ANNUAL REPORT

SFI **METAL** PRODUCTION

2016

” EDUCATION AND RECRUITMENT

sfi Centre for Research-based Innovation

The Research Council of Norway

metal production

NTNU

Norwegian University of Science and Technology

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OF THE 2016 ANNUAL REPORT FOR SFI METAL PRODUCTION

SFI METAL PRODUCTION IN 2016

Aud Nina Wærnes (Centre Manager)

The second year of the SFI Metal Production is over, the first whole year of operation. Looking back, this has been a year with new knowledge, several new PhD candidates and scientific highlights. We are very pleased to see how a robust SFI Metal Production consortium of academia and industry has developed through 2016 to strengthen our future cooperation, in line with the vision of SFI Metal Production: "Resource efficient metal production from a clean industry".

During 2016, Fesil Rana Metal was acquired by Elkem, and is now a plant within Elkem. So far, we have not included new members to the consortium. This has not been prioritised by the Executive Committee.

The SFI Spring meeting took place on the 26th to the 28th of April. The focus of the meeting was to introduce the Scientific Committee to the SFI Metal Production family, and to emphasise the importance of innovation with the industrial partners. Strategic- and long term goals for the centre were also discussed.

The members of the Scientific Committee contributed with valuable and interesting presentations at the Spring meeting. Topics for the presentations were "Solid state reduction of Metal Oxides" by Professor Emeritus Oleg Ostrovski, "Society and Metals – how it all started" by CEO Jean-Pierre Birat, "Science for Technological Innovation" by Professor Margaret Hyland, and "Circular Economy" by Director and Professor Markus Reuter.

Executive Vice President for the Aluminium Metal business area in Hydro, Hilde Merete Aasheim, presented Innovation in Hydro – the Aluminium Metal Business System (AMBS), and gave examples of how Hydro is using R&D and Technology as a key to improve value creation for the company. Ludvig Egeland, Chairman of Eramet Norway AS, presented: "Why produce manganese-alloys and perform R&D in Norway". One of the reasons for continued research activities in Norway is the 100 years of accumulated knowledge of Ferro alloy production in Norway, and the industrial drive to continuous improvement and innovation.

The second day of the Spring meeting was allocated to the Strategic and Long-Term goals for the SFI Metal Production. Gabriella Tranell presented the status of the Strategy process. Aasgeir Valderhaug then presented the FFF (The Norwegian Ferroalloy Producers Research Association) strategy, followed by Helene Flatmark "Eyde model – an example of industry clusters" and Stig Tjøtta/ Hydro "Research, Strategy and Communication". Hogne Hongseth ended this session with "Industry Norway AS – vision or a wild idea! Is the Norwegian Metal Industry a forgotten business in the shadow of the oil industry?".

At the beginning of the Autumn meeting, held 26-27 of October, Professor Emeritus Jørgen Randers, Climate Strategy, BI Norwegian Business School gave a one-hour talk about "The 2052 Forecast: What will happen? How can metal production contribute?" to an audience of more than 100 people. A very inspiring talk about future challenges facing humanity. The rest of the Autumn meeting was dedicated to scientific results, activities and work Plans for 2017.

The idea behind the SFI concept is to promote basic research at a high international level. The centre goal is a long-term investment in research, building a strong dynamic research community. The SFI shall give added value to the participating partners and spin-off effects through competence and recruitment with an impact far beyond the lifetime of the centre. The creation of Spin-Off projects or associated projects with relevance for the SFI are a KPI´s for the centre. Two new projects have been established since the start-up;

1) IPN – Waste to Value where a Post Doc candidate is shared between the SFI RD3 Refining & Recycling and the IPN-project. The project is a cooperation between several of the partners in the SFI.

2) ElMet – An Efficient Simulation Method for Current and Power distribution in 3-Phase Electrical Smelting Furnaces. The latter is organised and carried out at Teknova.

As a follow up of the Spring meeting, the Strategy process and long-term goals for the SFI Metal Production was one important topic also at the Autumn meeting. The SFI Strategy includes Competence and communication goals – i.e specific scientific competence (knowledge, skills and candidates), Long Term Technology goals i.e. 1) Reduction of climate-, and toxic- emissions, 2) Energy efficiency (coordinated with FME HighEff), 3) Raw material shortages, and Vision projects.

The Government's expert committee for Green competitiveness delivered its report, with proposals and recommendations to the Prime Minister, Erna Solberg and Minister of Climate and Environment, Vidar Helgesen in October 2016. The Norwegian Process Industries' Roadmap – Combining Growth and Zero Emissions by 2050, was one of several Roadmaps that was requested by the expert committee as input to the report. Several members of the SFI team participated in this work. The Green Competitiveness Report will be a guideline for the SFI Metal Production.

Several applications to the Research Council of Norway with relevance to the SFI were submitted by the SFI team in 2016. These include a KPN "Controlled Tapping - maximize metal yield, maximize operation load and minimize hazardous tapping conditions in the ferroalloy industry", and an IPN with the title "BEST aluminium cast slab quality by Studying and Implementing Measures to reduce oxide- and carbide inclusions".

The SFI is very proud to announce that an application to the International partnerships for excellent education, research and innovation (INTPART), a very important contribution to the SFI, was granted in 2016. The title of the project is INTPART - Metal Production. The overall goal is to establish and develop a long-term cooperation between the institutions of NTNU, SINTEF, MINTEK and North-West University (NWU, South Africa) regarding research and higher education. The main topic of the

cooperation is Carbon as a raw material, lining material and a reductant for metal production. Merete Tangstad and Eli Ringdalen are both key players in the INPART project.

Merete Tangstad the leader of RD2 Primary Metal Production was invited to join an EU Horizon 2020 – FET (Future Emerging Technologies) OPEN project with the title AMADEUS. The project will investigate the next generation materials and solid-state devices for ultra-high temperature energy storage and conversion.

In addition, a Horizon 2020 projects has been approved within MFA (Mass Flow Analysis) at NTNU, Industrial Ecology Programme (IndEcol). MinFuture – Global material flows and demand-supply forecasting for mineral strategies, is a part of H2020-EU 3.5.3 – Ensuring the sustainable supply of non-energy and non-agricultural raw materials.

Several Workshops and Seminars have been arranged in 2016 with good attendance from both industry and academia:

- By-products in the process industry
- PAH workshop
- Al short course – refining and recycling (students and industry)
- Si short course – production and refining (students and industry)
- RD1 Seminar- Fundamentals & Modelling Tools
- Strategy meeting with the Executive Committee

These Workshop/Seminars constitute a valuable meeting place that gave the SFI an excellent platform for strengthening the cooperation between students, researchers and industry. In addition, all PhD students now have dedicated industry reference groups that will follow up the PhD work to ensure an industrial perspective.

Education and Recruitment have a particular focus in the 2016 Annual Report. So far, eight PhD candidates out of a total of fourteen, and two postdocs out of four, are hired. In addition, four PhD candidates funded by associated project to the SFI are now a part of the SFI team. In 2016, 16 MSc and 25 Summer-students have been part of the SFI. In addition, exchange students from Brazil, Germany, and South Africa have all made valuable contributions to the centre!

> ***What makes it difficult is that research is immersion in the unknown***
>
> *Martin A. Schwartz, J. of Cell Science 121, 1771, 2008*

ABOUT SFI METAL PRODUCTION

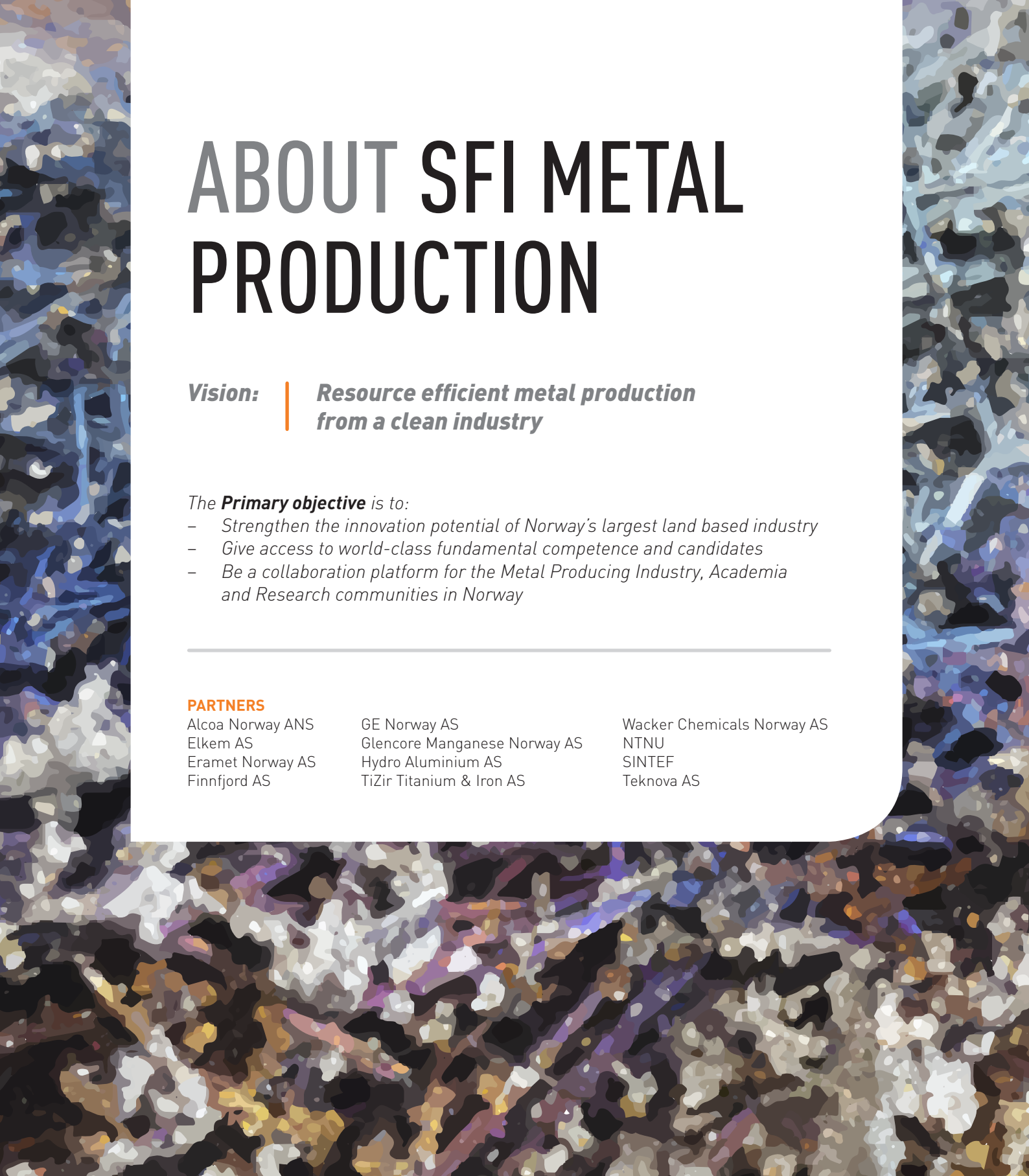
Vision: | ***Resource efficient metal production from a clean industry***

*The **Primary objective** is to:*

- *Strengthen the innovation potential of Norway's largest land based industry*
- *Give access to world-class fundamental competence and candidates*
- *Be a collaboration platform for the Metal Producing Industry, Academia and Research communities in Norway*

PARTNERS

Alcoa Norway ANS
Elkem AS
Eramet Norway AS
Finnfjord AS
GE Norway AS
Glencore Manganese Norway AS
Hydro Aluminium AS
TiZir Titanium & Iron AS
Wacker Chemicals Norway AS
NTNU
SINTEF
Teknova AS



Metals are, and will continue to be, a pre-requisite for modern society. The houses and offices we live and work in; the cars, planes and trains we use for transport; the computers and mobile phones we use to communicate – all rely on metals.

Metal producers in Norway are operating in an international market. They have owners with a long-term strategy for further operations in Norway and with an active focus on technological innovations.

The metal producing industry is one of Norway's largest land-based industry, with annual production of more than 3 000 000 tonnes metal and a turnover about 50 000 mill NOK. In addition, this industry "manages" about 30% of Norway's total electricity consumption and employs ~10000 people. In 2020, a significant surplus of electricity in Norway is expected, pointing to new opportunities for energy intensive industries.

At the same time, the framework conditions for metals producers are changing rapidly:

i. Unprecedented growth in the demand for metals, mainly due to industrialization and urbanization in emerging market economies;
ii. rising concerns regarding access to the raw materials used in electronics and new technologies that are essential for environmental protection;
iii. energy use and GHG emissions need to be reduced drastically to avoid dangerous anthropogenic interference with the climate system;
iv. Mature economies experience an increasing availability of scrap that may be used as a secondary resource and may thereby address (i)-(iii); however, unresolved quality challenges remain.

Metals producers need to adjust to these changing boundary conditions in order to remain competitive on the global markets.

This requires several breakthroughs:

i. new technologies for more resource-efficient and emissions-saving primary and secondary production;
ii. new tools for forecasting changes in the global material cycles and for identifying the most effective combinations of technologies to support decision-making in industry and government.

THE RESEARCH IS

DIVIDED INTO FIVE MAIN RESEARCH DOMAINS

RD1: FUNDAMENTALS AND MODELLING TOOLS

RD1 will combine existing knowledge and new fundamental data for production and refining of metals in an easily accessible and user-friendly library and work towards a generic, standardized framework for coupled scientific computing.

Research Objectives

- Establish a library for existing and new experimentally derived data accessible across various software platforms.
- Explore and develop a generic, standardized framework for coupled scientific computing.

RD2: PRIMARY METAL PRODUCTION

RD2 aims to develop fundamental knowledge and competence to support industrial innovations for the next generation metal production processes.

Research Objectives

- Find experimentally, and then model, reactions and reaction rates for ferromanganese-, silicon- and aluminium metal producing reactions.
- Determine the effect of raw material properties on operational parameters such as energy consumption and CO_2 emissions.

RD3: RECYCLING AND REFINING

In refining and recycling of metals, the behaviour of impurities is the main focus. In RD3, increased knowledge of the thermodynamics and kinetics of oxidation-, refining- and waste utilisation processes, is the overall objective.

Research Objectives

- Identifying the effect of the presence of minor/trace elements on aluminium oxidation/dross formation.
- Development of the thermodynamic and kinetic basis for Si refining.
- Recovery of metallurgical by-products and wastes, with or without residual metal content.
- Improving filter properties and filtration technology with the use of surface modifications and electromagnetically enhanced priming.

RD4: EMISSIONS AND ENERGY RECOVERY

It is important to develop a comprehensive understanding of the emission from metallurgical processes in order to improve process control, abatement and reporting. In RD4, emission formation, measurement methodologies and standardisation are key research areas

Research Objectives

- Develop a fundamental understanding of the mechanisms and challenges for enhanced energy recovery in Al electrolysis and Ferroalloy production.
- Develop the knowledge base of the relation between emission formation, emission discharge, spreading and emission avoidance.
- Development of measurement methods, standards and tools to enable emission control.

RD5: MATERIALS AND SOCIETY

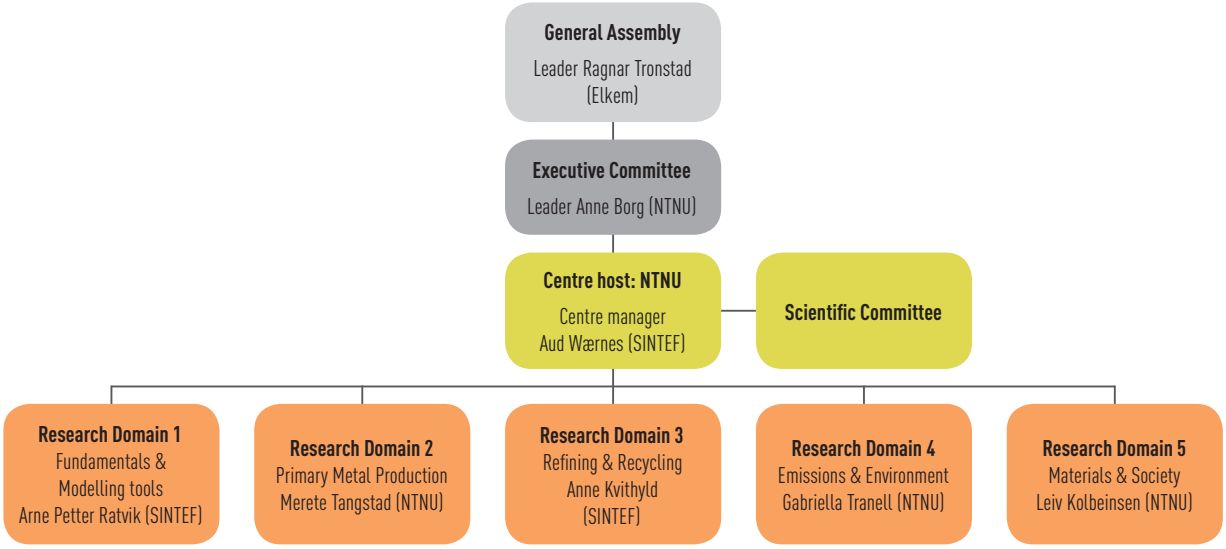
The main aim of RD5 is to increase the public awareness of metal production and its benefits in a modern society.

Metals are an integral part of a wider system that encompasses all aspects of modern society. This Research Domain has a special responsibility to identify opportunities and disseminate research aspects that can contribute to the understanding of the social value of metals and how they can support a sustainable development of society.

Tools and instruments are:

- Life Cycle Thinking and Material Flow Analysis
- Standards for Emission Measurements and Reporting
- Industry networking and recruitment
- Exchange of best practices for industrial innovation

ORGANIZATION AND LOCATION



SFI Metal Production is hosted by NTNU and the Centre manager is Aud Nina Wærnes from SINTEF. The General Assembly (GA) where all the partners, ten industry partners and three research partners, are represented makes decisions that involve major changes to the consortium. Ragnar Tronstad (Elkem) is the leader of GA.

The GA approved the members of the Executive Committee (EC) and Anne Borg (NTNU) was appointed chair of the EC at the first GA meeting in June 2015. In addition to Anne Borg, the other members of the EC are Nancy Holt (Hydro), Ketil Rye (Alcoa), Leif Hunsbedt (Eramet), Ragnar Tronstad (Elkem), Eli Aamot (SINTEF), Tor Einar Johnsen (The Research Council of Norway, RCN).

SFI Metal Production's Centre management is located at NTNU Gløshaugen in Trondheim. In May 2016, we moved into the newly redecorated third floor in "Bergbygget" at Alfred Getz vei 2. On this floor, industry, SINTEF, NTNU and students are sitting side by side.

The Centre Management Team consists of the Centre manager Aud N. Wærnes (SINTEF), project coordinator Marianne Lenes (NTNU) and the five Research Domain (RD) leaders. The RD leaders are: Arne Petter Ratvik (SINTEF), Merete Tangstad (NTNU), Anne Kvithyld (SINTEF), Gabriella Tranell (NTNU) and Leiv Kolbeinsen (NTNU).

Centre Management Team: Leiv Kolbeinsen (Professor), Merete Tangstad (Professor), Gabriella Tranell (Professor), Aud Wærnes (Senior Business Developer), Anne Kvithyld (Senior Research Scientist), Marianne Lenes (Coordinator) and Arne Petter Ratvik (Senior Research Scientist). (Photo: Thor Nielsen)

Vice-dean for research at the NV-Faculty Tor Grande and Centre Manager Aud N. Wærnes at the opening of the new SFI-area in June 2016. (Photo: Per Henning)

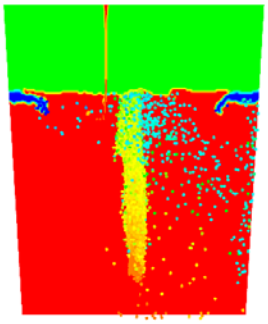
Our new and open areas at the SFI Centre.

HIGHLIGHTS OF 2016 FROM THE RESEARCH DOMAINS

1 Fundamentals and Modelling Tools (RD1)

by Senior Research Scientist Arne Petter Ratvik

Library functions. ThermoML, a software developed using extensible mark-up language (XML), was identified as the most appropriate tool for preserving experimentally verified data. ThermoML is adopted as IUPAC Standard for Storage and Exchange of Experimental Thermophysical and Thermochemical Property Data. ThermoML is designed to store and transport data in both machine and human readable format. If this tool answers the needs expressed by SFI members remains to be verified by user acceptance.



Methodology coupling of modelling tools. Silicon refining was used to demonstrate coupling between detailed computational fluid dynamic (CFD) modelling and pragmatic modelling in spreadsheet and MatLab. Key elements in the model require heavy computational power and takes a long time to calculate. Such key elements may be the surface of bubbles and droplets, which are extracted over short time intervals by computational fluid dynamics (CFD), before being applied in computing the complete refining cycle with moderate use of calculation time The work will be presented in the CFD 2017 (12th International Conference on Computational Fluid Dynamics in the Oil & Gas, Metallurgical and Process Industries) in Trondheim May 30 to June 1.

Modelling the SiMn reduction processes. As a part of RD2, postdoc Sebastien Letout is working on model expressions to enhance the understanding of kinetic processes within the SiMn pilot scale furnace. In the current approach, OpenFOAM (Open Field Operator And Manipulation), a free and open code, is used as an alternative to expensive commercial software for computational fluid dynamics. Modelling the smelting operations are complex and not straightforward, as most of the local kinetics in the furnace can not be observed in situ, and results from excavations after cooling the furnace may be ambiguous. Written documentation of similar processes and observations, and species analyses after excavations, are used to develop numerical simulations to test the hypothesis formulated on the internal behaviour of the furnace. A first stage is to understand phenomena taking place inside the coke bed, in the dripping zone where the slag flows around the carbon particles before accumulating at the bottom of the furnace. A paper will be presented at the CFD 2017 conference in Trondheim.

Road map. The road map process for RD1 finished in 2016. The main objectives for RD1 are slightly modified based on the discussions:

- Data Curation (libraries) - Verify systems suitable for collecting existing and new data in easily accessible and user-friendly libraries while still maintaining the need for proper and trackable verification of data and data uncertainties.
- Modelling - Establish methodology to verify generic modelling frameworks for coupled scientific computing, using readily available software tools with sufficient flexibility to establish a platform for innovations in the industry.

Many options for RD1 involvement with the other Research Domains are reported in the Road map document.

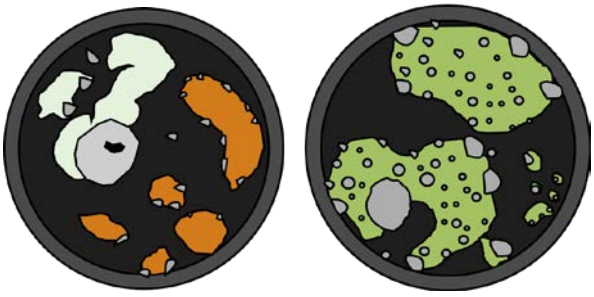
European materials modelling council (EMMC). Teknova is following up on this network. In the long run, this may be an gateway to participation in European projects.

Modelling alumina dissolution. A workshop was arranged in December 2016 to initiate activities related to alumina feeding and dissolution in aluminium electrolysis bath, starting in 2017. There will be two PhD candidates on modelling, one at the University of Oxford in cooperation with Teknova and one at NTNU. One associated PhD will focus on electrochemical activities related to alumina concentration in the bath.

2 Primary Metal Production (RD2)

by Professor Merete Tangstad

In 2016, the main focus continued to be on the reduction mechanisms in Mn and Si production. In **SiMn reduction** the effect of foaming and sulphur content on the reduction mechanism was found. In the Si process, one Si furnace was excavated and it was established how diverse the FeSi and Si furnace-interior may be. Samples with sulphur had metals inside the end-slag, as shown in the Figure. PhD candidate Pyunghwa Kim got the award for the best poster, "Behavior of Assmang and Comilog Ore in the SiMn Process" at the 10th International Conference on Molten 2016 Slags, Fluxes and Salts Reduction in Seattle (USA).



Without sulfur Without 1 mass % sulfur

In the small scale, **the formation of α-SiC** from β-SiC was found to occur above 2200 °C. It was also shown how Si was already produced at about 1700 °C in the siliconcarbide structure. PhD candidate Sethulakshmy tells more about her research at page 33.

In other areas it was shown that more than 50 % amorphous SiO_2 can be present when quartz transforms to cristobalite, how Mn-briquettes deteriorates with time, and how the phase structure in TiO_2 slags vary with cooling rate.

In RD2, a total of six students and one associated student finished their MSc theses. They have all continued working for this industry, as four of them continued with their PhD in the SFI or SFI related projects, and three of them started to work for the industry partners. There were two international exchange students in 2016; one master student from Japan working with SiMn reduction, and one PhD student from Brazil working with charcoal in the Si production. In 2016, a number of PhD students started their projects. In addition to one PhD student funded by the SFI, two new PhD students were funded by NTNU and two funded by SINTEF and Elkem as industrial PhD's. In addition to internal reports, four publications were presented at two conferences.

3 Recycling and Refining (RD3)

by Senior Research Scientist Anne Kvithyld

Oxidation. Understanding oxidation is an extensive part of the effort in RD 3. Refining oxidation during gas purging of silicon and oxidation of aluminium during melt treatment are main focus areas. PhD candidate Erlend Lunnan Bjørnstad has studied the fundamentals of Ca and Al mass transfer from Si metal to slag. Jan Erik Olsen and Thorvald A. Engh have also developed a mathematical description model of silicon refining during tapping. The studies of PhD candidate Nicholas Smith into Be as an inhibitor for Al alloy oxidation has been continued, see more about his research at page 34. Work in 2016 by Martin Syvertsen at SINTEF has also shown that while 2 ppm Be inhibits oxidation, it does not affect the strength of the oxide skin. However, at higher levels (0,3%) it decreases the strength, as shown in the Figure below.

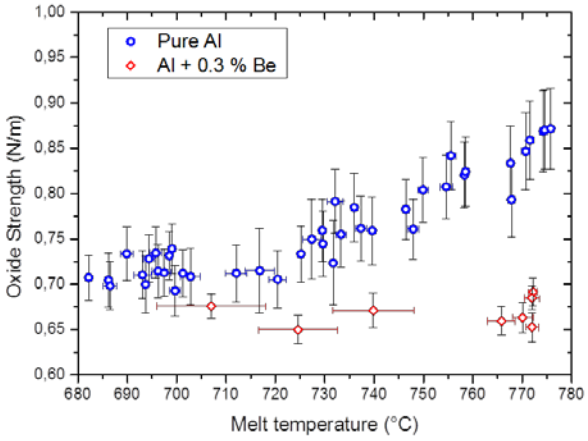
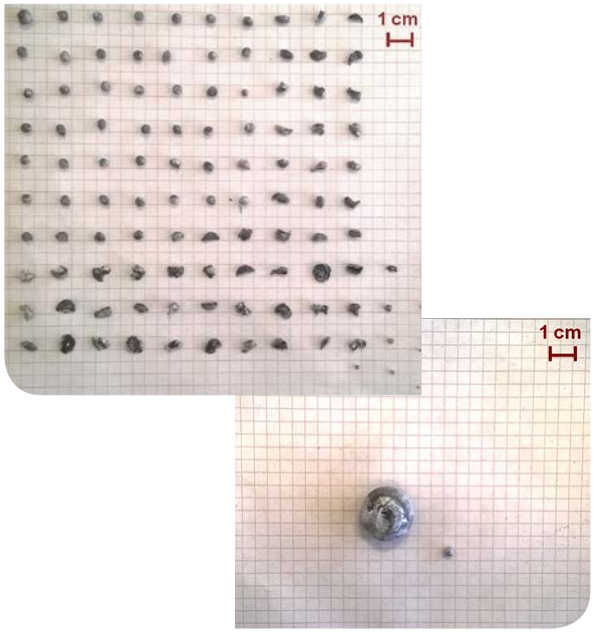


Figure above shows that Beryllium decreases the oxide strength.

Workshops/Seminars. On the 12th of April 2016, 24 experts from industry and research discussed what kind of- and how much waste and by products, the metal production generates. A common understanding between various metal producers and education/research is crucial to set a direction for future metal production with the motto "No waste" and "Value added by-products".

Recycling of post consumed scrap. In 2016, the SFI centre invited PhD candidate Stefano Capuzzi from the University of Padova (Italy) to visit for 4 month. The title of his thesis is "Optimzation of the aluminium refing process". The work resulted in one paper submitted to Light Metals and one paper submitted to Journal of Sustainable Metallugy. The results have also been useful for the industry; in particular for rotary furnace practice in aluminium recycling.



The figure above shows 100 pieces of coated aluminium that have been remelted under a salt flux. In the picture to the left the 100 pieces have been preheated to 400 ºC, and in the picture to the right to 600 ºC.

4 Emissions and Energy Recovery (RD4)

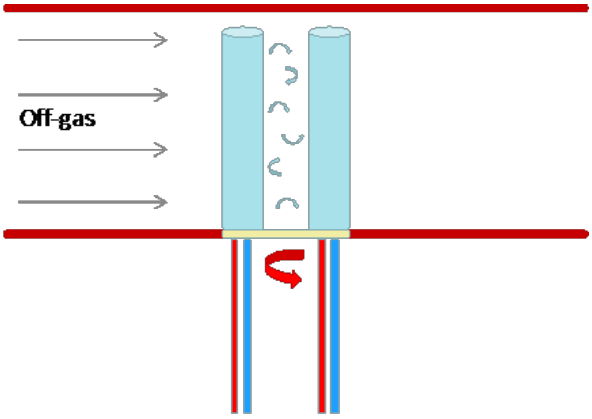
by Professor Gabriella Tranell

PAH measurement campaign at Elkem Thamshavn. Poly-aromatic hydrocarbon (PAH) emissions are common to all metallurgical industries. As a continuation of the efforts to understand their formation mechanisms, concentrations in off-gases and process-dependent variations in different industries, a test campaign was carried out by PD Heiko Gærtner together with Elkem staff at Elkem Thamshavn during the first week of November 2016. The objective of the campaign was to test the abilities of an extended measurement set-up for measurements of raw gas, clean gas, condensed silica fume (CSF) and cyclone coarse fraction to better understand process variations and their effect on emission and to attempt a PAH "mass balance" (particle and gas-bound PAH). The results will be summarized in a report and part of a conference publication submitted for Infacon 2018.

Energy recovery. In 2016, PhD candidate Daniel Clos, together with a SINTEF team, started work with the objective of better fundamental understanding of scaling in Al electrolysis cell off-gas channels. The work has focused on the design of a cold finger for sampling of off-gases/scales to be installed at Hydro Al Sunndalsøra in spring 2017. Together with PD Elmira Moosavi Khoonsari, Daniel will thermodynamically model the gas condensation and gas-solid reactions in the off-gas system.

Dust Generation and Thermodynamic Modelling. In 2016, PhD candidate Håkon H.A. Olsen started his work on kinetic and thermodynamic modelling of dust formation, growth and clustering, with particular focus on dust from liquid manganese alloys. Postdoc Elmira Moosavi Khonsari initiated thermodynamic modelling of the system while Stefan Andersson aided in establishing the kinetic model framework.

Review articles. As a first in a series of three review articles from RD4, emissions from the Si/FeSi industry was described in the article: Kero, I., Grådahl, S. and Tranell, G., "Airborne Emissions from Si/FeSi Production", JOM, 2016, vol. 69, pp. 356-380



5 Materials and Society (RD5)

by Professor Leiv Kolbeinsen

Material Flow Analysis (MFA): Professor Daniel Müller (Industrial Ecology) is essential in the RD5 activities in this field. This activity also involve cooperation with the EU-projects:

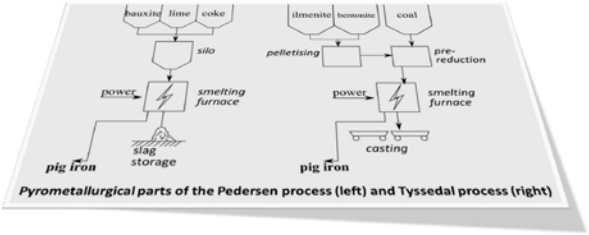
i. **MinFuture:** Global Material Flows and Demand-Supply Forecasting for Mineral Strategies,
ii. **MICA:** Minerals Intelligence Capacity Analysis &
iii. **MINEA:** Mining the European Anthroposphere

What if the iron in bauxites is removed before it becomes "waste"? One obvious way to deal with the Bayer Process Bauxite Residue (BPBR or Red Mud) is to remove the iron from the Bauxite at an early stage of the Alumina-production. This problem has been addressed by master student Hanne Sellæg in "Pedersen Process for Alumina Production" under the supervision of Jafar Safarian.

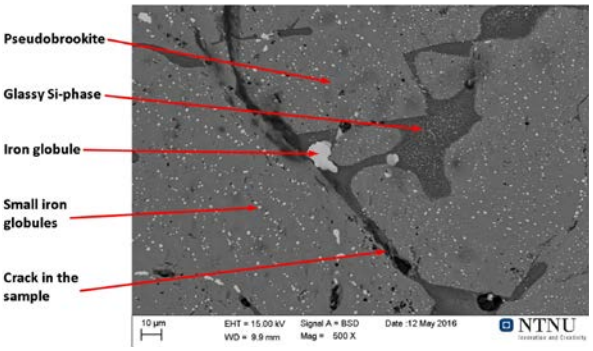
The Pedersen process is in principle capable of producing Alumina from Bauxites and Laterites in general via an intermediate slag product, while the iron in raw materials is converted into a commercially viable product (pig iron). This slag is treated further in a Na_2CO_3 solution without generating Red Mud and CO_2 from calcining is utilised for precipitation of aluminium hydroxide. This process strongly resembles the Tyssedal Process where a Titania (TiO_2) slag is produced along with iron from Ilmenite ($FeTiO_3$). The knowledge generated will be put to use in adjacent projects and initiatives.

Solidification of Titania Slag: Ilmenite is a titanium-rich ore, and accounts for almost all the world's consumption of titanium bearing minerals. One of the main uses of titanium is as powdered TiO_2, used extensively as whitening pigment. The first step in the process of making TiO_2 pigment is reducing the ilmenite to a titanium-rich slag. The slag needs to be purified and processed to make the pigment product. The MSc thesis by Rune Stana, "Solidification of Titanium Slags and Influence on Post Processing", focuses on the stage after reducing the ilmenite to a titanium-rich slag, and before the further purification of the slag. To get a better understanding of the properties of the solid slag after reduction in the blast furnace, both industrially collected and experimentally prepared samples have been analysed. It is believed that the cooling rate and access to oxygen of the slag during solidification will influence the micro-structure of the solidified slag. This gives rise to differences in both grain size and shape, as well as the phases present. This work continues in RD2.

Green Industry Clusters/Industrial Parks: Work on a "Cluster Model" is initiated. The main scientist in this activity is Magne Lysberg of Sintef Materials & Chemistry.



Pyrometallurgical parts of the Pedersen process (left) and Tyssedal process (right)



MAP OF NORWAY

SEEN THROUGH THE EYES OF SFI METAL PRODUCTION

Currently, metal and alloys are produced in more than 20 different locations in Norway. These locations are dispersed throughout the country in areas with good shipping ports and connections to renewable hydroelectric power. Good shipping ports ensure the transport of both raw materials and finished products. Many of the Norwegian plants have changed ownership in the past few years and the latest ownership change within the industry partners in SFI Metal Production, is that Elkem has acquired the ownership of Fesil Rana Metal.

Nine industry producers are partners in SFI Metal Production. These industry sites are spread over the whole country, from Finnfjord in the north to Kristansand in the south. The map shows these locations and what is produced. More details and the rest of the metallurgical industry can be found in the report "A overview of Norwegian Metal Production" written by Eirik Nøst Nedkvitne and Stephen Lobo under the supervision of professor Leiv Kolbeinsen.

The Table shows the production overview 2014 and 2015 in Norway [1000mt] taken from the SFI Metal Production Report, "Solid waste and by-products overview of the metallurgical industry in Norway", written by Sarina Bao, Martin Syvertsen and Anne Kvithyld (2017).

Production (1000mt)	2014	2015
Alcoa	282	286
Hydro	857	942
Total primary aluminium	**1139**	**1228**
Elkem	159	151
Wacker Chemie Holla	59	52
Total Silicon	**218**	**203**
Elkem	84	92
Fesil Rana	90	84
Finnfjord	87	97
Total ferrosilicon	**261**	**273**
Eramet	277	277
Glencore Manganese	5	14
Total ferromanganese	**282**	**291**
Eramet	206	206
Glencore Manganese	108	98
Total silicomanganese	**314**	**304**
Ti-slag TiZir	184	110
Total Ti-slag	**184**	**110**

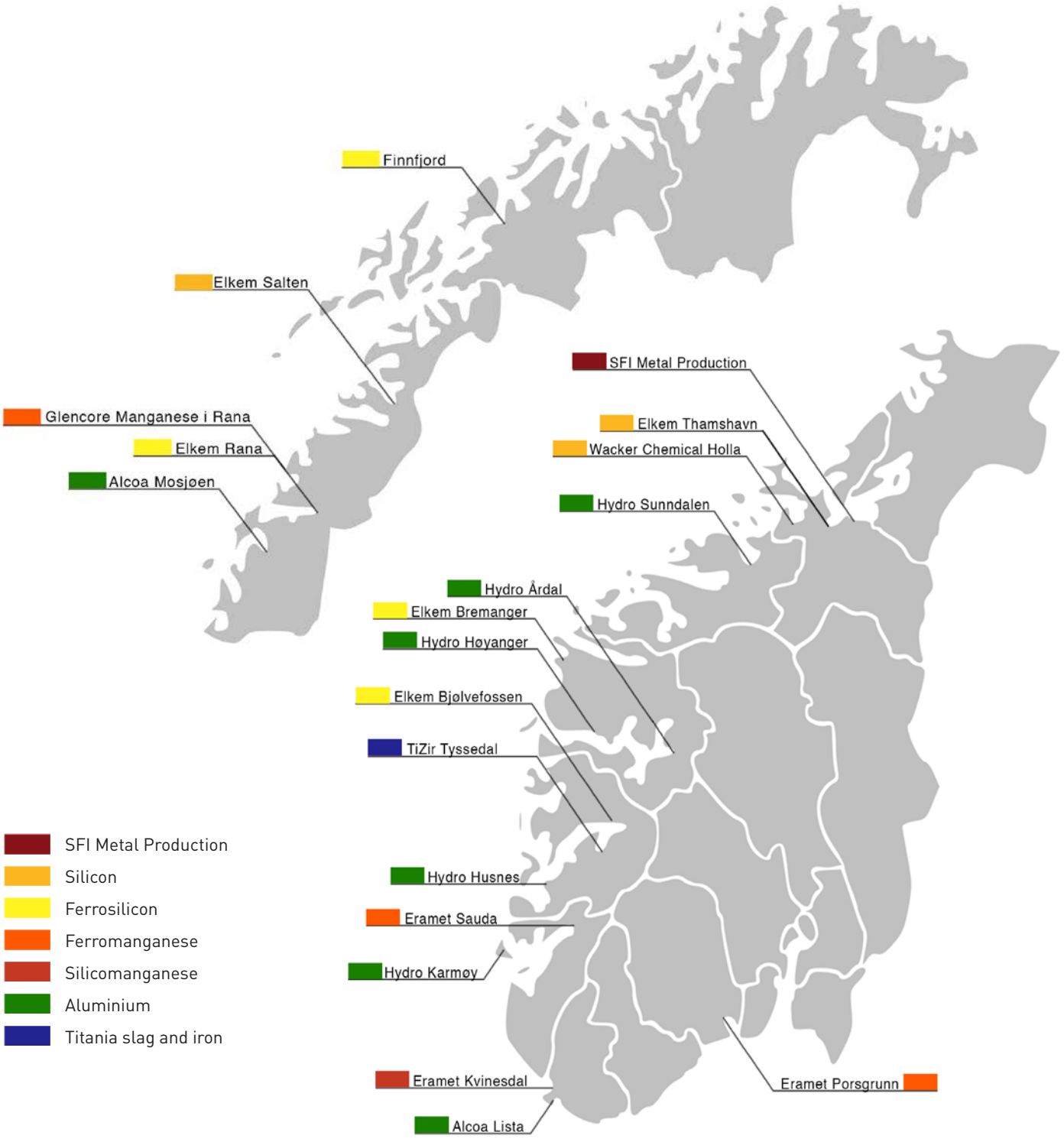
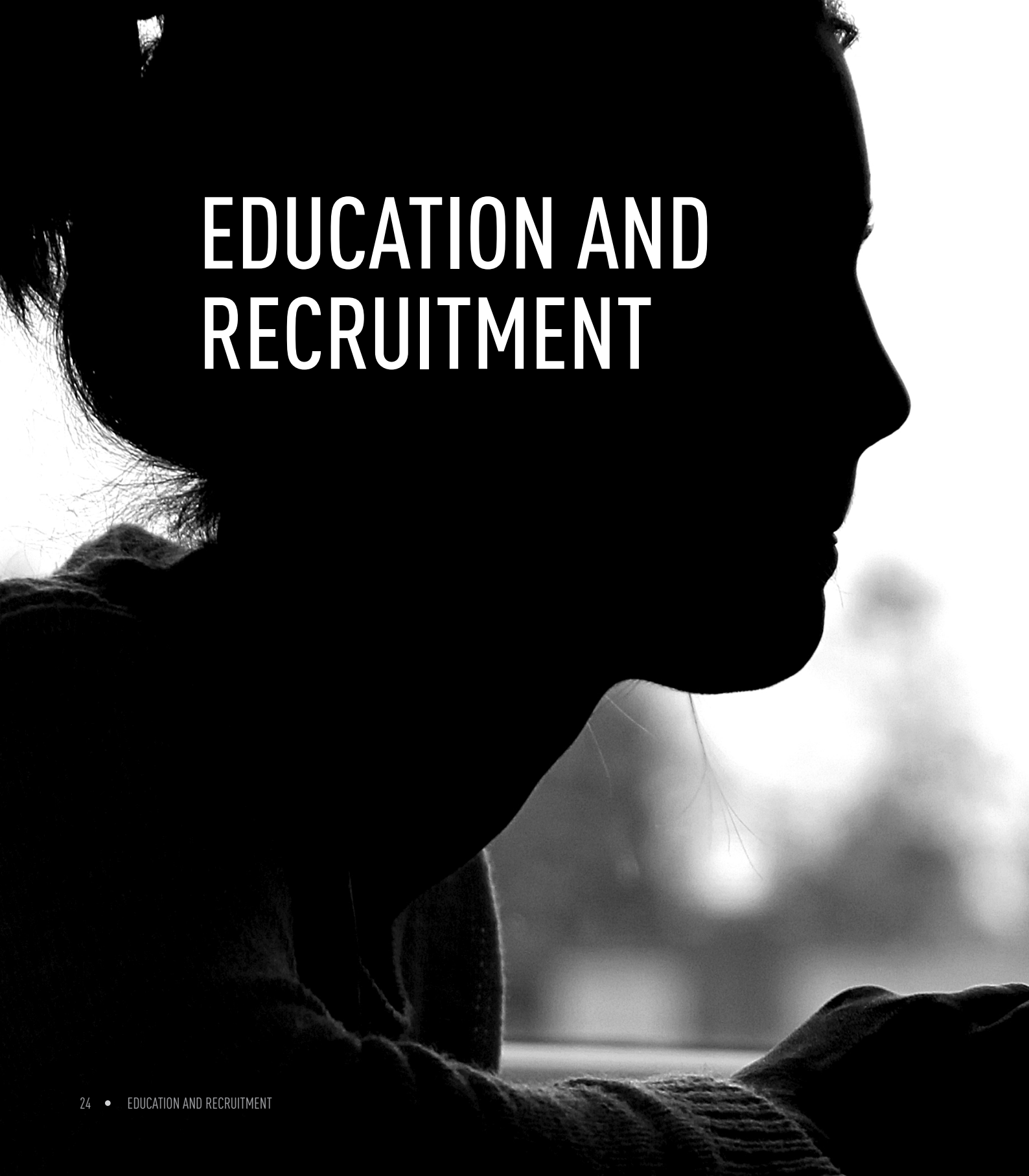

Finnfjord
Elkem Salten
Glencore Manganese i Rana
Elkem Rana
Alcoa Mosjøen
SFI Metal Production
Elkem Thamshavn
Wacker Chemical Holla
Hydro Sunndalen
Hydro Årdal
Elkem Bremanger
Hydro Høyanger
Elkem Bjølvefossen
TiZir Tyssedal
Hydro Husnes
Eramet Sauda
Hydro Karmøy
Eramet Kvinesdal
Alcoa Lista
Eramet Porsgrunn
SFI Metal Production
Silicon
Ferrosilicon
Ferromanganese
Silicomanganese
Aluminium
Titania slag and iron

Foto: Ingunn Kjøllmoen

EDUCATION AND RECRUITMENT



Anne Borg (Dean at NV-Faculty)
leader of the EC at SFI Metal Production

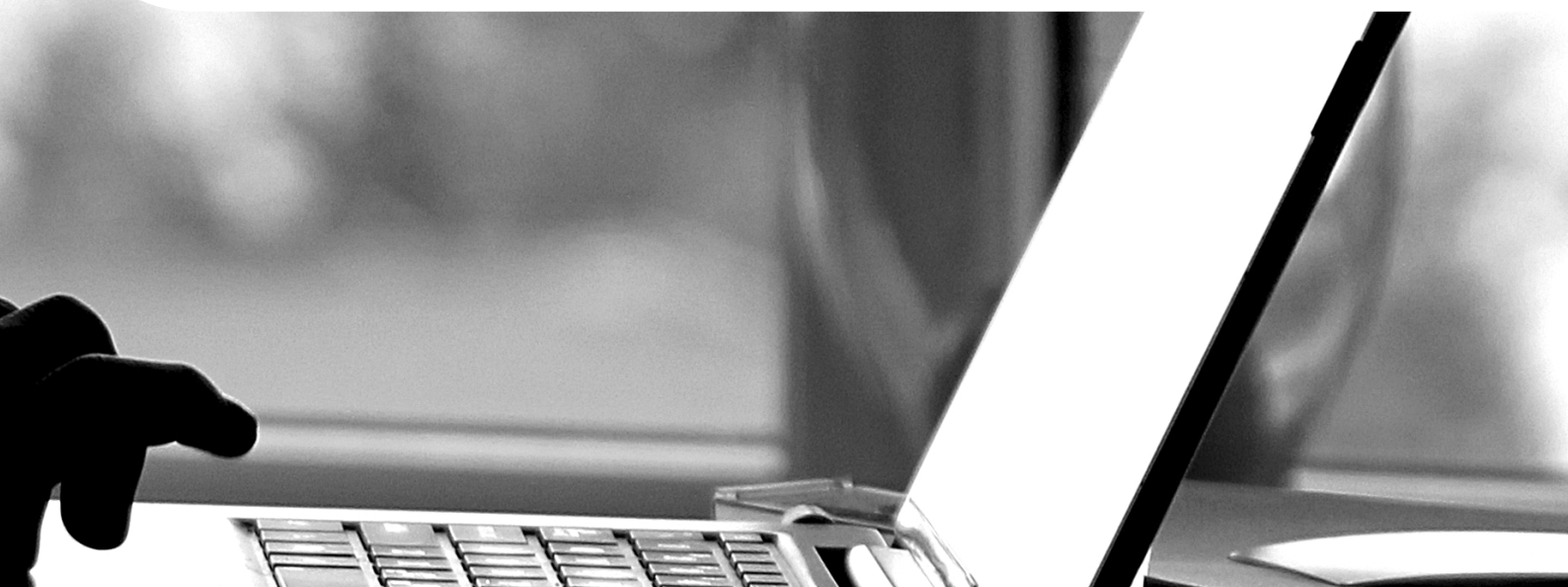
The research and innovation taking place in SFI Metal Production is in total harmony with NTNU's vision "Knowledge for a better world".

The SFI has been building up to full capacity in 2016, one of the reasons being the recruitment of talented PhD students and postdocs. Scientifically the progress of the centre during the year has been highly satisfactory.

Education of master and PhD students as well as postdocs is an important ingredient of an SFI centre. A vital part of NTNU's mission as a university is student and researcher training and SFI Metal Production is a valuable contributor in this respect. The asset of the SFI centre from an educational point of view, is that the young students and postdocs are exposed to timely scientific questions on topics highly relevant for the industrial partners and with strong innovation potential. Through the close collaboration between the university, institute and industry partners, these candidates learn the interplay between solving industrial questions and applied research, as well as formulating basic scientific questions based on industrial needs. Most significantly, these students and researchers are instrumental in carrying out the research activities within the centre in close collaboration with the university academics, SINTEF researchers and staff of the industrial partners. These candidates are potential future researchers and research leader in the field and possible employees for all partners in the consortium, with profound knowledge of metal production and understanding of industrial needs. This symbiosis is an asset for all participants in the centre as well as for the educational charter of NTNU.

Highly educated personnel are becoming increasingly important as Norwegian industry is facing stronger competition in a global market and expectations with respect to sustainable production and lower environmental footprints. These trends demand specialists with research experience to drive the industrial development and competitiveness. The PhD candidates and postdocs educated through SFI Metal Production are among these specialists. Societal aspects are integral topics of the centre, issues high on the agenda for all members and underpinning all research areas.

We are pleased with successful recruiting of talented young students and researchers to SFI Metal Production and look forward to following their scientific achievements in the centre and beyond. We believe that our candidates will contribute to shape the future of a strong and sustainable metal producing industry in Norway.




GESTA HEIMI
Elkem
GESTUR - VISITOR
33
34
35

... IN ELKEM

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.
The company has 3800 employees, four business divisions, production plants and sales offices in all parts of the world.


Photo: Elkem

The company works systematically to maintain and further develop their global organization in order to enable the people and teams to deliver on Elkem's ambitious strategic targets both within commercial and technological growth. Some examples of recruitment and development activities supporting.

Elkem's strategy:

1. Elkem University and other internal high level technology competence development programs
2. Elkem Leadership and Elkem Excellence management training programs
3. Elkem's global trainee program
4. Cooperation with Norwegian academia and industry within long-term programs for competence development at different knowledge levels and different areas of competencies.

Today, the Elkem trainee program serves as an efficient recruitment arena for technologists with an MSc background. In addition to excellent academic results during studies, personal qualities like; initiative, responsibility, engagement, attitude to safety and teamwork are highly valued.

To follow the students during their participation in, for instance in the "SFI Metal Production" centre, is therefore a good opportunity to get to know the candidates and guide them in the desired direction to a smooth transfer to employment in the industry.

Over the last 10 years, more than 40 MSc candidates have been through the trainee program in Elkem and are now employed as furnace metallurgists, process leaders, researchers etc. and some has returned to university as "Industrial-PhD" students. This continuous feed of highly qualified people into Elkem is necessary to secure a sustainable development of the company.

Elkem has a corporate R&D centre with more than 100 employees and, in addition, R&D groups in each division. A majority of the researchers have a background as PhD and/or postdocs from NTNU. SFI Metal Production represents a new possibility to educate new PhD candidates within the research areas that the Norwegian silicon-, manganese- and aluminium industry need most.

... IN ERAMET NORWAY AS

Eramet Norway is operating seven furnaces and two refining units in Norway. We consider ourselves to be among the world leaders in this business when it comes to process understanding, process control, efficiency and environmental performance. Consequently, we have a strong demand for highly skilled people. Today, Eramet has over 20 highly qualified people with a scientific background working within our metallurgy department. The knowledge they possess is crucial to the optimal performance of our processes and enables our goal of continuous improvement across our operations.

When recruiting today, Eramet places a strong emphasis upon high qualifications within the disciplines connected to metallurgy and is interested in candidates possessing an MSc or, in certain circumstances, a PhD. The competency that one finds within organizations such as NTNU, SINTEF, FFF and SFI is of great importance to our organization with regard to recruiting and with regard to research within our projects.

Eramet offers exciting job opportunities where theoretic knowledge is being used to develop and drive world-leading processes. Although there are many tools available today in the form of IT systems and programs that assist industry, Eramet believes that a fundamental understanding of theory and processes is vital for continuous improvement.

Eramet offers successful candidates the opportunity to develop within their chosen field, or towards a managerial career. Eramet has a philosophy that our research and development arm (R&D) shall have a close connection to our processes and operations at our plants. Eramet's participation in the research environment in Trondheim represents an important part of the total research program of the manganese division of Eramet. Eramet also uses the knowledge base found in Trondheim for further development and education of its own employees.

... IN ALCOA

Alcoa thrives by developing best practices that improve our business of mining, refining, smelting, casting and rolling aluminium. Just as important, we develop best practices for meeting environmental goals and supporting our communities, and we implement all of these ideas with consistency and precision across a global, multicultural organization. This kind of operating excellence takes a special kind of team, made up of special people. Alcoa cherishes its partnerships with Norwegian educational institutions, manufacturing and process industry expertise, and its work together with talents across the educational value chain; from helping local kindergartens create an interest in STEM, to supporting master and doctoral theses, postdocs, and knowledge hubs. One important initiative to drive innovation and development in the Aluminium industry, is the SFI for Metal Production at NTNU. Continuous improvement of our operations also requires continuous refill of knowledge; we therefore also enjoy hosting trainees and master students at our primary plants, as they provide us with new and fresh perspectives and up-to-date expertise. We also encourage employees to pursue additional education – to meet our need for diverse and multi-skilled employees.

Photo: Halvor Molland, Hydro

... IN HYDRO

Hydro has an extensive cooperation with strategic University/R&D partners and is actively building competence and networks in order to maintain top competence within Hydro's competence areas as well as attracting students – and their supervisors – to work with us. Competence that can be further developed either internally or in cooperation with academia and research institutes. In this context, cooperation with SFI Metal Production and other competence building programs is of importance both as a competence builder, new knowledge generation and as a potential recruitment pool.

Technical students are the main target group in the recruitment work in Hydro and we are always looking for top students with relevant competence, background and profile. Programs like SFI Metal Production can be a good way for Hydro to discover potential employees, and for the students to learn more about Hydro Technology and the aluminium industry. During cooperation, the students learn about the industry and Hydro can show the students a modern, technologically advanced, world leading, climate-effective and forward-looking industry.

Activities in SFI Metal Production (summer internship, project work, MSC and PhD) can be routes to introduce students to our industry and through this be attractive for future recruitment. When people come to Hydro, we can offer a many technical challenges in a friendly working environment with top technologists in the aluminium industry. We can also offer competence development and a specialist or a leadership career.

Hydro offers an internship program for students which can lead to a future career with Hydro. Each summer young and ambitious students come to Hydro as summer interns, to put theory into practice and get real-world work experience. In return, Hydro gets new and fresh views on how to solve problems – and an opportunity to create valuable relationships with some of the brightest students. Internship is for 3th and 4th years students.

Hydro's graduate program is popular for newly graduated and offers close follow up the first 1-2 year(-s); it is designed to fit the candidate, opens up for job rotation within a plant or process area, provides a thorough introduction program including common sessions with other Hydro young professionals and each graduate is given a dedicated buddy.

In Hydro, technology is a gateway to a technological specialist or a leadership career. All open positions – summer internships and graduate – are posted on www.hydro.com each autumn.

GAIN AN INSIGHT

INTO THE RESEARCH OF SOME OF OUR PHD'S AND POSTDOCS

POSTDOC
SEBASTIEN LETOUT

What are you researching?
I am trying to develop a numerical model for the flow in the furnace during metal production, but with a focus on the SiMn production process. The basis for the model is a pilot scale SiMn experiment carried out in RD2, and I am using thermodynamic and kinetic data from recent experiments in my calculations.

Who is involved in your research?
The SiMn process is a focus area within the SFI, and I am a part of a team of several students lead by RD2 leader Professor Merete Tangstad and RD1 leader Arne Petter Ratvik. Because of the focus on the project, there have been some achievements within the field, and this is where I got some of my modeling data.

Why is your research important?
A good numerical model of the process will give useful information that will provide a deeper understanding of experimental facility operations, whereas the experimental observations are necessary to set up the model correctly. If we understand what can be done better, we might, for example, be able to alter the process so less slag is produced and less raw material is wasted.

Tell us about an interesting result.
The first step to model the reaction is to understand the hydrodynamic inside the furnace. In this objective a modeling of the slag flowing into the coke bed has been done, to have an idea of both the size and the dynamic of the droplets falling by gravity at the bottom of the furnace through the coke bed, as seen in the Figure.

PHD
SETHULAKSHMY JAYAKUMARI

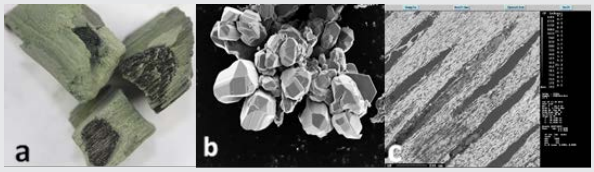
What are you researching?
In the silicon production process, black silicon crusts have been found within the furnace. These crusts will lower the process efficiency if present in large quantities. The crusts are also known as ***α***-SiC, and I am looking into how ***α***-SiC is formed at high temperatures. In the end, I will compare my results with already existing theories within the field.

How are you preforming the research?
I will try to produce the ***α***-SiC in a variation of ways, and then compare the final results with what is found in industrial furnaces. Because the formation of ***α***-SiC is a high temperature phenomenon, I am working with very high temperatures. For this work, I use furnaces such as a plasma furnace, a resistance furnace (ReSiNa furnace) and an induction furnace (IF75). A set of available characterisation tools such as chemical analysis EMPA, SEM, TEM and XDR, are used to study the SiC samples. Elkem, and my supervisors Merete Tangstad and Eli Ringdalen are also participating by giving me input along the way.

What are you hoping to find?
I am hoping to achieve a better understanding of the reaction mechanism of formation of ***α***-SiC in the furnace. If that is done, the industry will have a higher level of knowledge that may lead to new operation strategies and a more efficient process.

Tell us about an interesting result.
Recently, I carried out induction furnace experiments in order to produce ***β***-SiC (low temperature SiC) from coal and charcoal. We are excited to use this ***β***-SiC as the raw material for the production of ***α***-SiC in the future.

a. Silicon carbide (***β***-SiC) which is soft and green in color produced at 1850 °C from charcoal,
b. SEM image of the ***β***-SiC and
c. EPMA image of the ***β***-SiC (grey in color).



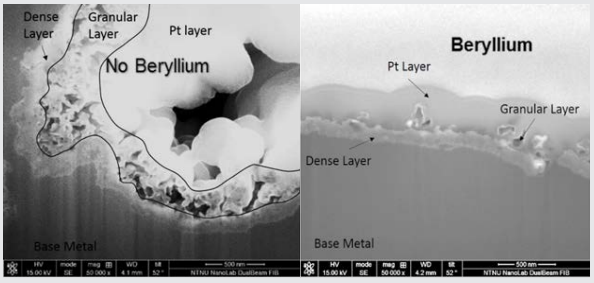
PHD
NICHOLAS SMITH

What are you researching?
I am studying the oxidation of molten aluminum, and especially what effect beryllium has on the oxidation. Traditionally, beryllium has been used to reduce oxidation in aluminum, but there are health risks connected to the use of it in the process, so I am trying to find alternative ways to achieve the same results.

How are you performing your research?
To find an alternative I first have to figure out exactly what beryllium does in the process. Therefore, I use a horizontal tube furnace at atmospheric pressure to oxidize small-scale samples of Al with and without beryllium. Then the oxidation layer is studied with an electron microscope, XPS and SIMS.

Who is involved in your research?
I have yet to understand the process completely, but it is an interesting project and Hydro and Alcoa, which are industrial partners, are very interested and the project is discussed thoroughly with them.

Tell us about an interesting result.
My most interesting result is in these two Figures, which show a sample with and one without beryllium. Both samples were oxidized at the same time and temperature. The figures show a cross-section through the oxide layer. The oxide layer consist of two parts, a dense and a granular layer. The granular layer was found to be significantly reduced in the sample with beryllium. It has been concluded that the beryllium has prevented the transport of magnesium through the dense layer thus reducing the amount of granular growth.



PHD
PYUNGHWA KIM

What are you researching?
I am looking at the reaction mechanism for the production of SiMn. The alloy is used as an important ingredient in steel production, and I am hoping to find a way to describe the rate of the process. It is uncertain how the reduction of MnO and SiO_2 occurs during the high temperature process and the reaction mechanisms of this process provide fundamental knowledge of the overall process. If we find a way to model the rate, it may lead to new strategies both when it comes to operation and when it comes to the use of various raw materials. The industry will thus be able to optimize the process to a higher extent and with that save energy, time and resources.

How are you performing your research?
I am doing this by studying the kinetics of the reaction; how fast the alloy is produced from various raw materials. For this work, I am using a TGA-type (Thermogravimetric analysis) furnace, which measures the weight of materials in experimental conditions. I am focusing on temperatures above 1500 °C where the significant metal producing reaction occurs.

What are your most important results so far?
Recently the rate models that I have considered seem quite acceptable to describe the reduction of MnO and SiO_2 in SiMn slags. The models are not complete and require a few more adjustments but it looks good so far.

Tell us about an interesting result.
I have tried different SiMn slags to describe the reduction rates of MnO and SiO_2. The figure below is one of them: The experimental results (circles and triangles) show good fitting to the calculated rate model results (solid lines). In addition, I am expanding my work to see if the rate models can also be applicable using different heating rates.

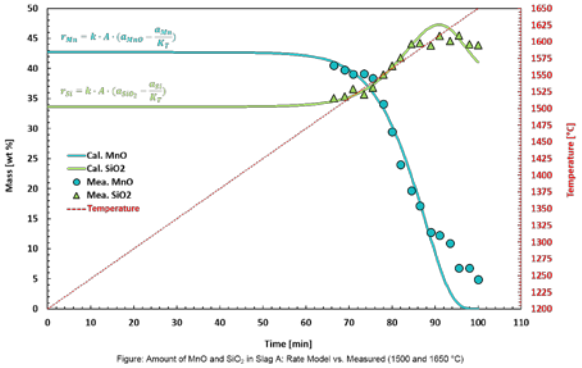


Figure: Amount of MnO and SiO_2 in Slag A: Rate Model vs. Measured (1500 and 1650 °C)

RECRUITMENT

– OUR PHD'S AND POSTDOCS

In 2016, four new PhD's and one postdoc started their work in SFI Metal Production. Totally, we have eight PhD's and two postdocs working in this centre now. In addition, we have five PhD students working in adjacent projects.

PhD student
Pyunghwa Kim

Research topic: Reduction mechanism in the SiMn process

Supervisor: Prof. Merete Tangstad

PhD student
Massoud Hassanabadi

Research Topic: Electromagnetically Enhanced Priming of Surface Modified Porous Media

Supervisor: Prof. Ragnhild E. Aune

PhD student
Sethulakshmy Jayakumari

Research Topic: Silicon Carbide production during Silicon process.

Supervisor: Prof. Merete Tangstad

Postdoc
Sebastien Letout

Research Topic: Numerical modeling of metallurgical production processes with a focus on the Si-Mn process

Supervisor: Prof. Merete Tangstad, Principal Scientist and Adjunct Professor Stein Tore Johansen and Senior Research Scientist Arne Petter Ratvik

PhD student
Nicholas Smith

Research Topic: Oxidation of liquid Aluminium

Supervisor: Prof. Gabriella Tranell

PhD student
Daniel Clos

Research Topic: Scaling in Al off-gas channels/heat exchangers

Supervisor: Prof. Ragnhild E. Aune

PhD student
Siri Marie Bø

Research topic: Slag properties in Si and Ti melts

Supervisor: Prof. Merete Tangstad

PhD student
Håkon Olsen

Research Topic: Modelling of dust formation and clustering in Ferroalloy Industry

Supervisor: Prof. Gabriella Tranell

PhD student
Erlend Lunnan Bjørnstad

Research Topic: Interactions in Si refining

Supervisor: Prof. Gabriella Tranell

Postdoc
Heiko Gaertner

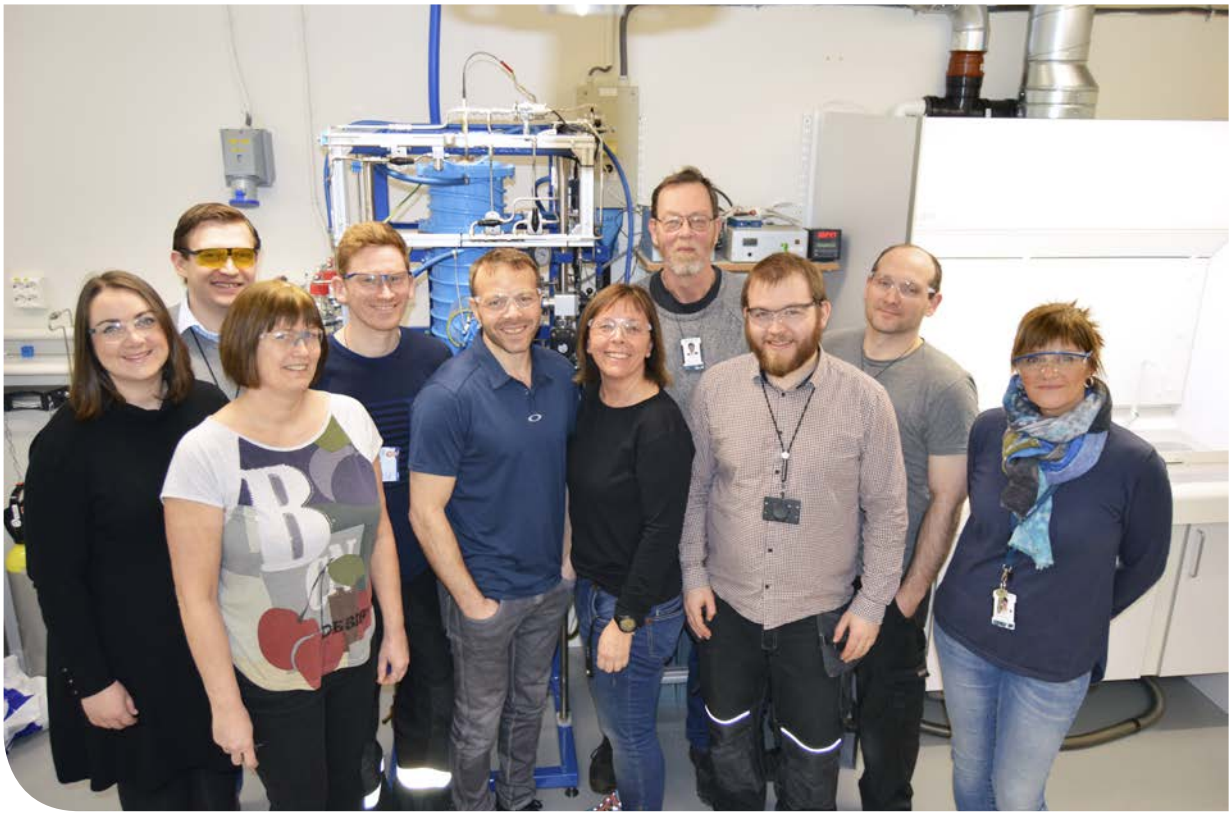
Research Topic: PAH standardisation

Supervisor: Prof. Gabriella Tranell

LABORATORY
INFRASTRUCTURE

The research at the SFI Centre are highly laboratory extensive. Almost all of our students, PhD's and postdocs are using a lot of different laboratory infrastructure for their research. Our highly qualified laboratory experts from SINTEF and NTNU are guiding, teaching and following up our students at the laboratory in an excellent way.

The laboratory experts: *Behind: Dmitry Slizovskiy, Jonas Einan Gjøvik, Steinar Prytz, Ivar Ødegård*
Front: Tine Christin Eikevik, Tone Anzjøn, Pål Tetlie, Birgitte Karlsen, Trygve Lindahl Schanche, Ingeborg Solheim



WHAT IS THE
SiManTi-GROUP?

The SiManTi-group is the research student group of the professors working with high-temperature processes within silicon, manganese and titanium, but it also includes the students working on other materials like aluminium, chromium and carbon. These are the students of Leiv Kolbeinsen, Ragnhild Aune, Gabriella Tranell, Jafar Safarian and Merete Tangstad. The student group was first founded in 2006, and has continuously been operating since. This group has several objectives, but the main objective is for the members to be a part of a group with similar challenges as themselves. Doing a PhD can be quite a lonely process, both metallurgically and socially, so it is important to be part of a bigger picture, and it is especially important to belong to a group of your peers, not just your professors and industrial seniors. The second motivation for this group is to develop yourself as a person, outside of a narrow project-view. The group is hence dedicated to presentation-technique, ethics in research, statistics, and effectiveness in writing and similar issues. The practical operation of the group are done through weekly meetings and yearly SiMnTi seminars. The social activities change over time, except for the yearly barbeque in June, and the baking of gingerbread models of famous buildings and structures in December.

The SiManTi (Al) group with three of their supervisors.

Foto: Dag Jenssen, Hydro

INTERNATIONAL COOPERATION

*Our professors, students and research scientist continuously collaborate with international researcher groups during their daily work, through their existing network, participations at **conferences, seminars, dialogue** and so on. Some of the international collaboration will shortly be listed here.*

The international conference **"Silicon for Solar and Chemical Industry"** in Kristiansand, June 13-15, was organized by NTNU and SFI Metal Production with Professor Merete Tangstad in charge. The conference focused on silicon production and primary chemical processes and the aim of the conference was to discuss silicon process technology, silicon quality assessment and performance in the subsequent chemical reactions. Resource, energy and environmental were important issues. A total of 140 Norwegian and international delegates from producers, users and academia, found this conference extremely interesting.

The **2nd School on Manganese Ferroalloy Production** took place at MINTEK, Johannesburg, South Africa at the end of June 2016. Professor Merete Tangstad (NTNU) and senior researcher Eli Ringdalen (SINTEF) were responsible for this second School on Manganese Ferroalloy Production. These schools were built on the collaboration between South Africa and Norway, and between individuals within the South African manganese industry, by including a larger number of local participants. The focus of the event was the identification of techno economic challenges faced by decision makers in the South African manganese industry, and finding ways to address these challenges.

Some of our scientist and students were visiting **RWTH Aachen University** in July. The scope of this seminar was a) to make plans for a common seminar for recycling of aluminium and b) Present SFI Metal Production and the possibilities for student exchange between RWTH Aachen and NTNU.

In 2016, **six exchange students** from five different countries, have been visiting and worked for the SFI centre under the supervision of scientists and professors form SINTEF and NTNU. These students have been working hard during their stay in Trondheim, and we are pleased with the research they have added to the centre. Some of the exchange students are a result of already existing networks and international cooperation and some of them are "new" and have given us the opportunity to build new international networks.

Professor Merete Tangstad was invited to join an **EU Horizon 2020 – FET** (Future Emerging Technologies) OPEN project with the title AMADEUS. The project got funding and will investigate the next generation materials and solid-state devices for ultra-high temperature energy storage and conversion.

Seminar at the Christ Church College in Oxford in September

A delegation of 50 persons from the industry, postdocs, PhD, master students and their supervisors from NTNU and SINTEF visited **Oxford University for a 2-days seminar**. The overall topic was "Metal Production" and this young scientist seminar was an important part of their education where presentation, scientific discussions and networking were the main issues. In addition to the Norwegian delegates, students and supervisors from MINTEK (South Africa) and Oxford participated.

The ***Scientific Committee*** (SC, leading academic experts) visited Trondheim one week in April 2016. All four attended our spring meeting and took part in discussions, both plenary and at the RD session.

Markus Reuter, Jean-Pierre Birat, Gabriella Tranell, Margaret Hyland, Aud Wærnes, Oleg Ostrovski (Photo: Thor Nielsen)

DISSEMINATION, MEDIA AND OPEN ACTIVITIES

In 2016, the students and education have been in focus. Two scientific courses have been carried out during the autumn of 2016, and both students and industry participants at these courses have acquired a lot of new knowledge.

- Aluminium refining and recycling short course 3-5 October – More than 50 people attended from Norway and abroad
- Si production and refining short course 17-19 October – More than 50 people attended from Norway and abroad

SFI Metal Production has started a good tradition by bringing together all partners for joint meetings twice a year. Some of the presentations are open activities and some are only for the partners.

Some of our PhD's have now been working with their projects for 1,5 year and in 2016 their results have been spread by participation in workshops, seminars, industry visits, meetings and conferences. We are proud to announce that at the 10th International Conference on Molten 2016 Slags, Fluxes and Salts Reduction in Seattle (USA) in May our PhD Pyunghwa Kim got an award for the best poster, "Behavior of Assmang and Comilog Ore in the SiMn Process".

In addition, several workshops on specific areas have been arranged: PAH Workshop (February), Heat recovery industry seminar at Alcoa (August), Mathematical Modelling in Metallurgical Industry seminar (August) are all a results of the close cooperation between research, education and industry.

Discussions at the **Spring Meeting**. Hilde Merete Aasheim (Hydro), Svenn Anton Halvorsen (Teknova) and Ragnar Tronstad and Aasgeir Valderhaug (Elkem)

Oxford seminar

At the **Autumn meeting** in October 2016 we hosted the open lecture "2052 – A Global Forecast" by Professor Jørgen Randers. This was a very interesting lecture for the approx. 100 attendees and inspired an interesting discussion afterwards.

In order to promote internationalisation between students in the field of metallurgy in the Scandinavian countries the International Seminar in Metallurgical Processes (ISMP) of process metallurgy and material science is annually arranged. Prof. Ragnhild E. Aune has actively been involved and attended all these seminars. In November 2016 NTNU had the pleasure to host the 21st seminar for 35 students from the three universities NTNU, KTH and Aalto.

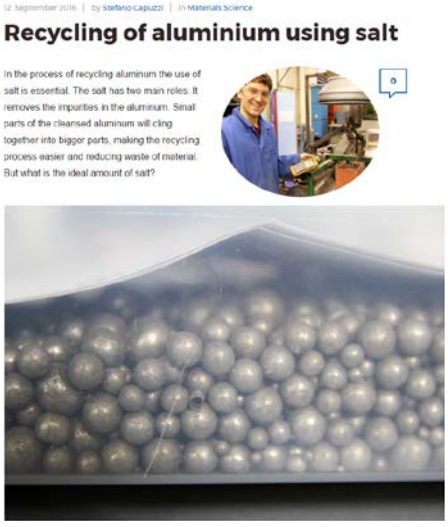
Final word from a student participating:
"This is a one in a lifetime experience, preparing us for what is to come, for most of us, very soon – the life of an engineer and the challenges of the 21st century."

MATERIALDAGEN

October 18th Aud Wærnes gave a lecture at **Materialdagen** where she presented the centre. She talked about the different research domains and what they focus on, the general structure of the centre and it's vision and goals for the future years – and how much fun it is to be a student within this area.

Each year we have between 7 and 10 **master students** connected to the centre. These young students are doing a lot of interesting research and are also a recruitment base both for PhD positions and for employment in the industry.

Opening of SFI the newly redecorated area in third floor in "Bergbygget" in June. On this floor the centre administration, industry, SINTEF, NTNU and students are sitting side by side.



12 September 2016 | By Stefano Capuzzi | In Materials Science

Recycling of aluminium using salt

In the process of recycling aluminum the use of salt is essential. The salt has two main roles. It removes the impurities in the aluminum. Small parts of the cleansed aluminum will cling together into bigger parts, making the recycling process easier and reducing waste of material. But what is the ideal amount of salt?

The exchange student **Stephano Capuzzi** was presenting some of his work done during his stay in Trondheim, at NTNU, NV-faculty blog.

In November 2016, the **Research Council** was on a Site Visit, which is standard procedure for all CRI Centres. For half a day we gave a presentation of the centre and the progress we have made. Fruitful discussions were also held, along with a guided tour of the labs.

ANNUAL ACCOUNTS FOR 2016

Funding (1000 NOK)	Amount
Research Council	14 310
Host Institution (NTNU)	4 688
Research Partners*	3 158
Industry Partners**	13 748
Total	**35 904**

Costs (1000 NOK)	Amount
Host Institution (NTNU)	16 196
Research Partners*	12 710
Industry Partners**	6 998
Equipment	0
Total	**35 904**

The annual account for 2016 was about 2 mill NOK higher than the budget, due to high activity and a high in-kind contribution for all the Industry Partners and NTNU in 2016.

* *SINTEF, Teknova*

** *Hydro Aluminium AS, Eramet Norway AS, Elkem AS, Alcoa Norway ANS, TiZir Titanium & Iron AS, Glencore Manganese Norway AS, GE Norway AS, Wacker Chemicals Norway AS, Fesil Rana Metall AS, Finnfjord AS*

PERSONNEL INVOLVED IN THE CENTRE IN 2016

Centre Administration

Aud Wærnes	SINTEF	Centre Manager
Gabriella Tranell	NTNU	Scientific leader and deputy Centre Director
Marianne Lenes	NTNU	Coordinator
Bodil Lervik	SINTEF	Financial Officer

WEB and design

The students Kari Ravenstad Kjørholt and Fabian Vold

Key Researchers

RD1:

Arne Petter Ratvik	SINTEF	Primary aluminium production, carbon materials
Jan Erik Olsen	SINTEF	Modelling
Svenn Anton Halvorsen	Teknova	Modelling
Stein Tore Johansen	SINTEF	Modelling
Olaf Trygve Berglihn	SINTEF	Modelling, library
Ulrik Thisted	Teknova	Mathematical modelling
Manuel Sparta	Teknova	Mathematical modelling

RD2:

Merete Tangstad	NTNU	Si/FeSi and Mn-alloys production, raw materials
Eli Ringdalen	SINTEF	Si/FeSi and Mn-alloys production, raw materials
Michal Ksiazek	SINTEF	Si/FeSi and Mn-alloys production, raw materials
Espen Sandnes	NTNU	Primary aluminium production
Asbjørn Solheim	SINTEF	Trace Elements in Aluminium Production

RD3:

Anne Kvithyld	SINTEF	Aluminium refining and recycling
Ragnhild Aune	NTNU	Aluminium refining and recycling
Martin Syvertsen	SINTEF	Aluminium refining and recycling
Gabriella Tranell	NTNU	Al oxidation

RD4:

Gabriella Tranell	NTNU	Production of ferroalloys, emissions and environmental issues
Ida Kero	SINTEF	Emissions and environmental challenges
Thor Anders Aarhaug	SINTEF	Emissions and environmental challenges
Heiko Gærtner	SINTEF/NTNU	Emissions and environmental challenges
Svend Grådahl	SINTEF	Emissions and environmental challenges
Jan Erik Olsen	SINTEF	Dust and Emissions
Petter Nekså	SINTEF	Energy, Heat recovery, heat exchangers
Daniel Clos	NTNU	Heat recovery, heat exchangers
Trond Andresen	SINTEF	Energy, Heat recovery, heat exchange
Hege Indresand	Teknova	Emmisions and environmental challenges

RD5:

Leiv Kolbeinsen	NTNU	Materials and society, Seed projects
Daniel Beat Mueller	NTNU	Materials and society

Visiting Researchers

Jean-Pierre Birat	European Steel Technology Platform	France
Markus A. Reuter	Helmholz Inst Freiberg	Germany
Margaret M. Hyland	Univ of Auckland	New Zealand
Oleg Ostrovski	Univ of New South Wales	Australia

Postdoctoral Researchers with financial support from the centre budget

Sebastien Letout	(2015-2017)	Modelling of SiMn pilot experiments/Comsol
Heiko Gaertner	(2016-2020, 50%)	PAH measurements and analyses

PhD students with financial support from the centre budget

Pyunghwa Kim	(2015-2018)	Rx mechanism in SiMn reactions
Sethulakshmy Jayakumari	(2015-2018)	SIC in Silicon Processes
Nicholas Smith	(2015-2018)	Effects of Impurities on Al oxidation
Massoud Hassanabadi	(2015-2018)	Wettability of Filters and Filtration
Siri Marie Bø	(2016 – 2019)	Slag structure i Si and Ti melts
Erlend Lunnan Bjørnstad	(2016 – 2020)	Interactions in refining og Si
Håkon A. H. Olsen	(2016 – 2020)	Modelling of dust formation & clustering in Ferroalloy Industry
Daniel Clos	(2016 – 2019)	Self-cleaning Consept fromAl Off-gas
Dirk Lauinger	(2016, 5 months)	Material Flow Analyses

PhD students working on projects in the centre with financial support from other sources

Rune Stana	(2016-2020, NTNU internal funding)	Ti Slag
Caoimhe Rooney	(2016-2019, KPN project, ElMet)	Modelling
Hamideh Kaffash	(2016-2018, NTNU internal funding)	Manganese
Raghed Saadieh	(2016-2019, Elkem, Industrial PhD)	FeSi
Karin Jusnes	(2016-2019, IPN project HighTempQuartz)	Quartz
Bendicte Hovd	(2016-2019, Institute PhD from Sintef)	Charcoal for Manganese production
Mads Fromreide	(2016-2019, KPN project, ElMet)	Modelling

Project students (Autumn 2016)

Stein Olav Lund	Al og Mg i Si-process
Hanne Sellæg	Smelting reduction of Bauxit-Pedersen Process
Stine P. Espelien	Si refining
Trine Asklund Larsen	SiMn reduction with Comilog ore
Nina Kvitastein	P-distribution between metal and slag phases
Tomas Bye	Mn-agglomerates
Stine Svoen	C-deposition on Mn-ores
Anh Quynh Nguyen	Modelling

Master students (Spring 2016)

Erlend Lunnan Bjørnstad	*Mass Transfer Coefficients and Bubble Sizes in Oxidative Ladle Refining of Silicon*
Ashkay Bhat	*Boron removal from silicon using refining and different crucible materials*
Claudio Sanna	*Boron removal from molten silicon by gas blowing using different gas mixtures*
Joakim Holtan	*Production of Silicomanganese from Comilog Ore*
Siri Marie Bø	*Phases and Zones in the Silicon Process*
Sofie Aursjø	*Wear of Carbon Refractory Materials in Silicon Furnaces*
Rune Hagberg Stana	*Solidification of Titanium Slags and Influence on Post Processing*
Karin Jusnes	*Parameters Affecting Softening and Melting of Quartz*
Marthe Erdal Kjeldstali	*Kinetics and Mechanism of Phase transformation from Quartz to crystobalite*
Håkon Olsen	*Theoretical study and mathematical modelling on the reaction rates in the SiMn-production process*

Exchange students

Stefano Capuzzi	(Italy)	Al recycling
Ryosuke Kawamoto	(Japan)	Refining of Al
Tiago Ramos Roberio	(Brasil)	Reduction for Si and Mn
Peter Eggenbauer	(Austria)	Properties of pellets from Mn sludge
Didier Ngoy	(South Africa)	Mn process
Diego Correa Ramires	(Brasil)	Charcoal use in silicon production

PUBLICATIONS IN 2016

Scientific publications

Kero, Ida; Grådahl, Svend; Tranell, Gabriella (2016) Airborne Emissions from Si/FeSi production *JOM: The Member Journal of TMS* vol. 69.

Kero, Ida; Grådahl, Svend; Tranell, Gabriella (2016) Airborne Emissions from Si/FeSi Production – A Summary *Silicon for the Chemical and Solar Industry Conference XII*

Kim, Pyunghwa; Holtan, Joakim; Tangstad, Merete (2016) Reduction Behavior of Assmang and Comilog Ore in the SiMn Process *The 10th International Conference on Molten Slags, Fluxes and Salts*

Kjos, Ole; Rolseth, Sverre; Gudbrandsen, Henrik (2016) A Laboratory Study of Electrochemical Removal of Noble Elements from Secondary Aluminum *REWAS 2016: Towards Resource Sustainability/ TMS 2016*

Kolbeinsen, Leiv (2016) Green Competitiveness in the Silicon Industry, *CRU Silicon Market Forum 2016*

Ksiazek, Michal; Tangstad, Merete; Ringdalen, Eli (2016) Five Furnaces, Five Stories *Silicon for the Chemical and Solar Industry XIII*

Olsen, Jan Erik; Kero, Ida; Tranell, Gabriella; Engh, Thorvald (2016) Model for Silicon Refining During Tapping – Removal of Ca, Al and other Selected Element Groups *Metallurgical and Materials Trans B*

Ringdalen, Eli; Tangstad, Merete (2016) Phase Transformations in Quartz and it's Effect on Furnace Operation, *Silicon for the Chemical and Solar Industry XIII*

Ringdalen, Eli; Tangstad, Merete (2016) Softening and Melting in SiO2, An Important Parameter for Reaction with Quartz in Si-Production *The 10th International Conference on Molten Slags, Fluxes and Salts*

Wærnes, Aud (2016) Use of Waste in Metallurgical Industry *ISWA Beacon Conference on Waste Minimization and Recycling*

Reports /Seminars/Thesis

Andersen, Vegar (2016) Recruitment to the Metal Producers *SiManTi Seminar in Oxford*

Aune, Ragnhild (2016) Innovations and New Technology – What is the role of research? *SiManTi Seminar in Oxford*

Bhat, Askhay (2016) Boron Removal from Silicon Using Gas Blowing With Different Crucible Material *Master Thesis NTNU Trondheim*

Bjørnstad, Erlend Lunnan (2016) Review of the Parameters Needed for CFD Modelling of the Central Bubble Column in Oxidative Ladle Refining of Silicon *Master Thesis NTNU Trondheim*

By, Thomas; Kolbeinsen, Leiv; Ringdalen, Eli (2016) Agglomeration for Manganese Ferroalloy Production *International Seminar in Metallurgical Processes (ISMP)*

Bø, Siri Marie (2016) Phases and Zones in the Silicon Process *Master Thesis NTNU Trondheim*

Dahle, Sigmund; Safarian, Jafar; Kolbeinsen, Leiv (2016) Microstructural, Chemical and Phase Analysis of Bauxite Ores During Their Calcination *National Conference for Material Technology*

Espelien, Stine; Safarian, Jafar (2016) Refining of Silicon Through Hydrometallurgical Process *International Seminar in Trondheim*

Folstad, Marit Buhaug; Tveit, Halvard; Ringdalen, Eli (2016) Effect of Quartz, Amorphous Silica and Cristabolite on the Reaction Between SiO2 and SiC in Si Production, *International Seminar in Metallurgical Processes (ISMP)*

Hassanbadi, Massoud (2016) Al-Filtration *SiManTi Seminar in Oxford*

Holm, Katrine; Tangstad, Merete (2016) Reduction of MnO and SiO2 from Comilog Based Charges *International Seminar in Metallurgical Processes (ISMP)*

Holtan, Joakim (2016) Production of Silicon Manganese from Comilog Ore – Reduction Behavior *Master Thesis NTNU Trondheim*

Jakobsson, Lars Klemet (2016) Elkem's Solar Cell Research *SiManTi Seminar in Oxford*

Jayakumari, Sethulakshmy (2016) Silicon Carbide Production During the Silicon Process *National Conference for Material Technology*

Jusnes, Karin Fjeldstad (2016) Softening and Melting of Quartz *Master Thesis NTNU Trondheim*

Kawamoto, Ryosuke; Tangstad, Merete (2016) Reduction Mechanism of Synthetic Siliconmanganese Ore *International Seminar in Metallurgical Processes (ISMP)*

Kero, Ida (2016) Emissions from the Si-Industry *SiManTi Seminar in Oxford*

Kim, Pyunghwa (2016) SiMn Reaction mechanisms *SiManTi Seminar in Oxford*

Kjeldstadli, Marthe (2016) Phase Transformations in Quartz *Master Thesis NTNU Trondheim*

Kolbeinsen, Leiv (2016) Hva kan grønn konkurransekraft innebære for norsk metallproduserende industri? *National Conference for Material Technology*

Kvitastein, Nina; Tranell, Gabriella (2016) Distribution of P and Si Between Slag and Metal Phase *International Seminar in Trondheim*

Kvithyld, Anne (2016) Effects of Different Salts on Aluminum Coalescence to Improve Aluminum Yield *National Conference for Material Technology*

Ksiazek, Michal (2016) Zones and Reactions in the Si Furnace *SiManTi Seminar in Oxford*

Larsen, Trine Asklund; Tangstad, Merete (2016) Reduction of Mn and Si from Comilog Based Charges *International Seminar in Trondheim*

Letout, Sebastien (2016) Modelling Reaction Mechanisms *SiManTi Seminar in Oxford*

Li, Xiang (2016) Use of Natural Gas in Mn Production *SiManTi Seminar in Oxford*

Lobo, Stephen; Nedkvitne, Eirik Nøst (2016) An overview of Norwegian Metal Production, Report.Lund, Stein Olav; Tangstad, Merete (2016) Al2O3 and CaO in the Silicon Furnace *International Seminar in Trondheim*

Olsen, Håkon (2016) Modelling f the SiMn Reduction Rate *Master Thesis NTNU Trondheim*

Olsen, Jan Erik; Panjwani, Balram (2016) Spredning og oppsamling av støv fra metallurgisk industri *National Conference for Material Technology*

Rodahl, Fredrik; Aune, Ragnhild Elizabeth; Kennedy, Mark (2016) Master Slag Production for the Recovery of Rare Earth Elements *International Seminar in Metallurgical Processes (ISMP)*

Sanna, Claudio (2016) Boron Removal from Molten Silicon by Gas Blowing Using Different Gas Composition, *Master Thesis NTNU Trondheim*

Sellæg, Hanne; Safarian, Jafar (2016) Iron Separation from Bauxite Through the Smelting-Reduction Process, *International Seminar in Metallurgical Processes (ISMP)*

Skogstad, Vegard (2016) Glencore and Metal Production *SiManTi Seminar in Oxford*

Smith, Nicholas (2016) Oxidation of A, *SiManTi Seminar in Oxford*

Smith, Nicholas; Tranell, Gabriella; Kvithyld, Anne (2016) Effects of 2 ppm beryllium on the oxidation of a 5183 aluminum alloy at temperatures between 500°C and 750°C, *National Conference for Material Technology*

Svoen, Stine; Ringdalen, Eli; Kolbeinsen, Leiv (2016) Deposition of Carbon on Mn Ore, *International Seminar in Metallurgical Processes (ISMP)*

Syvertsen, Martin (2016) Effects of Be on Oxide Skin Strenght on Al-Mg Alloy, *National Conference for Material Technology*

Tangstad, Merete; Tranell, Gabriella (2016) Excellence in Research – What do we mean? *SiManTi Seminar in Oxford*

Wærnes, Aud (2016) Senter for Forskningsdrevet Innovasjon (SFI) Metal Production *Lettmetallkonferansen, Norsk Industri*

Wærnes, Aud; Tranell, Gabriella (2016) SFI Metal Production *NMS Sommermøte, Norsk Materialteknisk Selskap*