Kompetanse om diffuse utslipp fra metallurgisk industri, erfaring fra FFF-prosjekter

Prof. Gabriella Tranell

Diffuse Utslipp, seminar NHO, 19-20 Mars 2019

Elkem Salten

FFF-The Norwegian Ferroalloy Producers Research Association

- **Formed in 1989**
- **Annual Budget – 4 mill € (incl. other industry partners). Total for the period 2000 - 2018, appr. 50 mill €**
- **More than 65 PhD candidates educated over the last 30 years**
- **Pre-competitive research, development and standard setting**

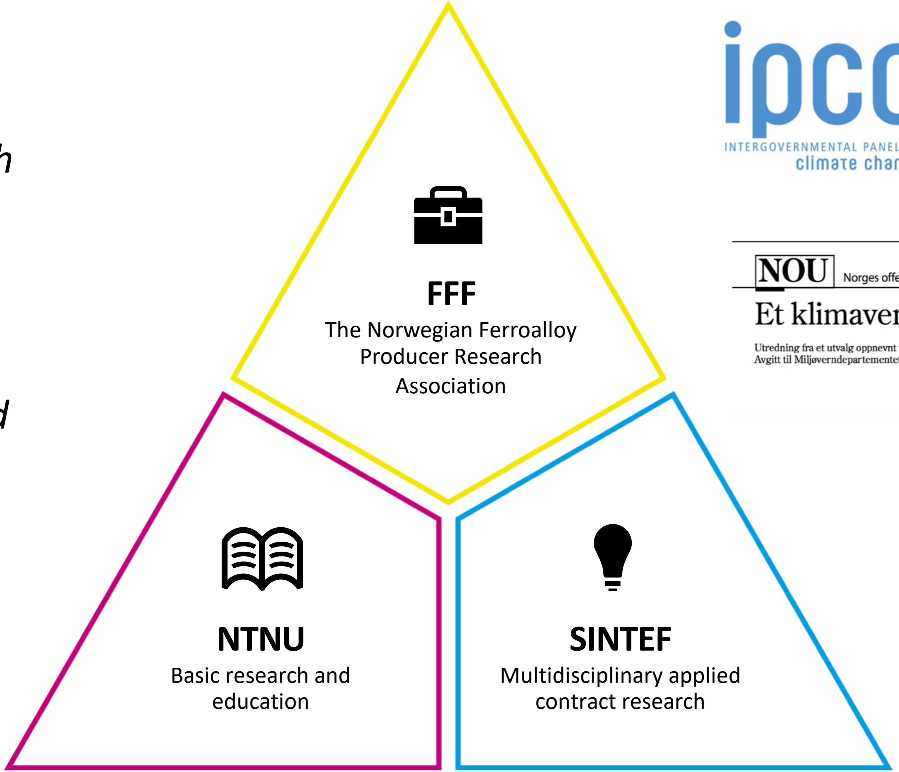
Largest area of cooperation – environmental issues

Members of FFF	**Board members**
Eramet Norway AS	Leif Hunsbedt **Benjamin Ravary** (Chair)
Elkem As	Aasgeir Valderhaug Edin Myrhaug
Wacker Chemicals Norway	Randi Chapana
Finnfjord AS	Erlend Olsen
NTNU/SINTEF	Leiv Kolbeinsen
Observers The Research Council of Norway The federation of Norwegian Industries	 Tor Einar Johnsen/ Sverre A. Høstmark/
Coordinator	Aud Wærnes

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

"The Norwegian industry's unique openness with regard to sharing of benefits around especially safety and environmental research outputs is worth noting as it elevates the socio-economic impact of the research conducted by the Centre. This unique characteristic adds to the value proposition of the Centre. The value-add to Norway (and the rest of the world) from this institutionalised open-access principle is highly commendable"

Quote from SFI Metal Productions international evaluation panel report, March 2019



NOU Norges offentlige utredninger 2006: 18

Et klimavennlig Norge

Utredning fra et utvalg oppnevnt ved kongelig resolusjon 11. mars 2005.
Avgitt til Miljøverndepartementet 4. oktober 2006

My main message:

It takes long-term commitment, investment and collaboration/critical mass to become international leaders. FFF has provided the required support!

A history of focus on fugitive emissions!

SFI Metal Production 2015-2023++

- **1997** — FFF initiated research projects "Environment and processes, I and II
- **2003- 2006** — Environment and processes III
- **2007 -2013** — ROMA
- **2008-2012** — FUME
- **2013-2017** — SCORE
- **2015-2018** — DeMaskUs
- **2019-2022** — PAHssion

The NO_x story – an example of long term research rewards

Common challenge of NO_x emissions from FeSi/Si production -
solved after 18 years of cooperation

Not a gas-cleaning project, but a technological innovation that reduces NOx formation.

1997 FFF initiated research projects "Environment and processes, I and II

2003 Environment and processes III

2009 -2012 Models-PhD-Pilot testing

2013 Furnace Measurements -benchmark- data models- design Presentation at Infacon XIII

2015 Technology implemented at Elkem Salten. A reduction of 40% in NOx is the result of 18 years of work by FFF.

2017 The Elkem Innovation Award in 2017.

35 reports/publications from FFF 1995-2012

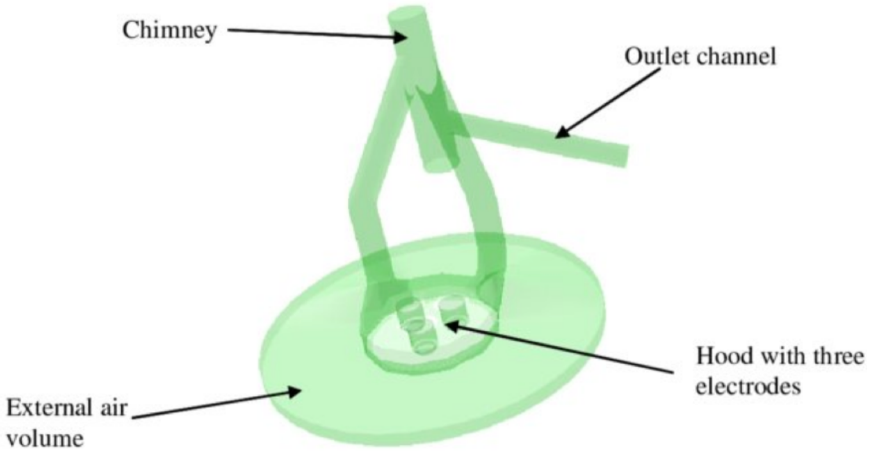
Environment and Processes I-III

Tabell 1: Målekampanjer i regi av FFF i perioden 1995-2010

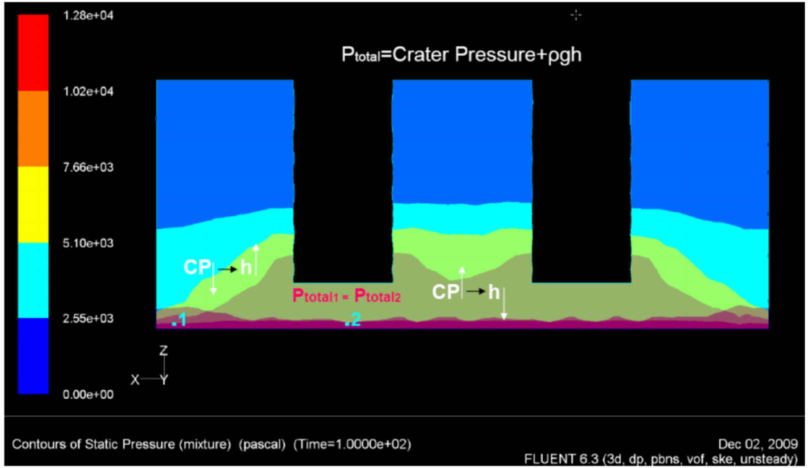
Nr	Dato målt	Smelteverk	Ovn(er) målt	Produkt&chargemåte	Målinger utfort av
1	1995-09-27	Rana Metall	Ovn 5&6	FeSi75: Batch**	Veritas
2	1995-11-02	Elkem Fiskå	Ovn 9+10+11+12	Si-met: Batch	Veritas
3	1996-06-27	Elkem Thamshavn	Ovn 2	FeSi75: Batch	SINTEF
4	1997-09-18	Elkem Thamshavn	Ovn 2	FeSi75 Dryss*	SINTEF
5	1997-10-28	Holla Metall	Ovn 4	FeSi65 Batch	SINTEF
6	1999-09-22	Elkem Thamshavn	Ovn 2	FeSi75 Dryss	SINTEF
7	1999-09-23	Elkem Thamshavn	Ovn 2	FeSi75 Dryss & høy temp	SINTEF
8	2000-12-14	Elkem Thamshavn	Ovn 2	FeSi75 Dryss	Kjelforeningen
9	2000-12-14	Elkem Thamshavn	Ovn 1	Si Batch&dryss	Kjelforeningen
10	2002-11-13	Elkem Thamshavn	Ovn 1	Si Batch&dryss	SINTEF
11	2002-11-13	Elkem Thamshavn	Ovn 1	Si Dryss	SINTEF
12	2003-02-13	Holla Metall	Ovn 4	Si Batch	SINTEF
13	2003-02-17	Elkem Thamshavn	Ovn 1	Si Dryss	Elkem
14	2003-11-04	Holla Metall	Ovn 4	Si Dryss	SINTEF
15	2003-12-05	Elkem Thamshavn	Ovn 1	Si Dryss	SINTEF
16	2004/2005	Finnfjord	Ovn 2	FeSi75 Dryss (auto)	SINTEF
17	2005-03-09	Elkem Thamshavn	Ovn 2	FeSi75 Dryss	SINTEF
18	2007-04-28	Elkem Thamshavn	Ovn 1 og 2	Si Dryss	TÜV
19	2009-04-28	Salten Verk	Ovn 3	Si Batch	SINTEF
20	2010-04-21	Salten Verk	Ovn 1	Si Batch	SINTEF

These projects marked the start of focus on NO_x measurements!

The beginnings of modelling gas and dust flows, CFD



Ravary, Colomb and Joghansen, Infacon, 2007

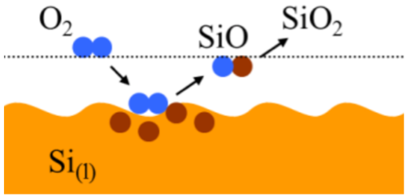


PhD Thesis M. Kadkhodabeigi, NTNU, 2011

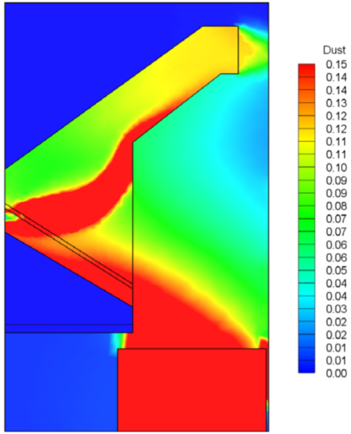
Modelling extraction hoods, NO_x and furnace gases!

FUME, KPN BIA, 2008-2013

- Fundamental studies
- Modelling and design
- Measurement campaigns



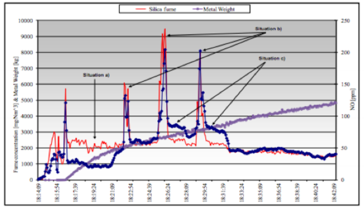
M. Næss, PhD Thesis NTNU, 2012

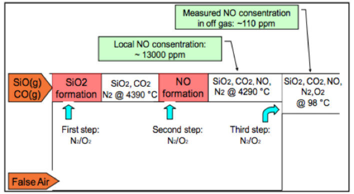


Fardal & Kadkhodabeigi, SINTEF Report F18726, 2011

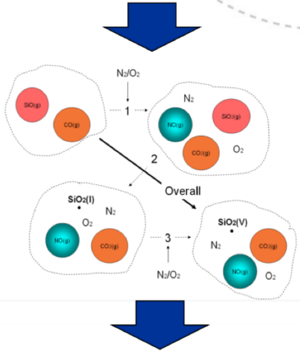
Grådahl, FUME project seminar 2013

Fundamental understanding of NO_x formation and coupling to fuming/ SiO

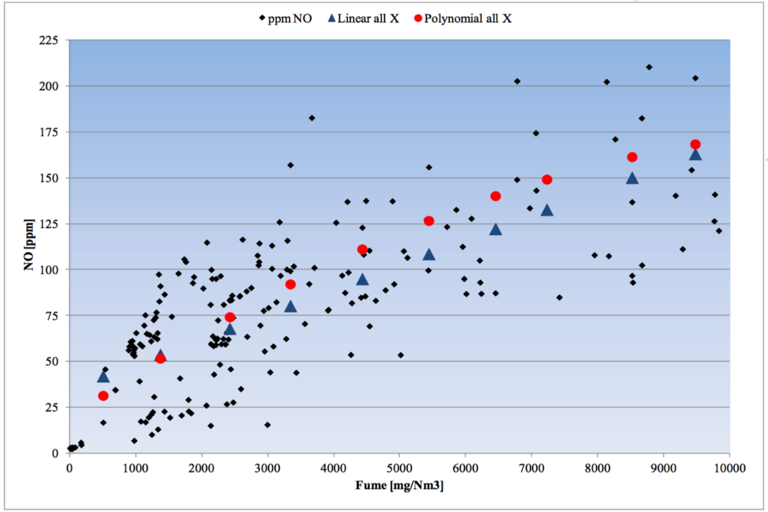




Tid/temp NO dannelse



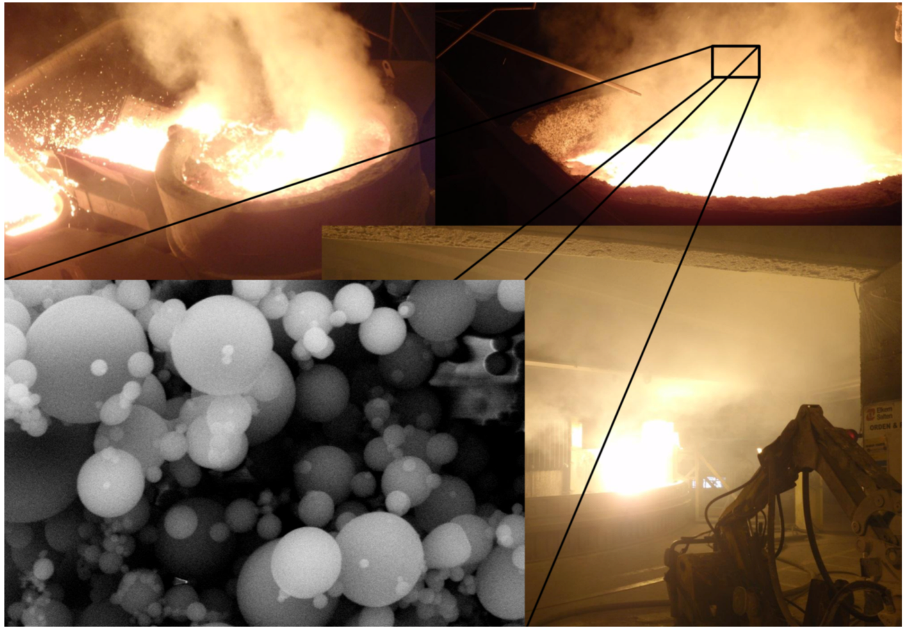
Tid partikkelvekst

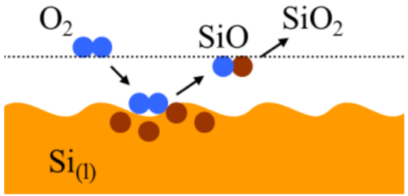


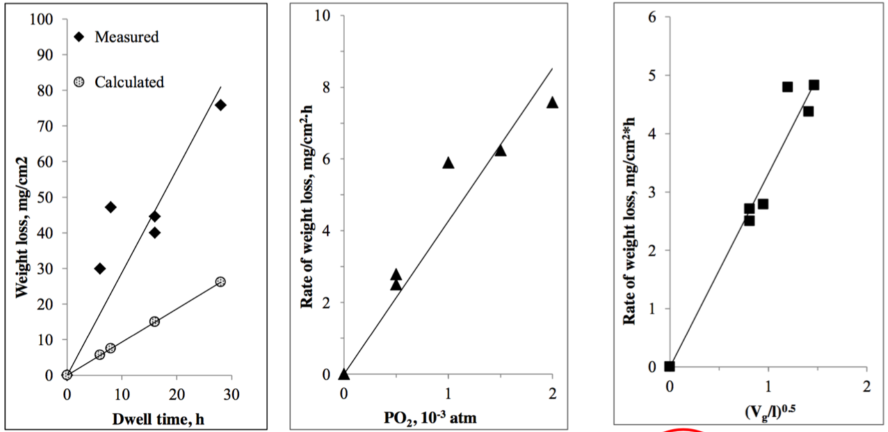
NTNU

N. E. Kamfjord, PhD Thesis, NTNU 2012

Understanding fuming/ oxidation from Si melt exposure







$$J_i = \frac{k_i}{RT} \cdot \Delta p_i \rightarrow k_i = 0.664 \left(\frac{D_i^4}{\nu_i} \right)^{\frac{1}{6}} \cdot \left(\frac{v_g}{l} \right)^{\frac{1}{2}}$$

12

M. Næss, PhD Thesis
NTNU, 2012

Fuming rate controlled by diffusion of oxygen to the Si surface

A large set of dust measurement campaigns

Measurements campaigns in the FUME project

- **Eramet Kvinesdal: Gas composition at tapping, slag duct, mud pit, electrode welding.***
- **Eramet Sauda: Hall wind, hood design, slag duct, tapping area, roof exhaust. *****
- **Eramet Porsgrunn** (ProMiljø)**
- **Tinfos Kvinesdal* (ProMiljø)**

- **Elkem Salten: Offgas,Tapping- & casting areas, hall wind, hood design, refining.*******
- **Elkem Thamshavn: Tapping area + hood design.****
- **FeSil & Glencore, Mo-i-Rana: Tapping- and refining area, Roof exhaust.*****
- **Wacker Holla: Preliminary assessment.***

*Internal report
*Published article
*Conference

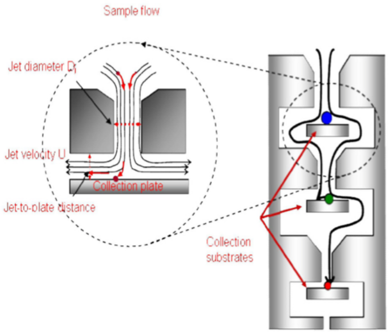
Measurement campaign instruments

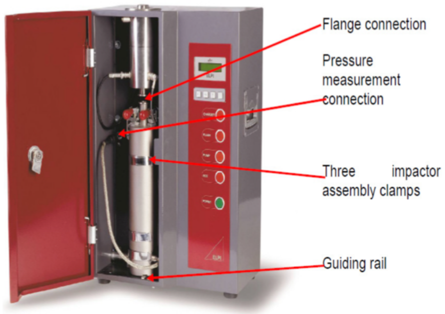
- Laser Dust monitors (Norsk Elektro Optikk, Sick)
- DustTrak (TSI)
- Gravimetric filters (MOLAB)
- Electric Low Pressure Impactor (Dekati)
- Thermometers, Thermocamera
- Wind velocimeters,
- Smoke «bombs»
- FTIR, OpenPath FTIR, GC-MS etc.

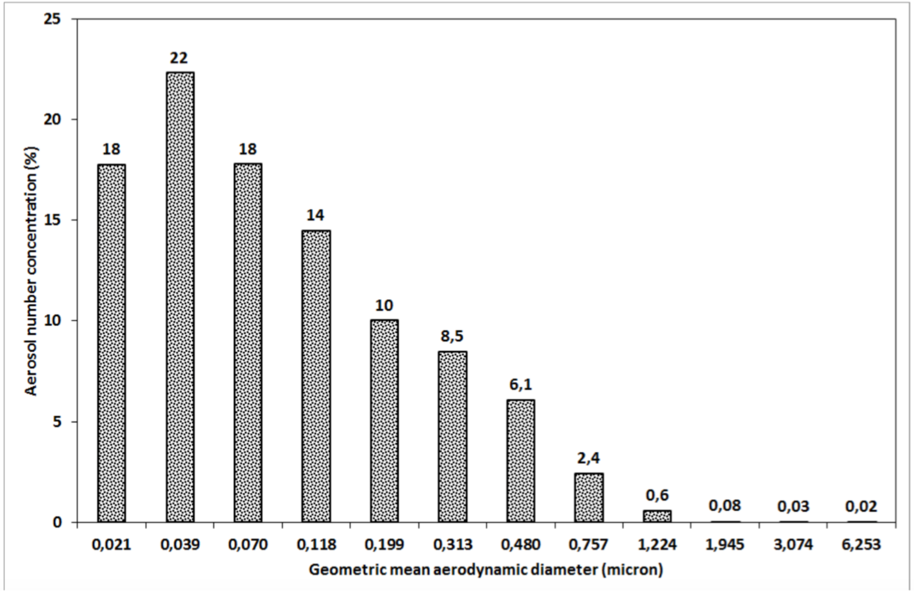



First time use of the ELPI to quantify particle size distributions in dust from ferroalloy production

- 7 nm-10 µm measuring range in 12 steps, 2-3 sec response time
- Gravimetric and chemical analysis possible after measurement
- High dust concentrations allowed due to extra diluters and cyclone
- Electrostatic measuring principle

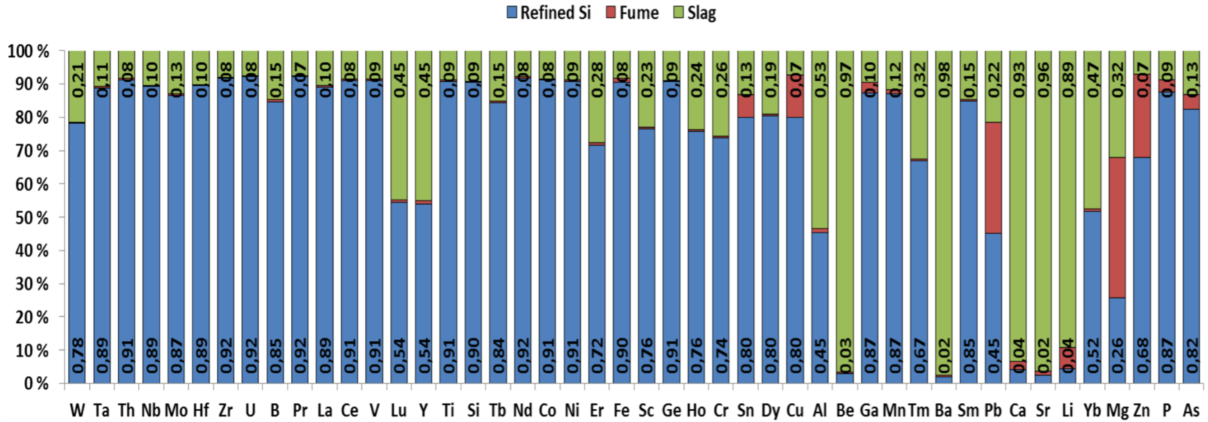


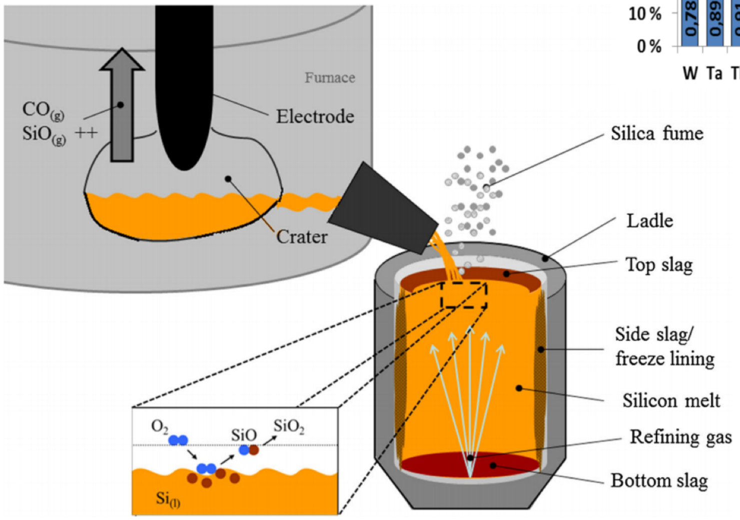




Kero, Næss, Tranell, J Occup Environ Hyg. 2015;12(1):37-44. doi: 10.1080/15459624.2014.935783

Understanding the distribution of elements to dust from fuming processes

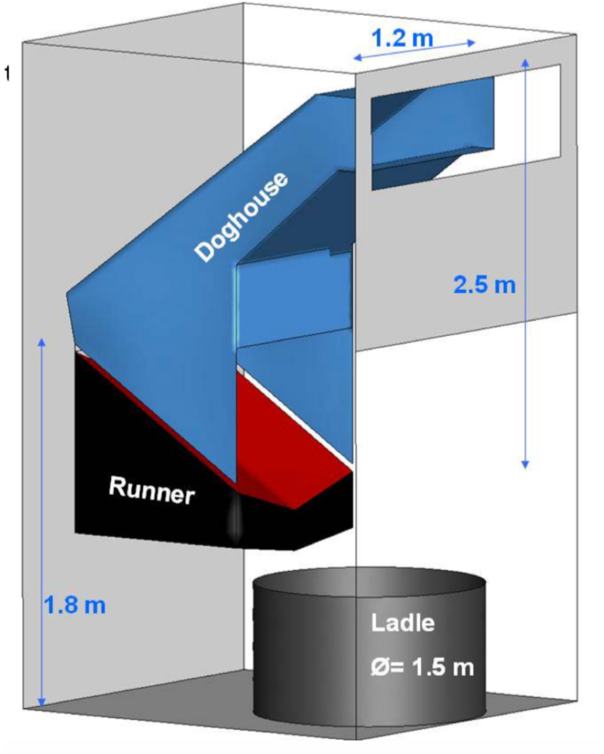


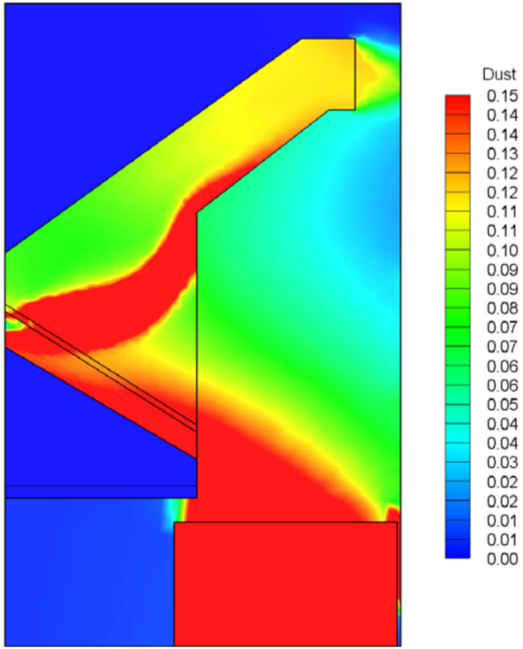


Follow-up of work done by Myrhaug and Tveit for the Si furnace in 2000.

Næss, Kero, Tranell, JOM (2014) 66: 2343.
https://doi.org/10.1007/s11837-013-0797-7

CFD tools extensively used for design of the new «doghouse» for extraction of tapping gases

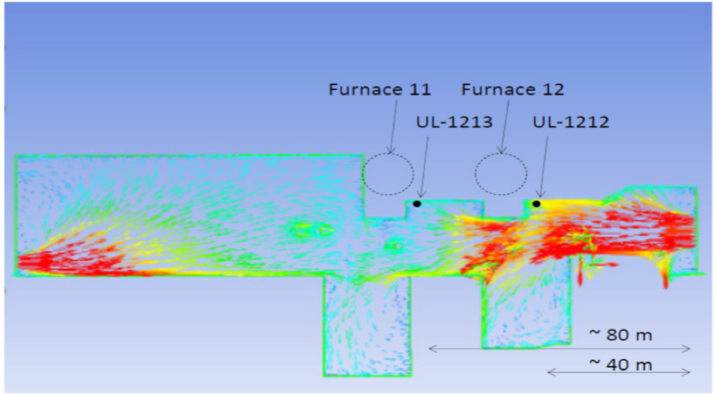




Fardal & Kadkhodabeigi, SINTEF Report F18726, 2011

Initiation of work on hall wind measurements and modelling

- Measurement of velocity, temperature and dust dispersion profile in industrial buildings
- Implement building with emission sources (dust, temperature, etc) in FLUENT
- Design measures:
  - Smart ventilation
  - Smart hood and duct design
  - Smart building design



Panjwani and Olsen, FUME Seminar 2011

DeMaskUs, Nano2021, 2015-2018

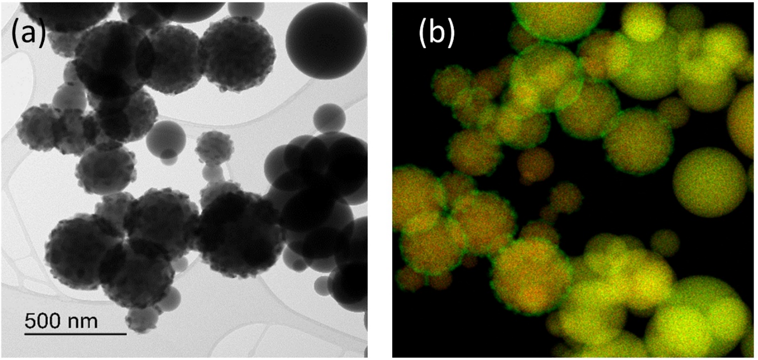
DeMaskUs Objectives

Establish cutting-edge Norwegian competence on the generation of, protection against and effects of ultrafine dust emissions in industry.

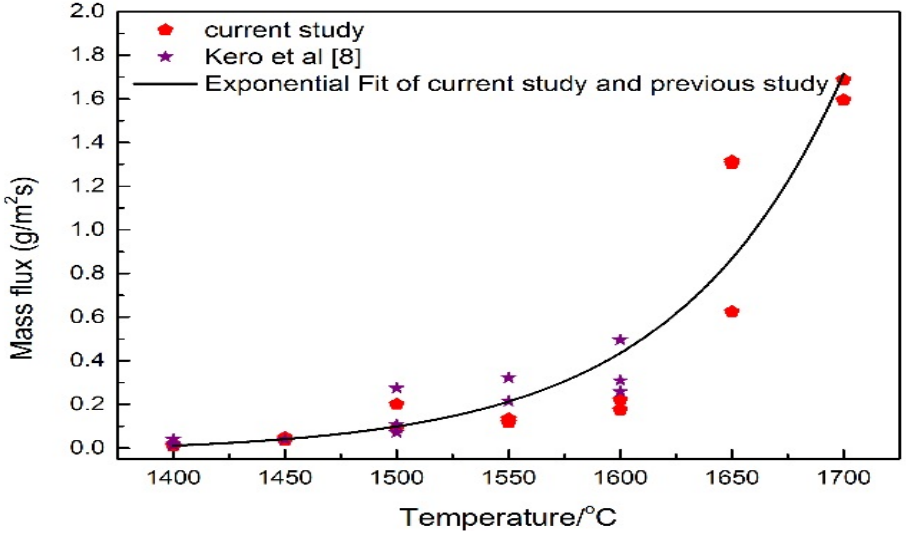
- ✓ Establishing cross scientific network of researchers, engineers, etc.
- ✓ Understanding how ultrafine particles form from Si, FeSi, SiMn, FeMn & SiC production and processing
- ✓ Optimising protection and strategies for use of personal respiratory protection
- ✓ Understanding health effects (through in vitro cell cultures) of relevant dust types

Dust formation and rates

The fume from silicon- and manganese alloys is formed in very different ways.



Ma, PhD Thesis NTNU, 2018



In general, there is more fuming at high temperatures. The graph shows that the fuming rate for a SiMn melt increases exponentially (very fast!) with temperature.

Can we reduce fuming with watersprays?

Gates et al, Infacon 2018
Ma, PhD Thesis NTNU, 2018

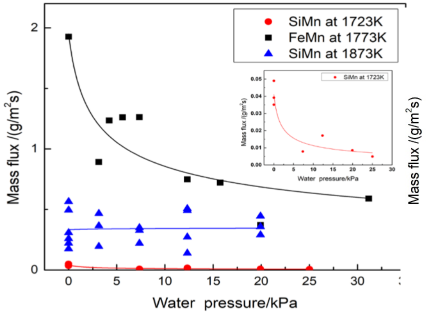
- For FeMn, YES.

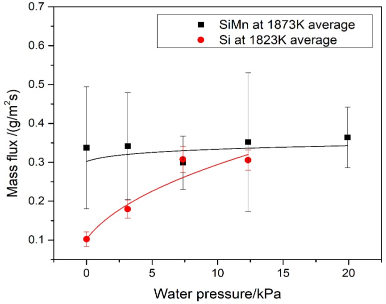
Moisture reduces fuming and increases agglomeration of the particles.

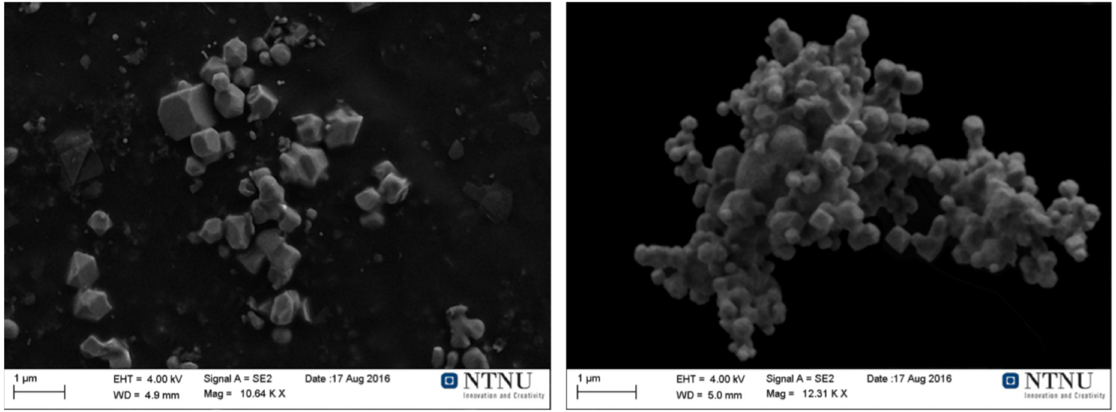
- For Si, NO.

Moisture actually increases fuming but the particles are not otherwise altered.

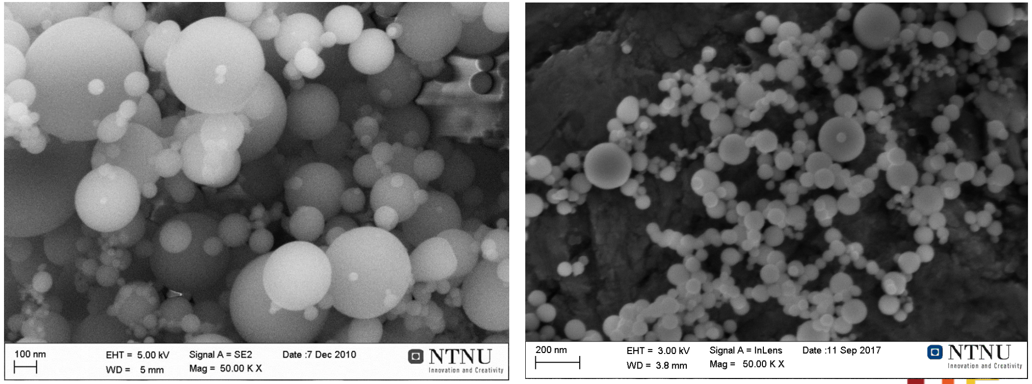
- For SiMn, the answer depends on temperature…







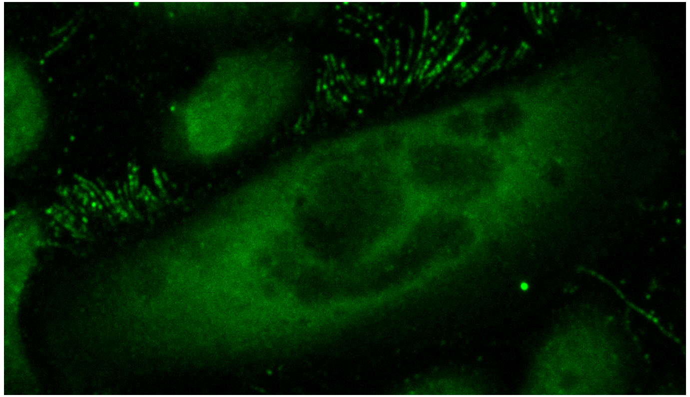
Dust from a ferromanganese melt with dry vs. humid air.



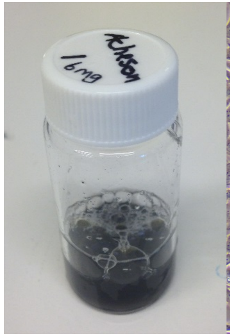
Dust from a silicon melt with dry vs. humid air.

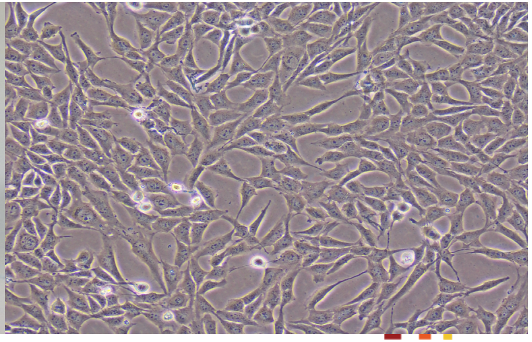
The effect of PM on Astrocytes In-Vitro

- Industrial Acheson SiC PM is not very toxic to astrocytes and very high doses are necessary to see any effects on the cells
- Laboratory SiMn and Si PM only have significant effects at high doses
- Crystalline SiO_2 powders have a much larger effect on the cells than the amorphous SiO_2 dust



Cells with dust particles under fluorescent light





- Arnoldussen et al. 2017 Neurotoxicology
- Arnoldussen et al. 2018 IJMS
- Arnoldussen et al. 2019 IJMS

Do the RPE´s used in Norwegian smelters fit the workers?

RPE fit was tested with a TSI Portacount pro, measuring leakage between face and mask.

Counts particles inside and outside of the respirator.

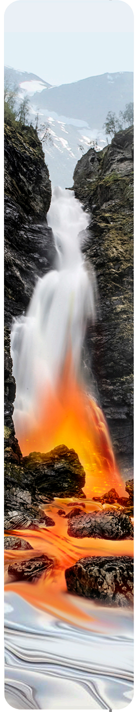
Picture: http://beautysouthafrica.com/hair-and-nails/sexy-summer-hair-for-men?fbclid=IwAR2Co30WETZl0BAIi1Af1Xkr_-auhbzO3llPKaaJ8-eYTt_g5uGBf2ZYFwM

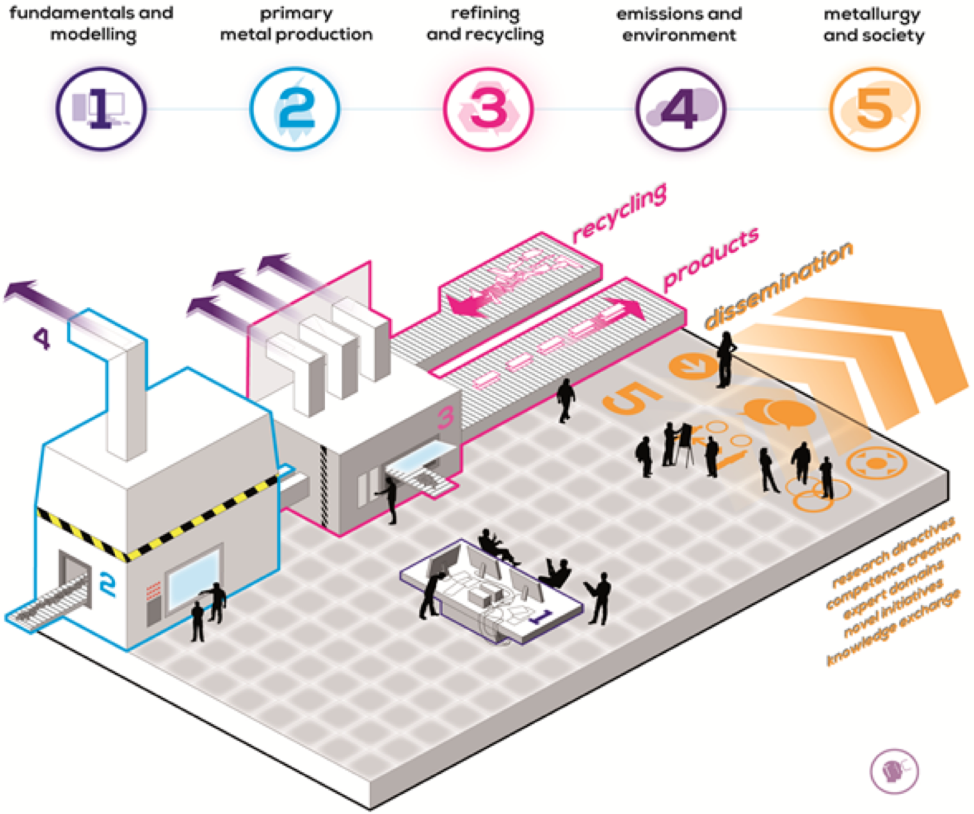
14 RPE models (filtering half-face masks), 4 smelters, 127 workers, 701 tests.
Main findings[1]:

1. 37% did not pass the test with the RPE they normally used
2. Talking and large movements often cause leakage
3. Pass-rate for the tested disposable RPE models varied between 19-87%.

Føreland et al. (Submitted to Safety and Health at Work)

metal production





SFI Metal Production

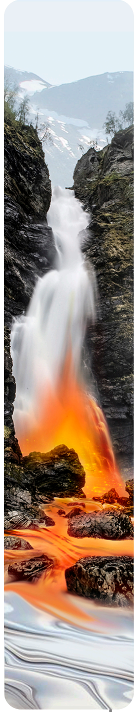
2015-2023

metal production

RD4

PAHssion etc *Associated Projects*

Topic area emissions: Fume/Dust, PAH, Scales



Academia

- Industrial campaigns
- Modelling
- Laboratory experiments
- Workshops
- PhD, PD, MSc, Researchers

Government NGO´s

- Workshops
- Standarisation/ Measurements
- Reporting

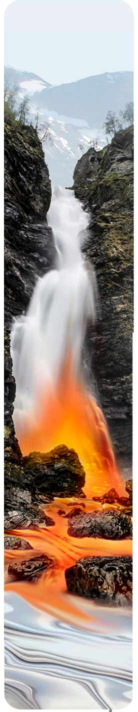
Industry

- Industrial campaigns
- Workshops
- Industry researchers
- Reference groups PhD students

metal production

Review articles – Si/FeSi, SiMn/FeMn and Al Production

Summarising state of the art in industrial emissions



JOM, Vol. 69, No. 2, 2017
DOI: 10.1007/s11837-016-2149-x

Airborne Emissions from Si/FeSi Production

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The management of airborne emissions from silicon and ferrosilicon production is, in many ways, similar to the management of airborne emissions from other metallurgical industries, but certain challenges are highly branch-specific, for example the dust types generated and the management of NO_X emissions by furnace design and operation. A major difficulty in the mission to reduce emissions is that information about emission types and sources as well as abatement and measurement methods is often scarce, incomplete and scattered. The sheer diversity and complexity of the subject presents a hurdle, especially for new professionals in the field. This article focuses on the airborne emissions from Si and FeSi production, including greenhouse gases, nitrogen oxides, airborne particulate matter also known as dust, polyaromatic hydrocarbons and heavy metals. The aim is to summarize current knowledge in a state-of-the-art overview intended to introduce fresh industry engineers and academic researchers to the technological aspects relevant to the reduction of airborne emissions.

JOM, Vol. 71, No. 1, 2019
https://doi.org/10.1007/s11837-018-3165-9

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ELECTRIC ARC SMELTING

Airborne Emissions from Mn Ferroalloy Production

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e emissions from metal production represent a health, safety, and
mental challenge to which more and more attention is being directed.
ies worldwide, as well as authorities and others, are resolute in their
imiting, reducing, and ultimately eliminating these emissions. Many
can be learned by sharing information between industrial branches, as
ndustries face similar challenges. Certain challenges are, however,
ranch specific. For the Mn ferroalloy industry, such examples include
s of dust generated in the primary processes and the management of
ic aromatic hydrocarbons (PAHs) and mercury with respect to furnace
nd operation. This article covers airborne emissions from manganese
y production, including greenhouse gases, nitrogen oxides (NO_x),
s gases, PAH, airborne particulate matter, and trace elements,
g mercury and other heavy metals. The aim is to summarize current
lge in a state-of-the-art overview intended to introduce fresh industry
rs and academic researchers to the technological aspects relevant to
n of airborne emissions.

JOM
https://doi.org/10.1007/s11837-019-03370-6

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ALUMINUM: RECYCLING AND ENVIRONMENTAL FOOTPRINT

Aluminium Primary Production Off-Gas Composition and Emissions: An Overview

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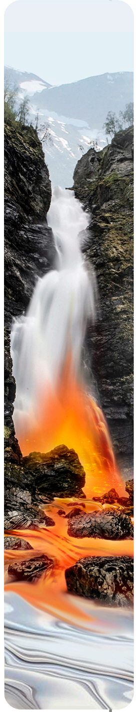
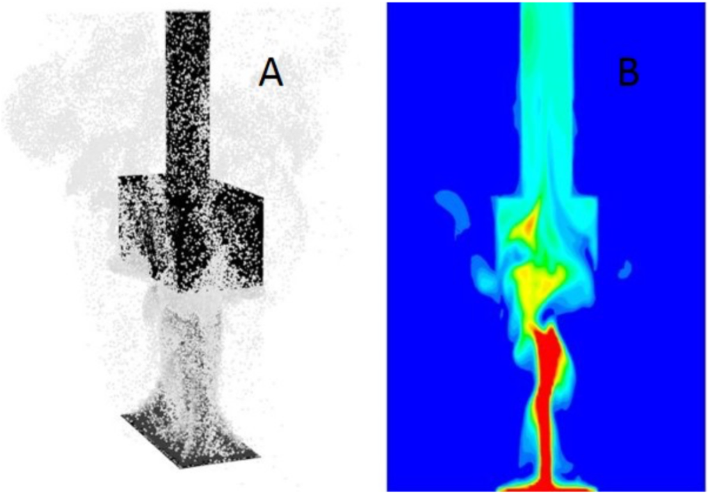
The raw gas composition from primary aluminium production depends mostly on the process technology applied and the composition of the raw materials. At steady state, a stationary condition is established among the material sources, gas production and sinks: the gas treatment centre and escaping gases. Only a few papers discuss the off-gas composition itself; most papers deal with the gas composition from laboratory-scale experiments performed under inert conditions. In this article, an overview of the literature describing gas production from aluminium electrolysis is given. Effects of temperature and chemical equilibrium on the stationary condition are also discussed. The typical chemical composition of the raw materials is presented to evaluate their input into the gas composition, especially with respect to their impurity levels.

metal production

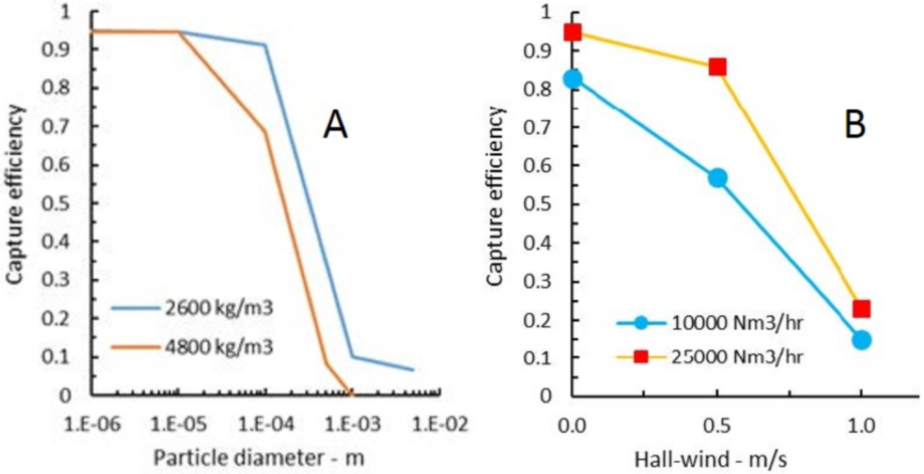
Modelling the spreading of dust

An effective tool for design of facilities and extraction equipment



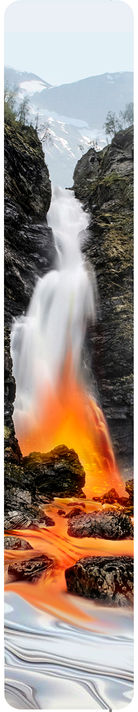


The spreading behaviour of fume from an emission point



The effect of particle density and hall wind on capturing efficiency

Panjwani and Olsen, Infacon, 2018



The sensor setup

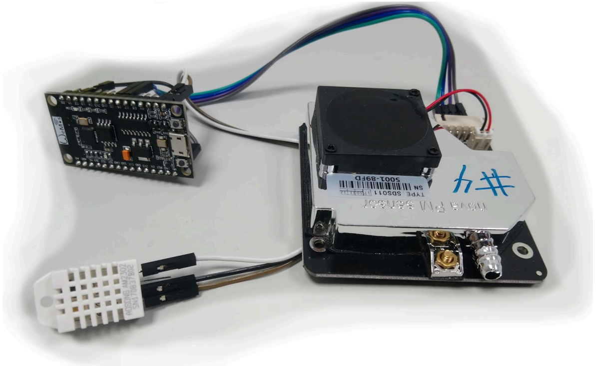
Small and cheap

- **Nova PM Sensor SDS011**
  - PM2.5 & PM10
- **DHT22 Temperature and humidity sensor**

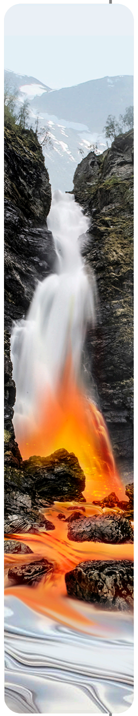
+ 500 times cheaper than FIDAS
+ Easy to place and replace
+ Multiple sensors can be used
  - Clusters for increased reliability
  - Distribution for increased coverage

+External access to data

- Limited measuring range (0-1000 ug/m3 for now..)
- Lower presicion and possible discrepancies
- Unable to handle high temperatures



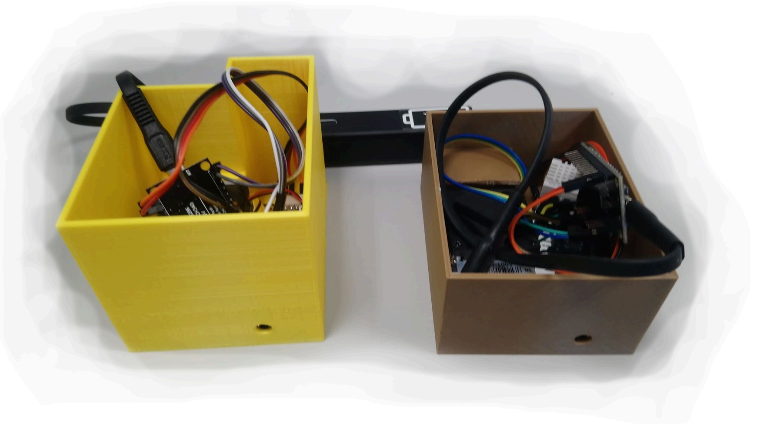
Olsen, Blogg NTNU, 2018



Industrial usage

How can we best make use of them?

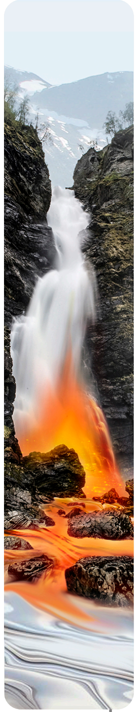
- Measure rough values
  - Red, Yellow, Green
  - The bigger picture
- Use clusters for reliability
- Perform tests to reduce dusting with constant measurements
- Monitoring the different zones over the course of the process – coupling to dust spreading models
- Where can changes have the greatest impact?



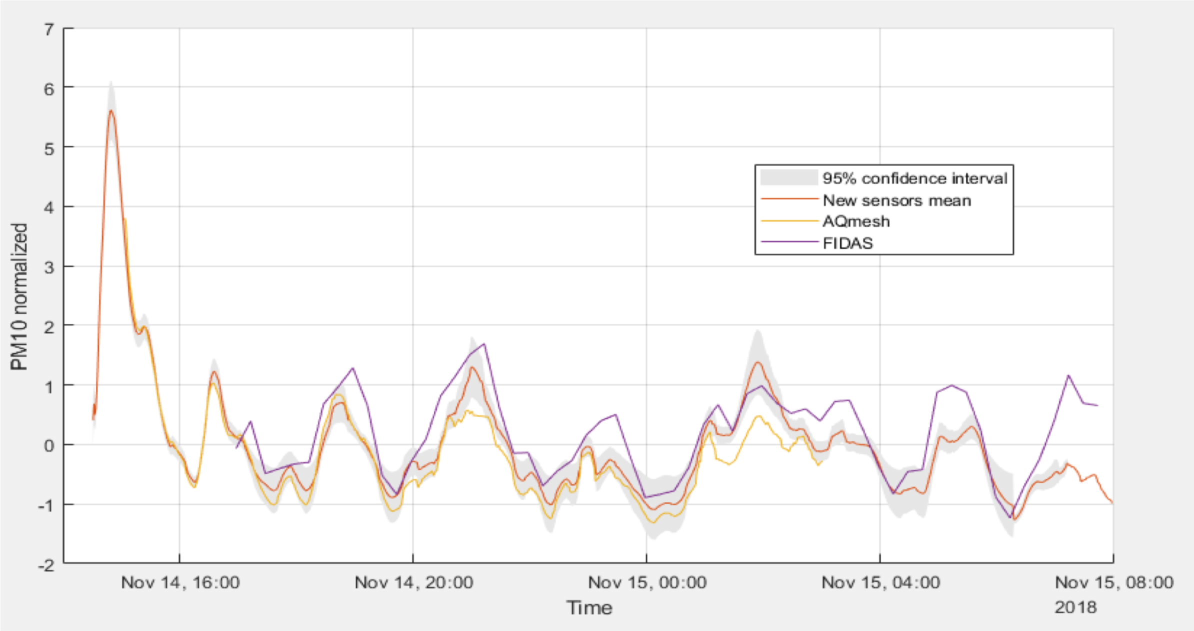
Olsen, Blogg NTNU, 2018

First testing -Kvinesdal November 2018

and the road ahead

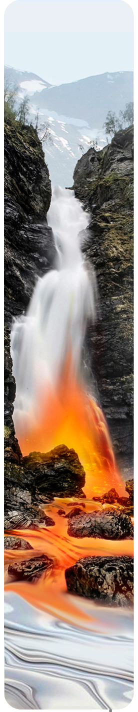


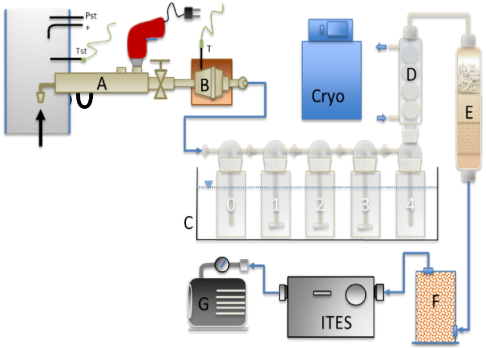
- 7 working sensors
- Measurements overnight
- Comparisons with:
    - AQmesh
    - FIDAS
- Encouraging results!
- Further long term testing and quantification of constraints

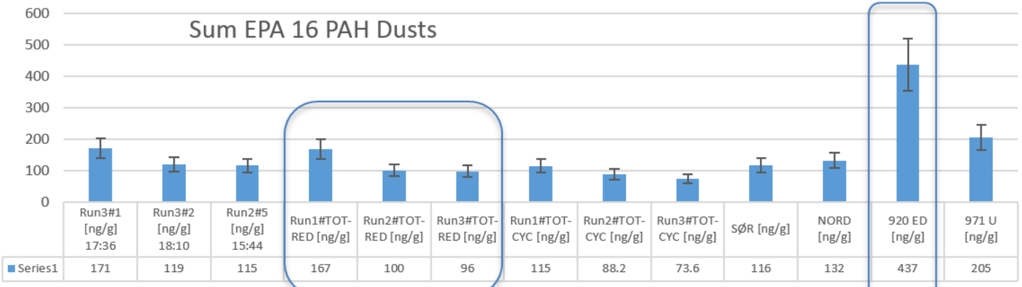


Olsen, Blogg NTNU, 2018

PAH emissions from Si Production







Component	Run3#1 [ng/g] 17:36	Run3#2 [ng/g] 18:10	Run2#5 [ng/g] 15:44	Run1#TOT-RED [ng/g]	Run2#TOT-RED [ng/g]	Run3#TOT-RED [ng/g]	Run1#TOT-CYC [ng/g]	Run2#TOT-CYC [ng/g]	Run3#TOT-CYC [ng/g]	SØR [ng/g]	920 ED [ng/g]	NORD [ng/g]	971 U [ng/g]
Sum bicyclic PAH:	45.3	35.7	33.5	72.9	27.4	33.5	45.4	28.3	29.4	46.9	54.0	43.4	53.4
Sum 3-7 ring PAH:	125	83	82	94	73	63	69	60	44	70	383	88	151
Sum Borneff 6	29.7	12.7	9.8	17.8	14.0	11.6	14.1	9.14	7.37	10.09	154.0	14.8	15.4
Sum EPA16 PAH	**171**	**119**	**115**	**167**	**100**	**96**	**115**	**88.2**	**73.6**	**116**	**437**	**132**	**205**
RSD % EPA16 PAH	16 %	16 %	17 %	19 %	17 %	16 %	17 %	17 %	18 %	18 %	13 %	17 %	17 %

ISO standard methods not suitable for measurements

Annual samples of silica give higher emission values than stable operation would grant

Gærtner et al., INFACON 2018

PAHssion (IPN BIA, 2019-2022)

Industrial efforts towards zero emission of PAH

Problems

- Large Variation & Uncertainty
- High Cost & Risk
- Knowledge Gap
- Not-Comparable Standards

→

Need:

New Methods

→

Innovations

- Better Analytical Services
- Better Material Selection
- Better Industrial Processes
- Better Emission Reports

Elkem, Eramet, Finnfjord, Wacker, Ferroglobe, St Gobain, Washington Mills, Tizir, SINTEF, NTNU, EYDE, Norce

My main message:

It takes long-term commitment, investment and collaboration/critical mass to become international leaders. FFF and the rest of the Norwegian Metallurgical Industry has provided the required support!

The Norwegian Ferroalloy Producers Research Association

www.ferroforsk.com