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MEMO

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Short overview of Norwegian silicon industry

1. Silicon plants in Norway

At the time the Norwegian smelting industries were established, their main products were very different from today's products. No industry originally started producing silicon. When the market for silicon developed, many enterprises changed to primary production of silicon.
At that time, silica fumes formed during production of ferrosilicon was considered as waste.
12 industrial facilities in Norway are currently producing silicon and silicon products. They are spread over the entire country (see map in Figure 1.). Their locations are at the coast or in the end of a fjord. The topographic conditions are quite complex in the surroundings of most of the industries. The industries are located rather close to residential areas, both in the vicinity of small villages (Ålvik) or larger towns (Kristiansand). Maps and images of each facility are given in Appendix A. In order to evaluate effects of the industries on the population, one also has to consider the topography and the main wind direction. Some of the silicon-producing industries are located in an industrial area with several more producing industries, both metallurgic industries and other industrial sectors, where the silicon-producing industry contributes to a part of the total effect on the population: e.g. Fesil Rana Metall is located in Mo industripark, Eramet Norway Porsgrunn is located at Herøya industripark, Elkem Thamshavn and Washington Mills are both located at Orkanger, Elkem Solar and several other industries are located close to each other SW of Kristiansand.
Silicon dust was originally a waste product from the production of ferrosilicon. Today's cleaning technology turned the material into a resource for regularly new areas of application, e.g. as an addition to concrete (increasing strength, prevents intrusion of chlorine and thus corrosion of concrete reinforcement), as a replacement for asbestos in building material, in cosmetics and contact lenses. Thus, microsilica became a major product.

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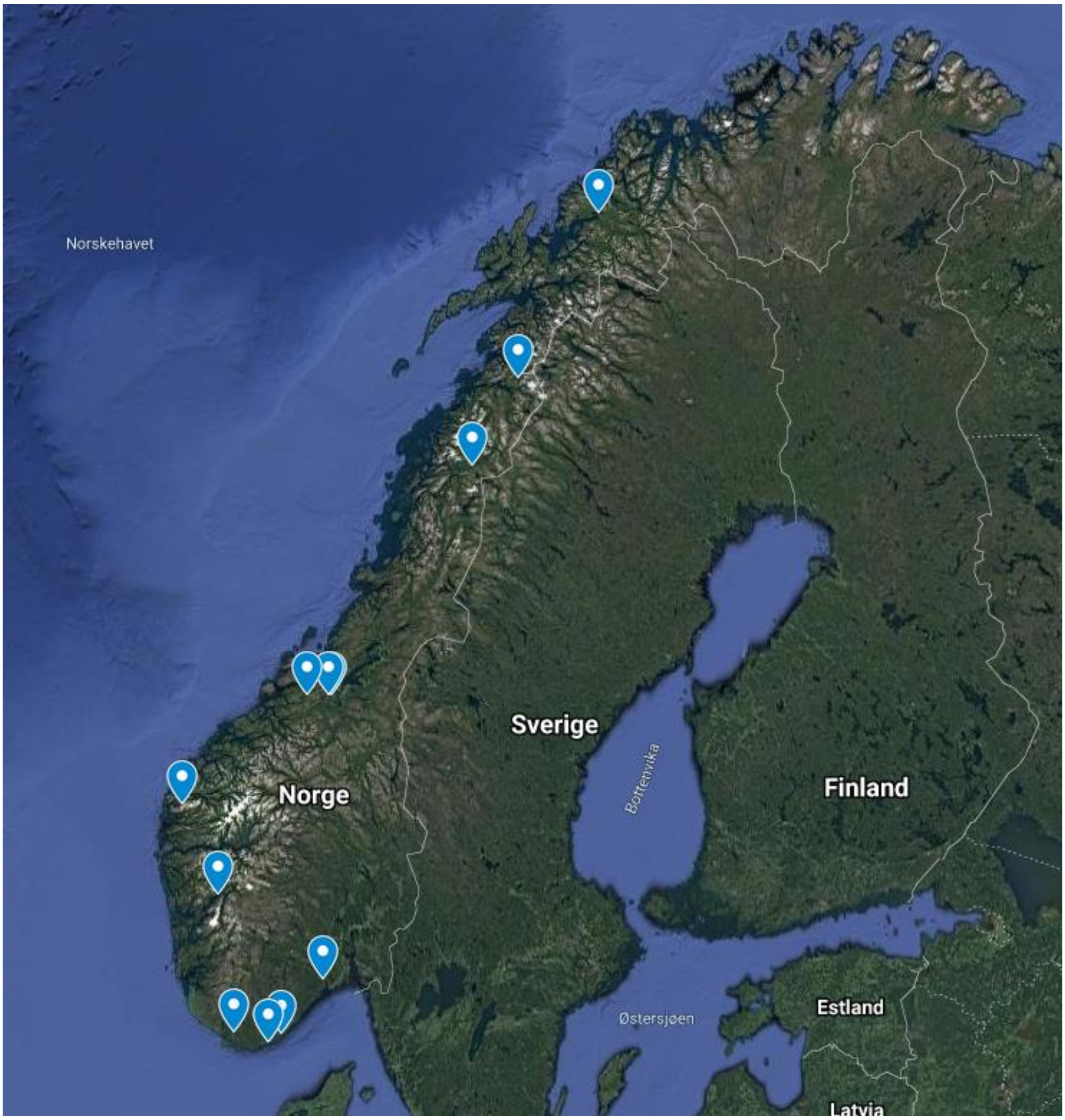

Figure 1: Geographic distribution of silicon-producing industries in Norway.

Finnfjord AS:
Finnfjord AS produces ferrosilicon (FeSi), silica and electrical power. The smelter is located in Finnfjordbotn, ca. 5 km from the town Finnsnes. The closest residential area is located ca. 900 m north of the smelter. In 1960 KS/AS Fesil Nord was established. The foundation of the ferrosilicon production is the building of the Innset power plant at Altevann in Bardu. The production of ferrosilicon started in 1962 with two furnaces, using quartz from an area close to Espejord at Dyrøya. Now, quartz from Tana is used as raw material. In 1973 the third furnace was completed. Finnfjord Smelteverk AS was established in 1983, after Fesil Nord went bankrupt in 1982. Finnfjord reopened the production units in 1983. Today, the facility produces ca. 100 000 tons ferrosilicon per year and is one of Europe's largest producers of ferrosilicon. Ferrosilicon is essential for the production of steel and several steel products. Finnfjord also produces silica, which is invaluable for modern concrete technology.

Elkem Silisium Salten verk:
Elkem Silisium Salten verk produces ferrosilicon for the European market. The smelter is located in the end of the fjord Sørfolda, close to the small locality Straumen with 900 inhabitants. Construction of the plant began in the mid-1960ies and the first electric smelting furnace came into operation in 1967. Three years later a second furnace was added and in 1972, the third and largest furnace began producing ferrosilicon. Over the years, the operation has been upgraded towards higher silicon purity. The main products from Elkem Salten are silicon with purity in the range of 96-99%, Microsilica and "SIDISTAR".

Fesil Rana Metall / Elkem Rana:
Metallurgic industry has a long history in Mo Industripark, which starts in the 19th century with iron production. In the 1980ies, it was decided to convert from iron production to the production of ferro alloys. From 1989, Rana Metall, later Fesil Rana Metall, started producing ferrosilicon in the former furnace no. 6. In 1990, also furnace no. 5 was finished and the smelter had full production with 2 furnaces. In four other furnaces, ferrochrome and other ferroalloys were produced. Fesil Rana Metall produces ferrosilicon and Microsilica and is located in Mo Industripark. The smelter consists of 2 FeSi furnaces and produces 9 grades of specialty and standard ferrosilicon with an annual capacity of 90 000 mt of FeSi and 23 000 mt of Microsilica. In 2016, Elkem AS overtook the smelter. Special products, including granulated and refined qualities, make up the bulk of the production. Mo Industripark is located just about 100 m from the closest residential area in Mo I Rana. Mo I Rana has a population of about 19 000 inhabitants.

Elkem Thamshavn:
In 1931, Orkla Mining Company established the smelter Orkla Metall (now Elkem Thamshavn) at Orkanger to produce sulphur and copper from pyrite (from Løkken verk in Trøndelag). Today, the smelter produces metallurgic silicon and Microsilica. Elkem Thamshavn is located ca. 1 km north of Orkanger along the fjord.

Washington Mills:
Washington Mills AS (before Orkla Exolon AS) is a Norwegian producer of silicon carbide. The smelter is located at Orkanger. It was established in 1962 with the owners Orkla Grube Aktiebolag, Christiania Spigerverk and The Exolon Company. Today it is owned by Washington Mills.

Wacker Chemicals Norway AS:
Holla Metall is a smelter at Kyrksæterøra in Trøndelag. The company was sold from Fesil AS to Wacker Chemicals in 2010. The smelter produces refined silicon. It has been expanded in the past 2 years, resulting in the world's largest oven (capacity 30 000 tons, total capacity at Holla 44 000 ton) for the production of silicon, starting production in 2019.

Elkem Bremanger:
The smelter was established in 1928 and started as an iron smelter. Bremanger smelteverk became part of Elkem when Christiania Spigerverk became a part of the Elkem concern in 1972. Today the smelter is called Elkem Bremanger. The main products are ferrosilicon and silicon-metal.

Elkem AS Bjølvefossen:
Activities started in 1905, when Bjølvefossen A/S was established to exploit hydropower in Ålvik. In 1918, Bjølvo kraftverk was finished and started producing electrical power for Bjølvefossen A/S. The facility started producing calcium carbide. In 1925, an electrical smelter was established, producing ferrosilicon and ferro alloys (magnesium-ferrosilicon master alloys) for the international metal industry. Today, Elkem Bjølvefossen has 2 electrical reduction furnaces. In addition to ferro alloys, the smelter also produces Microsilica. Microsilica is actually a by-product/waste product from production. Elkem Bjølvefossen produces ca. 60 000 tons per year. Bjølvefossen is amongst the world's largest producers of magnesium-ferrosilicon.
The plant is situated in the beautiful natural surroundings of the small town of Ålvik in the western part of Norway

Eramet Norway AS Porsgrunn:

The history of Eramet Norway Porsgrunn goes all the way back to the establishment of a process facility (Porsgrund Elektrometallurgiske Aktieselskab, PEA) on the island of Roligheten[1] in Porsgrunn in 1913. The smelter produced ferro alloys. Today, refined manganese alloys (silicomanganese and refined ferromanganese) are produced. The smelter is co-located with several other large industries (e.g. Yara) at Herøya Industripark.

Eramet Norway AS Kvinesdal:

In the early 1970ies, Tinfos, which was a ferroalloy producer at Notodden since 1916, was looking for expansion possibilities for its manganese production. A new smelter was built in Kvinesdal and established in 1974. Today, Eramet Norway Kvinesdal has a yearly production of 180 000 tons silicomanganese in three modern 30 MW-smelting furnaces. The location of the process facility was chosen due to the access to power. There was both, an ice-free harbour and a large open area which made it easy for optimum planning of logistics.

Eramet Norway Kvinesdal is centrally located in the Lister-region. There is little traffic and no queues. About 36 000 people are living in the region. Kvinesdal has ca 5800 permanent residents, 200 of them work at Eramet. The area around the smelter is not densely inhabited. The closest neighbours to the plant are located ca. 200 m from the industrial area.

Saint Gobain Ceramic Materials:

Norton AS at Lillesand was established in 1965 as a producer of silicon carbide. In 1987, Saint Gobain overtook the facility. Saint Gobain Ceramic Materials owns also the earlier Arendal Smelteverk [2]at Eydehavn, which today refines silicon carbide, which is produced in the smelter at Lillesand.

Elkem Solar / REC Solar Norway:

Elkem Solar is a company, owned by Elkem, which produces silicon for solar cells. In 2006, it was decided to build a factory at Fiskå, Vågsbygd in Kristiansand. The production facility was placed at the earlier Elkem Fiskå verk, a ferrosilicon-factory, which had used the same facilities for several decades[3]. Full scale production of pure silicon started in 2009. In 2016 the name was changed to REC Solar Norway.

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[1] It seems that Roligheten is equal with Herøya

[2] Arendal Smelteverk is located at Eydehavn in the municipality of Arendal. Earlier silicon carbide (sika) was produced there, based on electrical power. The activities started in 1912 with Sam Eyde as one of the initiators. Production of raw-sika was stopped in 2005, while the refinement continues, based on imported sika.

[3] Fiskå verk was established at Fiskå (Kristiansand) in 1917, producing chemical fertiliser. Production of FeSi at Elkem Fiskå verk started in 1926.

Overview of silicon-producing industries in Norway

Table 1: *Overview of silicon-producing industries in Norway. The name of the closest village or town is given, as well as the distance between the border of the facility and the closest residential area, and the population of the closest village or town. The main products produced in the individual facilities are listed. The last column indicates the year, the industry has been established. When available, it is shown in parentheses when the facility started producing silica-products (for the case this year differs from the year of establishment).*

Name	Location	Distance	Population	Product	Established
Finnfjord AS	Finnsnes	900 m	4 600	Ferro alloys: ferrosilicon, silica	1960
Elkem Silisium Salten verk	Straumen	1000 m	900	Ferrosilicon Silicon: pure silicon, silica fume products	1967
Fesil Rana Metall / Elkem Rana	Mo i Rana	900 m (150 m)	18 900	Ferroy alloys: ferrosilicon, Microsilica	1989
Elkem Thamshavn AS	Orkanger	1000 m	8 000	Silicon (metallurgic) Microsilica	1931
Washington Mills AS	Orkanger	200 m	8 000	Silicon carbide	1962
Wacker Chemicals Norway AS	Kyrksæterøra	1.1 – 3 km	2 500	Silicon (metallurgic)	1964
Elkem Bremanger	Svelgen	100 m	1 200	Ferro alloys: ferrosilicon, silicon (metallurgic and Microsilica)	1928 (?)
Elkem AS Bjølvefossen	Ålvik	100 m	500	Ferro alloys: ferrosilicon, Magnesium-ferrosiliconmaster alloys	1905 (1925)
Eramet Norway AS Porsgrunn	Porsgrunn	300 m	35 100	Ferro alloys: silicomanganese, ferromanganese	1913
Eramet Norway AS Kvinesdal	Øye	200 m	? (few)	Ferro alloys: silicomanganese	1974
Saint Gobain Ceramic Materials	Lillesand	400 m (hospital)	10 000	Silicon carbide	1965
Elkem Solar	Kristiansand	300 m	86 000	Silicon for solar cells	2009 (before there was Elkem Fiskå verk at the same location, producing FeSi since 1926)

2. Studies of impact on health caused by metallurgic industry

A search have been done in NILUs archives to find measurement projects that include assessment of health impact. Most measurement studies are only linked to health impacts through the Pollution Control Act and EU directives, where the limit values are set based on health and environmental impacts.
While there have been several measurement studies around Norwegian metallurgic industries, no studies especially link emissions to odor and/or health impacts on the nearest neighbours. Nevertheless, we have included summary of three older studies, which we believe are relevant even if the source of emissions is not silicon industries.

Study 1: "The health Effects of Traffic Pollution as Measured in The Vålerenga Area of Oslo"
(Chlench-Aas *et al*. 1991)

In the fall of 1987, circa 1000 randomly chosen adults participated in a cross-sectional study on the relationship between traffic pollution exposure and symptoms of health effects in Norway. The study was performed within a 2x2 km area in Oslo, where traffic is the single most important pollution source. It included a large questionnaire administered by trained personnel, and measurements and modelling of traffic air and noise pollution.

Air pollution modelling was based on extensive meteorological and pollution measurements. For each participant an index of air pollution due to traffic was calculated for his/her home address.   Pollution levels measured ca. 40 meters from heavy traffic, were for most typical poor-dispersion situations under air quality guideline values. The maximum 1-hr CO concentrations measured were 25-30 mg/m^3, 8-hr maximum 15-20 mg/m^3, and 1-hr NO_2 maximum 250-300 µg/m^3
The symptoms of health effects and well-being were reported as: "not", "sometimes" or "often bothered", based on symptoms experienced during the preceeding 6 months. To relate the symptoms to the air pollution index we used logistic regression, with explanatory factors such as age, sex, smoking habits, education level and marital status.

The most important explaining factors were sex and age. The results showed, however, that for some symptoms (cough, chronic bronchitis, muscle pains, tiredness, eye irritation, and headache) the air pollution index at values usually under guideline concentrations was an important explaining factor. For upper airways symptoms the effect of air pollution at low pollutionlevels is comparable to the effect of current smoking. In an attempt to evaluate at what level traffic pollution reduces health and well being, a cohort study was designed that associated air pollution exposure and reporting of health symptoms and the measurements of peak expiratory flow (PEF) for 160 individuals hour for hour for two weeks.

Air pollution exposure was estimated for each hour and each individual using known vehicular emission rates, estimated traffic counts for each road segment, and meteorological conditions. N02 was used as an indicator substance for traffic pollution in general.

Fatigue, sneezing, sore/irritated throat, tight chest, annoying smell and annoying noise were significantly associated with traffic pollution. At the hourly air quality guidelines of 200 µg/m^3 NO_2, the increased risk of having each of these symptoms compared to the risk at at an exposure of 10 µg/m^3, (low to moderate exposure) is indicated in the following table (a value of 1.84 for sneezing, for example means a 84% increased risk) **:**

***Table 2** Relative risk for symptoms*

	Relative risk at 200 µg/m^3 NO_2	 100 µg/m^3 NO_2
Fatigue	1.23	1.17
Sneezing	1.84	1.60
Sore/irritated throat	1.67	1.48
Tight chest	1.50	1.37
Annoying noise	3.22	2.45
Annoying smell	2.94	2.29

Variations in PEF did not show significant relationships to air pollution exposure.
In addition, co was measured in blood and breath, lead in blood and a full lung function test was done for each of the 160 participants. Body burdens of lead or CO did not show high levels that could be attributed to excessive exposure to air pollution. Increased lung function was correlated to concentrations of CO in blood, however, the results should not necessarily be interpreted as a cause-effect relationship.

Study 2:
"Short term cohort study of the relationship between health and air pollution in Grenland, Norway. Field work, data acquisition and data preparation."(Chlench-Aas *et al*. 1989)

In order to establish guidelines for pollutant concentrations, it is necessary to know at what levels pollutants disturb human health. In 1979, an investigation was done in an industrialized area of Norway, the Grenland area, which indicated that pollution was leading to adverse health effects. Pollution seemed to especially influence symptoms involving the airways, such as coughing or wheezing. However, there were also more cases of headaches in areas with heavier air pollution. This earlier study was a cross-sectional epidemiological study. As is usual in such studies it was impossible to separate whether the effects were in reality due to air pollution or rather to such confounding factors as age and socio-economic status. If the effect was due to air pollution, it was impossible to identify whichcompound was responsible for the effect, and to quantify at which concentration the pollutant caused effects.

There are several sources of air pollution in the Grenland area: petrochemical, paper, magnesium, cement industries, in addition to important contributions from long range transport and traffic pollution.

Therefore, a follow-up investigation was designed to attempt to identify which compound or compounds, if any, and at which concentrations were responsible for adverse health effects in the area. A cohort study, where a group of individuals is followed over time, can address this issue. Since each individual is his/her own control, problem of confounding factors is minimized. The study was designed to follow two groups of individuals, one suffering from chronic obstructive lung disease (COLD), and the other a randomly picked group representative of the population living in the Grenland area. Since pollutants originate from several sources in the area, pollutants vary independently of each other. Therefore individual pollutants can be identified, and the concentrations necessary to provoke a health effect can be quantified.

The aim of the investigation is therefore to establish if air pollution in the Grenland area has short term effects on health and wellbeing in the individuals living in the area. It is desirable to examine the effects of each compound individually and in combination, and also to examine possible synergistic or antagonistic effects of meteorological factors in combination with air pollution.

The cohort study was designed so that the two populations were followed hour by hour for two months in the winter and two months in the summer. Each participant described through a special diary where he/she was and whether or not the individual was bothered by a list of symptoms. In addition to self-reporting of symptoms, each individual measured peak expiratory flow and noted when and what medication was used.

Measurements made hour by hour at five locations outdoors, information on indoor air quality and detailed modeling based on known emissions of pollutants and meteorological conditions, were combined to allow an extremely detailed description of air pollution exposure for each compound to be calculated for each individual. Logistic regression is used to study the relationship between symptoms of health and wellbeing and air pollution exposure hour by hour. The regression coefficients thus generated are then studied, using a modified regression analysis, the Korn-Whittemore model, to establish on a population basis, which compounds, individually and/or in combination, had an effect on health.

Measurements of outdoor air quality and meteorology

In an effort to include all compounds that might have an effect on health, known from earlier chamber or epidemiological studies, the following compounds were measured for air quality:

Nitrogen oxides
Sulphur dioxide
Ozone
Haze
Sulphate
Nitrate
Chloride
Particulates (two fractions)
Ammonia
Ammonium
Aldehydes
Pollen
Soot
Lead

In addition, the following meteorological parameters were also measured:

Wind direction
Wind speed
Temperature
Relative humidity
Stability
Turbulence

Sulphur dioxide and nitrogen oxides were measured continuously at six stations. Sulphur dioxide was measured daily at three additional stations. Nitrogen dioxide was measured daily at two additional stations. Ozone was measured continuously at two stations (levels are known to be relatively constant over the entire area), and haze continuously at three stations. Particulates, both fine and course fractions, sulphate, nitrate and chloride were measured with 12 hour sampling times at five stations. Ammonia (24 hour sampling time), pollen (hourly), aldehydes (12 hour sampling time) and lead (24 hour sampling time) were measured at only one station each. Ammonium (24 hour sampling time) was measured at two stations and soot (24 hour sampling time) was measured at four stations.

Measurements of indoor air quality

People spend 90% of their time indoors. Therefore it is of primary importanceto know indoor air quality. It is important to quantify how much of outdoor air pollution penetrates into the home, and what kinds of indoor sources of air pollution might exist. In Norway gas cooking and heating is non-existent, and therefore not an indoor source of nitrogen oxides. The single most important factor for indoor pollution is smoking.

In order to determine the percentage of outdoor pollution that penetrates into the home, measurements outdoors and indoors were made simultaneously for a three day period for 15 homes, both in winter and summer. Each participant filled out a long questionnaire that went into detail about ventilation, type of heating used, presence or absence of smokers etc. both at home and at work. The homes were evenly distributed over the geographic area of interest.

Measurements were made in the living rooms of the homes since it was assumed that most individuals spent most of their time there in the evenings.

The following compounds were measured with 12 hour sampling times:
Particulates (both fine and course fractions), chloride, nitrates and sulphates. Nitrogen dioxide and sulphur dioxide were measured with 8 hour sampling times. Spot measurements were made of formaldehyde (methanal) and acetaldehyde (ethanal).

Modelling of air quality outdoors over the entire geographic area

In a study of this kind where hour for hour symptomatology is correlated with exposure to air pollution, it is essential to have as good an estimate of exposure as possible.

The major difficulty in estimating exposure is that people move about so much. In order to handle this, air pollution modelling of the entire geographic area was incorporated into this study.

The air pollution model is based on information on emissions coupled with information on meteorological conditions for a specific geographic area. All the factories in the area gave detailed information on emissions of all major pollutants, some on an hourly basis. In addition, questionnaires were sent to all companies to detail their use of heating oil. Traffic counts were used to estimate traffic's contribution to pollution along the major arteries. Finally, pollution from boat traffic up and down the fjord was also accounted for.

Data on emissions are then coupled to meteorological information to calculate the concentrations of SO, NOx and particulates for each hour and each day for each square kilometer in the area. Ozone pollution stems from long range transport and therefore was considered constant over the entire area. However, ozone concentrations decrease with increased NO since ozone reacts with NO to form NO_2. Ozone values in each square kilometer were corrected for calculated concentrations of NO. Twelve hour concentrations of sulphate and nitrate were interpolated using meteorological parameters for the entire area.

The outdoor concentrations of each of these pollutants that are estimated by the model, are then corrected based on the actual measured values in the five square kilometers where the measuring stations were located.

Estimation of exposure to air pollution

In order to estimate the pollution concentration each person is exposed to, one needs to know the concentrations of each pollutant outdoors in different geographic areas and a coefficient to correct for values indoors. Each person filled out a diary for each hour of each day where they specified where they were geographically, whether or not they were indoors or outdoors, and if they were indoors, whether or not the window was open. Individuals were to also indicate whether they were travelling or shopping and how much traffic they were exposed to. Each participant noted whether or not he/she was sleeping, doing normal daily activities or was jogging. Finally each person was to note how many cigarettes he/she smoked for each hour or (whether or not they were exposed to passive smoking. This information is to be incorporated with the outdoor concentrations estimated by the model and coefficients for indoor air quality to calculate each individual's exposure to each pollutant for each hour.

Choice of subjects

Two groups of subjects participated in this study. The first is a group with known chronic obstructive lung disease (COLD). The other was a randomly picked sub sample of the population living in the region.

85 individuals suffering from COLD (4 to 75 years of age), were selected for the study. The necessary sample size was estimated based on reported variability in a similar study in Houston concerning asthmatics and assuming use of the Korn-Whittemore model of analysis. Each person was selected from a list kept by the local hospital of those suffering COLD that come in for control.

315 individuals, aged 18 to 75 years, comprised the totally random population. A list of 600 names was randomly chosen within a specified geographical area from lists kept in Norway on each individuals home address. Each individual was sent a written invitation to participate in the study, while the local radio station simultaneously encouraged people to accept the invitation. An additional 200 names were necessary to acquire the needed 315. Since any study of effects of air pollution in a random population is dealing with rather seldom events, the Korn-Whittemore model could not be used as such and needed to be modified. Therefore, the sample size necessary for the investigation was calculated based on a variation of the model (based on a Poisson distribution). This calculation suggested that a sample size of at least 300 would be necessary.

Of the 85 COLD patients that started the study, 74 completed the first (winter) period, and 68 completed both periods. Of the 315 in the random group, 282 completed the winter period, and 239 completed both periods.

Health effect variables

In order to investigate if pollution has a short term or acute effect on the health and well-being of both the sick and healthy participants, each individual was asked to fill out on an hourly basis, in addition to the diary, if he/she had any of the following symptoms:

Disturbing noise
Disturbing smell
Disturbing industrial smoke
Headache
Dizziness
Nausea/feeling badly
Running/burning eyes
Sneezing/running nose
Feverish
Irritation of throat
Coughing
Wheezing or tightness in chest
Difficulty to breathe
Muscle pain (neck/back)
Stomach pains
Nervous/anxious
Tired

In addition, each person measured his/her own peak flow with a MiniWright Peak Flow Meter four times a day. Each Mini-Wright was calibrated using a modified version of the Jones Calibrator. The PEF meters were calibrated at five pressures: 3, 5, 7, 9 and 11 bars, which corresponded to results on the PEF meter ranging from 250 to 700 1/min. Calibration was performed before the study began, between the winter and summer periods and at completion of the study. Calibration of the PEF meter consisted both of checking that the meter read consistently the same PEF for each pressure, and that the meter was stable by repeating tests at a single pressure. The latter revealed meters where the arrow had loosened during the study and needed replacing.

Each participant noted once a day: how he/she felt during the day (on a scale from 1 to 5), whether or not he/she was sick, had a fever, had more sputum than normal and whether or not it was green in color, whether or not alcohol was consumed, and lastly whether or not he/she was exposed to any unusual pollution such as cleaning fluids etc.

Each individual noted how much medication was taken on a regular basis every day and time of day the drug was taken. On the daily form each participant also had the ability to note if they took any additional medication that day.

Each participant had a complete physical check prior to beginning the study, in addition to filling in an anamnesis form. Each participant filled out a form called "Symptom Check List" that was aimed at selecting out those individuals that tended to be rather heavy complainers.

Every two weeks the participants came into the hospital for control where they performed a full spirometric test, gave a urine sample for measuring of blood, sugar and proteins. Blood samples were also taken every month where carboxyhemoglobin, hemoglobin and sedimentation rate was measured and serum samples were frozen for future studies. At the beginning and the end of each period a bacteriological test was taken from the throat (behind the tonsils) to measure meningococcus and hemophilus influenza.

Study 3:
In the study "Lead in blood", air concentrations were measured and blood samples were collected of residents in heavy trafficated areas." (Clench-Aas *et al*, 1986).

In the spring of 1984, the Norwegian Institute for Air Research (NILU) in cooperation with the Institute of Occupational Health (YHI) studied blood lead concentrations in the inhabitants of Holmestrand (moderate traffic pollution) and Sørumsand (control town). Despite blood lead concentrations that are low to moderate as compared to values reported internationally, inhabitants of Holmestrand had higher blood lead values than were expected, especially in children exposed to passive smoking and smoking women (Clench-Aas et al. I 1984). Therefore in 1984, NILU, YHI and the City Health Department of Oslo, conducted a study of the effects of higher ambient lead exposure on the blood lead concentrations of the inhabitants of the Oslo- Nydalen area. This area is one of the more highly lead exposed regions in Norway having two industrial point sources and crossed by a major traffic throughway. It was necessary to compare blood lead concentrations in the inhabitants of Oslo-Nydalen, with individuals that are not exposed to high amounts of ambient lead. Therefore, values from a similar study in Sørumsand, done in May 1984, were used as a control.

METHODOLOGY
The study was conducted in two sites:

1) Oslo-Nydalen - a part of Oslo traversed by a major throughway (ca. 30 000 vehicles daily) and having two point sources of industrial lead emissions.
2) Sørumsand time of a small town having very little traffic (at the measurement estimated at 3 000 cars daily) and no industrial sources of airborne lead.

In Oslo-Nydalen, 470 people (ranging in age from 2 to 98 years; 186 children: 125 men; and 159 women) volunteered for the study. In Sørumsand, 118 (ranging in age from 3 to 91 years; 24 children; 28 men; and 55 women) volunteered.

One of the unique features of this study was its experimental design. For each individual a specific blood lead concentration was related to an estimate of that individual's own exposure to ambient lead during the two weeks prior to blood sampling.

Individual air lead exposure was estimated by combining information from diaries of weekly patterns of activity (hours per day for each day of the week, spent in each of several microenvironments such as indoor at home, indoor at work or school, outdoors at home, etc.) with both measured and estimated ambient lead concentrations. Blood and air lead for each individual was measured *by* electrothermal atomic absorption spectrometry. Zinc protoporphyrin concentrations were measured since they have been reported to be increased *by* higher concentrations of blood lead. In addition, the hematologic variables hemoglobin, hematocrit and mean cell hemoglobin concentration were also measured. The questionnaire included information on:

1) additional lead exposure via hobbies, occupation, and smoking (both active and passive), and
2) other socio-economic parameters such as alcohol consumption, use of vitamins and iron supplements, etc. that could influence metabolism.

RESULTS AND DISCUSSION

Measured blood lead concentrations in Oslo-Nydalen were low when compared to those reported in the international literature. Despite higher amounts of lead in air in the Oslo-Nydalen area than those measured in Holmestrand in 1983 before the opening of the tunnel, concentrations of lead in blood were lower.

Ambient lead in the Oslo-Nydalen area ranged from 0.02 µg/m^3 to 5 µg/m^3 during the measuring period. Ambient lead at the five stations, situated where people who participated in the study lived, averaged for the month of February: 0.2, 0.3, 0.3, 0.3, and 0.6 µg/m^3. These values can be compared to Sørumsand where ambient lead ranged from 0.01 to 0.04 µg/m^3 during the sampling period (May 1984).

Concentrations of lead in blood in Oslo-Nydalen averaged 6.0 µg/100 ml in children, 5.2 µg/100 ml in women and 5.7 µg/100 ml in men. These compare to those values measured in sørumsand, 3.8 µg/100 ml in children, 3.4 µg/100 ml in women and 5.9 µg/100 ml in men.

The following table summarizes the principal findings of the study by comparing the median blood lead concentration in children, women and men in Oslo-Nydalen and Sørumsand. The median value of the air lead exposure estimate is also given.

	Children		Women		Men	
	Air lead exposure (µg/m^3)	Blood lead concentration (µg/100 ml)	Air lead exposure (µg/m^3)	Blood lead concentration (µg/100 ml)	Air lead exposure (µg/m^3)	Blood lead concentration (µg/100 ml)
Oslo- Nydalen	0.21	6.0	0.19	5.2	0.21	5.7
Sørumsand	0.03	3.8	0.04	3.4	0.05	5.9

Single regression analysis between the logarithms of blood lead versus air lead exposure estimates, resulted in significant correlations in women and children (both boys and girls), but not *in* men. The measured slope (β) of the regression agreed quite closely with those values of β reported in the literature. It has been reported in the literature that a decrease in the ambient concentrations of lead of 1 µg/m^3 would result in decreases in blood lead concentrations between 1 and 2 µg/100 ml. The regressions done in this study predict decreases in blood lead concentrations of 1.2 µg/100 ml in boys, 1.3 µg/100 ml in girls, and 0.9 in women with a 1 µg/m^3 decline in ambient lead levels.

The results found in this study in Oslo-Nydalen are different from those reported earlier for Holmestrand in 1983. Despite exposure to higher air lead concentrations in the Oslo-Nydalen area than those found in

Holmestrand, blood lead concentrations were lower. For example, whereas children in Oslo-Nydalen had an average of 6.0 µg/100 ml lead in blood, in Holmestrand the average was 9.6 µg/100 ml. Similarly in women, the average in Oslo-Nydalen was 5.2 µg/100 ml whereas in Holmestrand the average was 6.7 µg/100 ml. Even in men, averages were 8.4 µg/100 ml in Holmestrand asopposed to 5.7 µg/100 ml in Oslo-Nydalen. Calculated regression coefficients in the earlier Holmestrand study indicated greater reductions in blood lead with a 1 µg/m^3 reduction in air lead than those measured in Oslo-Nydalen or those reported in the literature.

The hypothesis is put forth in this report that the findings in the two studies differ due to differences in the sources of ambient lead in the two towns. In the Oslo-Nydalen area, the primary source of high ambient lead are the industrial sources, while in Holmestrand the only source is traffic pollution. This could be verified by comparing ambient lead and cadmium values in Oslo-Nydalen with those values found in Sørumsand and Holmestrand. It is suggested that lead is concentrated on smaller size particles when the lead source is traffic emissions than when lead is emitted from the industrial sources in the area. The result could then be that smaller size particles can penetrate further into the alveolar region of the lung leading to greater absorption. Another hypothesis is that the chemical form of the lead may be different in the two sources leading to different absorption factors in the two geographic areas. Yet a third hypothesis, is that the pattern of emissions when the sources are industrial or traffic are different. For example, lead concentrations from industrial sources can be very high, but only over a short time-span, whereas vehicle exhaust may result in lower ambient lead concentrations but over a longer time-span. It is possible that such differences in emission patterns can in some way affect absorption.

In the earlier Holmestrand study, passive smoking in children and smoking in adult women seemed to increase the uptake of lead in air by these two population subgroups. These findings were not confirmed in this study.

In addition to directly examining the relationship between the concentrations of air lead and blood lead, this study also studied the relationship of other socio-economic parameters to blood lead concentrations using multiple step-wise regression. In children there was a significant difference between the two sexes, with female children having the lower blood lead concentrations. In adults, sex, age, social class, and alcohol consumption were significantly related to blood lead concentration. These relationships were such that age and alcohol consumption increased the impact of air lead on concentrations of lead in blood. Blood lead concentration, if high enough, has been shown to interfere with heme synthesis, altering such parameters as hematocrit, hemoglobin, and the enzyme zinc protoporphyrin. Since measured blood lead concentrations were not high, it was not surprising that there was no measurable effect of lead in blood on the parameters hemoglobin, hematocrit, mean cell hemoglobin concentration or zinc protoporphyrin.

3 Reported emission incidents

Each silicon plant must annually report its emissions to the Norwegian Environmental Agency. Data from these reports are publicly available via the website norskeutslipp.no. The annually report includes the substances that are specifically regulated in their permit, as well as emissions of other relevant substances that result from the company's operations. In Norwegian silicon industry, emission permits are given for the following substances: PAHs (EPA16), dust, SO_2, NO_x, varying metals such as Cd, As, Hg, Pb, but also Cu, Cr, Ni and Zn.

The companies are obliged to inform the Norwegian Environment Agency as soon as possible of abnormal conditions that have or may have a significant impact on pollution.

A search in the post journal of the Environmental Agency show that 5 out of 12 silicon plants reported unintentional emissions to air during the past year. Most of the events involved periodically increased emissions of smoke, dust or uncleaned furnace emissions. A single company reported to have received complaints of odor. This company produces silicon carbide. To accsess detailes, document access must be asked for in each case. This is not done at this time.

4 Recent measurement projects for silicon industry in Norway

Assignement NILU has had for Norwegian silicon industry in recent times has been purely measurement projects. No assessments of possible health impacts have been included.
Earlier measurement projects were largely about SO_2 monitoring, but recent projects have been more focused on monitoring of suspended particulate matter. In a single project PAHs were sampled using passive sampler. Several silicon industries annually send composit samples of microsilika from the bag filters, for determination of PAH content. References to measurement projects or dispersion caluculations NILU have done around metallurgic industry (exclusive Aluminium industry) are given in Appendix B.

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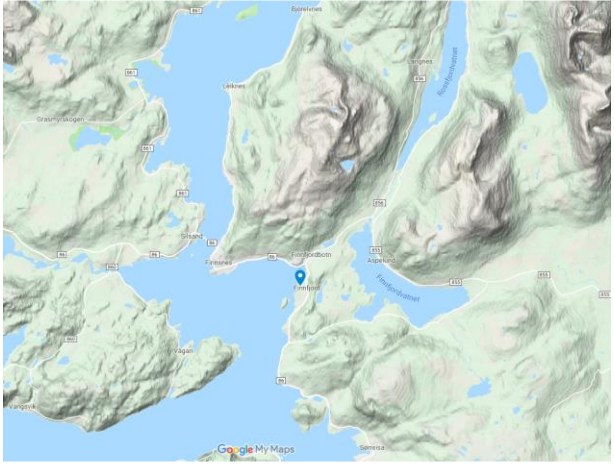
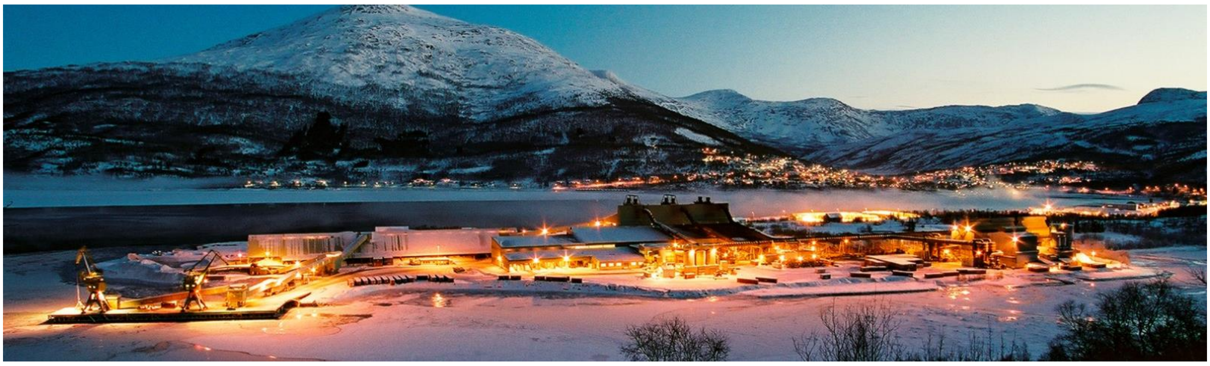
Appendix A

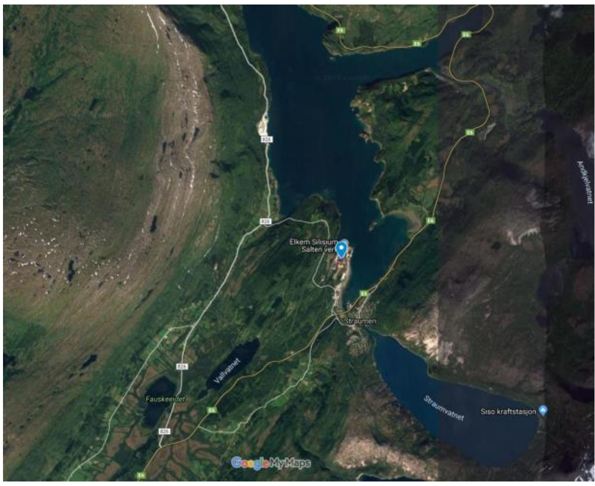
Maps and pictures from each of the 12 industrial facilities in Norway that are producing silicon and silicon products.

Finnfjord AS

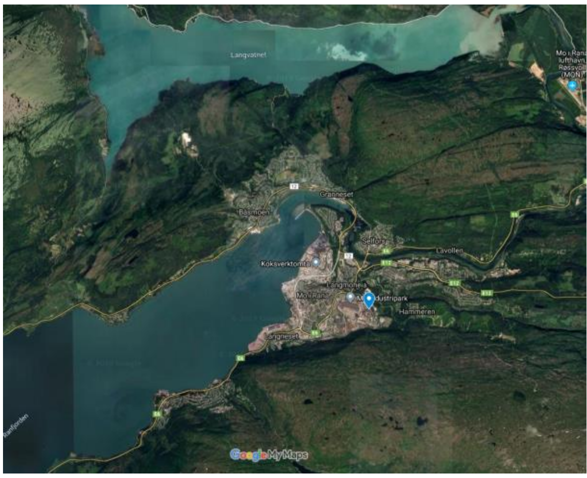


Elkem Silisium Salten verk



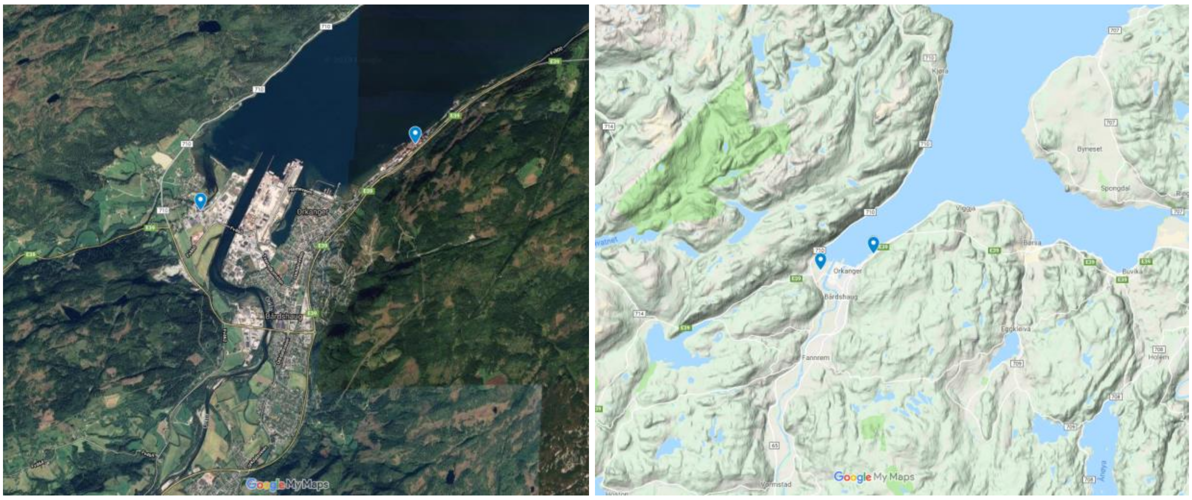


Fesil Rana Metall / Elkem Rana:



https://www.mip.no/stikkord/varslet-utslipp/

Elkem Thamshavn:



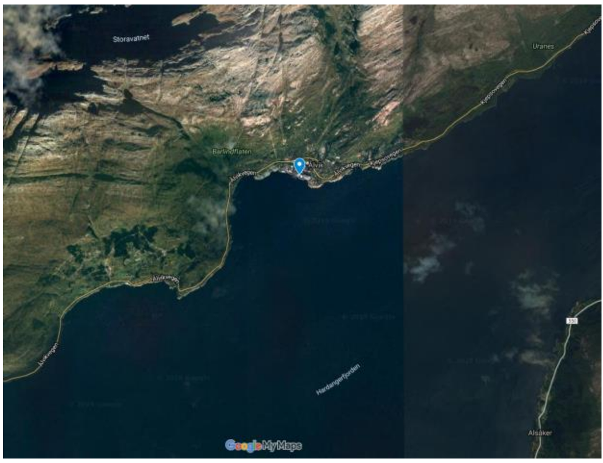
Elkem Thamshavn is the plant located northeast of Orkanger. The plant located west of Orkanger is Washington Mills.

Washington Mills

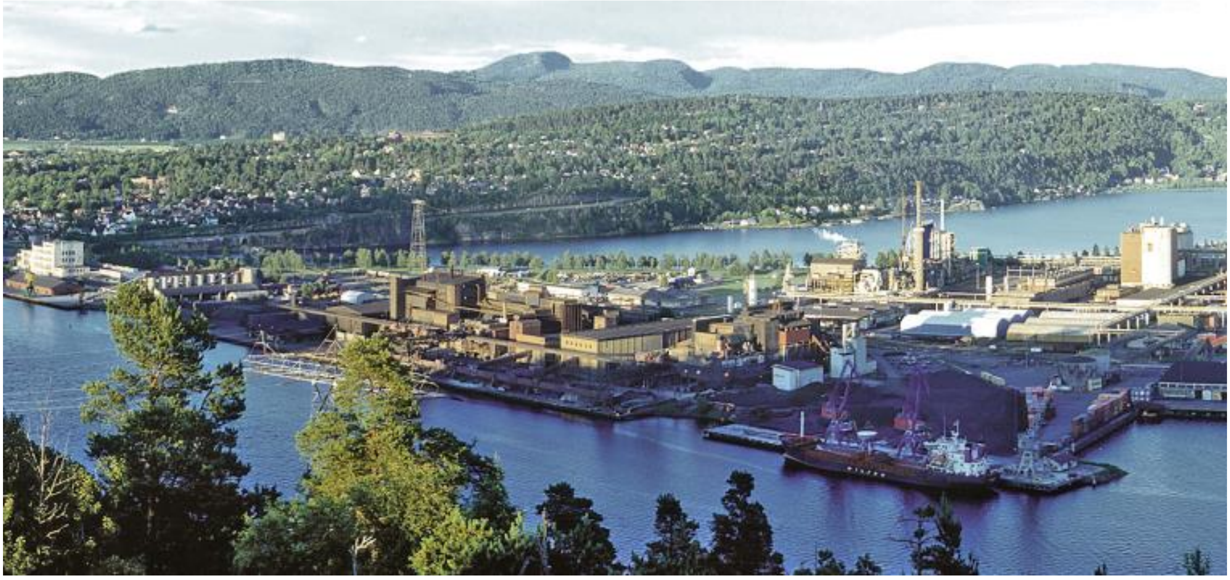
In the foreground: Washington Mills. In the background on the right-hand side, emissions from Elkem Thamshavn can be seen. For maps, see section on Elkem Thamshavn.

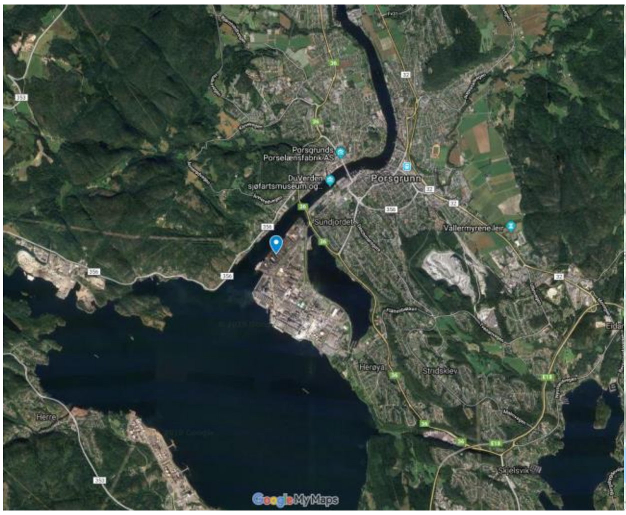
Wacker Chemicals Norway AS

Elkem AS Bjølvefossen

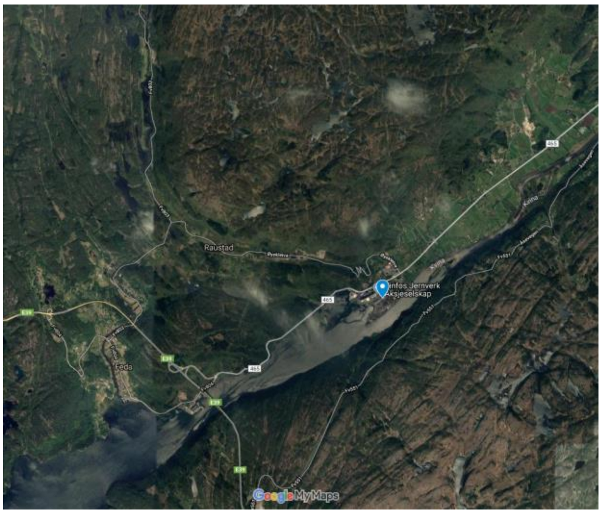


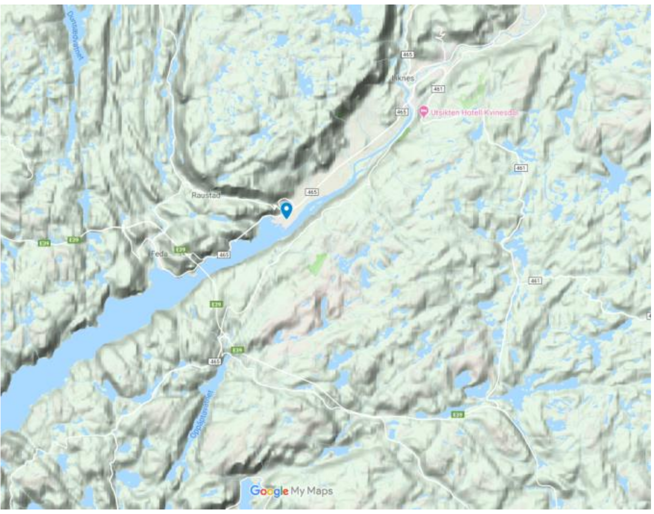
Eramet Norway AS Porsgrunn



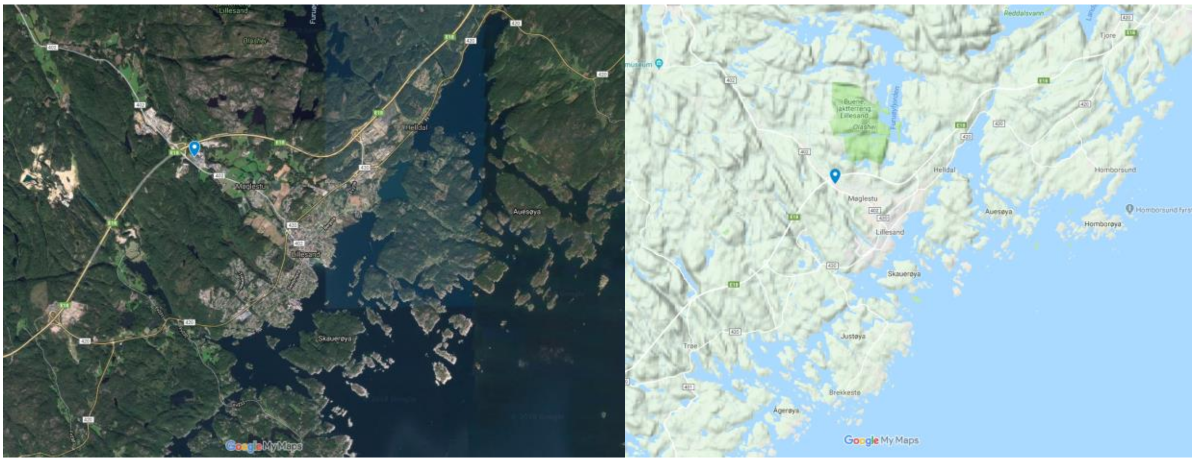


Eramet Norway AS Kvinesdal

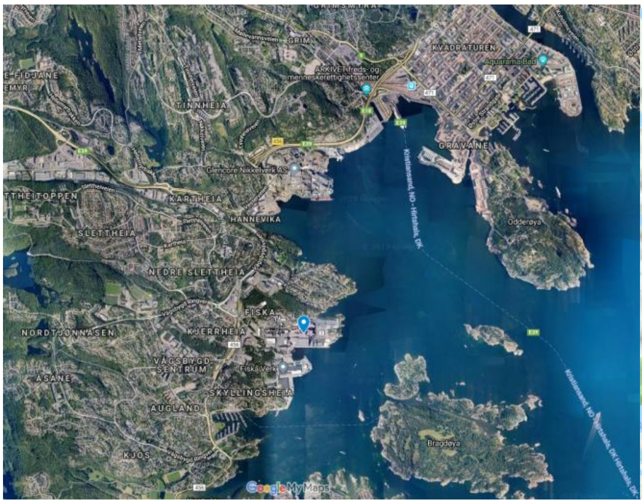


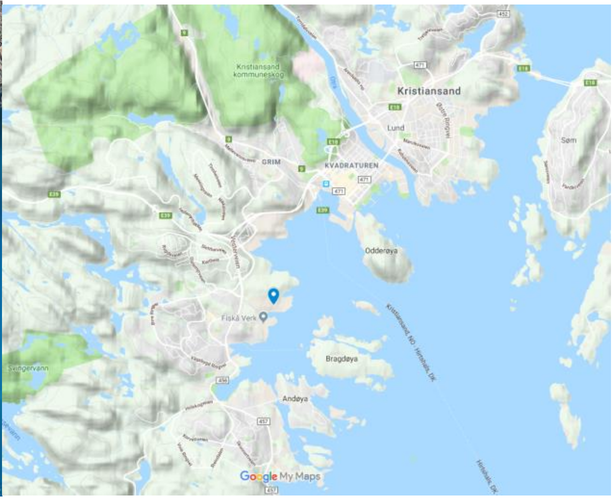


Saint Gobain Ceramic Materials



Elkem Solar / REC Solar Norway





Appendix B

References to measurement projects or dispersion caluculations NILU have done around metallurgic industry (exclusive Aluminium industry).

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