



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

The SisAl Pilot project - Innovative pilot for Silicon production with low environmental impact using secondary Aluminium and silicon raw materials - has been funded by the European Commission under the H2020 Funding Programme, topic CE-SC5-07-2018-2019-2020 "Raw materials innovation for the circular economy: sustainable processing, reuse, recycling and recovery schemes".

The main objective of this 4-year project is to demonstrate a patented novel industrial process to produce silicon (Si, a critical raw material), enabling a shift from today's process to a far more environmentally and economically alternative: in SisAl Pilot quartz in slag is reduced through aluminothermic reduction that utilizes secondary raw materials such as aluminum (Al) scrap and dross, as replacements for carbon reductants used today.

The project started on the 1st May 2020 and is being implemented by a first-class international consortium led by the Norges Teknisk-Naturvitenskapelige Universitet (NTNU). The SisAl Pilot project brings together raw material provider (Explotacion de Rocas Industriales y Minerales – Erimisa), silicon and aluminium key actors (Wacker Chemicals Norway, Elkem, DOW Silicones Corporation, Silicor Materials Iceland ehf., SiQAI, Hydro Aluminium AS, FUNDICIONES REY, Befesa Aluminio SLU, MYTILINEOS HOLDINGS S.A), SME´s/consultants/ equipment manufacturers (BNW-Energy AS, SIMTEC, CiaoTech Srl, Innovation Engineering srl and Silbucam S.L.) and research organisations (NTNU, RWTH Aachen University (RWTH), National technical university of Athens – (NTUA), Consorcio Instituto Tecnológico de Matemática Industrial (ITMATI), SINTEF Industry, Helmholtz-Zentrum Dresden – Rossendorf e.V. (HZDR), MINTEK) to demonstrate the SisAl process with different raw materials and product outputs in 4 different countries. These pilots will be accompanied by environmental, economic and technological benchmarking, and industrial business cases will be assessed for locations in Norway, Iceland, Germany, Spain and Greece.

Which are the involved partners and what they will do?



Norges Teknisk-Naturvitenskapelige Universitet (NTNU), Project Coordinator.

NTNU is Norway's main technical university. The Department of Materials Science and Engineering (DMSE) at NTNU is the nationally leading institution for materials science and engineering, and responsible for research-based education as well as basic and applied research in the fields of material technology, physical metallurgy, process metallurgy (materials production and recycling), electrochemical process technology, and materials for energy technology along with inorganic chemistry. The research work is conducted in close cooperation with Norwegian and international industry and the business community at large, as well as the public sector.

The Industrial Ecology programme (IndEcol) at NTNU was initiated in 1994. IndEcol's research activities cover a wide range from global material flows, multiregional input-output databases, to impact assessment of specific technologies. IndEcol supports the global community to achieve the UN's Sustainable Development Goals, with several lead authorships in UN's climate change and resource panel report.

NTNU (DMSE) is the coordinator of this project. DMSE will work specifically with aluminothermic reduction, hydrometallurgical processing and materials testing. IndEcol will lead the LCA/environmental assessment/benchmarking studies in the project.



SIMTEC EURL ST (SIMTEC) is a French engineering modelling company, whose goal is to assist Industrial Professionals and Academics in their processing development, research and innovative approaches. With strong collaboration and continual interaction, the company helps its partners structure their research and study scientifically their new ideas based on

their experience. Furthermore, SIMTEC develops easy-to-use custom numerical software to provide its partner with a decision support tool based on scientific computations. SIMTEC has a proven experience in modelling processes, in which different physics are involved, like CFD, Heat Transfer and Phase changes, for our main clients. SIMTEC has been involved in a FP7 project named REEcover (Project ID: 603564), and is currently involved in a H2020 project named SHARK (Project ID: 768701), in order to model and simulate numerically surface engineering.

In SisAl Pilot, SIMTEC will intervene in WP2 as the numerical expert to model Physical flows and kinetic aspects for reactor design and demo within the software COMSOL Multiphysics® (geometry, mesh, physics (both equation and boundary conditions), solve and post processing. SIMTEC will exploit the results of WP2 within its everyday business.



The Aluminum Refinery and Smelter, formerly known as Aluminium of Greece (AoG), currently **MYTILINEOS S.A** - Metallurgy business unit, was founded in 1960, in order to take advantage of Greece's important bauxite deposits for the production of alumina and aluminum. MYTILINEOS is committed to the constant satisfaction of all the needs and expectations of its clients, by offering products such as alumina and primary aluminum

metal - and relevant services to meet their quality requirements. In order to achieve this capital goal, the company manages several products and services-related processes, taking advantage of all performance enhancement opportunities. The company has also participated in numerous national and EU projects, concerning the optimization of its energy efficiency, the reduction and exploitation of its wastes and the reduction of its GHG emissions. MYTILINEOS is the largest vertical integrated primary aluminum producer in Europe, owning bauxite mines, alumina refinery and aluminum smelter plants and recently having installed a 334 MW co-generation plant producing electrical energy from LNG. High temperature steam from this co-generation plant is used in the alumina refinery, saving valuable resources through industrial symbiosis. Starting on 01/01/2020, MYTILINEOS will be an associate partner in the EIT KIC on Raw Materials.

MYTILINEOS is Work Package leader of WP3 Hydrometallurgy Pilot and Alumina Testing, with the main responsibility to design and pilot testing, at TRL7, a hydrometallurgical slag treatment process to separate and recycle CaO and Al₂O₃ compounds from slag produced in WP2.



RWTH Aachen University (RWTH) has 9 faculties and 260 institutes. With currently over 45.000 students, it is one of the largest Universities in Germany and the largest employer in the region of Aachen. The participating **IME Institute** represents RWTH in all research and teaching fields of “metallurgical process and the metal recycling”. Core competencies are under- and postgraduate education, practical training of

process engineers as well as the development of sustainable, environmentally friendly and cost-effective methods for the manufacturing and recycling of metal containing materials. A second research platform comprises all technologies for liquid metal processing, especially vacuum (re)melting and purification. The available know-how and equipment allow the validation of production processes for metal winning, recovery and refining. New recycling and environmental optimized routes as well as the in-house production of chemicals and powders in lab- and pilot-scale can be tested. The aim of IME is to develop innovative application-oriented processes from lab to industrial scale by considering the economic and ecological aspects.

In SisAl Pilot, RWTH is involved in the characterization of metal/alloy slag products in WP1, in the designing and verification of the process in WP2 and in the optimization of the hydrometallurgical treatment of the slag in WP3. Large-scale demos will be performed at RWTHs 1MW furnace facility placed from SMS group at their demo center.



BNW-Energy AS (BNW) is a software and consultancy company established in 2014. The company assists customers in assessing techno-economic and environmental viability of new opportunities in the circular economy and fast changing energy markets. BNW-Energy applies both commercial software and proprietary software, depending on the issue at hand. Our proprietary software suite is dedicated to assessment of energy technologies and hybrid energy systems by an extended Levelized

Cost of Energy (LCOE) methodology, and we have also recently developed an investment analysis module to assess the economic viability of industrial processes in a lifecycle perspective, including impact of CO₂-e emissions and emission costs. This module will be instrumental in our work in SisAl Pilot. BNW was founded by and is led by Dr. Torstein Haarberg.

BNW is Work Package leader for WP4: Exploitation. Main responsibilities for BNW will be to bring together economic and technical data from WPs 1-3 & 5, for the evaluation of the different business cases with their individual integrated process CAPEX, OPEX, NPV and IRR. Moreover, BNW will together with prospective commercialising partners work out value propositions, investment funding options, and technology and licensing models, as preparation for industry up-take. Dr. Torstein Haarberg from BNW will be the project's Exploitation Manager.



Befesa Aluminio SLU (BEFESA) is a leading international company that provides innovative sustainable solutions for the management and recycling of industrial residues. Befesa manages more than 1.300 Mt of residues annually, with a production of more than 600 Mt of new materials, which Befesa reintroduces in the market, reducing the consumption of natural resources. Its services are divided into two business units: Recycling steel dust and aluminium waste recycling. Industrial activity Befesa

Aluminio is framed within eco-industry sector, due to dedication to recycling, recovery and recovery of all types of waste from the aluminium industry. The total recycling process operated by Befesa allows free metal recovery of all materials and oxide, which they process. The activities developed by Befesa are a fundamental and important link in the life cycle of aluminium. Activities in the primary aluminium production plants, processing facilities and aluminium finish, or aluminium smelters in general, would be totally unfeasible without the existence of industries like Befesa in charge of treatment, recovery and recycling of waste they generate. Befesa transforms the waste into raw materials assimilated.

In SisAl Pilot, Befesa is responsible for characterizing, selecting and preparing Al scrap and dross suitable for the SisAl process. Befesa is the main provider of Al scrap and dross to business case 5. In addition, Befesa will provide CaO-Al₂O₃-slag to MYTILINEOS for further processing of SiO₂-CaO-Al₂O₃-slag in WP3.



Explotacion de Rocas Industriales y Minerales (ERIMSA) is a Spanish company that was founded in 1980 in order to produce and cover the demand of metallurgical quartz. Today it is part of the Norwegian Elkem Group. ERIMSA is the Spanish quartz branch of the Group with 4 production sites, located in the provinces of A Coruña, Lugo, Pontevedra y Salamanca, and selling quartz also outside the Group to others silicon and ferroalloys

companies. ERIMSA have almost four decades of experience developing technologies in the extraction of quartz, aggregates and sands applying a methodology that respects the environment and is fully compatible with agriculture, livestock and forestry. ERIMSA produces annually more than 740,000 tons of metallurgical quartz and aggregates for construction. Quartz is entirely exported to Norway and others countries through the ports of A Coruña and Avilés.

In SisAl Pilot, ERIMSA is work package leader of WP 1 In- and output material properties, mixes and analyses with the main focus to select, characterize and prepare quartz from ERIMSA`s mine suitable for the SisAl process. ERIMSA is the main provider of quartz to business case 5 and also the lime which will be taken in Spanish well-known mines for its high quality.



The National Technical University of Athens (NTUA) is the oldest and most prestigious technical educational institution in Greece. Over the last 30 years NTUA has been actively participating in numerous national and international research and development projects. Last year only, was coordinating or participating in 67 European projects and the last decade was funded from European Commission 400M€. NTUA is a Partner in EIT

Raw Materials. The Laboratory of Metallurgy (LabMet) has experienced significant progress in the last 30 years in terms of research and development projects in various fields, like extractive metallurgical process development, rehabilitation of sites polluted from mining and metallurgical industries, thermodynamic studies of metallurgical systems, mathematical modelling, simulation of metallurgical and environmental protection processes, synthesis of inorganic polymeric materials from mining and metallurgical wastes, networking in the areas of mining, ornamental stones and processing. NTUA LabMet has expertise in hydrated aluminas precipitation from alkaline solutions and has invented and patented the "boehmite process", a process for precipitating boehmite from supersaturated aluminate solutions.

In SisAl Pilot, NTUA will be involved in the hydrometallurgical processing of slags, after the reductive smelting of raw materials, including leaching with $\text{Na}_2\text{CO}_3/\text{NaOH}$ solutions for the production of aluminate solutions suitable for subsequent treatment, precipitation of tri-hydrated alumina from aforementioned solutions and calcination thereof, in order to produce metallurgical grade alumina. In addition, NTUA will assist MYTILINEOS in performing the pilot scale tests.



Hydro Aluminium AS (Hydro) is an international Aluminium company, with its main office in Norway Oslo. Hydro is fully integrated with production of energy, alumina, anode plants, primary metal, casthouse and down-stream processing for all major primary products and a wide range of recycling activity. Hydro have internally R&D activities on smelters technology, covering anodes plants and electrolysis, casthouse processes and products.

Hydro has developed own technology for carbon, electrolysis and casthouse casting. Comprehensive cooperation with several universities and other institutes.

In SisAl Pilot Hydro is the main provider of Al scrap, dross and 2nd cut Spent Pot Lining (SPL) to business case 2 and 3. Hydro is responsible for supplying information on provided fractions for the process in WP1 as well as characterising the hydrometallurgical produced alumina in WP3.



The Technological Institute for Industrial Mathematics (ITMATI) provides advanced solutions for productive sectors of society, especially businesses, industries and the public administration. Our main function is to transfer mathematical technology to help improve competitiveness and support innovation in the productive sector. ITMATI is a public consortium in which the three Galician universities participate. Its main aim is to become a

centre of technological research of international reference in the field of Industrial Mathematics. ITMATI offers its customers research and development tailored to provide solutions specific to their unique needs. Confidentiality of the work performed can be assured, and is based on customer requirements. In addition, it also collaborates in seeking funding, protecting the results, and can advise the client on the best ways to commercialise the results. According to its previous experience, the research group from ITMATI is willing to participate in the numerical simulation tasks of the project related with both the furnaces and the subsequent solidification (casting) processes.

The main responsibility for ITMATI in SisAl Pilot is to provide a model-based support to the pilot at FRey in WP2 in terms reactions in the induction furnace and segregation of the different element, in particular the silicon, during the liquid cooling and also the dynamic chemical reactions in the Befesa process.



Sintef Industry (SINTEF) is the largest independent contract research organization in Scandinavia and the 4th largest in Europe with approximately 2000 employees (70% of them are researchers). It aims to be a world leading research institute. SINTEF works closely with industry in development of advanced materials, products, processes and new tools, and seeks out new, environmentally friendly processing methods that will

increase productivity and raise quality standards. SINTEF is one of the top 20 research organizations in the European Framework Programs with more than 273 projects between 2007 and 2013. The department for Metal Production and Processing in Trondheim will be mostly involved in the SisAl project.

In SisAl Pilot, SINTEF will perform tasks dealing with analysis, characterisation and selection of material mixes, assessment of melting properties (WP1), demo-support and design of experiments (DoE), statistical based evaluation (WP2), and hydrometallurgical small scale test in WP3.



Silbucam S.L. (SBC) is a consultancy company specialized in the sector of ferroalloys and particularly in silicon metals and ferrosilicon. They assist their customers in assessing everything related in this field from the raw materials until the end products going by the different process existing in the industrial factories. In addition, SBC provides support in environmental and safety aspects, process layout, running procedures etc. The main

speciality is related to electrode operation and the metallurgical way to purify the silicon metal until the level of solar grade. SBC was founded by Ing. Javier Bullón, who is the managing director of the company.

In SisAl Pilot, SBC is responsible for the Spanish business case as well as the coordination between the Spanish partners; ITMATI, where Mr Bullón is “professor ad honorem”, ERIMSA, Fundiciones Rey and Befesa. SBC is also strongly involved in WP1 and WP5 by sharing extensive knowledge from the silicon industry.



FUNDICIONES REY, SL (FRey) is a Spanish company that was founded in 1944. With over 75 years of experience in foundry activity, they manufacture all types of cast parts from drawings or patterns in grey and nodular cast iron, cast steel, cast bronze and cast aluminum, using greensand mould process and furan resin. FRey can also supply centrifugal casting, as well as machining, heat treatment, shot blasting and painting.

FRey has developed a symbiosis between traditional casting production and new industrial techniques. Their objective is to attend their customer's satisfaction, completing the requirements of delivery and quality. Over the years, FRey has manufactured and sold their castings to customers all around the world. Their products are aimed at a wide range of industries, for example the Marine, Pulp and Paper, Wind Energy, Chemicals, Cement, Oil, Machine Tool and Hydro industries, among many others. FRey has a close relationship with R&D company called Rey bronzed casting SL, which can be considered as third company in terms of the SisAl project because it has smaller furnaces and for some test it will be used before to go to the industrial furnaces in the mother company FRey.

FRey, is responsible for laboratory and pilot tests aiming at producing Al-Si alloys by induction enhanced reduction in WP2 and also the use of the rotary gas furnace in high temperature and element for casting the mix Al-Si-slag and separate the different elements. These tests are related to the 5th business case.



Wacker Chemicals Norway AS is part of the German company Wacker Chemie AG (WACKER). WACKER has a global network of production sites spanning all key regions. 14.700 employees on five continents devise innovative solutions locally for maximum customer benefit and generate synergies for efficient collaborations. To this end, WACKER maintains and

further develops an integrated management system in accordance with ISO, GMP and sustainable development, as well as actively participates in the global Responsible Care® program. Quality, health, safety, and environmental awareness are the cornerstones of WACKER's mind set and practices at all WACKER sites. In the town of Kyrksæterøra in Norway, WACKER acquired its first silicon metal production plant effective July 1, 2010; Wacker Chemicals Norway AS. It was a strategic decision towards further vertical integration of WACKER's Silicon metal based businesses, to further improve security of supply of this important raw material. The plant has been operational since 1964. The process runs continuously and in total approx. 200 employees are running the operations.

In SisAl Pilot, WACKER will provide quartz fines, slag and potentially other raw materials to the pilot tests, prepare, select and characterize raw materials, help running the pilot tests at RWTH Aachen and in addition support running business cases and process evaluations.



SiQAL UG (SiQAI) Specialty raw materials, namely High Purity Alumina (HPA) and Silicon, are cornerstones of the energy transition with a current market volume of \$5'000 million and double digit yearly growth. Further cost reductions in solar cells and expansion in efficient lightening (LED) may soon be limited by inefficient legacy production processes of the raw material supply chain. SiQAI was founded in February 2018 and establishes

a metallurgical production process for HPA and silicon that is resource efficient, highly profitable and specifically designed to serve the needs of the energy transition.

SiQAI is participating in WP2 and WP3 within this project. The company will focus on business case 4 and demonstrate the refining of Si and alumina products for application as SoG-Si as well as HPA for sapphire growth.



Dow Silicones Corporation (DOW) combines science and technical knowledge to develop premier materials science solutions that are essential to human progress. DOW has one of the strongest and broadest toolkits in the industry, with robust technology, asset integration, scale and competitive capabilities that enable it to address complex global issues.

DOW's market-driven, industry-leading portfolio of advanced materials, industrial intermediates, and plastics businesses deliver a broad range of differentiated technology-based products and solutions for customers in high-growth markets such as packaging, infrastructure, and consumer care. Dow Performance Silicones, a global business unit of DOW, is the largest producer of silicone products globally. The principle raw material for the production of silicones is metallurgical silicon, of which Dow both produces and purchases a significant quantity. Dow Performance Silicones also has a significant presence within the EU, where it produces and processes silicones.

In SisAI Pilot, DOW will participate in developing the international business case (WP4), determining if the technology is capable of producing a commercially viable metallurgical silicon for the production of silicones. DOW will also participate in the pilot scale tests for the production of metallurgical silicon (WP2), assisting in the development of a robust and industrially viable process, as well as ensuring the raw materials selected are viable in multiple geographies (WP1).



The Helmholtz-Zentrum Dresden – Rossendorf e.V. (HZDR) is a non-profit research organisation and a member of the German “Helmholtz Association”. HZDR is dealing with application-oriented basic research, focused on three major research topics: matter, energy, and health. Around 1,200 people are employed at HZDR. It consists of eight institutes, of which the Helmholtz Institute Freiberg for Resource Technology (HIF) participates

in the SisAI proposal. HIF is engaged in the development of innovative technologies for the economy so that different raw materials can be made available and used more efficiently or recycled in an environmentally friendly manner. To achieve these goals HIF holds extensive knowledge and experience in the fields of exploration, processing and metallurgical treatment of complex ores or recycling materials, the analysis and characterisation of those materials as well as the process simulation and efficiency evaluation.

In SisAI Pilot HZDR leads WP5, which will demonstrate the feasibility of the sub-processes and main products developed in SisAI with respect to environmental, economic and technical (EET) performance using detailed datasets generated within the project for simulation of the SisAI value chain. Additionally, a benchmarking towards existing technologies and supply chains also with respect to energy will be done.



MINTEK is South Africa's national mineral research organisation and is one of the world's leading technology organisations specialising in mineral processing, extractive metallurgy and related areas. Mintek works closely with industry and other R&D institutions and provides service test work, process development and optimisation, consulting and innovative products to clients worldwide. Mintek is a state-owned science council which reports

to the Minister of Mineral Resources of South Africa. Mintek's mandate is to serve the national interest through research, development and technology transfer, to promote mineral technology and to foster the establishment and expansion of industries in the field of minerals and products derived therefrom. Mintek was established in 1934 and currently employs around 750 people of which 250 are professionals in the field of process metallurgy. The Pyrometallurgy Division employs 83 people, including 29 engineering staff, 3 with Ph.D. degrees, and 5 with master's degrees in engineering.

In SisAI Pilot, Mintek is involved in the designing and verification of the process in WP2 and in the business case development in WP4. A large-scale demo will be performed at Mintek's 3MW furnace facility.



Silicor Materials Iceland ehf. (Silicor) 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.

Silicor is participating WP2 and WP4 within this project. The company will focus on business case 4 and has the plan to demonstrate the refining of Si products for application as HP-Si.



Elkem AS, Technology (Elkem) is a business unit in in Elkem AS responsible for corporate R&D projects, technology development and industrial projects. Elkem is one of the world's leading companies for environmentally responsible production of materials. Its principal products are silicon, silicones, ferrosilicon, foundry alloys, carbon materials and microsilica. Elkem has four business areas and about 6200 employees.

In SisAI Pilot, Elkem is WP2 leader and will perform a set of large scale aluminothermic experiments (>10) in an induction furnace at Elkem's pilot station in Kristiansand, Norway. Different raw material mixes will be run to target different Si and slag products will be evaluated.



CiaoTech Srl, (CTECH) the Italian branch of PNO Group, represents Europe's largest independent public funding and innovation consultancy with 30 years of hands-on expertise with more than 500 funding programmes in most EU countries, annually raising approximately 1 Billion Euro for its clients. PNO's "Innovation Management" services deliver high quality support to large sized companies, SMEs, Universities, Research Institutes,

Associations and clusters in the full cycle of the innovation process including analysis, definition and innovation processes planning building innovation networks, partnerships and projects and managing projects and driving innovation. PNO has a unique positioning in defining and managing innovation ecosystems, while providing scouting, intelligence and business acceleration services, taking particular care of exploitation and IPR aspects.

In SisAI Pilot, CiaoTech leads WP6, the dissemination and Communication Work package focusing on defining and implementing the dissemination and communication strategies in strict collaboration of all project partners.



Innovation Engineering Srl (INNEN) is a private company located in Rome and Milan (Italy) focused on the design and development of advanced IT solution to search, access and manage relevant knowledge within Enterprises, with specific focus on Security, ICT and Transport domains. The company focuses on robust methodologies and IT solutions based on Java language and Open Source, to drive innovation through the search,

manage and analyse of information that should be translated into valuable knowledge. Innovation Engineering is focused on the development advanced Knowledge Search and Management solutions. The company is currently involved in several R&D projects. The main competences rely in Knowledge Management Systems, Applications Development, Web Service and Back End Integration, Rich Internet Applications (RIA), and Mobile Development.

INNEN is involved in WP6, dedicated dissemination and communication activities, by developing the project dissemination kit and website.

Partners



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