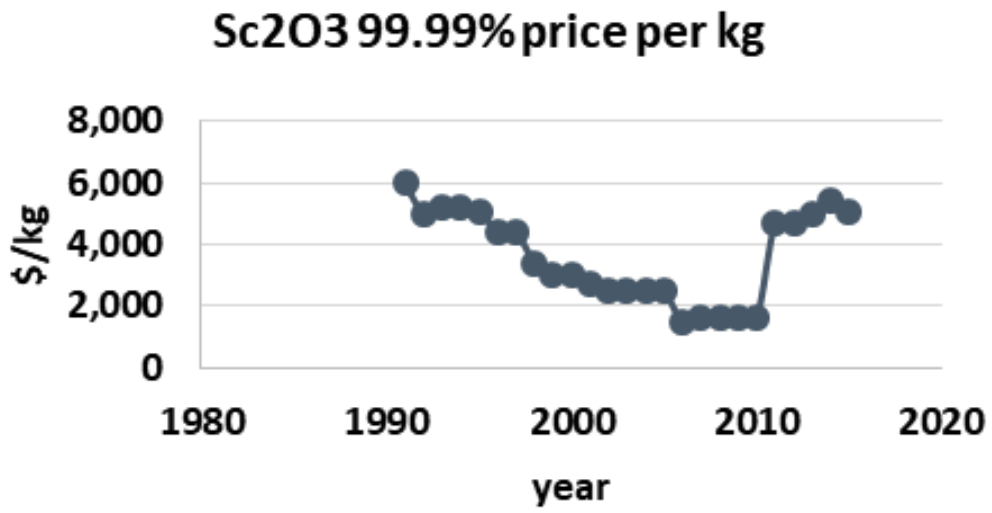
100-150 $/g

Sc VALUE CHAIN:

2013 Data

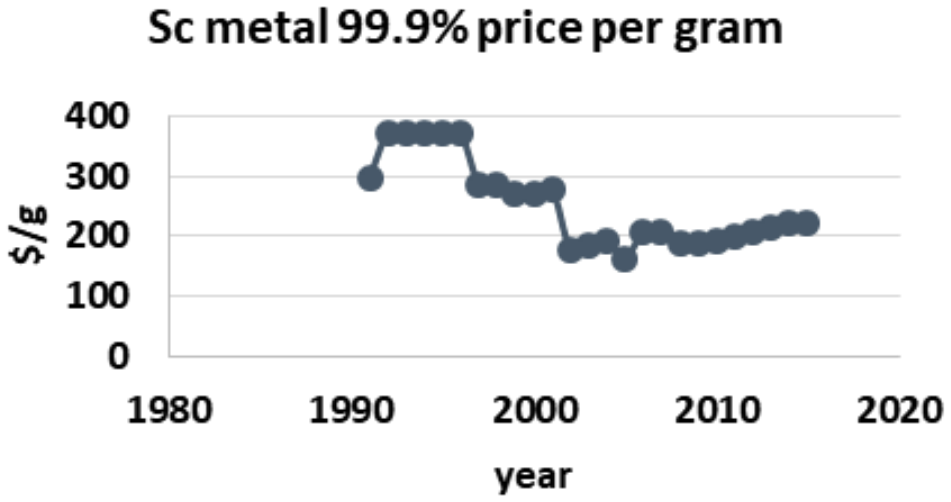
0.9 $/g	5 $/g	253 $/g	206 $/g
Sc_2O_3 99%	Sc_2O_3 99,99%	ScF3 99,99%	Sc Metal

Scandium Market



On 24 February 2010, BLOOMENERGY announced that their devices (SOFC) were making electricity for $0.08–.010/kWh using natural gas (using Sc_2O_3 in the solid electrolyte)

Sc included on the 2017 list of Critical Raw Materials for the EU



Sc HAS SUPERPOWERS!

Sc achieves superior results than Y in material applications

SOLID OXIDE FUEL CELLS

Sc-stabilized Zirconia has **lowered operational temperatures** facilitating the **commercialization** of the technology

LASERS WITH Sc GARNETS

have **3 times higher efficiency** than Y garnets

NATURAL LIGHT

Sc compound is used as phosphors for **high intensity 'natural' light** - close to solar optical spectrum

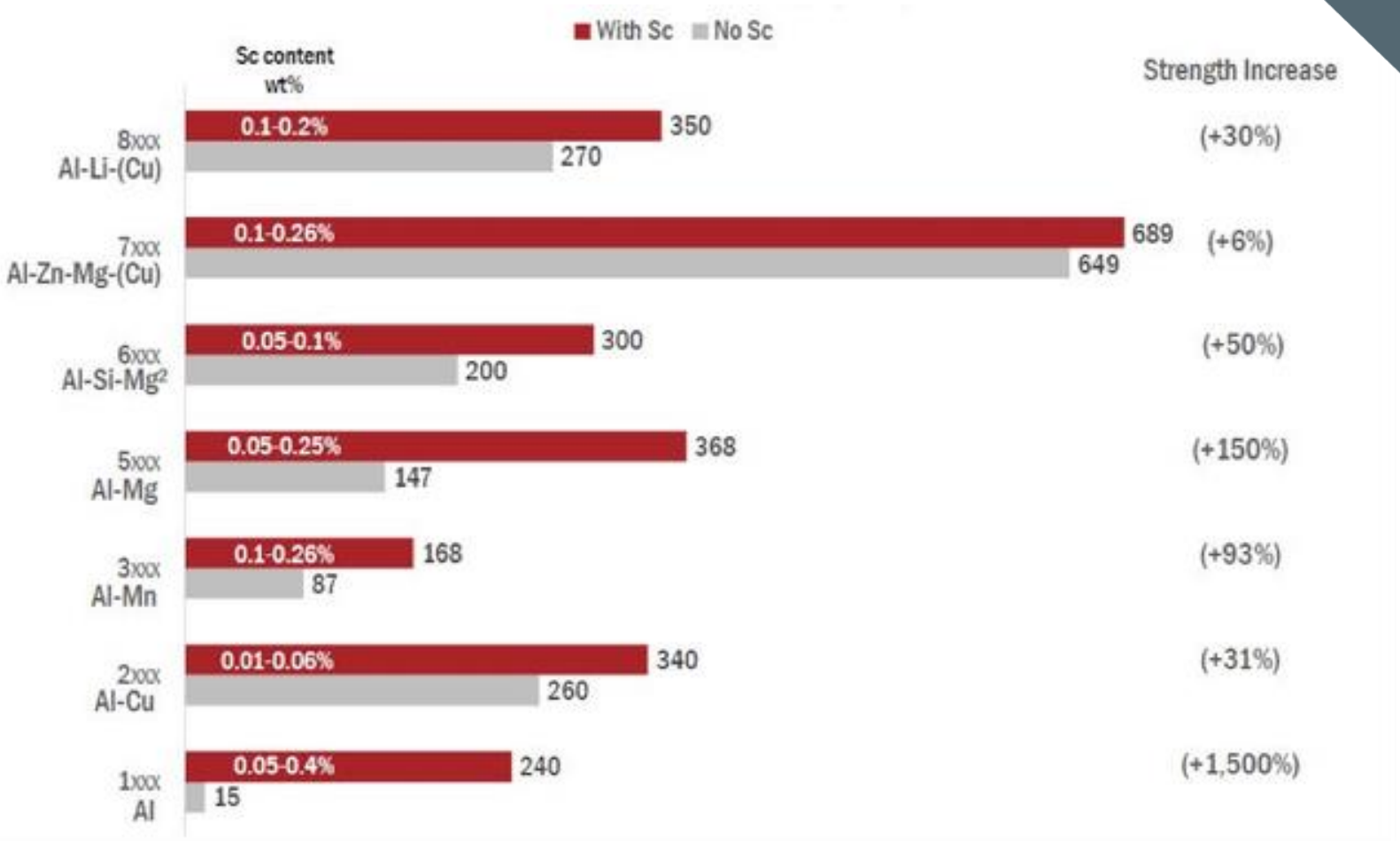
Lazer Garnet by II-VI (gadolinium-scandium-gallium)

BLOOMENERGY Sc-SOFCs deployed at NASA building

Scandium Aluminium Alloys

- Scandium –Aluminium alloys were first used in the 1980s for structural purposes in Soviet aircrafts and missiles.
- The strength that Scandium alloys brought to weldable alloys, allowed Soviet to built aircrafts (MIG-29) and **utilize welded structures**. This gave these planes tremendous weight, maneuverability and range advantages.

Scandium Aluminium Alloys



Sc offers the highest increment of strengthening per atomic percent of any alloying element *when added to Al*

Sc reduces ***hot cracking during welding*** *of Al-alloys*

Sc Applications

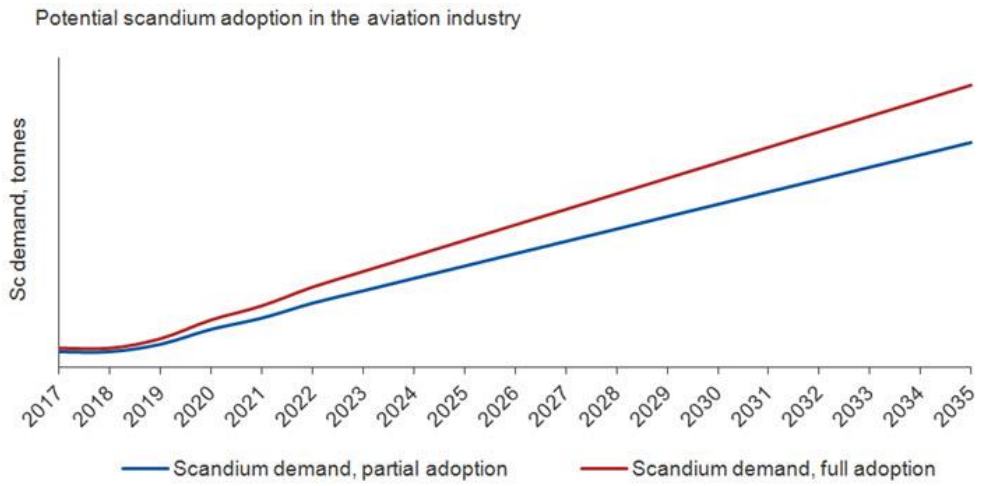
Sc Compound	Application	Today	Future
Sc_2O_3	SOFC – SSZ solid electrolyte	in market by Bloomenergy	Household use
Sc_2O_3	Er: YSGG garnets (**$Er:Y_3Sc_2Ga_30_{12}$**) for optics in lazer application		Er:YSGG has 3 higher efficiency then Nd,Er:YAG in solid-state lasers radiating in the 3 µm
Sc-Al alloy	High resistance Al alloy used in welding or casting – best Al alloy available	High End sporting equipment	Aerospace, Automotive
Al-Mg-Sc (Scalmalloy®)	3D Printing –licensed by Airbus to Apworks		Aerospace, Automotive
ScF_3	Material with negative thermal expansion coefficient		Advanced material composites
20% Sc-80% Ti Carbide	doubling of the hardness TiC, to about 50 GPa, second only to diamonds in hardness.		Advanced materials
Phosporous / Lighting	Scandium has a broad emission spectrum that generates a 'daylight' effect. Sc2O3 and ScVO4 are typical host materials for phosphorus in monitors	Stadium / studio lighting	Household lighting

The future is limited by high prices and unreliable value chain

Scandium Emerging Applications

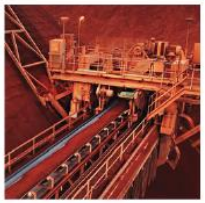
- In SOFC Sc-stabilized Zirconia has lowered operational temperatures leading to commercialization of the technology
- The Al-Sc-Mg alloy powder is used in 3D printing by AIRBUS

Sc demand expected to increase 30 fold in the next decade



APWorks. 2 December 2015

"We did produce 122 out of the 162 parts on our M400 out of SCALMALLOY®.
The partition weights a massive 45% less than current Airbus A320 partition designs"



Bauxite
Residues
TiO2 Pigment
Acid Wastes

mg/kg

EXTRACTING

Sc from waste

g/kg

REFINING

Sc
concentrates

scale

SCANDIUM ALUMINIUM EUROPE

PRODUCING

Sc Metal

Sc_2O_3

SCALE:

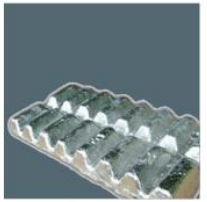
Production of
Sc compounds &
Sc-Al alloys from
European metallugical
by-products

LASERS:
YSG GARNETS

II-VI

SSZ LAYER
SOLID OXIDE
FUEL CELLS

AL-SC ALLOY

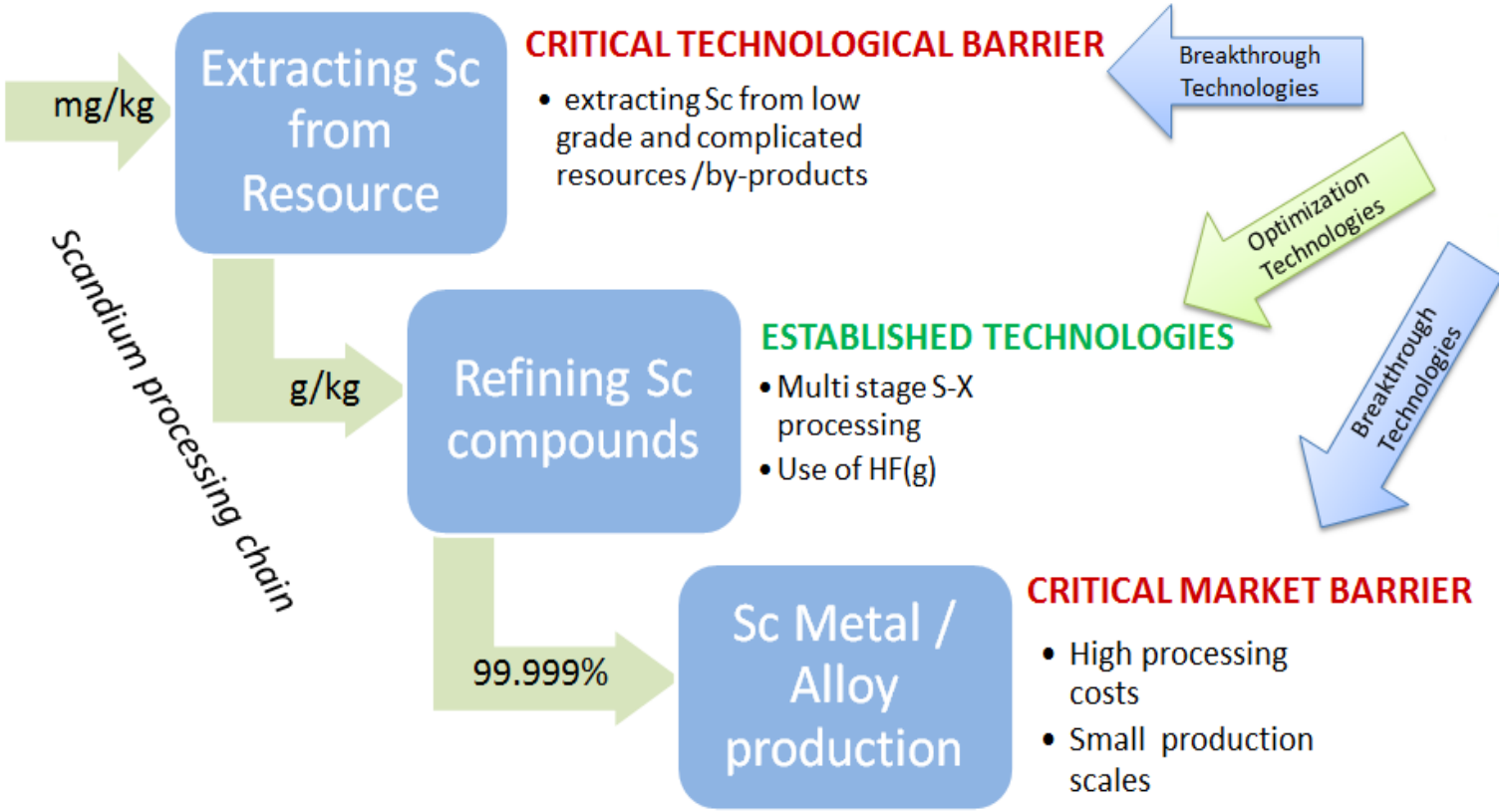


IKBM AFFILIPS MASTER ALLOYS

SCALMALLOY
3D PRINTING

AIRBUS

Scandium Production today



SCALE: AN RTD PROJECT DEDICATED IN DEVELOPING A NOVEL Sc SUPPLY CHAIN

Horizon 2020 | 4 year project | € 7,000,000.00 | AoG demo plant

Extracting Sc from Bauxite Residue (BR)

Mytilineos, Aluminium of Greece (AoG) ✓Sc: 97±3 mg/kg

Aluminium Oxid Stadte, Germnay (AOS) ✓ Sc: 81±2 mg/kg

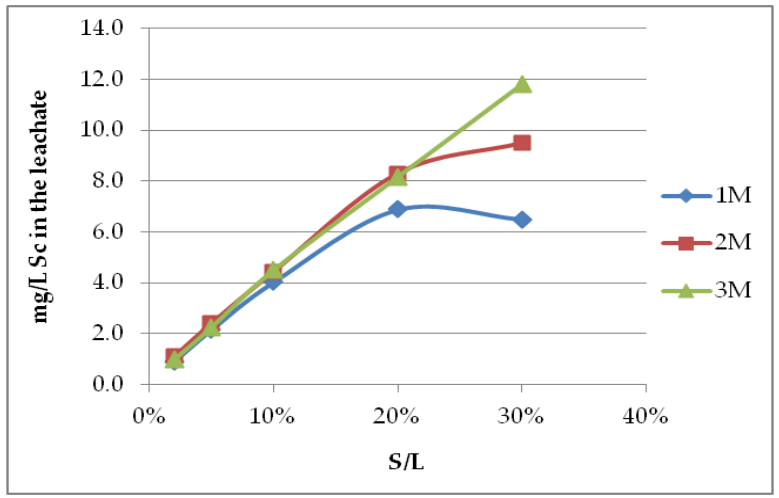
MYTILINEOS

ALUMINIUM OF GREECE

METALLURGY BUSINESS UNIT

aluminiumoxid

Selective Leaching of BR with H_2SO_4



Acid molarity effect on (a) Sc concentration for different S/L ratios (2-20%) and 60 min leaching period.

Concentration of Sc, Ti and Fe by different recycling steps [mg/L]

	Sc		Ti		Fe	
Cycle	1M	2M	1M	2M	1M	2M
1	3.9	4.5	1335	1520	905	1006
2	7.2	8.6	2200	3184	1400	1933
3	11	12.7	2800	4655	1500	2892

✓**Maximum Sc recovery from AoG BR ~ 60%** when using fresh H2SO4 for three leaching steps. Fe recovery close to 10%.

✓**Maximum Sc concentration in final leachate ~13 mg/L** when recycling the leachate on fresh BR, thrice (ambient conditions).

NTUA-ChemLab

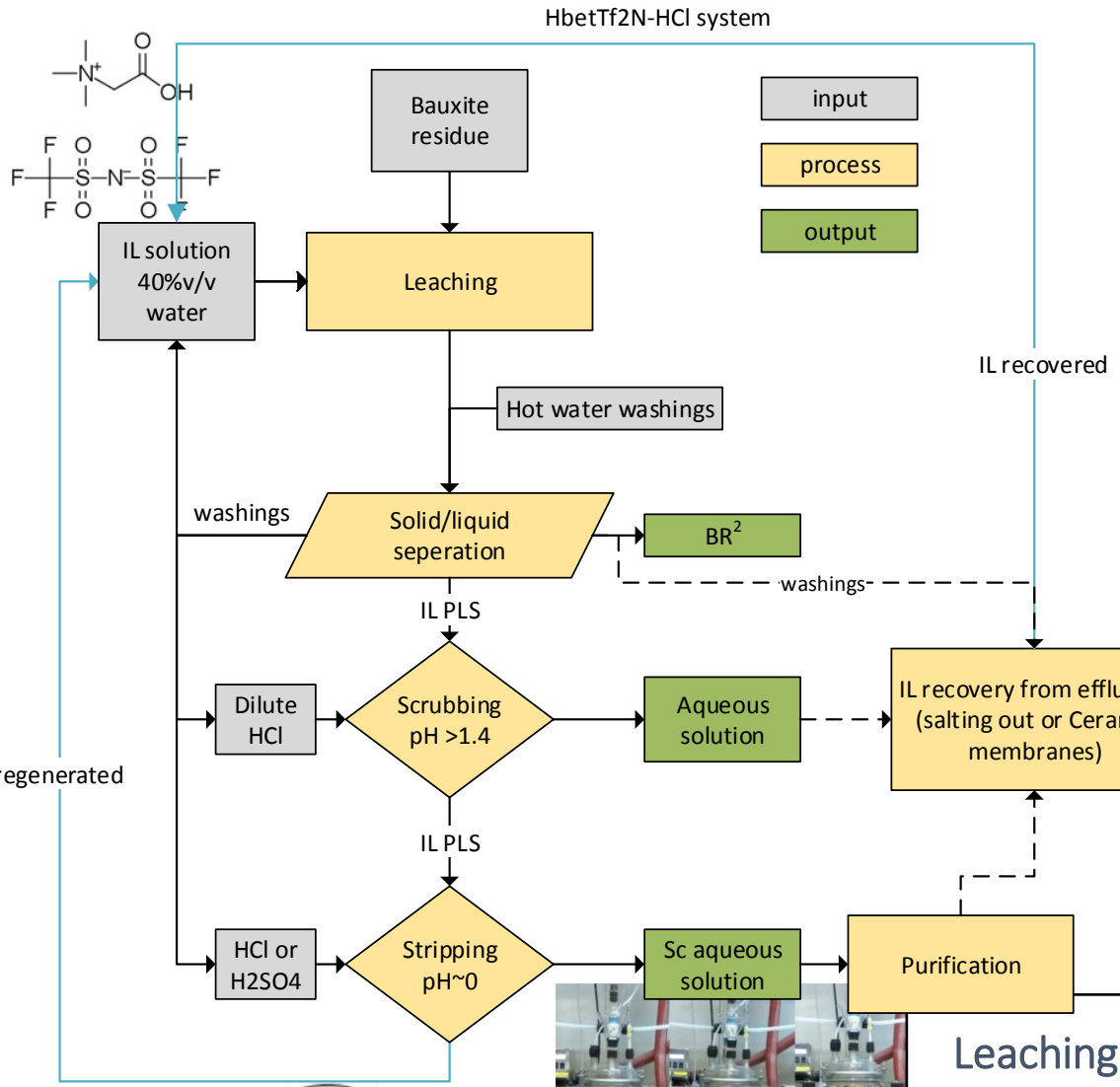
Mechanochemical leaching of BR

Working steps in mechano-chemical leaching, ①grinding breaker and balls with the red mud; ②added acid; ③grinding; ④separation of the grinding balls; ⑤&⑥separation of solution and solid by centrifugation; ⑦&⑧resulting solution and solid residue

- ✓The **recovery of scandium is about 55-60%** even with comparatively low acid concentration
- ✓With l/s = 5 a scandium **concentration of 11-12 mg/L** can be achieved in a single leaching step

Fraunhofer ISC
PROJECT GROUP IWKS

Leaching of BR with ionic liquid

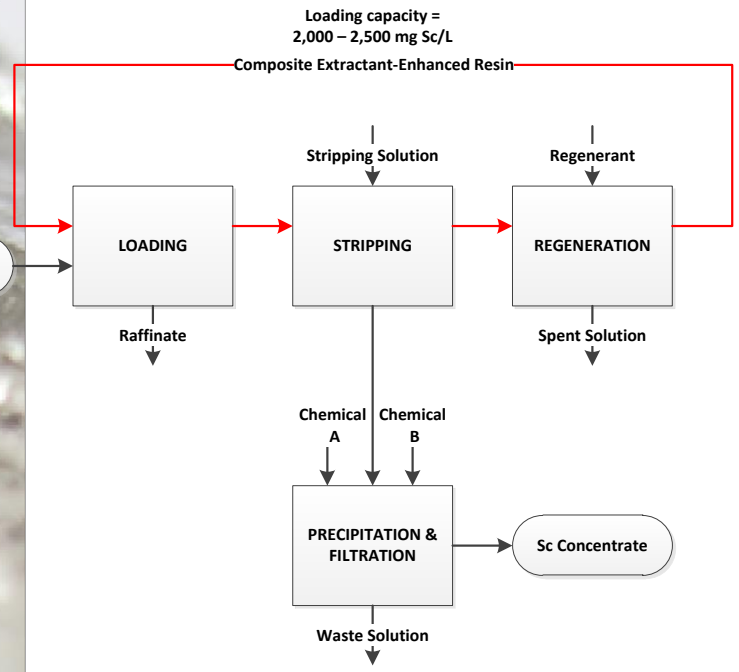


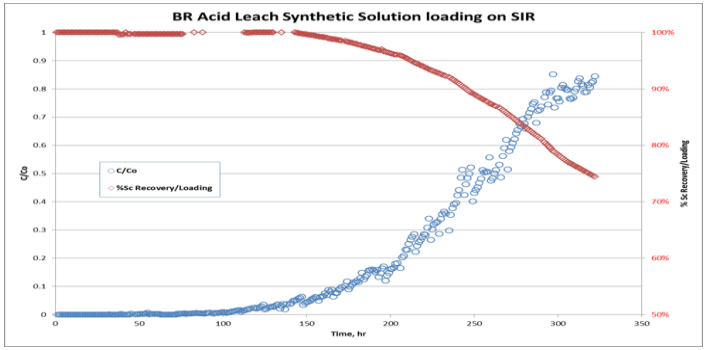
- ✓ Leaching 90°C, 10% pulp density.
- ✓ **Sc recovery ~50% after 4h.**
- ✓ More than 90% of Ca and Na dissolves while Al recovery is 38%, **Fe is 3-4 %, no Si leaching**
- ✓ **10% IL losses per cycle**.

Leaching and 2 step stripping with HCl and H_2SO_4

Sc 43 ppm, Fe 11340 ppm, Ti <2.5 ppm

II-IV SIR® Sc extraction from BR PLS





- ✓Starting from a synthetic PLS and after 314 hours of loading (more than 450 bed volumes) cumulative **% Sc recovery of 74%** with a calculated loading capacity is **2,325 mg Sc/L II-VI SIR resin** was achieved.
- ✓**100% Sc recovery can be achieved at 100 hour loading**.
- ✓**Thus a concentrate with 60gr/kg Sc (as oxide) has been produced from an initial PLS of 6 mg/L Sc.**
- ✓The limits for the presence of other metals in the PLS has been established. The iron concentration was found not be so critical as **the titanium, zirconium and thorium ones**.

Extracting Sc from TiO_2 Acid Waste (AW)

TRONOX, Netherlands

TRONOX

- ✓Sc: 84±10 mg/kg in slurry
- ✓As filtercake ~250 mg/kg

II-IV SIR® Sc extraction from AW

- ✓The SIR has been tested successfully in lab scale with the TRONOX acid waste stream.
- ✓Sc uptake for this solution was **3,505 mg Sc/L II-VI SIR resin.**
- ✓Cumulative percent **recovery of Sc after 60 bed volumes was 97%**.
- ✓**The use of spent acid (15% HCl solution) from Tronox as reagent for SIR process** (resin regeneration) was tested so as to take advantage of the availability of the solution in the Tronox plant facility, and was found to be a viable option.

➢ **10 000 L AW pilot scale tests underway @ II-VI**

Nanofiltration of Acid Waste from TiO_2 production

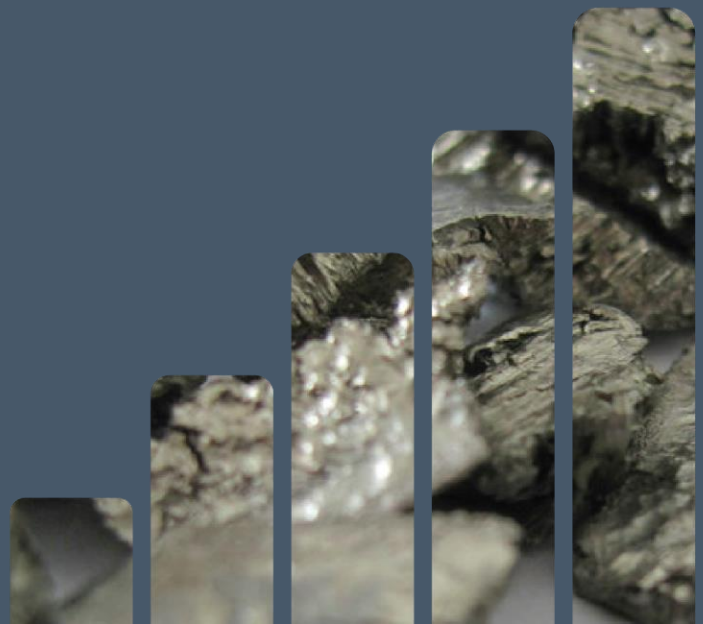
Using self-developed membranes, **up to 93% of Sc retention** from the acid waste steam has been achieved **using acid resistant nanofiltration at 5 bar pressure, with up to 12-fold higher Sc retention in comparison to Fe.**

- ✓ Sc conc. x 2.5
- ✓ Total volume more than halved
- ✓ Extraction interfering metals >90 % removed
- ✓ NF-concentrate ready for metal extraction tests
- ✓ Pilot design in progress in conjuction with new S-X flowsheet

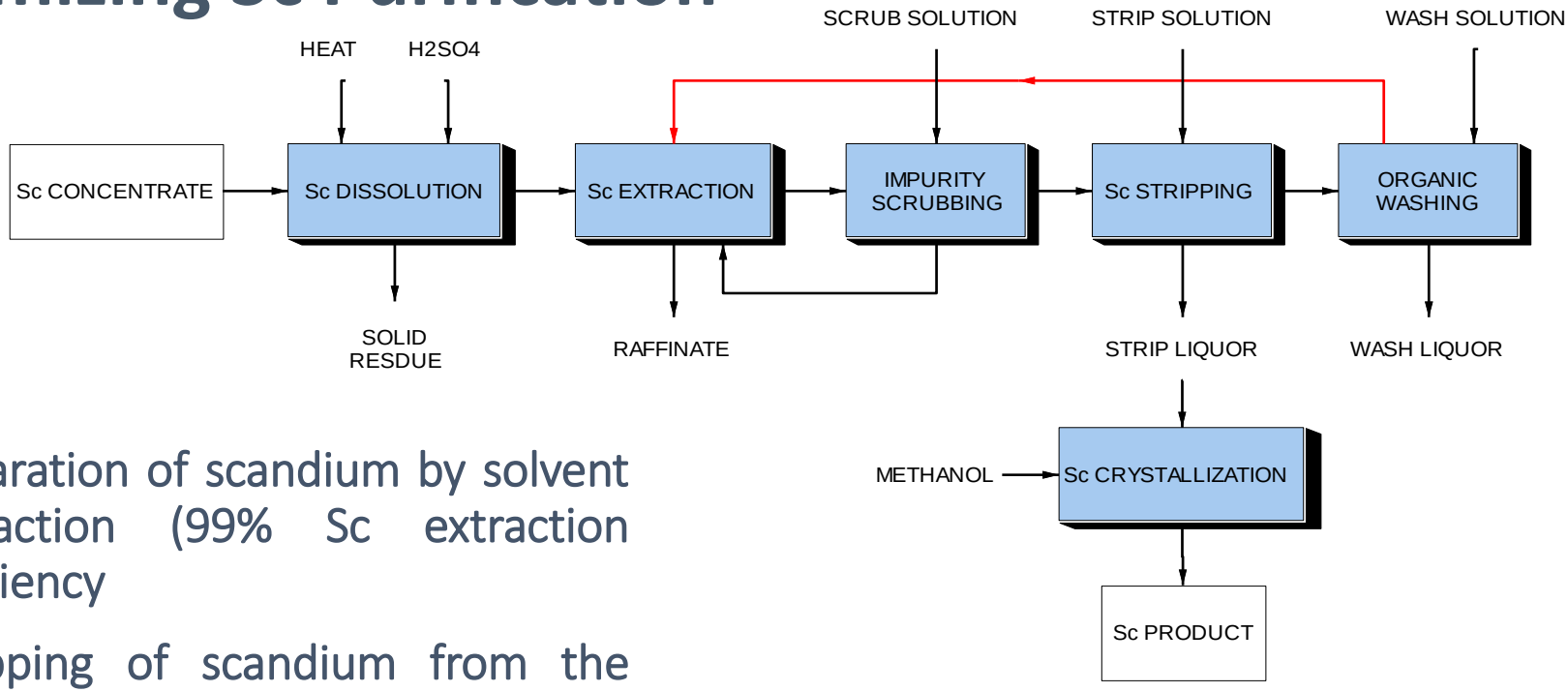
University of Applied Sciences and Arts Northwestern Switzerland
School of Life Sciences

Optimizing the Sc purification

From concentrates to pure compounds



Optimizing Sc Purification

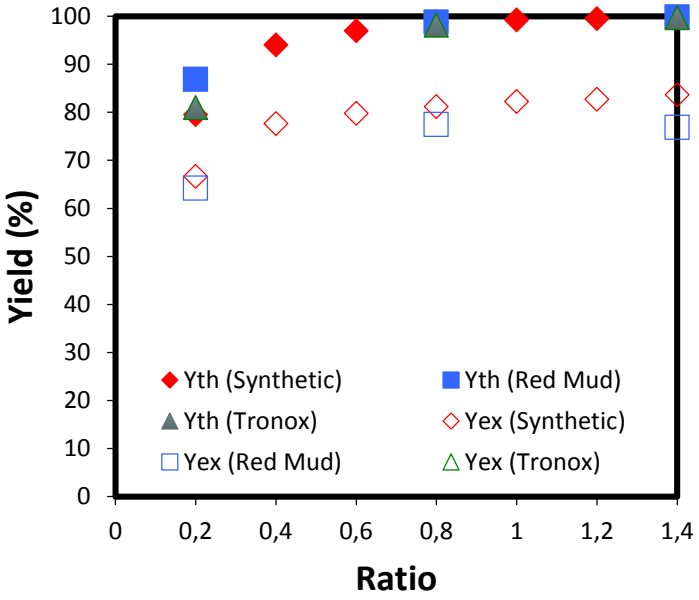


1) Separation of scandium by solvent extraction (99% Sc extraction efficiency
2) Stripping of scandium from the loaded organic solution using aqueous ammonium fluoride solution.

MEAB

3) Precipitation of tri-ammonium scandium hexafluoride by addition of methanol
4) The tri-ammonium scandium hexafluoride can be calcined to produce ScF3
5) Recovery of methanol by evaporation

Anti-solvent crystallization

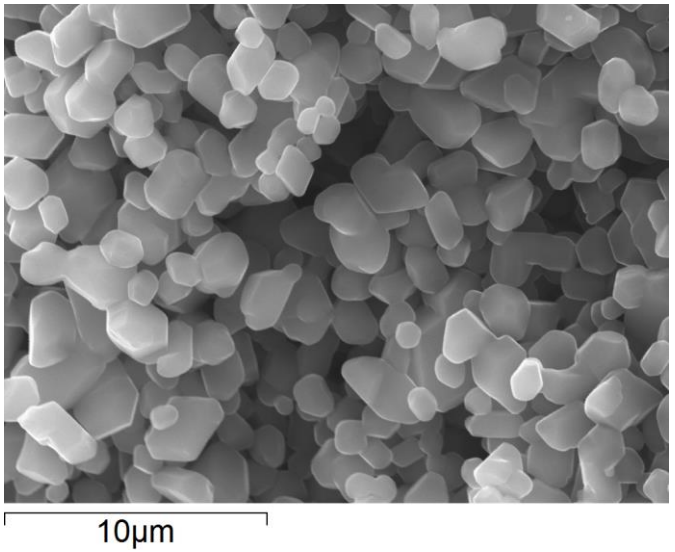


✓Precipitation from real strip liquors

✓$(NH_4)_3ScF_6$ was obtained as the precipitate in all experiments.

Organic to strip liquor v/v ratio vs precipitation yields

Ratio	BR	AW
1.4	99.20	100
0.8	98.54	98.73
0.2	98.31	98.46



Novel technologies for Sc and Al-Sc production

1937: First metallothermic reduction of Sc

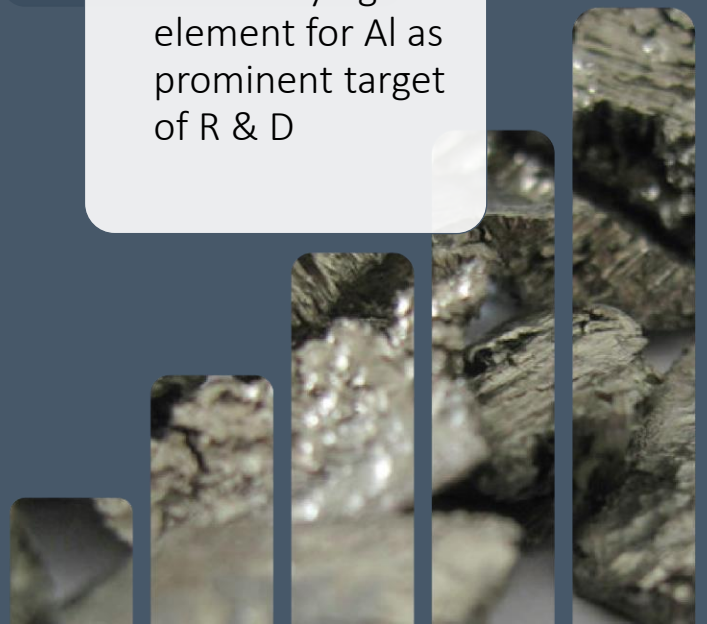
- Oxidic crucibles: low yields and purities

1960: Advancement of the process

- Tantalum crucibles used, 10 g pure metal obtained

Up to date: in-situ production of Al-Sc

- Sc as alloying element for Al as prominent target of R & D



Metalothermic production of Al-Sc

- ✓Lab scale aluminothermic production of Al- Sc master alloy from ScF_3 @1400 ^oC.
- ✓**Bulk Al-Sc alloys with contents up to 27 wt.-% Sc could be produced with no other impurities, at a Sc reduction yield of 77 %.**

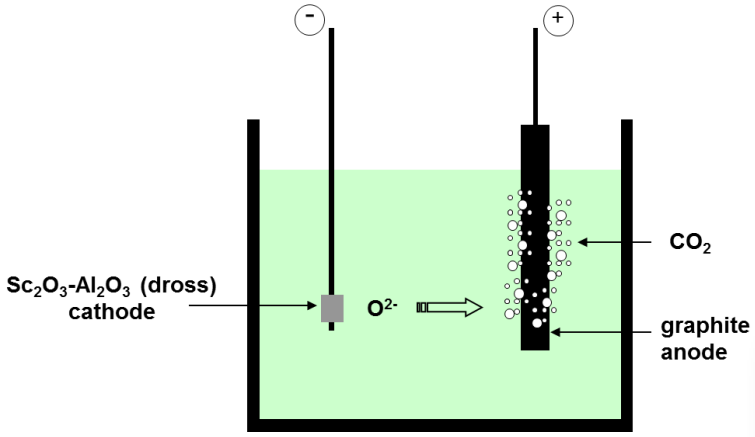
Al-Sc 27%

- ✓Lab scale calciothermic of Al_2O_3-ScF_3
- ✓Results indicate higher Sc yields at low pressures and high Ca surplus – gas-solid reaction probable.
- ✓Intermediate temperatures around 1300 ^oC optimal

Al-Sc rich metal phase

Electrochemical production of Al-Sc

Electrochemical de-oxidation process



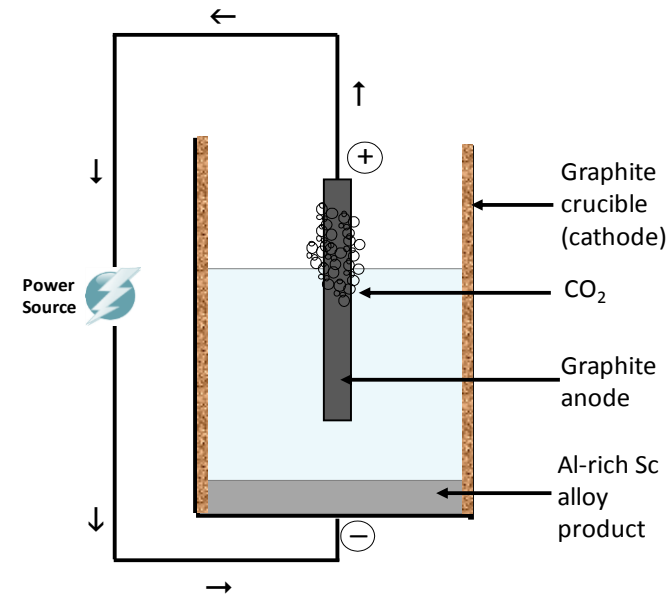
- ✓ **Al with 1 wt% Sc** has been produced using **dross waste from KBM** as raw material in the $CaCl_2$-based melt at 900 °C.
- ✓ **Efficiency ca. 21%**

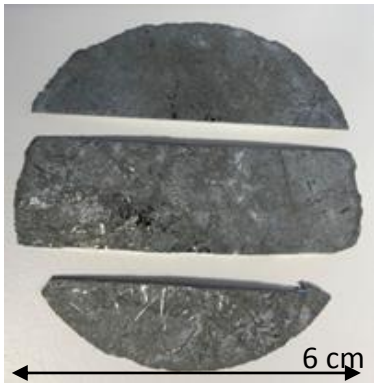
SINTEF

KBM AFFILIPS MASTER ALLOYS

Electrochemical production of Al-Sc

Modified Hall-Heroult process



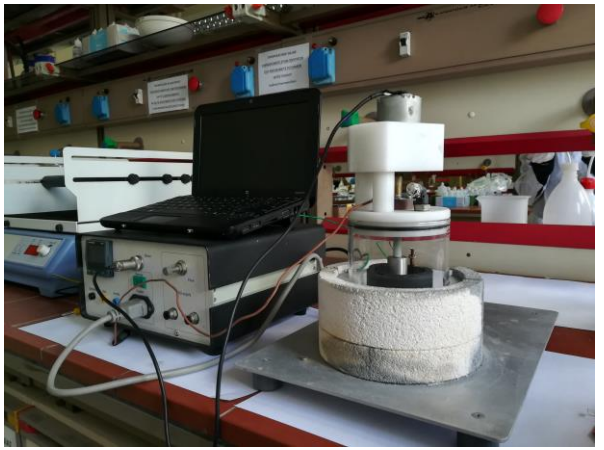


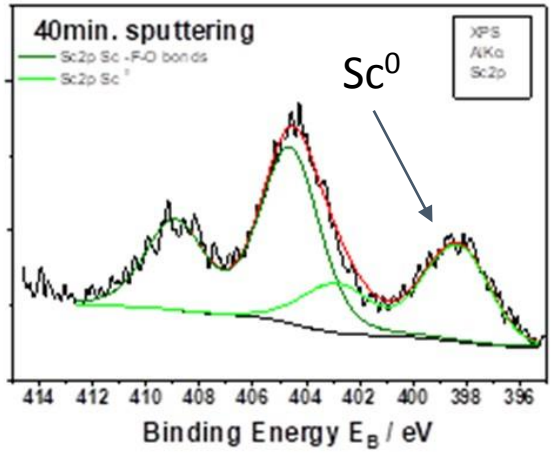
- ✓ **Al with 2.6 wt% Sc** has been produced using Sc_2O_3 as raw material in the cryolite-based melt at 980 °C.
- ✓ **Efficiency ca. 85%**

SINTEF

Ionic Liquid electrowinning of Sc

- **Direct metallic Sc production from $ScCl_3$** dissolved in an ionic liquid (0.12 M [Sc]) was achieved **at 30°C** electrolysis temperature.
- **0,013g of Sc were deposited on an Al cathode**
- The estimated energy consumption for Sc production on an Al cathode is **5-8 kWh/Kg Sc** which is substantially lower to the one for production with molten salts (41kWh/kg) as well as the one of primary Al production (12-14kWh/kg)



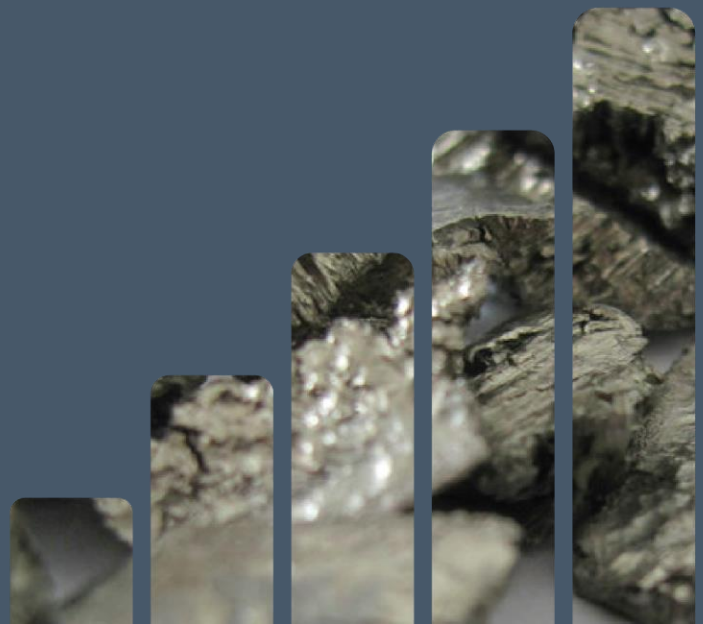


NTUA-LabMet

io·li·tec
Ionic Liquids Technologies

Sustainable value chain

Waste to Critical Resource

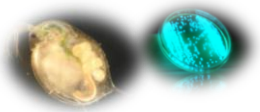


Sustainability Evaluation

ongoing

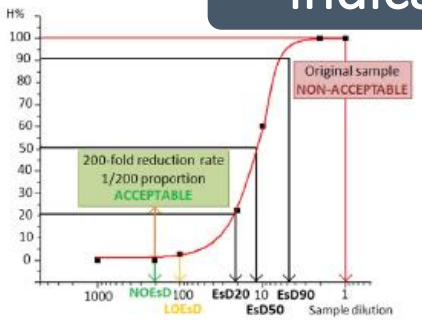
Established ecotoxicity toolkit

- Ecotoxicity studies
  - Sets of ecotoxicity tests (all trophic levels)



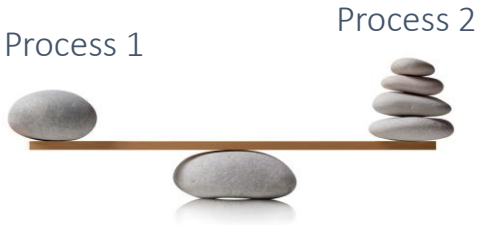
  - Dose-response relations → *Effect Concentrations* $L(E)C_{50}$
  - Sc-materials, by-products, chemicals…

First ecotox indicators



- Inclusion in USEtox model
- ecotoxicological characterisation factor cf (fate, exposure + effects)

- First time inclusion ecotoxicity in Life Cycle Impact Assessment



- Energy, emissions, costs + ecotox

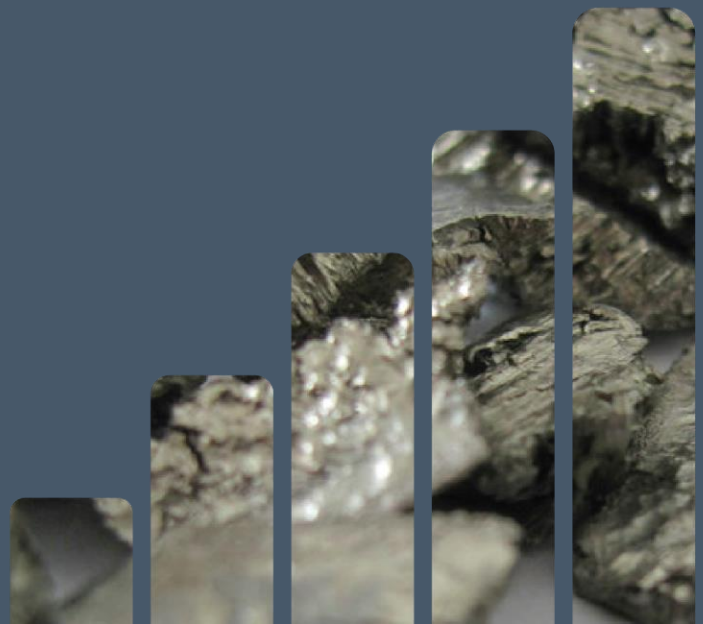
University of Applied Sciences and Arts Northwestern Switzerland
School of Life Sciences

MŰEGYETEM 1782

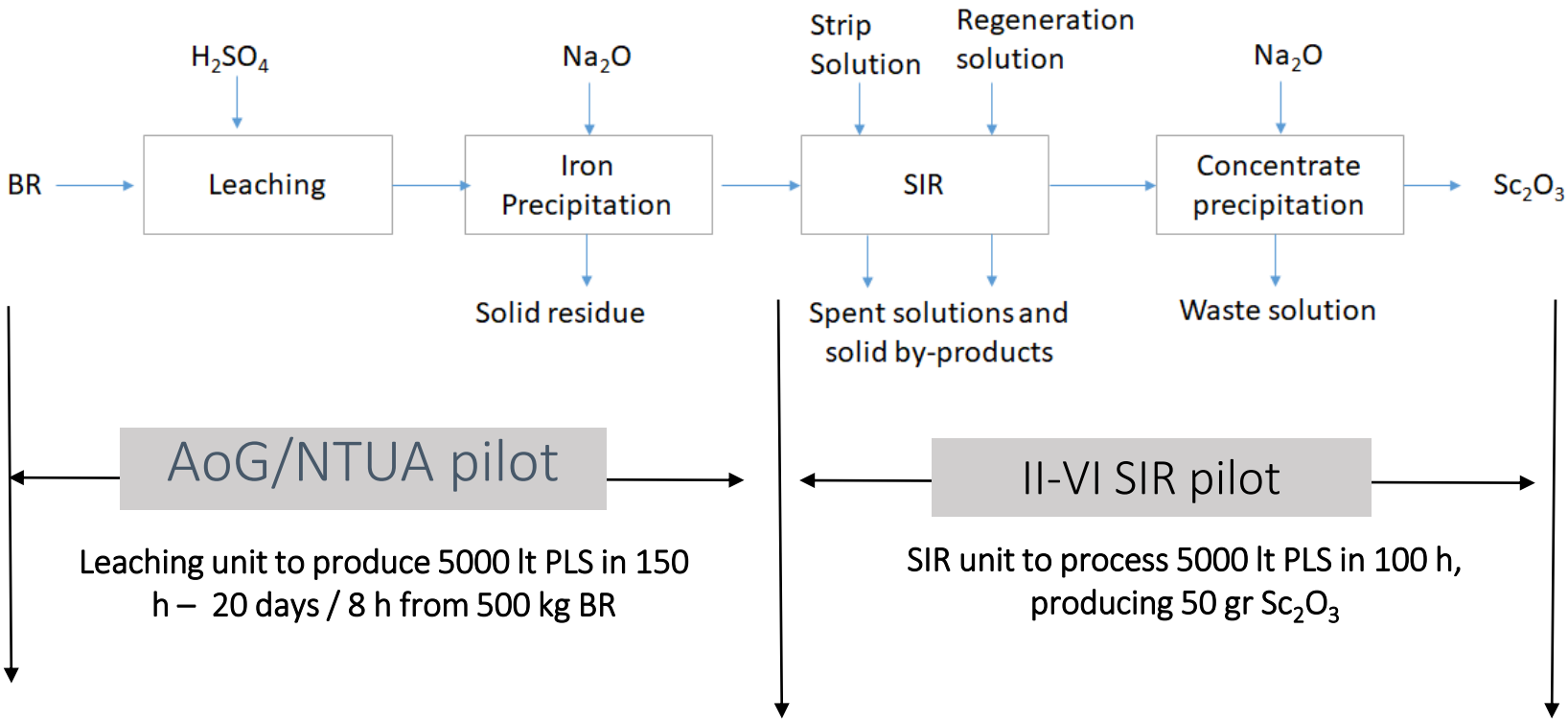
ITRB GROUP

Pilot plant testing

From concentrates to pure compounds



Pilot tests at Mytilineos



BR Sc 0.1 gr/kg

BR	ppm (mg/kg)
Sc	104
Fe	298,108
Al	132,811
Ti	28,885
Na	14,833

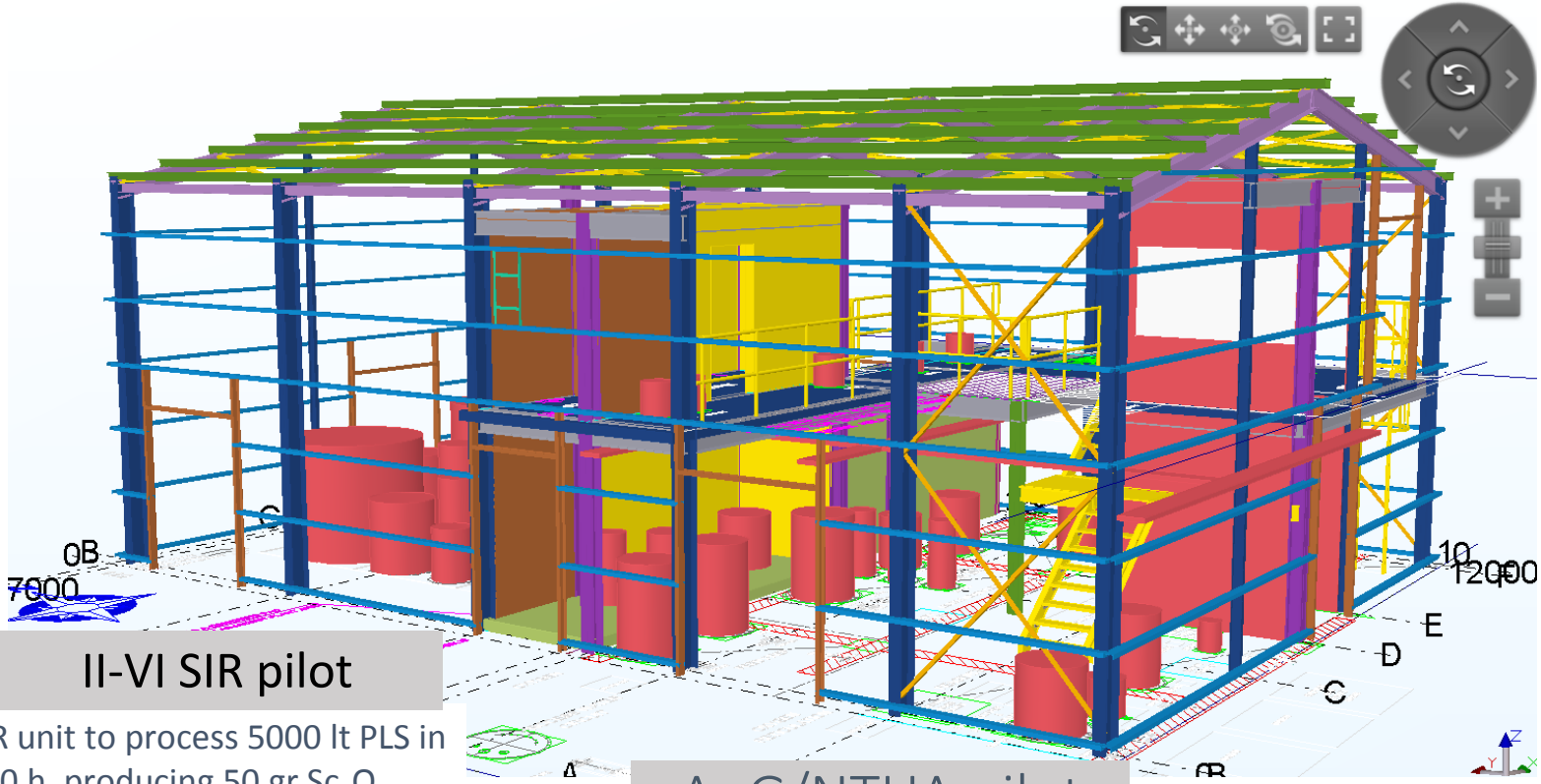
Dilute PLS Sc (10 -20 ppm)
Precipitate up to 0.4 gr/kg

Sc Conc.	ppm (mg/kg)
Sc	405
Fe	172,515
Al	131,688
Ti	9,833
Na	41,696

Concentrate up to Sc 60 gr/kg

Sc conc.	ppm (mg/kg)
Sc	59,791
Fe	857
Al	391
Ti	5,265
Si	3,3524
S	1,280

Pilot tests at Mytilineos



II-VI SIR pilot

SIR unit to process 5000 lt PLS in 100 h, producing 50 gr Sc_2O_3

AoG/NTUA pilot

Leaching unit to produce 5000 lt PLS in 150 h – 20 days / 8 h from 500 kg BR

Commissioning March 2019

EU MARKET POTENTIAL

- **Alumina Sector:**
  up to 500 t/y of Sc
- **Titania Sector:**
  up to 140 t/y of Sc

SCALE RAW MATERIAL SOURCES

AoG Bauxite Residue:
130 g/t Sc; 750,000 t/y

AOS Bauxite Residue:
93 g/t Sc; 900,000 t/y

TRONOX acid waste filter cake:
150 g/t Sc; 50,000 t/y

The research leading to these results has been performed within the SCALE project and received funding from the European Community's Horizon 2020 Programme (H2020/2014-2020) under grant agreement n° 730105.

MYTILINEOS, II-VI, TRONOX, io-li-tec Ionic Liquids Technologies, KTH, RWTH AACHEN UNIVERSITY, MŰEGYETEM 1782, n|w University of Applied Sciences and Arts Northwestern Switzerland, BAM

ALS aluminiumoxid, LCM less common metals, ITRB CONSULTING, Kurt Salmon, KBM AFFILIPS MASTER ALLOYS, MEAB, Fraunhofer, SINTEF

ERES2020 – The 3rd European Rare Earth Resources to be organized by SCALE

Details to be announced soon – The program will feature dedicated Scandium sessions

http://eres2017.eresconference.eu/

European Rare Earth RESources

http://scale-project.eu

http://www.circulary.eu/project/scale/

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Thank you for your attention. Questions?