SisAL Pilot

SisAL Slag

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Valorisation of side streams through Industrial Symbiosis between the Al and Si industries

for resource efficient, low carbon Si alloy and alumina production

Prof. Gabriella Tranell

Clustering Workshop

6 October 2022

The project has received funding from the European Union’s Horizon 2020 research and innovation program under Grant Agreement N°869268.

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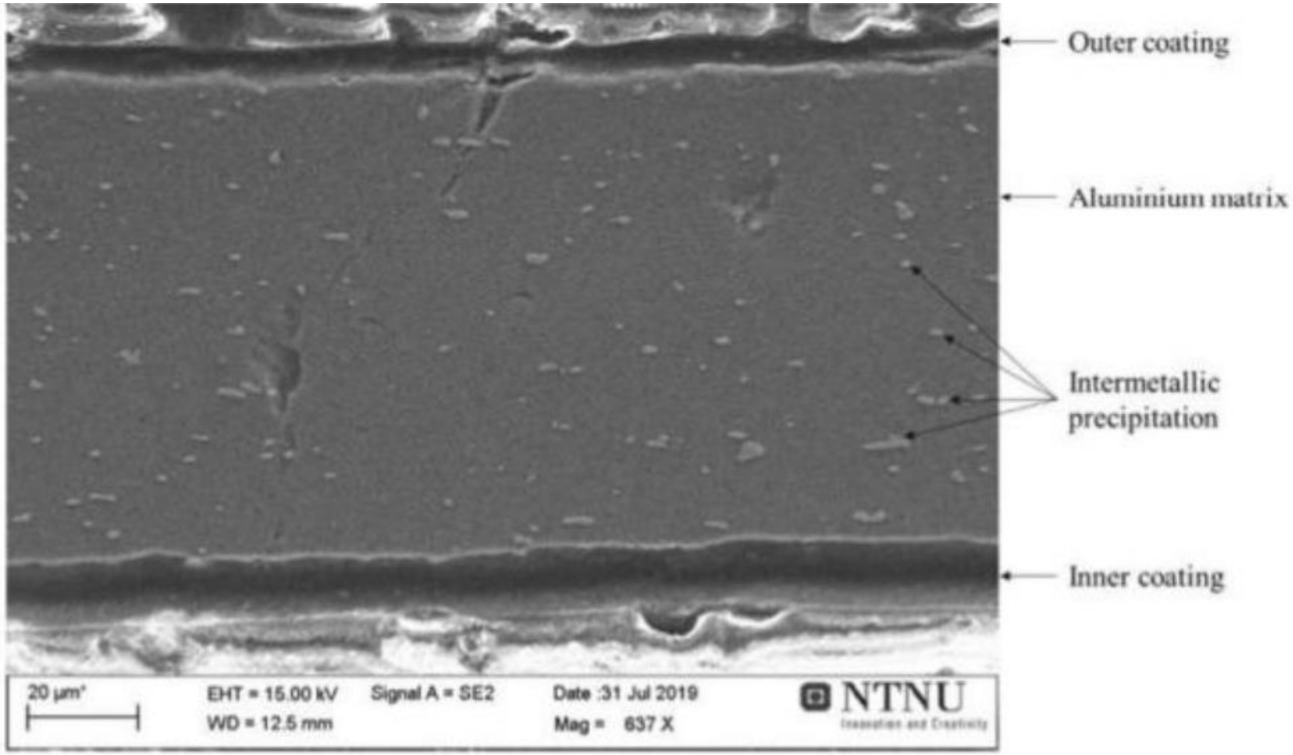
Si – a key alloying element for Al!



From cast alloys to foils…… Around 40% of Si produced used for alloying aluminium

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Industrial Si production needs re-invention to meet sustainability demands!

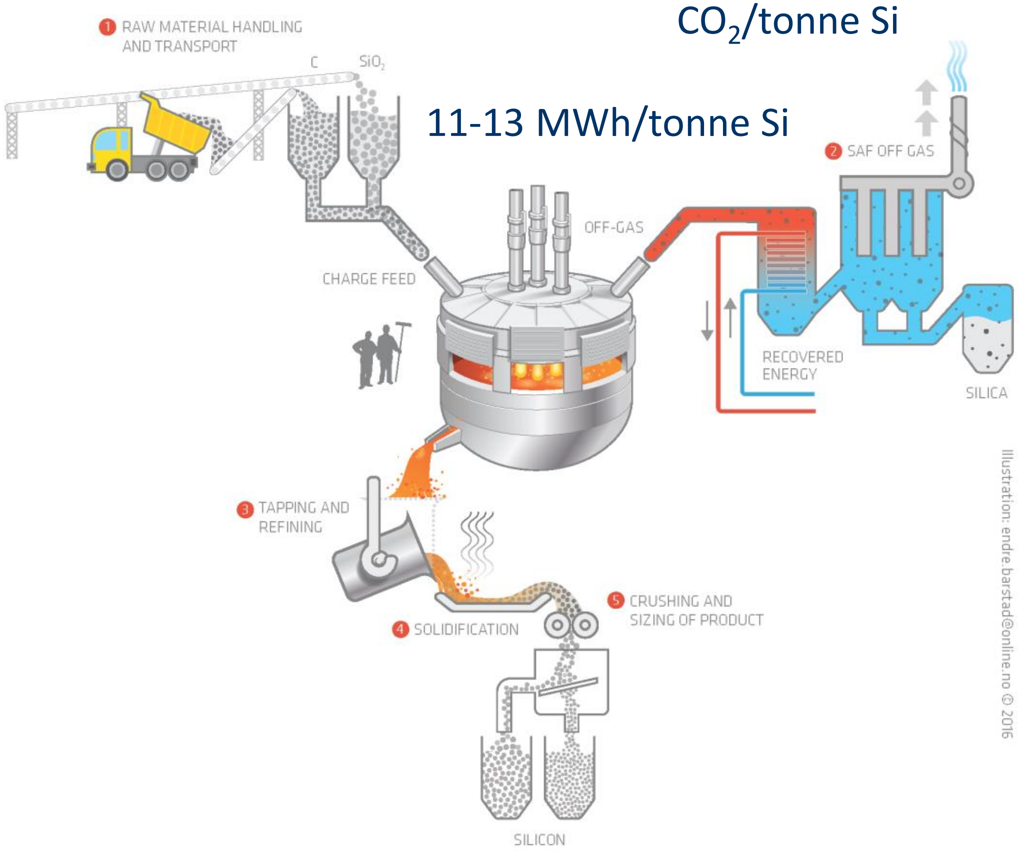
+

$SiO_2 + 2C = Si + 2CO$

- **High specific energy consumption**
  - **energy losses in off-gas**
- **Significant specific GHG (CO_2, NO_x) emissions**
- **Can not use SiO_2 fines**

Approx 5 tonne of CO_2/tonne Si

11-13 MWh/tonne Si



Industrial state of the art: Submerged arc – semi-open furnaces

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The Al industry also has its challenges – not just in reduction!

- Global annual Al production approximately 60 Mton, 20* the size of Si and currently the largest user of Si
- > 600.000 tonnes Al scrap exported from Europe annually
- > 80.000 tonnes of Al dross (>70% Al, rest oxide) generated per year in Europe and processed via salt treatment with varying Al yield and significant environmental footprint
- Industry puts increasing pressure on suppliers to fulfill/deliver low carbon footprint commitments/products - CO_2 free Si!

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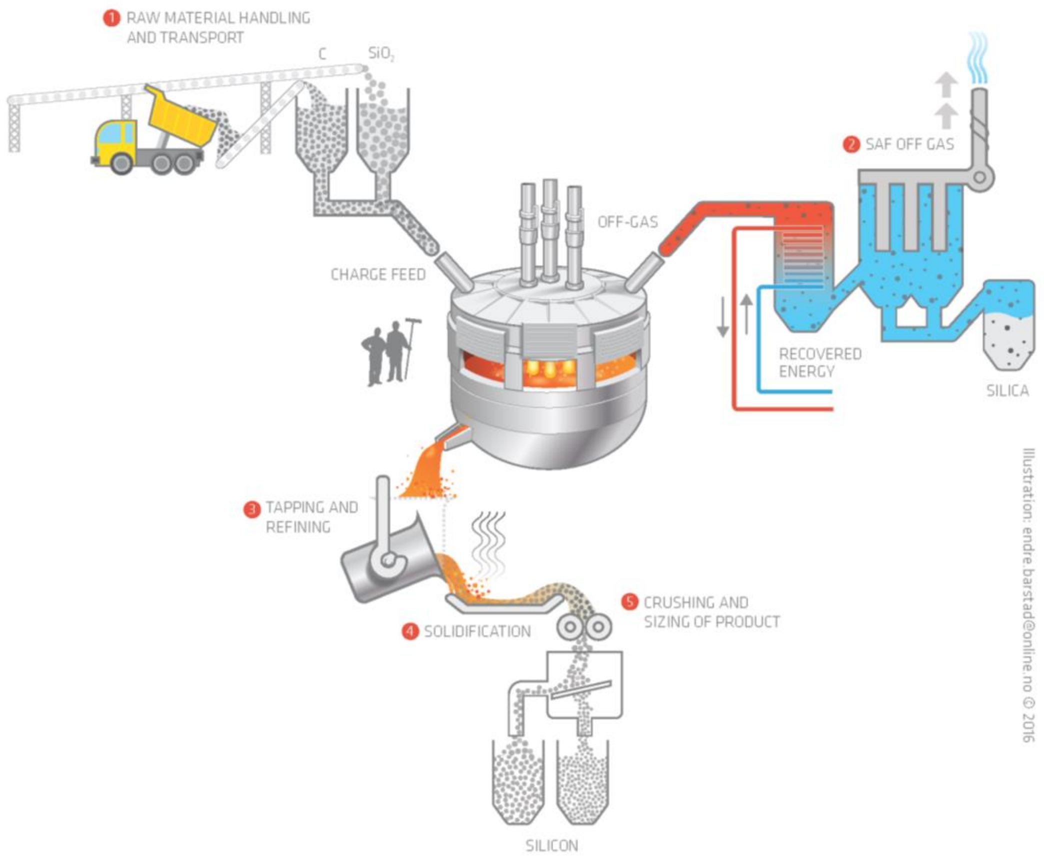
The SisAl Process

Industrial Symbiosis between Si and Al industries!

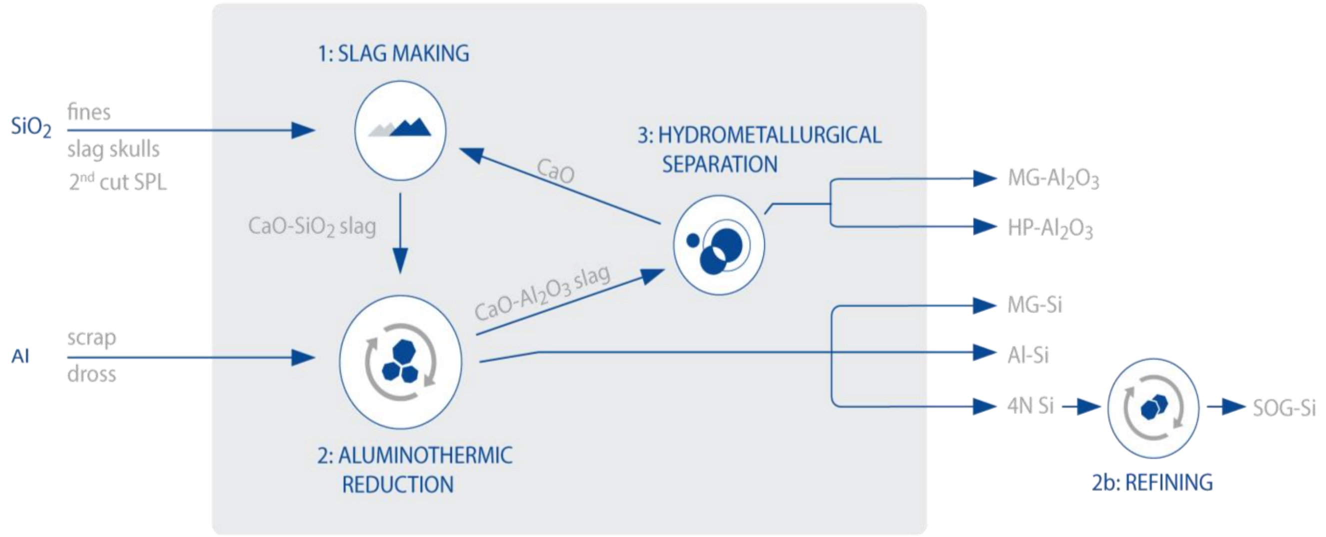


vs

$$3SiO_2 + 4Al = 3Si + 2Al_2O_3$$

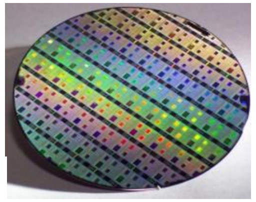
Process taking place in liquid slag
Exothermic Process

- **No direct CO_2 emissions, no Nox**
- **Lower energy consumption**
- **Path to effective use of difficult scrap and dross**
- **No loss of SiO_2 fines**

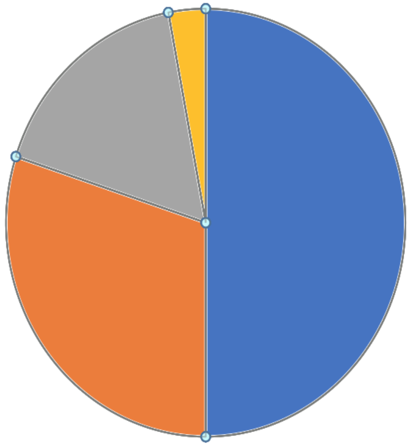


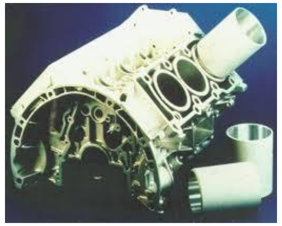
Two products: Si alloy and CaO-Al_2O_3 based slag

PV ca 20%



Other 3%



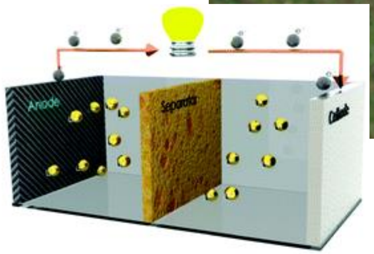


Silicones 30-40%

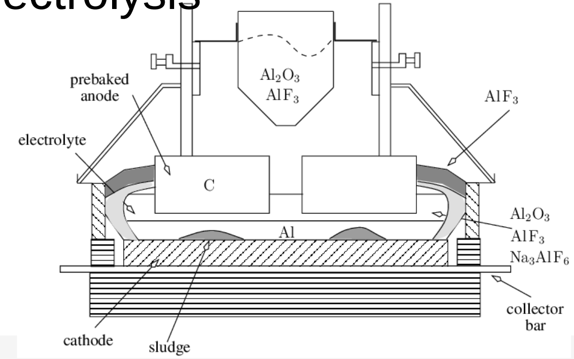
Al alloys 40-50%

MG-Si applications

Production of HP-Al_2O_3 for LED and battery separators



Production of MG-Al_2O_3 for Al electrolysis



Slagformer for ladle refining of steel

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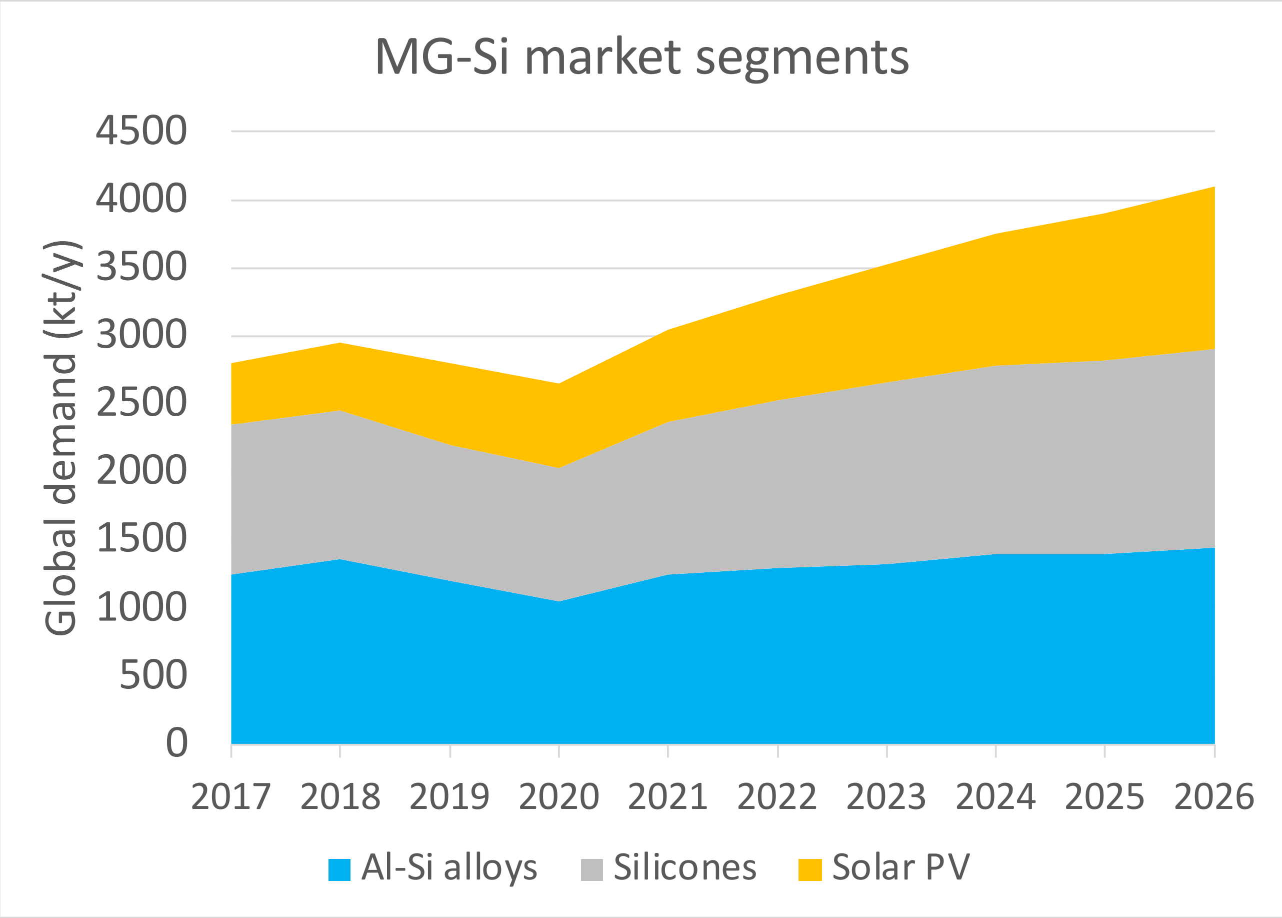
Market for Si and Export of Al scrap



- Strong projected growth particularly in the Solar PV narket
- Policies for import/exports are fluctuating

Market segments - HPA

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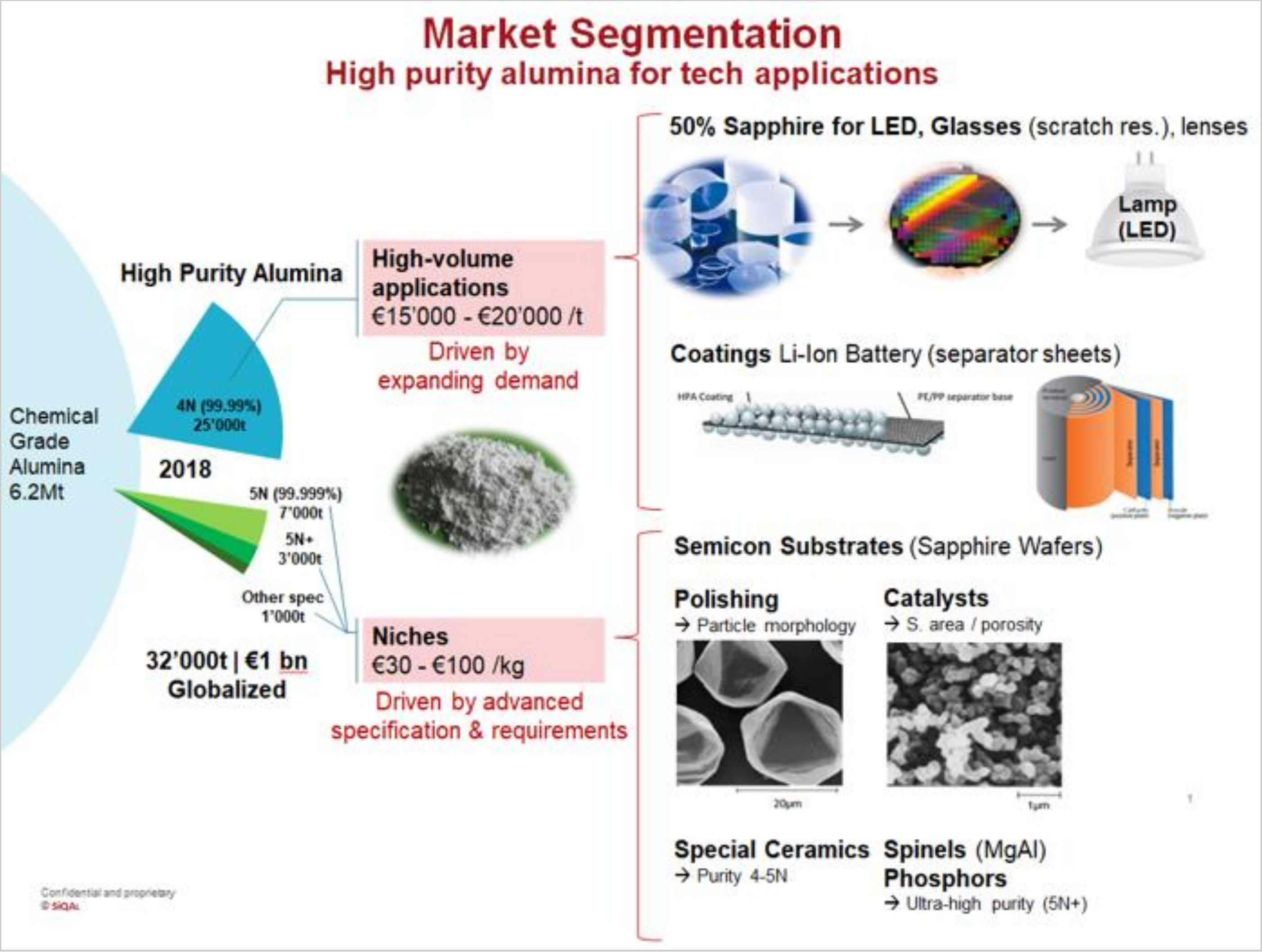

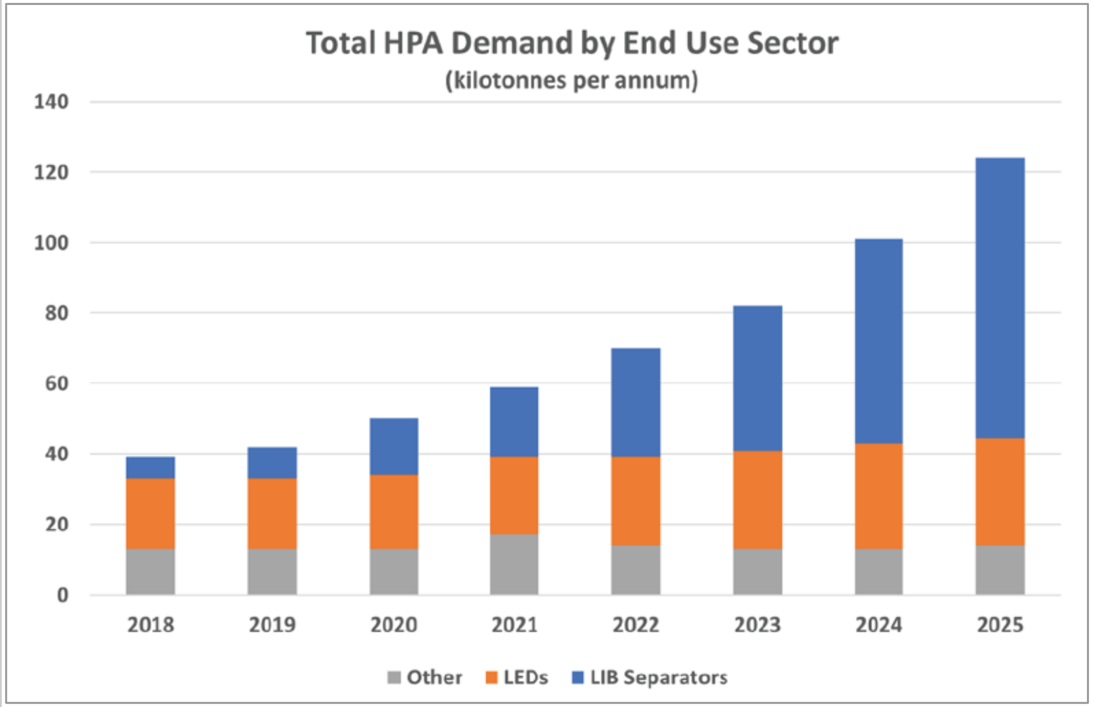

HPA - A strongly growing market!

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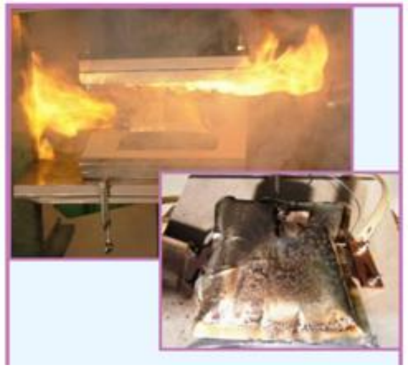
Li-ion battery separator nail penetration test (from Evonik)

With HPA



Without HPA

- The global Ceramic Coated Separator market size is expected to grow from about USD 1000 million in 2019 to about USD 2500 million by 2025 at a CAGR of 23.3% from 2020 to 2025.
- Major players making Ceramic Coated Separators: AsahiKasei (Celgard), SEMCORP, W-Scope, SK Innovation, Freudenberg, UBE-Maxell, Shenzhen Senior Technology, Entek, Mitsubishi Paper Mills, Shanghai Putailai New Energy, Sinoma Science & Technology, Yuntianhua Newmi-Tech, Green Zhongke, Cangzhou Mingzhu, etc.
- The contact with Freudenberg should be strengthened as Freudenberg has no formal or active role in relation to the project. To be followed up.

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SisAl Pilot - Overall Project Objective

Demonstrate an industrial process to produce CRM silicon together with Alumina products, enabling a shift from today's carbothermic Submerged Arc Furnace (SAF) process to a more environmentally and economically sustainable alternative: an aluminothermic reduction of quartz in slag that utilizes secondary raw materials such as aluminium (Al) EoL scrap and dross, as replacements for carbon reductants used today.

IA in SC5, Total budget: 14.5 MEuro , 22 partners, project length: 4 years (2020-2024)

NTNU RWTH AACHEN UNIVERSITY SINTEF HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF MINTEK ITMATI
MYTILINEOS Hydro BEFESA FUNDICIONES REY Erimsa Elkem WACKER DOW
BNW ENERGY SIMTEC SBC SiQAL Supplying the energy revolution CiaoTech PNO CONNECTING AMBITIONS INNOVATION ENGINEERING Silicor MATERIALS

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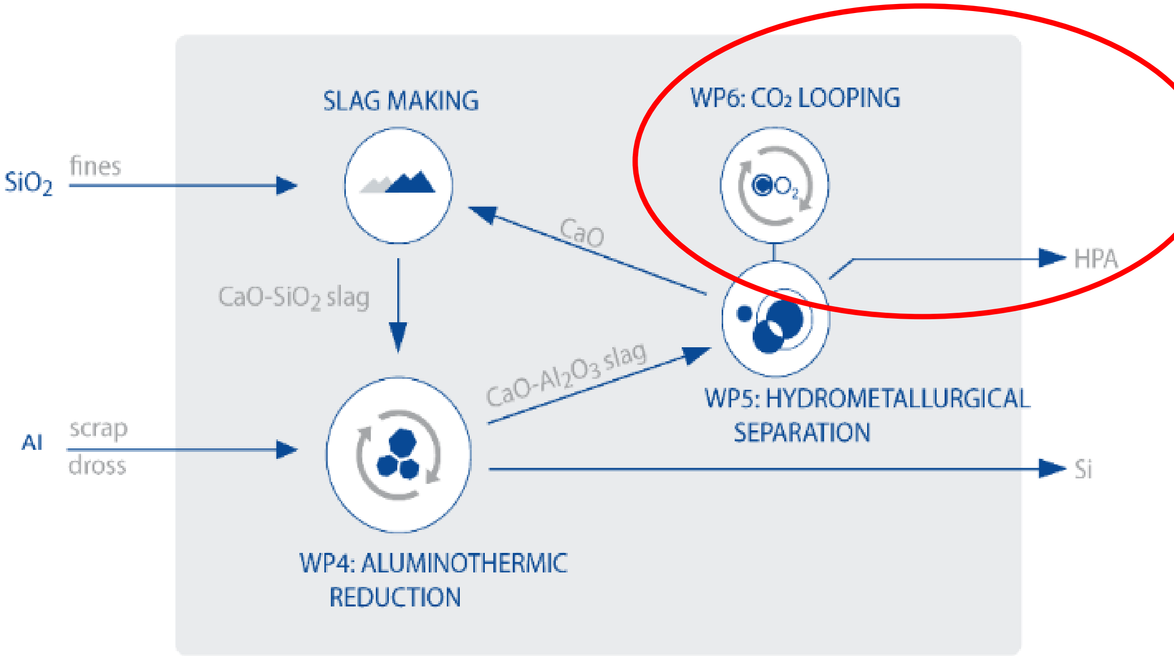
Main project objectives

- Valorization of the $CaO-Al_2O_3$-based slag from the SisAl process:
  - Making and demonstrating the suitability of HPA for the Li-ion separator market
  - Demonstrating the suitability of the slag as CO_2 capture media
- Building and demonstrating operation of a mobile CO_2 looping rig
- Making Go-to-market/commercialisation plans and environmental assessments for the above products and processes
- Disseminate and communicate results to industry, students and the public/other stakeholders at large



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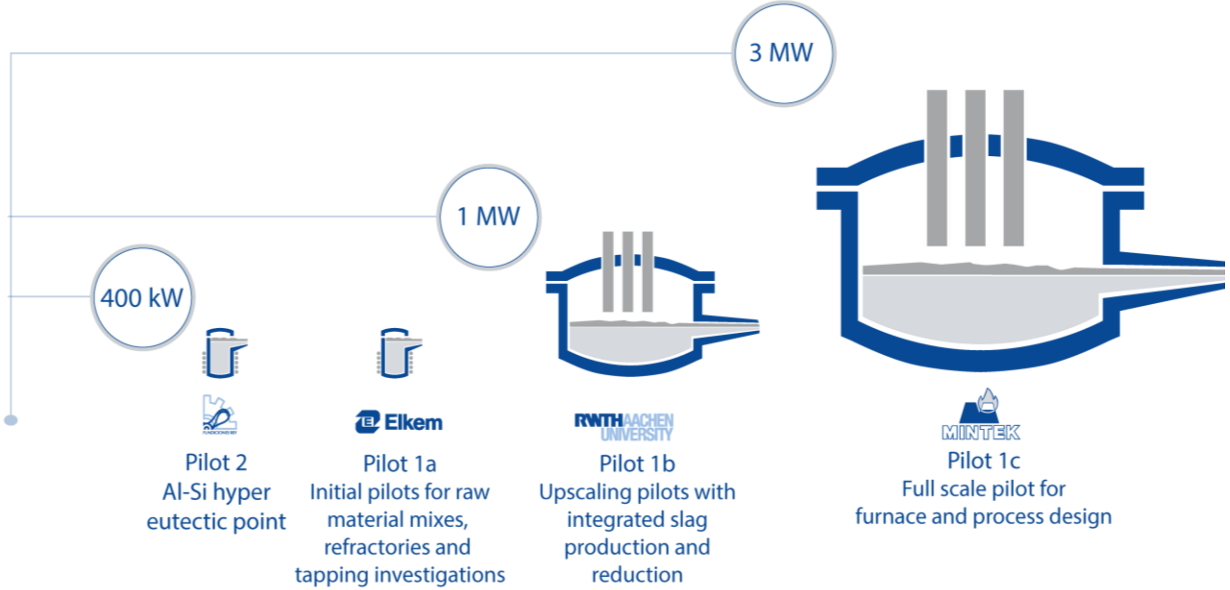
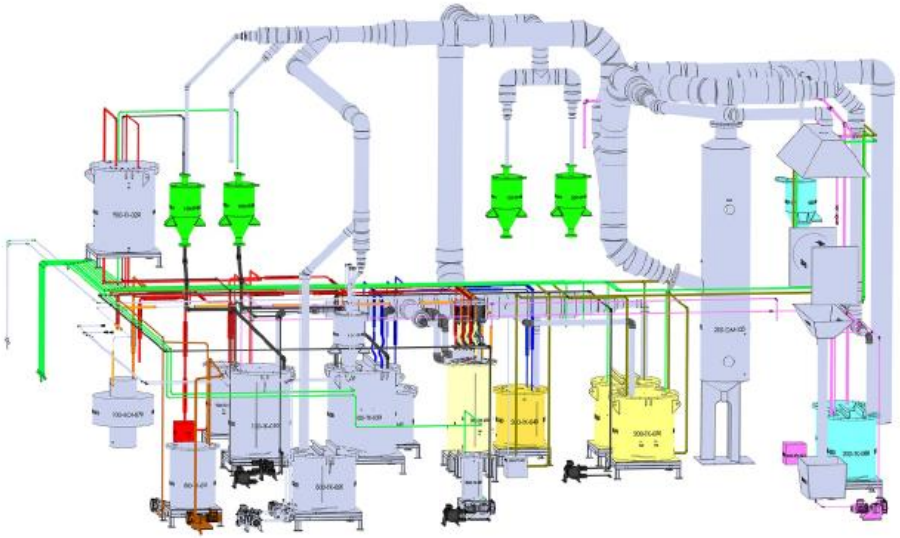
Piloting at 5 different sites in 5 countries



Year 2 Year 1 Year 2 Year 3

Pyrometallurgical Pilots: Si alloy production with different RM



Year 3

Hydrometallurgical Pilots: MGA and HPA production from slag

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So what have we achieved so far?
Alloy production

22 campaigns at Elkem Pilot centre:

- Producing more than 3 tonnes of Si alloy and 10 tonnes og $CaO\text{-}A_{l2}O_3$ slag using:
- Quartz fines and refining skulls
- Dross, shavings and Al blocks

10 Trials at the FREY foundry in Spain in 50 kg scale:

- Producing high Si alloys from:
- Lower melting point slags
- Various Aluminium-containing scraps, drosses and bottom ashes

Experience is easy operation, fast reactions!

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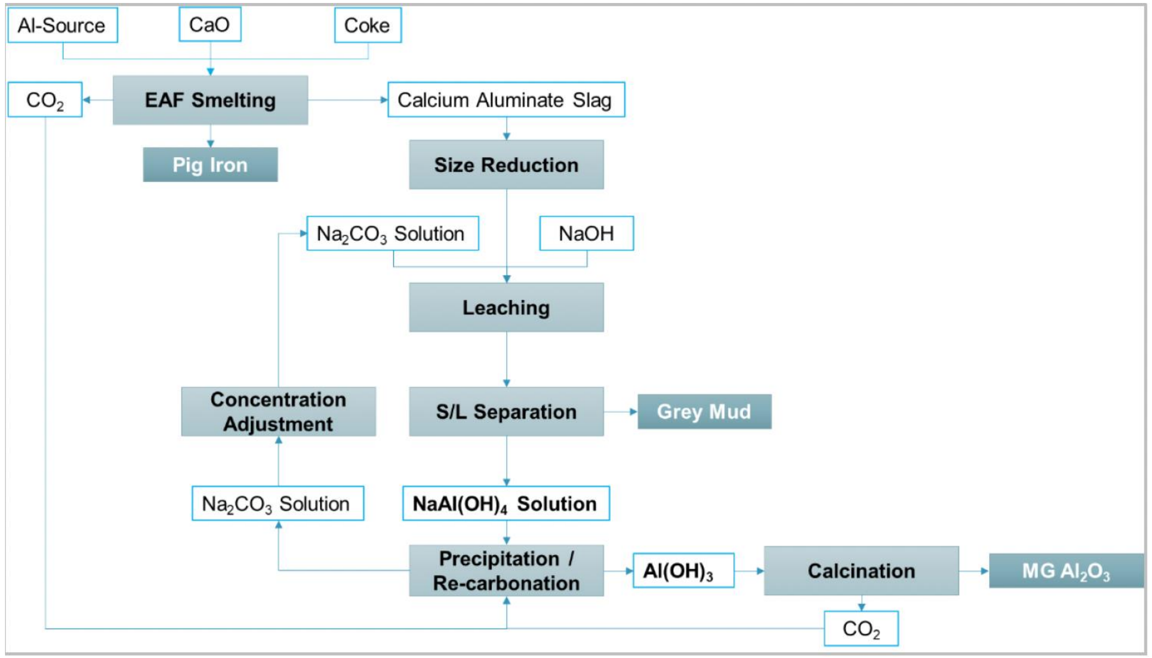
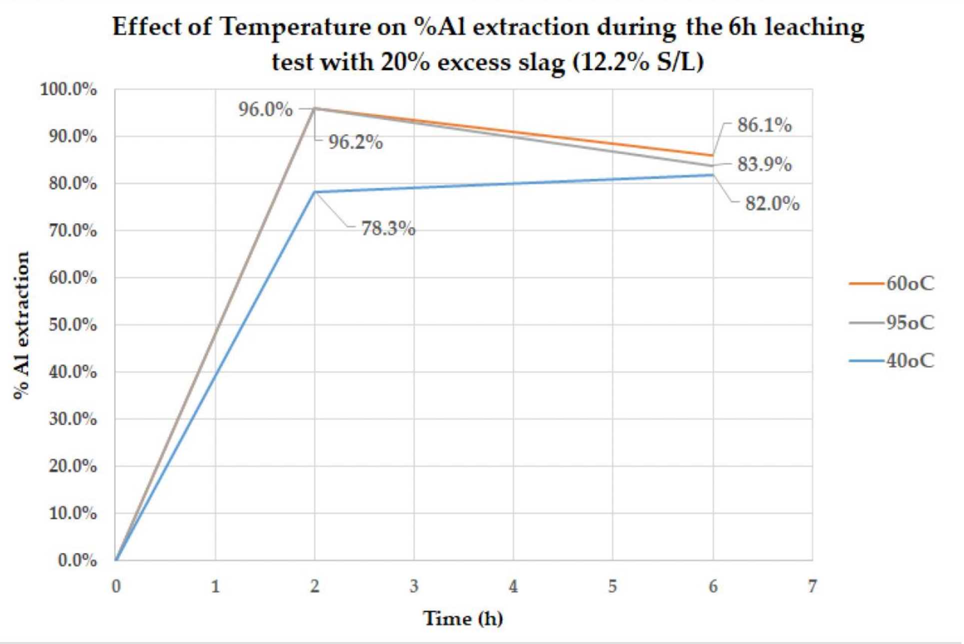
Hydrometallurgical extraction of Alumina from slag

- Alkaline route for MG-Al_2O_3 production





> 95 % extraction of Al_2O_3 from slag

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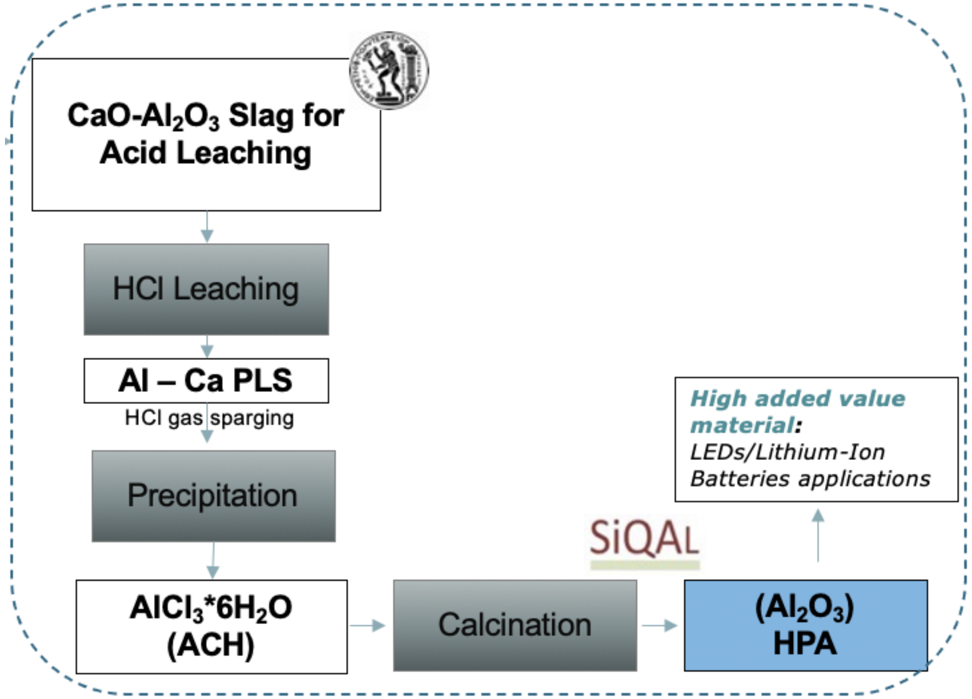
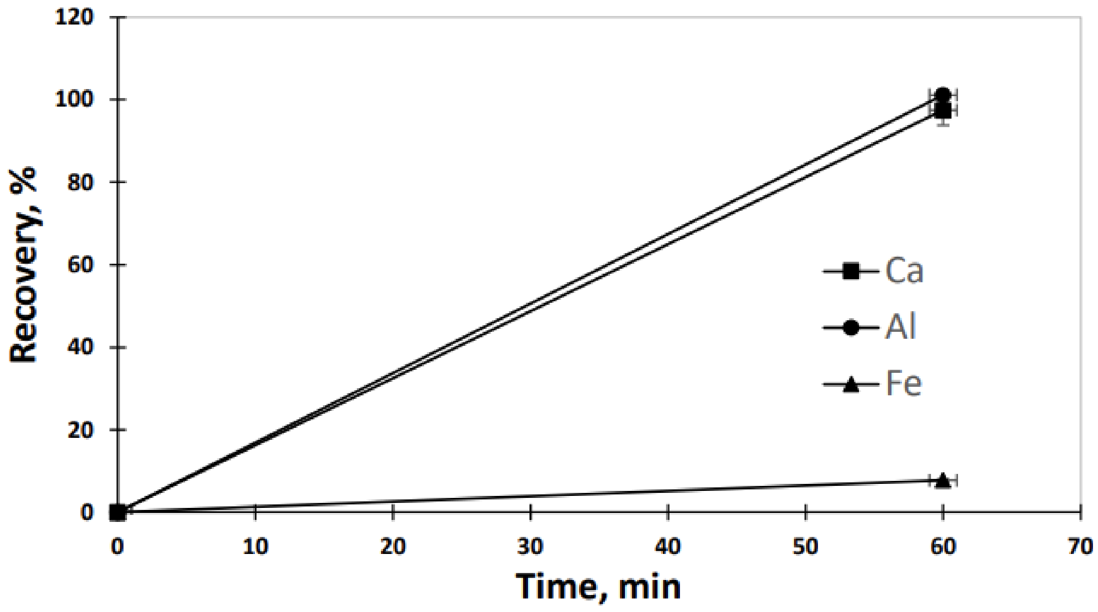
Hydrometallurgical extraction of alumina from slag

- Acid route for HP-Al_2O_3 production





leaching with 5.87 M HCl, at 80 °C, agitation 300 rpm for 1 h, solid to liquid ratio (S/L) 1/10.

> 90 % extraction of Al_2O_3 from slag, HPA at 3N produced, 4N in the process of being verified

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Alumina retrieval from slag and its use in Li-ion batteries

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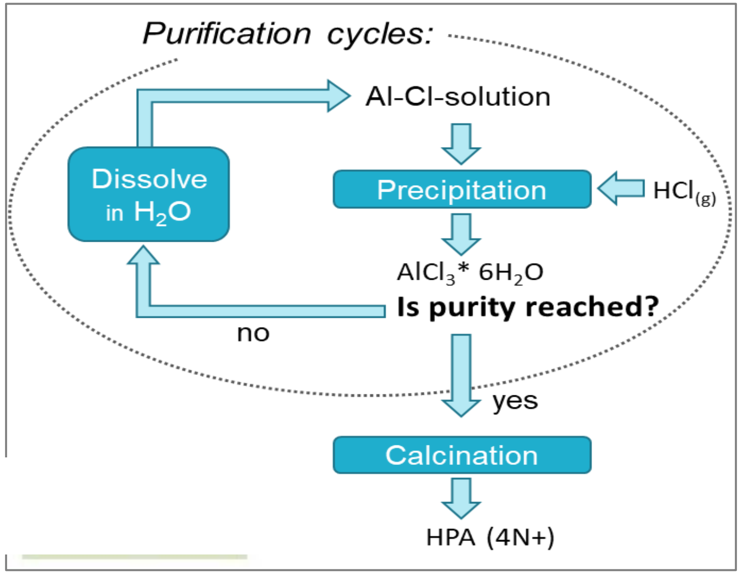
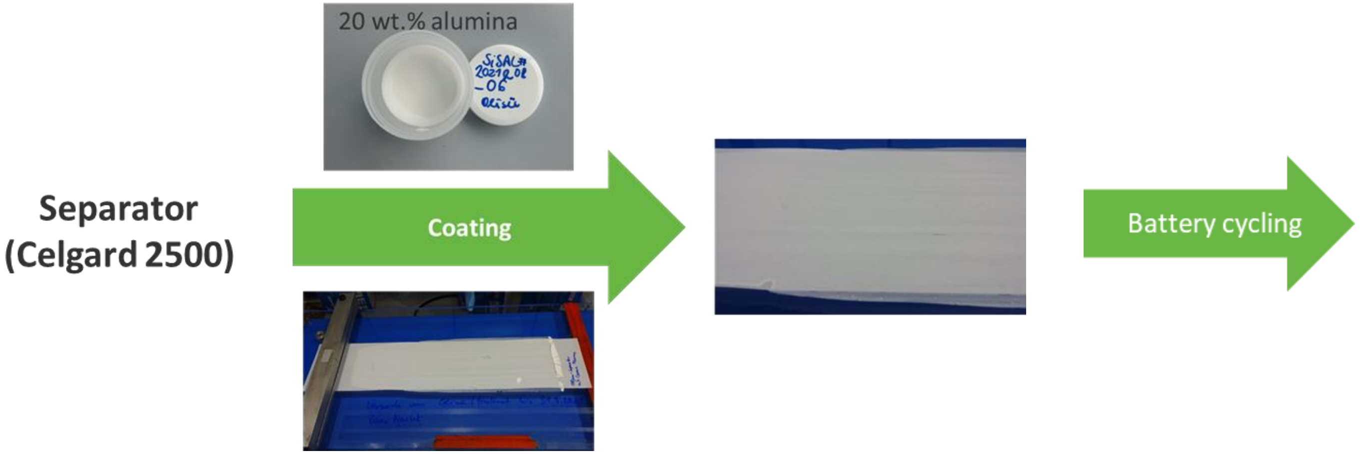


Figure 1: Purification process(es) to achieve high-purity alumina (HPA) from slag/dross

- We are producing high-purity alumina by recycling the by-product of a Si/Al metallurgical slag process (Figure 1)
- The alumina may be used in ceramic coatings within Li-ion batteries. This introduces a safety measure by stabilizing the battery to thermal runaway effects
- First battery cycling trials for in-house coated separators compared with commercial equivalent separators are promising (Figure 2)



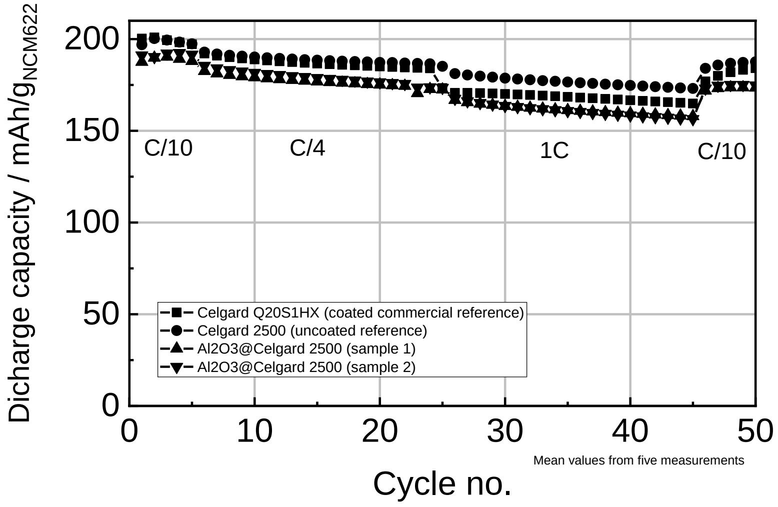


Figure 2: Cycle data comparing a commercial coated separator from Celgard, uncoated separator, and two samples of separators coated in-house with commercial gamma-alumina

Product Development

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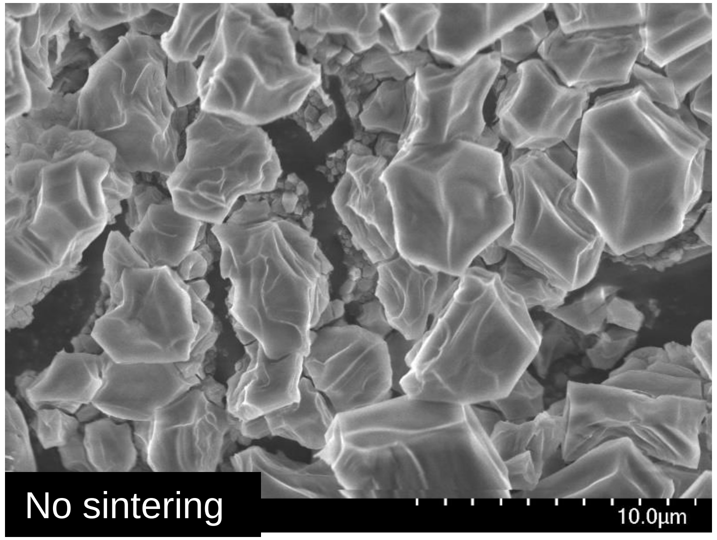

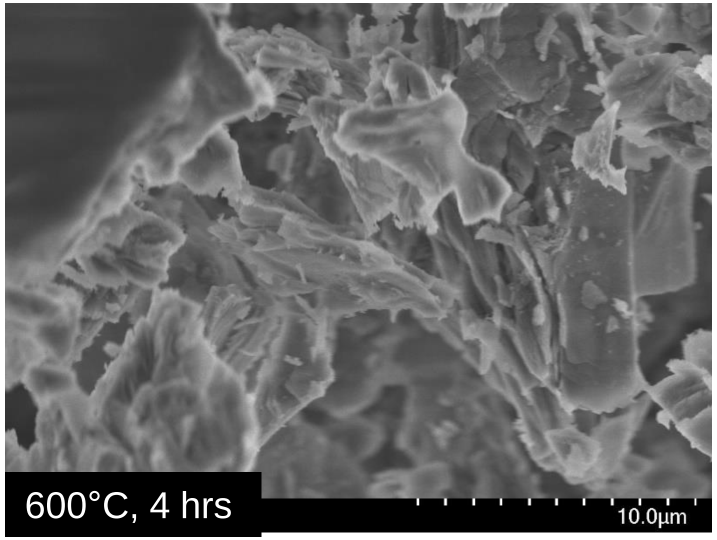

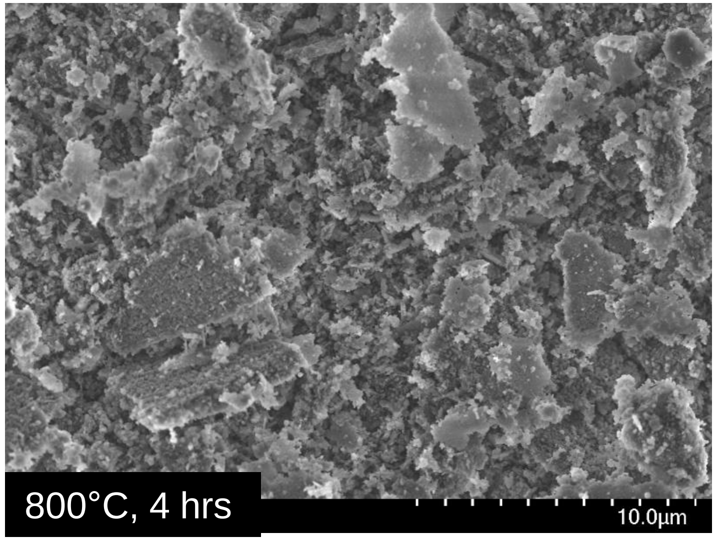

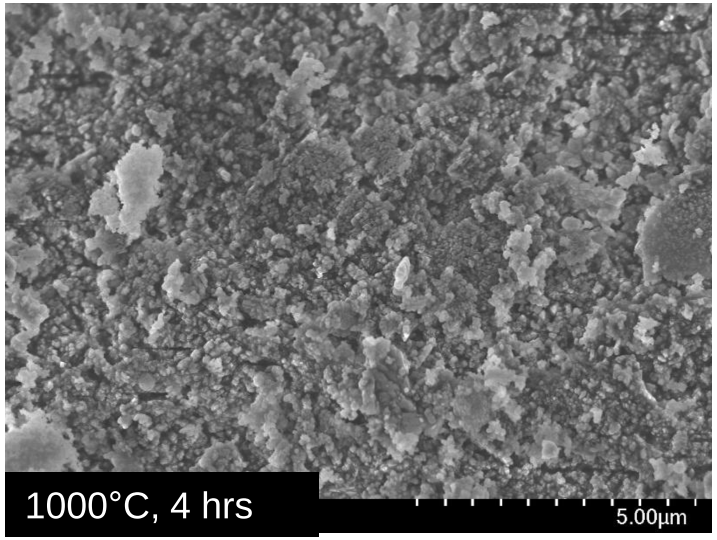

- Optimisation of purity
- Optimisation of morphology (shape, structure (γ vs α) and PSD
- Production of testable amounts in separator industry

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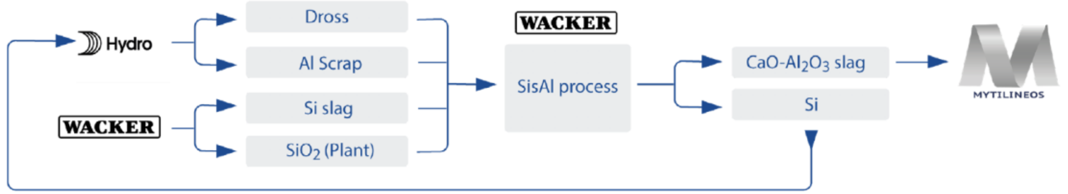
Additional project activities

- Mapping of available raw materials in Europe
- Flow sheeting (HSC Sim/FactSage) for LCA and economic assessment
- Business case development
  - Different Si al and based products (MG-Si, AlSi alloy, HP-Si, MG-Al_2O_3, HPA and CaO-Al_2O_3 slag)
  - Business clusters/partnerships



Economic performance calculations are based on the *short/medium term* projections.

OPERATING COSTS	**Tonnes / y**	**€ / t**	**€ / t Si**	**€ per year**
Slag skulls	9 000	200	658	1 800 000
SiO2 fines	1 500	20	11	30 000
Al dross	4 400	700	1 127	3 080 000
CaO extra for slag making, 50 wt% CaO	7 135	60	157	428 098
Sum raw materials			1 952	5 338 098
Personnel			160	437 440
Maintenance			130	355 420
Refractory, consumables, misc.			280	765 520
Slag skulls handling & crushing	9 000	25	82	225 000
Power (3.9 kWh/kg Si at 0.025 €/kWh)			98	266 565
TOTAL OPEX			**2 702**	**7 388 043**
CAPEX (Table 2.8)	**1 920**	**€ / t Si**	**5 249 280 € total**	
REVENUES				
Si metal from aluminothermic reduction	2 734	2 000		5 468 000
Si metal from slag skulls	1 800	2 000		3 600 000
CaO-Al2O3 slag	17 150	100		1 715 000
TOTAL REVENUES				**10 783 000**
Operational margin				3 394 957
IRR	**62,1**	**%**		
NPV (WACC = 20 %)	**10 878 000**	**€**		
NPV (WACC = 7 %)	**32 738 000**	**€**		

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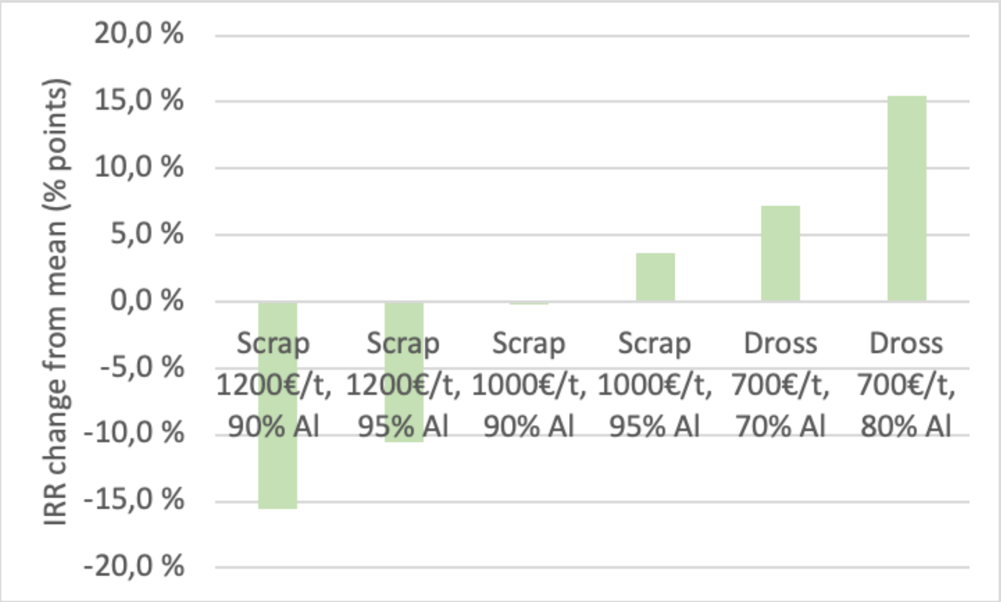
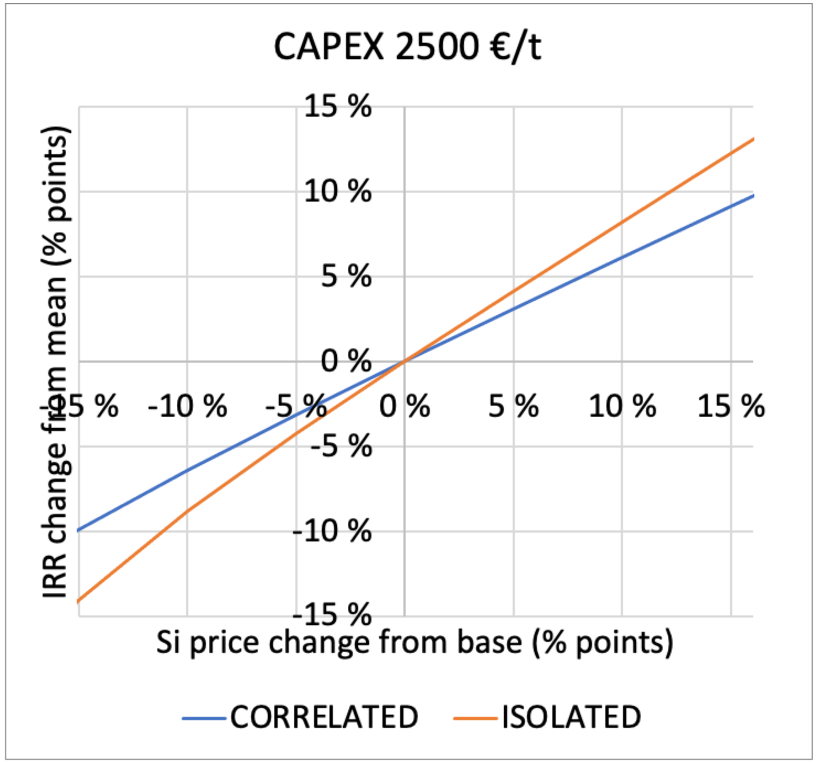
Business cases and economic modelling

- Significant influence of Al source price and quality on the economic performance of the process
- Indicating significant economic advantage using dross before scrap



- Co-fluctuation of Si and Al prices make the price sensitivity low



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Summary

- SisAl concept of aluminothermic production of Si alloy and CaO-Al_2O_3 slag demonstrated in 100´s of kg pilot scale using Al and Si side streams
- Si alloy >98% Si
- High yield in recovery of alumina using both alkaline and acidic routes
- MG-Al_2O_3 with sufficient purity produced. HPA still to be verified at 4N from slag
- Preliminary economic considerations show positive and robust business cases
- Environmental assessments of the SisAl value chain have pointed at opportunities and pitfalls of utilisation of different secondary raw materials such as dross and scrap

Non-linear value chains are not trivial BUT by necessity the future!

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