Ferroalloy research for sustainable development

FERROLEGERINGSINDUSTRIENS FORSKNINGSFORENING

The Norwegian Ferroalloy Producers Research Association

The Norwegian Ferroalloy Producers' Research Association (Norwegian Abbreviation FFF) is an association established by the Norwegian ferroalloys industry to carry out joint research on ferroalloy processes and products.

Through this research FFF aims to maintain the Norwegian ferroalloys industry's position at the forefront of developments in the production of ferroalloys and the supply of electrometallurgical technology and equipment.

It is our aim to pursue environmental improvements in the ferroalloys industry and to enable a shift to a carbon neutral production of ferroalloys by 2050. An important part of our work is the education of qualified personnel for the ferroalloys industry. The research programme is also intended to support the education of students to a Ph.D. level.

Our vision is *Ferroalloy research for sustainable development*.

Frontpage photo: Finnfjord

Photo: Finnfjord

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FFF was formed in 1989

The FFF member companies directly employ 2400 persons and represent a turnover of NOK 16 billion.

Elkem is one of the world's leading suppliers of silicon-based advanced materials. The company has operations throughout the value chain from quartz to specialty silicones, and attractive market positions in specialty ferrosilicon alloys and carbon materials. Elkem has more than 6 800 employees with 29 production sites and an extensive network of sales offices worldwide. Elkem has 1542 employees in Norway and total sales of 7.6 billion NOK. *www.elkem.com*

Eramet Norway, with its three smelters in Porsgrunn, Sauda and Kvinesdal, as well as an R&D department in Trondheim, is a world-leading producer of refined manganese alloys for the global steel market. Eramet Norway has 532 employees and total sales of 5.6 billion NOK. *www.eramet.no*

Finnfjord is one of the world's most energy-efficient and environmentally friendly producers of ferrosilicon with a total production capacity of 100,000 tonnes. In addition, Finnfjord has an energy recovery system with the capacity to generate 340 GWh of electric power. Finnfjord has 135 employees and total sales of 1 billion NOK. *www.finnfjord.no*

Metallurgical-grade silicon is one of **Wacker's** most important raw materials and is needed to produce silicones and hyper-pure polycrystalline silicon. Today we generate around a quarter of our silicon-metal requirements from the Holla production site. Wacker has 210 employees and total sales of 1.4 billion NOK. *www.wacker.com*

SINTEF is one of Europe's largest independent multidisciplinary research organisations and conduct R&D for both private and public sectors. We have 2 100 employees, 3600 clients, and an annual turnover of 3,4 billion NOK. Our vision is Technology for a better society. *www.sintef.com*

NTNU is a Norways largest university with an international focus, with headquarters in Trondheim and campuses in Ålesund and Gjøvik. NTNU has a main profile in science and technology, a variety of programmes of professional study, and great academic breadth. NTNU has 9 000 employees, 42 000 students, 400 doctoral degrees and an annual turnover of 9.4 billion NOK. *www.ntnu.no*

Industrial activities

Ferroalloy smelters (FFF) in Norway

From the chair of the board

2020-21 were peculiar years for the companies in FFF due to the Covid-19 situation. Despite this we continued our work almost as normal although mainly in Teams meetings instead of physical ones.

We have had good discussions with Bellona during this period, starting with the seminar “Green power and green industry”. Together we are planning new seminars on the topic of biocarbon in Norwegian process industry, taking advantage of FFF’s work on this topic over many years. We appreciate the educational discussions and good cooperation and are looking forward to continuing this in years to come.

We have had a process on establishing a new strategy and in that context we have made some organizational changes. We have established groups for research management led by Benjamin Ravary, communication led by Viktor Myrvågnes and education led by Merete Tangstad. These changes have given us a better focus on how we work with these topics.

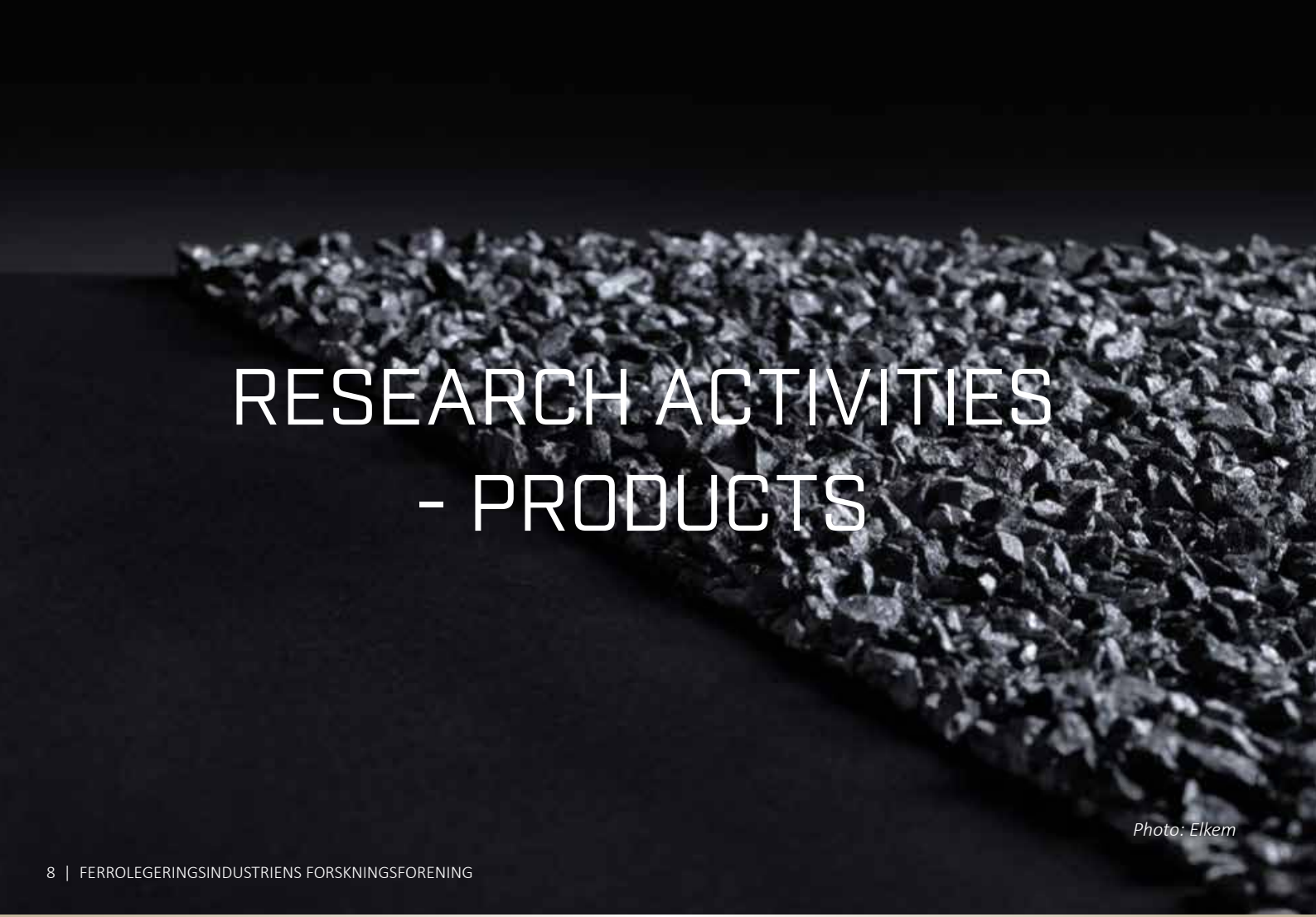
Process 21 - Industrial strategy for the process industry, a forum for sustainable growth, established by the Norwegian government in 2018[1)]. The main report was published in the beginning of 2021. Process 21 has influenced our discussions and was a topic at the strategy meeting in august 2021. The Green Platform programme in the Research Council of Norway[2)] has also been a topic for discussions that resulted in an application for a pre-project in 2020.

FFF is participating in 5 ongoing projects and centres with funding from the Research Council. Through such participation, FFF confirms the organization’s commitment to materials research. Our ability to increase value creation whilst ensuring low carbon and environmental footprints from the production depends upon such research. To reach the goal of carbon neutral production in 2050, we need to continue the good work FFF has done since 1989.

Erlend Dårflot Olsen, *Chair of the Board*

[1)] www.prosess21.no/
[2)] www.forskningsradet.no/utlysninger/2021/gronn-plattform-naeringsliv/

Wacker, Norway. Photo: SINTEF



RESEARCH ACTIVITIES - PRODUCTS

Photo: Elkem

Silicon and Ferroalloys – production in Norway

- Silicon – 225 000 tons
- Ferrosilicon – 265 000 tons
- Ferrosilicon master alloys – 56 000 tons
- FeMn – 300 000 tons
- SiMn – 230 000 tons

	Aluminium	Silicon	Ferrosilicon	Ferro/Silico-manganese
European production:	1 Russia	**1 Norway**	1 Russia	1 Ukraine
	2 Norway	2 France	**2 Norway**	**2 Norway**
	3 Iceland	3 Spain	3 Ukraine	3 Russia

Source: The Norwegian Pollutant Release and Transfer Register and Eramet Sustainability Report 2019.

Silicon and Microsilica

Silicon

- A wide range of silicon qualities are used as alloying agents in the aluminium industry. Aluminium-silicon alloys are widely used in the automotive industry due to the high strength-to-weight ratio, good corrosion resistance and good castability.
- Silicon is used for chemical applications and is the basis for the silicones industry and the production of fumed silica.
- Silicon is also used in specialty applications in the ceramics and battery industries.
- Silicon is the starting material for production of polysilicon which again is the basis for production of semiconductors and solar panels.
- The world's most environmentally friendly silicon production for use in solar cells takes place in Norway.
- The solar power market has doubled from 2018-2019 in Norway and has since continued to increase. Assuming around 3 grams of silicon per Wp, production of solar panels with a total capacity of 3000 GWp will require the use of ~ 10 million tonnes of silicon with an estimated value of 60-100 billion NOK.
- Over 90% of the world's solar cells are made of silicon.

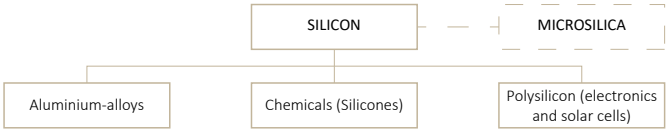


Photo: Shutterstock

Microsilica

- A wide range of microsilica qualities are used in the construction-, oilfield- and refractory industries.
- Microsilica is used to make the high-strength concrete that is essential for constructing the world's tallest buildings, such as the record-breaking Burj Khalifa in Dubai at 828 metres. Here microsilica is used to increase the strength of the concrete mix by its unique particle packing ability combined with pozzolanic reactivity.

Burj Khalifa, Dubai, United Arab Emirates.
Photo: Elkem

Ferrosilicon

- The metal industry uses a lot of energy, but is also a prerequisite for sustainable renewable energy production.
- Wind turbines contain more than 70% steel.
- Steel is an important material in hydropower which accounts for 93,4% of Norwegian power production. Here, steel is used in generators, among other things.

Ferrosilicon is used in the steel and iron industry. 3-4 kilograms of FeSi is used to produce one tonne of regular carbon steel, whereas stainless steel requires 5-10 times the amount.

FeSi increases the strength, hardness and corrosion resistance in the steel.

Ferrosilicon, master alloys

The ferroalloy industry manufactures a wide range of FeSi alloys for the use in the iron casting industry (inocculants, nodulisers and conditioners) and steel industry (alloying, deoxidisers).

Photo: Elkem

Manganese alloys

Steel is the world's most widely used construction material, and is used in everything from structures, industrial equipment and cars, to consumables.

Steel, and thus also manganese alloys that make steel ductile and durable, is an essential input factor in the transformation of important sectors such as energy generation and transport.

Robust, long-lasting infrastructure is also crucial to create economic development and prosperity. This is needed in order to meet the many challenges that come with population growth, urbanisation, poverty alleviation and measures to reduce the negative effects of natural disasters.

Steel can potentially be recycled indefinitely without losing its properties, and the global recycling rate is now more than 80%.

The global consumption of steel has more than doubled since the turn of the millennium and is expected continue to increase in the years towards 2050.

SUCCESS STORIES

Photo: Geir Mogen / NTNU

More than 70 PhD candidates since 1990

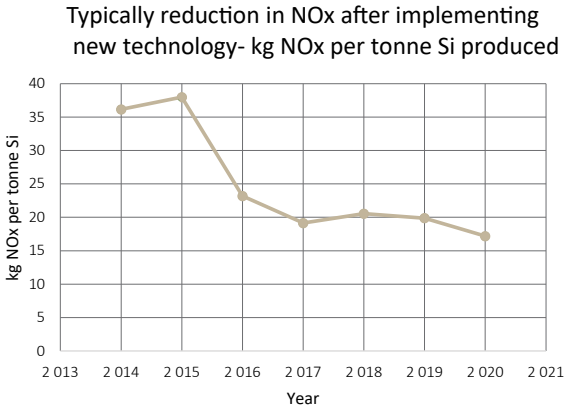
In close co-operation with NTNU, education is an important part of FFF's activities. In the period from 1990 until the end of 2021, more than 70 PhD candidates have graduated with the support from FFF, the Research Council of Norway and other industries, such as aluminium producers.

The PhD students have been part of research projects together with researchers and co-workers from SINTEF and NTNU. 18 PhD students are today part of ongoing FFF projects. Master students within FFF projects are also a recruitment base for the ferroalloy industry.

NTNU Campus, Trondheim

Reduction of NOx emissions from FeSi/Si

Common challenge - solved after 20 years of cooperation



Elkem Salten. Photo: Elkem

The main environmental impacts regarding NOx:

- Acid rain (oxygen depletion and global warming)
- Ground-level ozone (respiratory disorders)

40 publications from FFF 1995-2012

1997-2003	2009-2012	2013	2015	2017	2019
FFF initiated three research projects to understand more about formation of NOX in Si/FeSi production.	Models-Pilot testing PhD.	Furnace Measurments-benchmark-data models-de-sign Presentation at Infacon XIII.	Technology implemented at Elkem Salten. A reduction of more than 40%.	The Elkem Innovation Award in 2017.	Implemented on all three furnaces at Elkem Salten and Elkem Bremanger. Reduced NOx emissions by 50%. Supported by the NOx-fund.

Use of Biocarbon in the production of ferroalloys

Photo: Shutterstock

Facts about the use of biocarbon in the Norwegian Silicon- and ferrosilicon industry:

- The use of biocarbon is an efficient climate action. Combined with CCS, the use of biocarbon will be even more favourable.
- Technologies for sustainable production of biocarbon are ready for industrialization.
- Today, the use of biocarbon in the production of Si/FeSi is around 20% of the total carbon used in Norway.
- A conversion to 100% biocarbon in the Norwegian Si/Fe industry, will require 5 mill fm^3 wood a year, corresponding to 40% of today's logging.
- Biocarbon is expensive compared to fossil carbon. However, it is expected that CO_2 taxes will balance the cost difference in the coming years.
- Predictable access to, and the price of wood is crucial for industrialization.

1996	1997	1998-2001	2002-2004	2005-2007	2012	2014-2017	2018-2022	2019-2022
Increased use of biocarbon in the Si/FeSi industry.	Use of biocarbon in the Norwegian ferroalloy industry, pre-study.	Use of BioCarbon for reducing the CO_2 emissions.	Environmentally friendly reduction processes.	Biocarbon for the production of ferroalloys.	Alternative carbon sources, FFF pre-study.	**BioCarb+** Enabling the biocarbon value chain.	**Reduced CO_2 emissions**. Develop methods for substituting fossil carbon in ferroalloys.	**BioCarbUp** Optimising the biocarbon value chain for a sustainable metallurgical industry.

ONGOING PROJECTS

Photo: Svend Grådahl / SINTEF

Controlled Tapping

Aim: To maximize metal yield and operation load and minimize hazardous tapping conditions. The focus for the Mn-producers is slag/metal separation while the Si/FeSi producers are focused on taphole gassing.

The tapping process is an important subprocess, deviations lead to a higher energy consumption, less metal yield and less safety. Advanced modelling of tapping shows how slag and metal exits the tapping hole mixed, and how metal and slag separation is affected by varying tapping parameters. It has been discovered that the temperature in tapped metal is substantially higher than previously believed for FeSi and Si. It has been observed that slag tapped from Si-furnaces are enriched in CaO and Al_2O_3. The SiO production rate is not affected by the quartz source, but very dependent on the temperature.

www.sintef.no/controlled-tapping

Key figures	
Project owner	NTNU
Project manager	Merete Tangstad
Duration	2017 - 2022
Budget	28 MNOK
Partners	Elkem, Eramet, Wacker, Finnfjord, SINTEF, NTNU and MINTEK

Reduced CO_2 emissions

Aim: To develop the basis for reduced climate effects from the production of Si, FeSi, Mn- alloy and TiO2 slag, with an aim to obtain 30% lower CO_2 emissions in 2030 and zero CO_2 emissions in 2050.

Most CO_2 emissions from the metal industry are caused by solid carbon used in the reduction process.

- In order for biocarbon to be able to replace fossil coal, it must result in a more efficient production of metal. A number of different biocarbon qualities have been compared to fossil carbon.
- Carbon from biogas is a possible carbon source in the production of Mn alloys.
- Several new technologies have been considered for further research. This has resulted in two spin-off projects- one on the use of hydrogen plasma in metal production and one to study electrolysis in manganese production.

www.sintef.no/reducedco2

Key figures	
Project owner	SINTEF
Project manager	Eli Ringdalen
Duration	2018 - 2022
Budget	27 MNOK
Partners	Elkem, Eramet, Wacker, Finnfjord, SINTEF, NTNU and TiZir

PAHssion - Industrial efforts towards zero-emissions of PAH

In PAHssion, the industry joins forces with the R&D partners to develop new and improved methods for PAH emission detection, quantification, and prediction.

New methods for PAH emission monitoring and for testing new raw materials will result in new services offered on the market and improved guidance capability of laboratory subcontractors to the industry. It will also improve assessment of environmental footprints and limit associated costs for the industrial companies. Additionally, it will aid companies in selecting materials and design processes on the basis of anticipated emission behaviour. In total, this will create value in terms of new and improved measurement services, raw material selection, abatements methods, operational savings and new best practice guidelines. But most importantly, it will ensure that the industrial consortium partners can continue to operate in Norway.

www.sintef.no/pahssion

Key figures	
Project owner:	Elkem ASA
Project manager:	Ida Kero, SINTEF
Duration:	2019 - 2022
Budget:	20 MNOK
Partners:	Elkem, Eramet, Wacker, Finnfjord, SINTEF, NTNU, Ferroglobe, Tizir, Eyde, Washington Mills, Norce, Fiven and SINTEF Norlab

Electrical Conditions in Submerged Arc Furnaces - Identification and Improvements (SAFECI)

The project aims at establishing the basis for substantially reduced energy consumption. We believe that the total potential is in the range of 5-10 % of the energy consumption, where one per cent reduction for our partners corresponds to an annual saving of some 70 GWh.

The project intends to provide substantial new information on inner furnace conditions and how they can be measured/detected. The combination of physical and data-driven models will pave the way towards future digital twins. If successful, the project will supply a breakthrough within metallurgy, that will enable early detection of deviation from good operating conditions and ensure safe transfer back to suitable operation. Potentially, the project may also lead to improved knowledge-based guidelines for future furnace design.

Key figures	
Project owner:	NORCE
Project manager:	Manuel Sparta
Duration:	2021 - 2025
Budget:	19.1 MNOK
Partners:	Elkem, Eramet, Wacker, Finnfjord and NTNU

Recursive - Reduced energy consumption by increased reduction volume

Recursive will contribute with the knowledge needed to reduce energy consumption and CO_2 emission pr tonne of alloy from production of Si, Si- and Mn-alloys.

The main objective in Recursive is to increase the yield of valuable elements and to minimise consumption of energy and carbon by reactions that are not desired.

Topics for the project are:

- Conditions responsible for slag accumulation
- The slag properties going from primary slag to tap slag
- The effect on condensed materials in the low temperature zones
- The main conditions resulting in bad tapping
- The effect of softening, melting and dissolution of quartz
- The formation conditions and properties of carbide banks

Photo: Elkem

Key figures	
Project owner	NTNU
Project manager	Merete Tangstad
Duration	2021 - 2025
Budget	19.7 MNOK
Partners	Elkem, Eramet, Wacker, Finnfjord, SINTEF, NTNU and SINTEF

FME HighEFF

Centre for Environment-friendly Energy Research

HighEFF has defined ambitious goals for development and demonstration of technologies that may improve energy efficiency and reduce emissions from industry.

Improved industrial energy efficiency can be achieved by improving the core industrial processes, as well as by capturing and harnessing waste heat and other surplus energy streams, either within the individual industry, or in nearby buildings or industries. In cases where the heat cannot be utilised directly, this may be done by upgrading the heat to a higher temperature level by use of heat pumps or by converting the heat to power. These are tasks that are addressed in FME HighEFF-Centre for an Energy Efficient and Competitive Industry for the Future.

Large amounts of surplus energy are wasted in industry, mainly in the form of heat. Inefficient processes result in losses in the form of heat or other surplus energy streams. The amount of annually produced waste heat is as high as the total heating demand in Europe! The heat may however not be available at a high enough temperature level for utilisation, and often there are no potential users near the plant. In this context, conversion, energy storage and development of industry clusters are important elements to obtain optimal utilisation of the energy.

Energy efficiency measures are to be considered as necessary and enabling for a transition to a low emission society, as presented by the IEA projections to meet the 2-degree target put forward in the Paris agreement. A kWh not used does not have to be produced.

Measures to reduce the energy consumption and emissions from the industry are often less costly than alternative measures. Energy efficiency measures will thus be very important for an optimal transition from a social economic and environmental perspective, and in order to maintain and increase value creation in society.

www.sintef.no/higheff

Photo: SINTEF

Key figures	
Project owner	SINTEF Energy
Project manager	Petter E. Røkke
Duration	2016 - 2024
Budget	400 MNOK
Partners	41 partners including FFF companies, NTNU and SINTEF

SFI Metal Production

Centre for Research-based Innovations

Vision: Resource efficient metal production from a clean industry.

Primary objective:

- To strengthen the innovation potential of one of Norway's largest land-based Industries
- To give the industry access to world class fundamental competence and candidates
- To create a collaboration platform for the metal producing industry, academia and research communitis in Norway

Examples of Research areas:

- Modelling metallurgical processes
- Investigate chemical reactions of sub-processes and their effects on surroundings and operation
- Refining and recycling of metals
- Energy- and waste recovery
- Emissions and measurements
- Mass Flow Analysis (MFA)

www.ntnu.edu/metpro

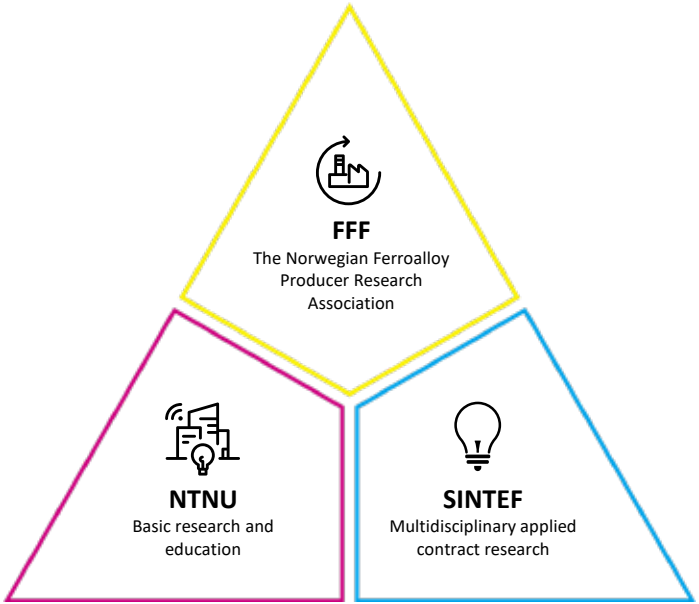
Photo: NTNU

Key figures	
Project owner	NTNU
Project manager	Aud N. Wærnes
Duration	2015 - 2023
Budget	250 MNOK
Partners	SINTEF, NORCE, Hydro, Alcoa, FFF, Eramet, Finnfjord, Elkem, Wacker, Tizir, GE

COOPERATION

Photo: Berit Fossum / SINTEF

Close working relationships between FFF, NTNU and SINTEF generate innovation and high quality research



Important partners

The Research Council of Norway

www.forskningsradet.no

The Research Council works to promote research and innovation of high quality and relevance and to generate knowledge in priority areas to enable Norway to deal with key challenges to society and the business sector. RCN is co-funding most of FFFs research projects.

Norsk Industri

www.norskindustri.no

The Federation of Norwegian Industries works for framing conditions for businesses in sectors and industries. The most important task is to ensure that society understands how important a viable industry is for our future welfare. A representative is an observer in the FFF board.

BELLONA

www.bellona.no

An independent non-profit organisation that aims to meet and fight the climate challenges, by identifying and implementing sustainable environmental solutions.
FFF and Bellona work with long-term and key challenges between the process industry and society, climate and environment, and aim to seek technological solutions, develop tools and influence framework conditions that provide reduced emissions, increased energy efficiency, more efficient utilization of resource and a future-oriented, sustainable ferro-alloy industry.

INFACON XVI
27-29 September 2021, Norway

www.infacon16.com

INFACON - the International Congress on Ferroalloys - the intention is to stimulate technical interchange on all aspects of ferroalloy production. INFACON contributes to the exchange of research and development covering the major and most of the minor ferroalloys. INFACON was arranged in Trondheim in 1995 and 2021.

Organization

Ferrolegeringsindustrien
Forskningsforening

www.ferroforsk.com

FFF is run by a board consisting of nine members, eight of whom are appointed by the member companies and one by SINTEF Industry which manages FFF. The Research Council of Norway and Norsk Industri are represented by observers at board meetings.

- FFF was established in 1989
- Key figures research: Budget 2021 – 4 mill € (incl. other industry partners)
- Total for the period 2000- 2021, approx. 45 mill €

Dog-house – Improvement of the internal environment

Members of the board:

- Erlend Olsen, Chairman, Finnfjord AS
- Birger Andresen, Deputy Chairman, Wacker Chemicals Norway
- Viktor Myrvågnes, Elkem ASA
- Halvard Tveit, Elkem ASA
- Aasgeir Valderhaug, Elkem ASA
- Paul Calvert, Eramet Norway AS
- Sten Yngve Larsen, Eramet Norway AS
- Benjamin Ravary, Eramet Norway AS
- Merete Tangstad, NTNU and SINTEF

Observers:

- Oddvar Gorset, The Research Council of Norway
- Sverre A. Høstmark, The Federation of Norwegian Industries

Administration:

- Aud Nina Wærnes, Coordinator, SINTEF
- Berit Fossum, Administrator, SINTEF

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Ferrolegeringsindustrien
Forskningsforening

www.ferroforsk.com

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