SisAl Pilot

SisAl Pilot Project
Innovative pilot for Silicon production with low environmental impact using secondary Aluminium and silicon raw materials

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The SisAl Pilot project: a new EU initiative in the raw materials field

First year project results

Foreword by Coordinator

Already one year out of four has passed in SisAl Pilot and many achievements have been reached despite the COVID-19 pandemic. We have all had different challenges within the consortium, such as lock down, delay in delivery of spare parts and materials and, last but not least, lack of social interaction.

Frequent online discussions within and between all work packages, internal workshops, including a modelling workshop and a resource mapping workshop, as well as virtual project meetings have been the key for success to reach all goals during the first year.

Examples on things that have been achieved during the first year are:

- Almost a complete first version of a comprehensive resource mapping thanks to good collaboration within the consortium.

- Successfully performed small-scale experiments at NTNU used as input in the upcoming pilot trials at Elkem, starting in April 2021. Slags from the small-scale experiments have been sent to NTUA and SiQAl, who are currently optimizing the separation of the different compounds through hydrometallurgical treatment.

- Digital solutions for optimal knowledge transfer between the technical work packages have been tested out and will be used during Elkem's pilot trails. This will allow all members in the consortium to attend and discuss the trials virtually instead of in person.

- Discussion about plans and technical solutions for the upcoming pilot trials at RWTH and MINTEK have been initiated to ensure good progress in the project.

- The modelling team, ITMATI and SIMTEC, have done their first models of the small-scale tests and will now start modelling the pilot furnaces. HZRD has completed a first version of the SisAl Pilot process in HSC.

- First version of the exploitation roadmap has been finalised and delivered to EU.

- A project video, homepage and social media channels have been realised and the project has been presented at different events, such as the Silicon for the chemical and solar industry XV conference, PROMETIA 7th Scientific Seminar and at PDAC.

We are looking forward to three more years with lots of interesting discussions, results and physical meetings with the SisAl Pilot team.

With kind regards,

Gabriella Tranell and the NTNU team

Main updates from the partners

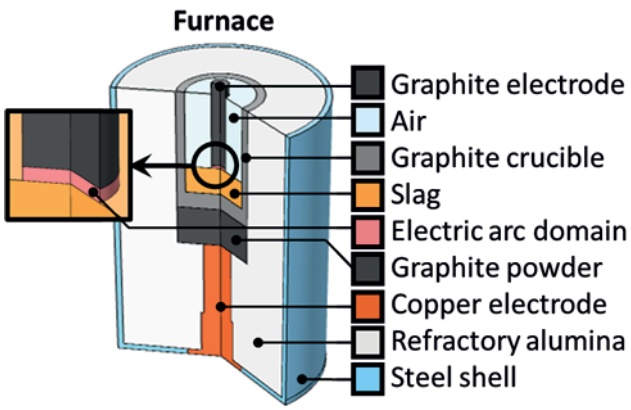
NTNU
Norwegian University of Science and Technology

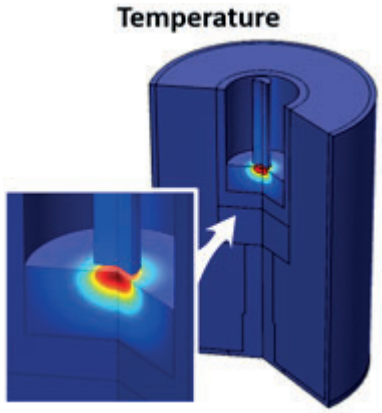
In the processing of aluminium, a significant amount of the by-product aluminium dross (mixture of metal and oxide) is produced. Since considerable amounts of valuable aluminium is contained in the dross (typically 70-80%), additional industrial processes, with considerable cost and negative environmental impact, are employed to recover parts of this aluminium. Therefore, alternative routes that can better utilize the valuable aluminium in the dross are of interest. **While the SisAl process is previously validated using aluminium metal/scrap as reductant, NTNU has for the first time demonstrated experimentally in kilogram scale that dross is a suitable reductant for SiO_2 containing slags as well.**

Production of Si alloy (shiny grey) using dross

NTNU has also made a first LCA model for the SisAl Pilot process that is currently being validated in cooperation with WP5.

Aluminothermic reduction in electric arc furnace (EAF) involves various complex physical phenomena. During the first year of SisAl Pilot project, **SIMTEC** has proposed several numerical models in order to gain insight on the process. Simplified electric arc models provide sufficiently fast computer simulations of the energy supply to the molten material inside the furnace. Heat transfer and slag melting have been modelled to predict required energy input. Chemical reaction and diffusion process have been modelled to determine the reaction kinetics. Computational fluid dynamics models involving two phases (slag and metal) have been also developed to determine how both phases mix together. A simple model of tracking the material loss due to evaporation has been also proposed. Using necessary measurements and input parameters from the laboratory-scale experiments, these models could be useful to predict and to provide recommendations on how to optimize the technological process and expand it to an industrial scale.





MYTILINEOS, as Work-package 3 leader, has been coordinating and supervising the laboratory scale tests to optimize the SisAl slag leaching recipe. The goal is to achieve the production of alumina bearing precursor solutions out of which commercial aluminium oxide product can be precipitated. Also. MYTILINEOS has begun in parallel to study the ways to retrofit its existing hydrometallurgical pilot plant (see photo attached), in order to accommodate the pilot scale demonstration of the developed technologies in the coming years of the project.

The focus of the first year was on testing different process routes and melt compositions. For this purpose, after prior thermochemical modelling, several modes of operation of the electric arc furnace (EAF) were tested in small scale. Since energy input during the aluminothermic reaction in the DC-EAF is hampered due to the formation of a metal phase with a lower density than the slag, a new theoretical process route for the reaction outside the furnace in a reactor was developed. This is now being verified to guarantee pilot-scale feasibility.

BNW completed the first deliverable from WP 4 Exploitation at month 6: "SisAl Pilot Exploitation Roadmap, version 1".

In this deliverable, relevant supply chains and market demands are described as well as customer value and advantages achieved by using our solutions, assessing the competitive advantage versus incumbent industrial processes, and a description of the IP status.

Value propositions for different stakeholder groups are suggested, including the European community at large, as follows:
- Reverse carbon leakage by investing in new European raw materials production with accompanying industrial jobs
- Become more self-sufficient and hence reduce criticality of the Critical Raw Material silicon
- Take a larger part in the fast-growing industrial supply chain for Li-ion batteries and other high purity alumina (HPA) markets

Take important steps contributing to a European low carbon circular economy.

Befesa is responsible for characterizing, selecting and preparing Al based raw materials (WP1) and Befesa secondary Alumina (BSA) (WP3) for the SisAl process.

In the first year, the characterization of these materials has almost been completed. Particle size, chemical analysis before melting, metal content and chemical analysis after melting have been analysed in the Al based raw materials, while BSA has been characterized by chemical analysis, crystallographic analysis, specific surface area, porosity, density and SEM images.

Nowadays, Befesa is working on the interpretation of the analyses, in order to deliver the materials when necessary.

In the first year of the SisAl Pilot project, **ERIMSA** took fully advantage of its extensive experience in developing technologies in the extraction of quartz applying a methodology that respects the environment and is fully compatible with agriculture, livestock and forestry. As partner in the work package 1 “In- and output material properties, mixes and analyses”, it worked on selecting, characterizing and preparing quartz from ERIMSA’s mine suitable for the SisAl process.

The work performed proved the chemical characterization of available different types of quartz and possible sources are by-products presently sold as aggregates for concrete industry or metallurgical quartz for ferroalloys industries.

NTUA is involved in the acidic and alkaline leaching of slags produced by WP2. Currently, the characterization of two different slag samples has been carried out, received from SIQAL and NTNU, respectively. The first slag sample was characterized (chemically and mineralogically) and used as raw material for acidic leaching study, consisting of kinetic experiments in order to define the optimum leaching conditions. The results indicated higher than 95% Al and Ca extraction either at mild or at intensive leaching conditions, in terms of temperature, pulp density and HCl concentration. The optimum leaching conditions came out as a combination of high metals recovery as well as of minimum silicon content in the PLS. The second slag sample (from NTNU) is still being characterized, while an initial leaching test was performed at the optimum conditions determined previously, to assess the efficiency of NTNU slag’s acidic leaching. After optimizing the acidic leaching conditions, a precipitation study will follow. For this study, a custom-made crystallization reactor will be used at the Laboratory of Metallurgy for the precipitation of ACH, through HCl gas sparging.

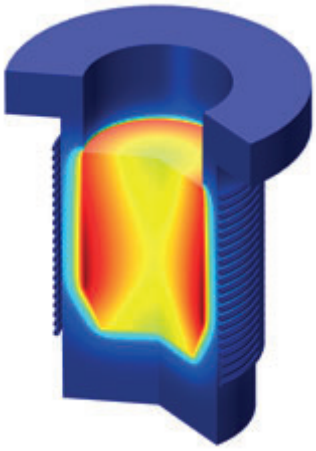
As far as the alkaline leaching is concerned, NTNU slag will be investigated as potential raw material (according to chemical and mineralogical analysis results) in order to be further processed by Na_2CO_3 for the extraction of valuable metals, based on a well-known process that has been already applied in similar like calcium aluminate slags treatment. The interaction of WP3 and WP2 is very crucial, as the leaching progress is highly depended on the suitability of slags, which are produced by WP2. In this point of view the production of a high aluminium content slag with eliminated silicon content will lead to efficient leaching either by acidic or by alkaline route.

In the first year of the SisAl pilot activities, **Hydro** has sent materials for the upcoming pilot tests at Elkem and what needed was received on site.

Pure aluminium from our cast house was provided. Pressed shavings from the rod sawing process an end-capped material represent to types of material for testing.

In addition, dross from rotary cooler station was includedin the shipment.Typical metal content in this type of dross is above 70 wt%, mostly finely distributed as lumps below 20 mm in size.

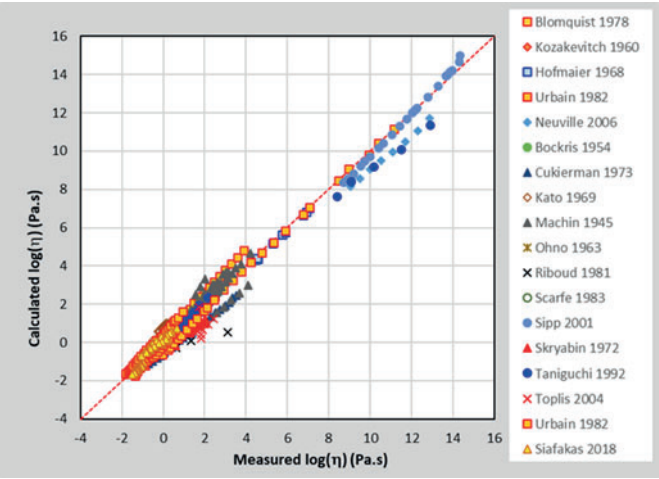
In the SisAl pilot project, **ITMATI** performs the numerical simulation of induction furnaces to model, assess and optimize interactions between physical phenomena. After one year of activity, the progress of the research shows that SisAl Pilot goes beyond the limits of the literature on this topic. The experience of the researchers and the cooperation with industrial partners could make the difference in achieving the objectives. Therefore, ITMATI participated in the Modelling Workshop, where the advantages, limitations and opportunities of the furnace models for SisAl Pilot were explained in detail to the key partners. Research efforts have been focused on developing and implementing models that represent the behaviour of the slag making by melting quartz and lime in induction furnaces with the specific characteristics of Fundiciones Rey.



Temperature in a typical induction furnace

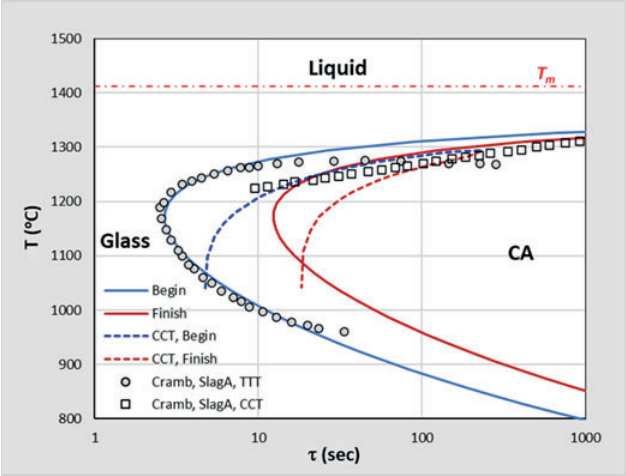
WP2 Activities

In order to design and optimize the aluminothermic reduction of SiO_2 slag, we have first developed a phenomenological model for the evaluation of the viscosity of Al_2O_3-CaO-SiO_2 slags. The model is able to calculate the rheological properties covering homogenous liquid to heterogenous, partially solidified Al_2O_3-CaO-SiO_2 slags.



The kinetic model calculated time-temperature-transformation (TTT) and continuous cooling transformation (CCT) curves of $CaAl_2O_4$ phase from a molten slag. The experimental data are also shown in the figure.

Equilibrium modelling of the aluminothermic reduction of SiO_2-slags under different conditions has also been carried out at **SINTEF** Industry. The model calculations agree reasonably with the laboratory experimental results carried out at NTNU. The model calculations have then been used to define the best conditions for the further pilot tests at Elkem.



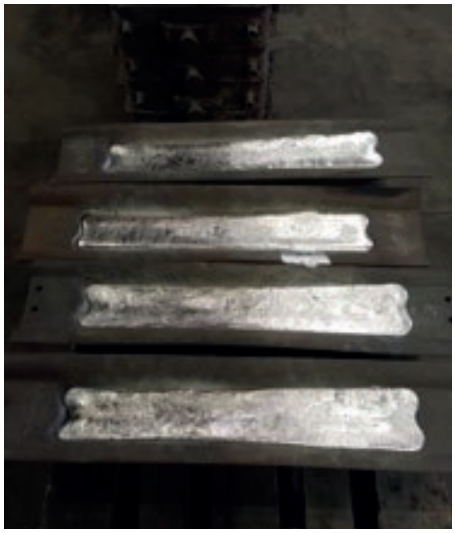
WP3 Activities

Kinetic models have been developed for the prediction of the relations between incubation time and cooling temperature of the slags. The model can be used to control the solidification of Al_2O_3-CaO based slags. The optimized Al_2O_3-CaO based slags will be further used to produce Al_2O_3 by hydrometallurgical treatments for Al production.

In SisAl Pilot, **SBC** is responsible for the Spanish business case as well as the coordination between the Spanish partners. The company attended several meetings with the different partners involved, i.e. Erimsa, Befesa, Itmati and Fundiciones Rey, with the aim of preparing the pilot test, which will be done in the second half of this year at Fundiciones Rey. The team selected the raw materials and studied the refractories of the furnace, and they are also planning to put in operation a new induction furnace for R&D. SBC also participated in other work packages sharing its knowledge in the silicon production by the electrical arc furnace (EAF), the old and existing method, and with comments in the different test made until know and in the business cases.

During the first year of the SisAl Pilot activity, first trials at small scale in a "low temperature" gas furnace were performed, studying the behaviour (knowledge and handling) of different secondary aluminium types received from BEFESA. The following tasks were accomplished:

- casting in specific ingot mould
- analysis by means of spark emission spectrometry (impurity levels and Al performance) to compare with BEFESA´s characterization.
- Process time, melting point, suitable crucible, type of slag, etc. has been analysed.

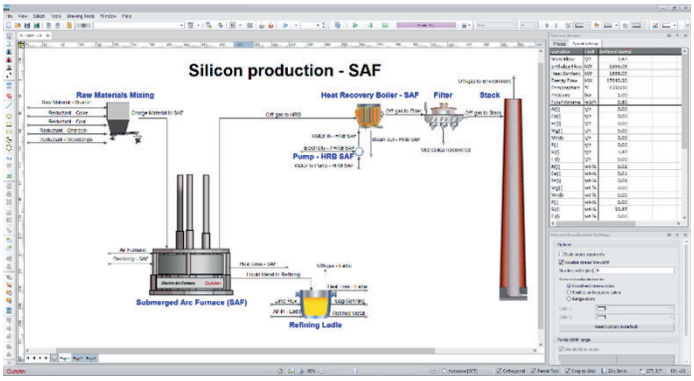


By- or side-products from **WACKER**´s Silicon production site at Holla, Norway has been identified and its potential availability confirmed as potential raw materials for the SisAl technology. Representative samples of these materials have been screened, prepared and sent for analysis and pre-testing to NTNU. Sampling was extended to Elkem for respective pilot test runs as scheduled, starting Q2 2021.

SiQAL performed slag leaching tests on materials delivered by NTNU with the aim to find the optimum process parameters as well as input data for the Pilot scale testing of the process by MYTILINEOS. Also, first purification cycles have been carried out to understand the correlation between quality of the input leaching liquid and SiQAL's final product (High Purity Alumina). At both ends good progress has been made and promising results were achieved.

Dow is both a producer and user of chemical grade silicon, so is excited by the sustainability and economic possibilities offered by SisAl. Together with the other consortium partners, we have been collaborating to build robust business cases to enable implementation of SisAl technology in viable markets. Current efforts are focused on understanding the diverse range of available aluminium scrap and how different sources will impact the final silicon composition produced, a critical requirement for replacing existing silicon sources.

The first process simulation models were developed by **HZDR** using HSC Sim during the first year of the project. The SisAl process for the production of silicon and alumina was digitalized to obtain its detailed mass and energy balances. These mass and energy balances will be used to benchmark the SisAl process against the conventional silicon production route from a technical, environmental and economic perspective. For this reason, a process model for conventional silicon production process via the Submerged Arc Furnace (SAF) was also developed (see figure). Accordingly, a good systemic view of both silicon production routes was obtained for their comparison.



"Process simulation model for the production of silicon through the SAF route in HSC Sim"

In the first year of the SisAl Pilot activities, **Mintek** developed templates that can be used to capture the details of infrastructure and operational parameters during laboratory scale test and Pilot plant campaigns.

The templates will use the captured operational data and calculate mass and energy balance for laboratory scale and pilot scale tests. Mass and energy balance data captured during pilot campaign will be used for design of commercial scale furnace.

Physical measurement and details of DC Furnace at Mintek were provided to SIMTEC for modelling purpose.

Silicor Materials Iceland ehf. (Silicor) has over the last six years Silicor inc. (USA) developed a process to produce Solar Grade Silicon from silicon metal (MG-Si) using simple metallurgical methods at low costs. While standard industrial methods like the Siemens process require a lot of energy (70-90kWh/kg) and stabilized at costs of (13-15 USD/kg) Silicor's process requires 60% less energy and has costs below 10 USD/kg. Running a pilot line in Ontario (Canada) the process yields were verified and, based on this experience, a cost model, layout and specification for a plant producing 10k metric tons (MT) of silicon was developed and is now in a final stage of planning. However, there have been delays due to COVID-19.

Silicor is participating in WP2 and WP4 within this project. The company will focus on business case 4 and plans to demonstrate the refining of Si products for application as HP-Si. Silicor monitors the actions and activities of other SisAl partners currently ongoing, especially those related to the future work, and expects to ramp up the participation later in the year.

In the first year of SisAl Pilot, **Elkem**'s objectives on the pilot were to test and verify process parameters, phase separation, tapping operations and behaviour of different Si and Al raw materials in a planned set of 22 tests, using a 600 kW induction furnace. The Pilot operations were planned for April /June and the following recent actions were performed:

- 600 kW Induction furnace was modified for SisAl pilot operation
- The Robot was installed to handle hot&heavy operations and this is a very-first Robort for Elkem Technology
- The Live streaming of pilot operations were planned and tested. In order to successfully perform the operations needed, it will used MS Teams and youtube as dissemination channels for project partners
- SisAl Pilot project was also presented to Elkem corporate management and enthusiastic reactions for the results achieved so far were shown.

Robot to be used for handling of hot&heavy equipment and operations

Real Wear two-ways communication kit to be used during specific pilot operations

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In the first year of SisAl Pilot, **CiaoTech**, leader of the Dissemination and Communication work package, planned a sound communication strategy to engage the general public towards the key messages vehiculated in the project, dealing mainly with circularity and significant lower environmental impacts. The dissemination strategy of the project addressed selected stakeholders interested in the fields of aluminium and silicon, spreading the main project results and findings. All the actions implemented by the partners in the D&C plans were coordinated and supervised to deploy what previously defined, including setting up a project identity. The project website was always updated with interesting events in line with the project scope; the SisAl Pilot social media channels are continuously managed to provide information and updates about the project activities and the main D&C outputs were made public also during online events and initiatives virtually attended by the partners.

Innovation Engineering S.r.l. (INNEN) is a private company focused on the design and development of advanced IT solution to search, access and manage relevant knowledge within Enterprises. It is involved in several Research and Development projects financed internally or co-financed by European Commission funds or Regional Funds. It focuses its research and development activities on Information Retrieval and Extraction, Natural Language Processing (NLP), big data, and User Experiences, the latter with a specific focus on mobile applications.

In the framework of SisAl Pilot project, INNEN is involved in WP6, which is dedicated to dissemination and communication activities, and at the end of this first year the main important and biggest outputs can be listed as follows:

- dissemination kit (available to the link: https://www.sisal-pilot.eu/documents_cat/dissemination)
- website online at the URL: https://www.sisal-pilot.eu
- Promotional video: https://www.youtube.com/watch?v=YK4mKrjT-Qo

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