LIFE Project Number

LIFE17 ENV/FI/000173

Final Report

Covering the project activities from 01/07/2018 to 30/06/2022

Reporting Date

26/08/2022

LIFE PROJECT NAME or Acronym

Green Foundry LIFE

Data Project

Project location:	Finland
Project start date:	01/07/2018
Project end date:	30/06/2021 **Extension date:** <dd/mm/yyyy > 30/06/2022
Total budget:	2,088,998 €
EU contribution:	1,216,781 €
(%) of eligible costs:	60%

Data Beneficiary

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2. List of abbreviations

AR	Amendment Request
BAT	Best Available Technologies
BREF	Best Available Techniques Reference Document for the Smitheries and Foundries Industry
BREF TWG	BREF Technical Working Group
GA	Grant Agreement
HTP value	Concentration known to be harmful
IED	Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (the Industrial Emissions Directive)

3. Executive summary

The main objective of the Green Foundry project is to decrease the environmental impact of the European foundry industry by introducing novel technologies for sand moulding systems. The general idea is to demonstrate new inorganic binder systems in ferrous foundries.

The application of modern sand moulding systems based on inorganic binders would have a significant positive environmental and economic impact leading to increased competitiveness of the industry. To reach the main objective, the project has defined seven specific objectives to be reached within the framework of this project:

1. Decrease hazardous air emissions from the casting process – the project aims to replace the currently used organic binders with new inorganic binders

2. Improve the indoor air quality for a safer work environment – organic binders emit hazardous casting fumes and fine particles like binder aerosols

3. Improve the use of natural resources – using inorganic binders would allow foundries to use the foundry sand more efficiently. Project aims to demonstrate different methods for purification and re-use of surplus sand.

4. Provide encouraging examples for the industry on an EU level by implementing the new inorganic sand moulding systems in iron and steel pilot foundries.

5. Produce the necessary practical tools for the industry with required information on the implementation of inorganic sand moulding systems in ferrous foundries.

6. Disseminate the results on EU level for immediate implementation of the best practices

7. Provide Smitheries and Foundries BREF with BAT publication including technical solutions of inorganic binder systems in ferrous foundries.

Main actions:

1. Small scale tests casts were carried out in Finland and Poland to measure the emissions of the casting processes. These measurements were made for ferrous castings using both organic and inorganic binder moulds. Three inorganic and three organic binder systems were tested and emissions measured at AGH-UST laboratory in Poland successfully and at HARDKOP pilot foundry in Poland by AGH-UST. One organic binder system test cast was made at URV and two inorganic binder system test casts at Karhula foundry in Finland.

2. By the end of the project in total emissions in five pilot foundries were measured and compared representing both inorganic and organic binder systems.
   - *Karhula Foundry* in Finland (organic binder system)
   - *URV* foundry in Finland (organic binder system).
   - *Valumehaanika* in Estonia (uses organic binder system but also two inorganic binder systems were tested and emission /indoor air quality were measured)
   - *KSMCastings* in Germany (inorganic binder system)
   - *Stavanger Steel* in Sweden (traditional inorganic binder system waterglass).

3. Full production scale test series with inorganic binder system moulds were made in three ferrous foundries in Finland, Italy and Estonia. Three inorganic binder systems were demonstrated and tested at *Karhula Foundry*. In total of 42 tons of test castings with inorganic binders and 39 tons of organic binder were produced. After several test series and different recipes suitable inorganic binders were found.
   Due to the COVID-19 Karhula withdrawed from the project and remaining test casts were completed at iron *Valumehaanika foundry* in Estonia. Results from Karhula foundry tests were utilised and two self-setting inorganic binders were tested. About 20 tons of test castings with inorganic binders and 16,5 tons of organic binders were produced. This means that totally 118 tons of tests castings were produced in Karhula and Valumehaanika with inorganic and organic binders in production scale test casts. All sand moulds made of inorganic binders and the quality of test casts were promising. For the implementation of the inorganic binders in full production it requires more production scale tests and also high investments for new moulding lines.

   Fonderie di Assisi (former FOM Tacconi) in Italy tested two inorganic binder systems in core making. Over 300 pieces of cores were made of inorganic binders by their core external supplier and test casts were produced at Fonderie Assisi. The results were good, the quality of the cores and the test casts were comparable with the cores and casts made of organic binders. The foundry is interested in applying the innovative inorganic binder system in core-making production line the future. But more production scale tests are needed and the investment costs and sand reclamation methods must be clarified and demonstrated.

4. Different surplus foundry sand recycling and cleaning options were demonstrated.
   - Thermal reclamation method was demonstrated at the existing reclamation plant in Finland were both organic binder system waste sands (furan, green sand and phenol) and inorganic binder system sands from Karhula foundry test casts were tested.
   - Composting demonstrations actions were carried out in Finland and Spain. In total 360 tons of composting material were treated and cleaned in Finland and 120 tons in Spain. The aim was to find new reuse options for organic and inorganic binder system surplus foundry sands and dusts and to produce clean mixture soil material in the composting process that can be reused in green construction purposes instead of landfilling.
   - Washing method was tested in laboratory scale tests in Spain. Different organic and inorganic waste sands were washed with distilled water and HCl (hydrochloric acid) and then rinsed. Harmful substances and metals were well degraded but this method need more tests in bigger scale and e.g. need for the wastewater treatment must be studied.
   - CTIF carried out several laboratory scale tests with different inorganic binder system waste sands. Mechanical, hydromechanical and ultrasonic treatment methods were tested to find suitable techniques to clean waste sands and recycle back e.g. in core making process.

5. The results of the project were actively disseminated during the project. Project partners participated in 41 events/webinars/exhibitions/seminars were relevant national and international audience were present. 13 publications/articles were released in magazines and technical publications. The ***key deliverable as BAT report*** describing the implementation of inorganic binder system in ferrous foundries was produced and presented in the public webinar and then delivered to the Technical Working Group of the BREF document. The Green Foundry LIFE project ***Conclusion report*** is a summarized project activities and main outcomes.

4. Introduction

The foundry industry is an important contributor to the EU economy with more than 3970 foundries employing more than 243 700 people in 2020 (www.caef.eu/download-links). It is also one of the most environmentally polluting sector, due to high gas emissions and waste generation. Foundry industry has greatly contributed to all kinds of industries including such as shipbuilding industry, auto-parts industry, industrial machine industry and construction machine industry. Although the casting foundry industry is an essential industry for the growth and development of EU, there are numerous problems concerning the industry such as environmental issues, price fluctuations in subsidiary materials, policies and lack of manpower. Moreover, the environmental problems have been set as a priority to be solved. Since the casting industry has been regulated in regard to greenhouse gas emission by the Muskie Act, the Kyoto Protocol, and the like, a method for getting rid of discharge of basic pollutants and a technical method for reduction in energy consumption, improvement in working environment, and greening of manufacturing sites is urgently needed. The most significant emissions are discharged during PCK-processes: pouring, cooling and knock-out of moulds. Most of the contaminants originate from combustion of organic binders in sand moulds after coming to contact with liquid metal in temperatures of over 1400^{o}C. This causes hazardous emissions evaporate to the ambient air and to indoor air. Remarkable part of contaminants condensates back into moulds making the sand used for the moulds also hazardous. If the sand is disposed in a landfill the binder residuals begin to degrade causing many GHGs to add to the environmental contamination. The most effective solution to eliminating all of these problems is the application of inorganic binders.

The main objective of the Green Foundry project was to decrease the environmental impact of the European foundry industry by introducing novel technologies for sand moulding systems. With the objective of introducing new clean technology moulding systems that use inorganic binders, the "Green Foundry" project targets three environmental problems at once:

1) Decreasing emissions from the casting process;
2) Improving foundry indoor air quality;
3) Recycling surplus foundry sand.

1) Decrease hazardous air emissions from the casting process – the Green Foundry project aimed to replace the currently used organic binders with new inorganic binders to make sand moulds and cores necessary for the casting process. The impact of these binders has been proven on small scale studies but the industry is currently lacking practical applications, a problem that the Green Foundry project was looking to solve.
2) Improve the indoor air quality for a safer work environment – organic binders emit hazardous casting fumes and fine particles like binder aerosols. By accelerating the uptake of inorganic binders, the Green Foundry project would have a significant impact on improving the working environment for foundry workers.
3) Recycling of foundry surplus sand - using inorganic binders would allow foundries to use the foundry sand more efficiently, leading to lower consumption of natural resources such as natural sand, water and energy. In order to decrease waste the project aimed to demonstrate different methods for purification and re-use of surplus sand.

Other objectives:

4) Providing encouraging examples for the industry on an EU level by implementing the new inorganic sand moulding systems in pilot foundries.
5) Providing Smitheries and Foundries BREF with BAT publication including technical solutions of inorganic binder systems in ferrous foundries.

As a result of the Green Foundry project, it was measured in the project chamber tests and waste sand quality analyses that the uptake of inorganic binders would rapidly increase leading to less emissions in foundries and less hazardous compounds in waste sands. The expected results and environmental benefits of the project were follows:

- Hazardous airborne emissions including ambient air improvement and reduction of local health risk and odor nuisance will be reduced by about 80-95% according to the small scale chamber tests carried out in lab scale tests and pilot foundry conditions;
- Indoor health improved by approximately 70-80% according to the small scale chamber tests carried out in small scale tests in pilot foundry conditions;
- Waste problem of hazardous surplus foundry sand reduced by recycling next to 70-75 % when implementing the inorganic binders in the production;
- Three pilot foundries (Karhula Foundry, Finland; Fonderie di Assisi (former FOM Tacconi), Italy and Valumehaanika in Estonia) implemented the inorganic binder system in production scale tests- two of them are interested to start implementing inorganic binders in the production in near future.
- 100-150 foundries are expected to implement the inorganic binder system 5 years after the completion of the project;
- A new BAT publication describing the implementation of inorganic binder systems from a technical, economic and environmental perspective.

5. Administrative part

During the project in total **27 project meetings were arranged** by TEAMS, Skype or face-to-face meetings. In addition, individual TEAMS meetings with partners and pilot foundries were arranged when needed e.g. for planning the activities. Coordinator was on weekly or monthly basis in contact with partners via emails/Teams meetings for planning and updating the project activities.

Steering Committee meetings were arranged on 31.10.2019, 15.4.2021 and 20.1.2022 where confidential issues as partnership changes and the amendment requests were discussed and decided.

Project monitoring meetings and TEAMS meetings with Neemo and EASME were arranged on 6.2.2019, 4.10.2019 (site visit at Karhula foundry in Finland), 3.12.2020, 12.5.2021, 10.3.2022 (site visit at KSMCastings foundry in Germany) and 15.3.2022.

Progress reports delivered: 1st Progress report on 29.3.2019, Midterm report on 16.6.2020, 2nd Progress report on 9.1.2021 and Final report on 22.7.2022.

Two Amendment Requests (AR) were made.
First, an organisation was replaced from Valty to Technology Industry of Finland (TI). No changes in the project activities, objectives, budget or personnel occurred. The new PA was signed on 22.1.2019 and it was attached to the AR. **The 1st Amendment request was approved and signed by the Commission on 23.5.2019**.

The 2nd amendment request was delivered to the Commission on 6.4.2022. Two substantial changed were made. The partner, Karhula Foundry, withdrawed from the project because of the lack of time and financial problems caused by COVID pandemic in Europe. Second reason was a prolonging of the project duration of 12 months to be able to complete the unfinished activities which were not able to be completed due to the COVID pandemie and problems to travel to Europe to complete the missing emission and indoor air quality measurements in Germany and France. **The second amendment request was approved and signed on 29.6.2021**.

The remaining test casts of Karhula foundry were subcontracted by a new pilot foundry Valumehaanika in Estonia. No new partner was needed. Meehanite and Foundrytream carried out the missing activities and reports of withdrawn Karhula Foundry and the remaining costs were reallocated to them e.g. for subcontracting the test casts from Valumehaanika.

No other changes in the project administrative part. Key-person Mr Pekka Kemppainen from Karhula foundry participated in the project webinar, Conclusion and BAT report preparation work.

All signed PA's were attached in the 1st progress report on 29.3.2019.

All requested clarifications with relevant documents from the progress reports, midterm report and monitoring visits have been delivered to the monitoring team NEEMO as requested and discussed in the following monitoring meetings.

Project partners delivered financial reporting documents every 5 months to the coordinator with copies of invoices, signed timesheets and updated individual cost statements. Due to the COVID pandemic as majority of the personnel were working outside the office, there were some delays in signing the timesheets in due time. Cost statements are corrected if requested and attached with original signatures in this final report.

According to the Special Provisions I.4.4 Request for payment of the balance and supporting documents an auditing is not needed as no partner claim more than 750 000€ EU contribution.

> **"**1. LIFE projects 2017 onwards (i.e. Grant agreements signed as of May 2018 and later):
> Certificate is requested for each beneficiary and for each affiliated entity, if simultaneously (i.e. both conditions apply):
> (i) the cumulative amount of the Commission contribution that the *beneficiary requests as reimbursement of actual costs is EUR 325 000 or more*; AND
> (ii) the maximum amount of the Commission's contribution, *indicated* for that beneficiary and its affiliated entities in *the estimated budget in the grant agreement* as reimbursement of actual costs is EUR 750 000 or more. **"**

6. Technical part

6.1 Technical progress, per action

6.1.1. A1 Preparatory actions for pilot foundries and foundry sand recycling activities

Foreseen start date: 1.7.2018 | Actual start date: 1.7.2018
Foreseen end date: 31.3.2019 | Actual end date: 24.8.2021 (*permit for composting tests at the new site in Iisalmi 24.8.2021*)

Action A1.1: Visiting pilot foundries
According to GA five pilot foundries would be visited. In the beginning of the project the two French foundries informed that they can not participate in the project activities due to the other running projects or classified projects ongoing. Substitute foundries were contacted in France. The Commission/Agency was informed of the new pilot foundries in the 1st progress report. Planned emission measurements could be made at the CTIF experimental foundry in Paris and at the KSMCastings foundry in Hildesheim, Germany. These were approved by the Commission/Agency in the letter dated on 10.5.2019.

Meehanite and AX visited *Karhula and URV foundries in Finland* in the beginning of the project. These foundries are old customers, so coordinator is familiar of the processes.

Due to the COVID 19 restrictions in place in autumn 2021 in Europe it was suggested that the planned CTIF experimental foundry in Paris be replaced with *Valumehaanika foundry in Estonia.* The travelling from Finland to Estonia was easier than travelling to France due to the restrictions in Europe. There would not be any mandatory quarantine for employees when returning from Estonia back to Finland. Meehanite and Foundryteam visited the Valumehaanika foundry on 11-12.8.2021. Francesca Ettore in EASME was requested of this possibility in the email on 24.8.2021, and an approval was received on 6.9.2021.

KSMCastings foundry in Hildesheim, Germany was not visited before the measurements due to the COVID but phone calls and TEAMS meetings were arranged to plan the measurements carefully. The preliminary plan was to make the emission measurements in April 2021 but this was cancelled because of the COVID. After the situation got better in Europe, new timetable was set in 8-10 of March 2022 when also Neemo and EASME officers visited the foundry.

The partner *Foundryteam, Erkki Karvonen, had visited Stavanger Steel foundry in Sweden* several times before the project activities and there was no need for additional site visit before the measurements. Detailed plans were discussed in teleconference with the foundry managing director Thorvald Strand.

This subaction was delayed due to the pilot foundry changes but was eventually successfully completed.

Action 1.2: Preparation of small-scale pilot castings
Planning the small scale chamber tests in Finland and Poland progressed as planned. At AGH-UST they planned to test 12 samples in Method I and 12 samples in Method II chamber tests. At Karhula one inorganic binder system chamber test was planned and at URV foundry the organic phenolic Alphaset binder system chamber test arrangements was planned.
AX/Meehanite were responsible for chamber test arrangements at Finland and AGH was responsible for the test arrangements in Poland. Pre-plans completed by 12/2018.

This subaction completed.

Action 1.3: Preparatory actions for the environmental permits for tests
Permits for composting tests were applied from local authorities in Finland; Centre for Economic Development, Transport and the Environment in Tampere on 5.7.2019. New permit for the new composing site in Iisalmi was applied on 12.6.2019 and renewed on 24.8.2021.

In Spain, the pilot site, Composgune, S.L, located in the centre of the Basque Country, Ormaiztegi, Northern Spain, 50 km from the Cantabrian Sea. There was no need for environmental permission because the pilot site had already existing permit from local authorities Composgune in Spain.

No need for permit for thermal reclamation or washing tests. Thermal reclamation plan is a full-size plant in Nuutajärvi in Finland with existing environmental permit. Washing tests were carried out on laboratory scale by Tecnalia. The washing tests were originally planned to be done by Ecofond company in Italy, but the company went bankrupt just before the project started.

This subaction completed.

Action 1.4: Preparatory seminar about sand binder technologies
The preparatory seminar was merged with the kick-off meeting on 15th November 2018 in Tampere where all partners were presented and also two relevant inorganic binder system suppliers were invited. Suppliers presented the current state of inorganic binders in the market and future activities planned in the project. BAT technology and state of art inorganic binders used in aluminium foundries were presented by binder system manufacturers and discussed in the meeting. Currently the inorganic binders are used in aluminium foundries (about 40 aluminium foundries).
Before and after the kick-off meeting project partners were actively in contact with the different inorganic binder system suppliers to get them to participate in the project activities. Two most relevant suppliers were present at the kick-off meeting and they presented the current problems and state of art of the inorganic binders available in the market. Four relevant inorganic binder system suppliers which have commercialized inorganic binder system products on the market were contacted and they all delivered materials for project test purposes. The results are handled confidential and each supplier were asked if their names can be used in project deliverables.

Deliverable*: DeA1.Preparatory Workshop, State of art of inorganic binder system used in Europe*. Deliverable submitted in 1st Progress Report (29.3.2019) (longer version of the progress reports where deliverables were attached).

This subaction completed successfully.

6.1.4 B1 Emissions of different binder systems during small-scale test casts

Foreseen start date: 1.1.2019 Actual start date: 1.1.2019
Foreseen end date: 31.1.2020 Actual end date: 30.6.2020

Method I and II by AGH-UST:
AGH University carried out inorganic and organic binder system chamber tests and emission measurements in laboratory and Hardkop pilot foundry in Poland (Methods I and II). 12 samples (3 organic and 3 inorganic binders) in Method I and 12 samples (3 organic + 3 inorganic binders) in Method II. All tests were repeated twice; in the first tests PAHs and BTEX amounts were measured and in the second test the total gas volumes were measured. So 3+3*2 = 12 tests at lab scale (Method I) and same tests 3+3*2 were made at foundry conditions at HARDKOP foundry in Poland (Method II). Markku Tapola (Meehanite) and Seppo Heinänen (AX) visited AGH-UST

in Poland during the laboratory scale tests on 8-10.10.2019 and at Hardkop foundry on 20-23.10.2019.

Method I: Testing foundry at AGH-UST - laboratory test
Investigation of the gases emission in the small test were performed according to the original method developed in the AGH-UST Krakow (Poland). A sample of the investigated moulding sand of a cylinder shape of dimensions 50 mm x 50 mm, weight about 150 g is poured with liquid cast iron of a temperature of 1350oC. Gases emitted from the sample – after pouring it with liquid metal are led by means of a steel pipe via the drying system and heating system and the capsule with activated carbon (during BTEX measurement) or polyurethane foam (during PAHs measurement) into pump. The six binders (tests repeated twice = 12 samples) for moulding sands were tested:

- organic binders: furan resin (code MF) and phenol-formaldehyde resin (code MA).
- inorganic binders; 2 binders on water glass base (code MI and code MC) and 1 binder on aluminosilicate base (code MG).
- greensand – activated bentonite (code MB).

Table 1. Total emission BTEX and benzene calculated per 1 kg of binder and 1 kg of moulding sand

CODE	Per 1 kg of binder, mg		Per 1 kg of moulding sand, mg	
Compounds	Total BTEX	Benzene	Total BTEX	Benzene
MF	43 852	40 158	658	602
MA	32 994	30 911	495	464
MG	3 342	2 837	60	51
MC	715	496	24	16
MB	2 510	2 301	176	161
MI	860	556	22	14

Table 2. Total emission PAHs and benzo(a)pyrene calculated per 1 kg of binder and 1 kg of moulding sand

CODE	Per 1 kg of binder, mg		Per 1 kg of moulding sand, mg	
Compounds	Total PAHs	Benzo(a)pyrene	Total PAHs	Benzo(a)pyrene
MF	806	16	12.09	0.24
MA	658	11	9.87	0.17
MG	175	3	3.14	0.06
MC	66	0.39	2.18	0.01
MB	83	2.19	5.80	0.15
MI	76	0.6	2.0	0.02

Main conclusions:

1. moulding sand with organic binder generated 2 to 3 times more gas volume than inorganic
2. green sand (MB) showed relatively low emission of compounds from the PAHs and BTEX groups because in the bentonite mixture the coal dust was partly replaced by more environmentally friendly components.

Fig 1. Small scale chamber tests at AGH laboratory.

Method II: Tests at Hardkop foundry – small scale chamber

Research on the composition of gases (BTEX and PAHs groups) formed during pouring and cooling of moulds and knocking out of castings were conducted in foundry. The weight of the test casting was ca. 22 kg, and sand/metal ratio was 2,8…3,0. The six binders for moulding sands were tested:

- organic binders: furan resin (code MF) and phenol-formaldehyde resin (code MA),
- inorganic binders; 2 binders on water glass base (code MI and code MC) and 1 binder on aluminosilicate base (code MG),
- greensand – activated bentonite (code MB).

Table 3. Amounts of compounds from BTEX group emitted during pouring, cooling and knock-out.

Test No.	Benzene [g/process]	Toluene [g/process]	Ethylbenzene [g/process]	m+p xylene [g/process]	o-xylene [g/process]	SUM [g/process]
	[mg/kg][a]	[mg/kg][a]	[mg/kg][a]	[mg/kg][a]	[mg/kg][a]	**[mg/kg][a]**
	[mg/kg][b]	[mg/kg][b]	[mg/kg][b]	[mg/kg][b]	[mg/kg][b]	**[mg/kg][b]**
BTEX Test 1 MF	1.2	4.1	0.03	0.14	0.03	**5.5**
	18	63	0.46	2.1	0.46	**84**
	52	178	1.3	6.1	1.3	**238**
BTEX Test 2 MA	1.5	0.47	0.02	0.20	0.03	**2.2**
	23	7.2	0.31	3.1	0.46	**34**
	65	20	0.87	8.7	1.3	**96**
BTEX Test 3 MB	0.17	0.11	0.01	0.03	0.01	**0.33**
	2.6	1.7	0.15	0.46	0.15	**5.1**
	7.4	4.8	0.43	1.3	0.43	**14**
BTEX Test 6 MI	0.07	0.03	0.01	0.02	0.01	**0.14**
	1.1	0.46	0.15	0.31	0.15	**2.2**
	3.0	**1.3**	**0.43**	**0.87**	**0.43**	**6.0**

(a)-kg of moulding sand, (b)-kg of metal

Fig 2. Chamber tests at Hardkop pilot foundry in Trzebinia, Poland.

Main conclusions:

In order to compare the harmfulness of the tested moulding sands, measurements of amounts of emitted substances from the BTEX and PAHs groups under an influence of high temperatures, were performed. Measurements were conducted for the whole cycle containing: pouring, cooling and knocking-out. The obtained results were recalculated into the emission from 1 kg of the moulding sand and 1 kg of the binder applied in the given technology. The following conclusions can be drawn on the bases of tests performed under the small scale chamber conditions:

1. Emissions of PAHs, as well as BTEX in case of moulding sands with organic binders are several dozen higher than the emission of these compounds from moulding sands with inorganic binders.
2. Moulding sands with inorganic binders (MG, MC and MI) are characterised by lower harmfulness for the environment and employees than moulding sands with organic binders.
3. Relatively environment friendly were green sands (bentonite sand MB), in which a part of coal dust was substituted by additions able to produce lustrous carbon.

Method III: Chamber tests at pilot foundries by AX

As according to the grant agreement, AX carried out two foundry production type emission measurements under normal casting conditions in two pilot foundries: Karhula and URV foundries in Finland. At URV foundry the organic phenolic Alphaset binder system was tested and at Karhula foundry two inorganic binder systems instead of planned one were tested in chamber test arrangements. Two inorganic binder systems were tested due to their different properties: one is a fully inorganic system that requires heating at an elevated temperature, the other is "semi" inorganic (inorganic binder + organic hardener) which hardens at ambient temperature and is thus called as "self-curing".

URV foundry: Emission measurements of two small scale test casts with organic binder system (phenolic Alphaset) were carried out at URV on 29. – 31.1.2019 (Fig 3). The aim of the measurements was to find out the concentration of components, emissions and mould temperatures during the casting process. During normal casting process, it is impossible to measure released emission concentrations, so test castings were carried out with special arrangements. Measurements were carried out during two days on the row. During both days the casted amount and quality was same (500 kg). Because of the measurement arrangements, the exhaust gas coming to analyzer had to be diluted. This is a measurement procedure to make the concentrations suitable for the measuring devices, but the dilution ratio used will be taken into account in the emission calculations.

Results: Both test results demonstrate clearly that there were short-termly really high concentrations of carbon monoxide (CO) during melt was poured and while cooling concentrations started evenly decrease. CO had clearly the highest concentrations, especially during melt was poured, concentration was very high and it exceeded the measurement area of the analyzer.

During the melt was poured, VOC compound concentration (Volatile Organic Compounds) was quite high. After that, concentration degreased more slowly than with carbon monoxide, because different compounds are evaporating from the mould in different temperatures. Because mould is warming up and different compounds have different evaporating temperature, VOC concentration is not decreasing as fast and linearly than other measured gaseous components.

While the melt was poured there was also a small peak in sulphur dioxide concentration. As soon as the melt was poured the concentration degreased. During the measurements no nitrogen oxides were detected. Oxygen concentration degreased for a while when the melt was poured from 20.9 to 20.7%. At the same time there was small amount of carbon dioxide. Anyway, concentrations decreased rapidly to the level of normal air. The average particle concentration from the first test measurements was around 34 mg/Nm^3 and from the other around 26 mg/Nm^3.

Fig. 3 Pictures of the emission measurements of small scale test casts at URV foundry.

Karhula foundry: At Karhula foundry it is was originally planned to carry out chamber test with one inorganic binder system. During the test casts with different inorganic binders (Action B3) it became obvious that emissions from other more suitable inorganic binder system should be also measured. Therefore, chamber tests with TWO inorganic binders instead of planned ONE were carried out and emission were measured on 24.-25.4.2019 and 19.-21.10.2020. Additional measurements caused more personnel/travel costs for AX and personnel costs for Karhula partners as planned. But the emission measurement results are very important for the foundries when making decisions on the basis of the emission reductions.

Results: Based on the results of the chamber tests carried out with the steel test casts and using two inorganic binder systems, the total emission measurements demonstrated very small emission concentrations compared to the organic phenolic binder system. In the table 4 the results from these three chamber tests are presented.

Table 4. Emission measurement results in the chamber tests at URV and Karhula foundries with different binder systems.

	Test	URV	Karhula	Karhula	Emission
		chamber	chamber	chamber	reductions
	Resin	phenolic Alphaset	Inorganic Peak	Inorganic Inotec	%
Emission per casting [g/ton casting]	dust	211	56,10	7,40	96,50
	CO	10 129	361	128	98,74
	SO_2	203,31	6,51	3,30	98,38
	VOC	3 256	111,6	35,2	98,92
	BTEX	665	8,50	1,05	99,84
	asetaldehyde	81,3	8,76	0,72	99,11
	formaldehyde	1,92	6,23	0,63	67,22
	phenol	109	0,89	0,13	99,88
	o-cresol	152	<1,50	<0,08	99,95
	p-cresol	74,1	<1,50	<0,05	99,93
Sum		14 883	563	177	

Fig. 4 Pictures of emission measurement of small scale chamber test casts at Karhula foundry.

This action was successfully completed. More chamber tests were made than planned in the GA but valuable and relevant information of the emissions from different inorganic binder systems were received. As a summary:

- Two inorganic binder system chamber tests completed at Karhula foundry, Finland
- One organic Alphaset binder system chamber test completed at URV foundry, Finland
- 12 samples laboratory tests Method I completed at AGH-UST (inorganic and organic biner systems), Poland and
- 12 samples pilot foundry Method II tests completed at Hardkop foundry (inorganic and organic binder systems), Poland.

List of deliverables in this action.
DeB1C Results of emission measurements of inorganic and organic mould sands in testing foundry at AGH laboratory. Delivered in Midterm report 16.6.2020, attached also in Final report as ***Appendix 62***.
DeB1D Results of emission measurements of inorganic and organic mould sands in pilot foundry in Poland. Delivered in Midterm report 16.6.2020, attached also in Final report as ***Appendix 63***.
DeB1B Results of emission measurements of organic binder system chamber test casts in URV foundry in Finland. Delivered in Midterm report 16.6.2020.
DeB1A Results of emission measurements of chamber test cast carried out in Karhula foundry, Finland. Delivered in Midterm report 16.6.2020, updated with second inorganic binder system test result and is attached in Final report as ***Appendix 61.***

6.1.5 B2. Total emissions and indoor air quality measurements of pilot foundries

Foreseen start date: 1.1.2019 Actual start date: 1.1.2019
Foreseen end date: 30.6.2020 Actual end date: 13.5.2022

Due to the COVD-19 pandemic there where changes with the pilot foundries to be measured and the timetables due to the travelling restrictions in Europe. In spite of foundry changes, there where no changes in the overall objectives and measurement plans.

This action is divided into 2 subactions:

B2.1 Emission measurements in 3 inorganic and 2 organic pilot foundries
B2.2 Indoor air quality measurements in 3 inorganic and 1 organic pilot foundry

Changes were made with the pilot foundries when Saint Jean Industries, Peugeot or Renault foundries in France could not participate in the project activities. These were replaced by *KSMCastings foundry in Germany* and *Valumehaanika foundry in Estonia*. The Agency was informed in advance. KSMCastings foundry was approved in the Commission letter dated on

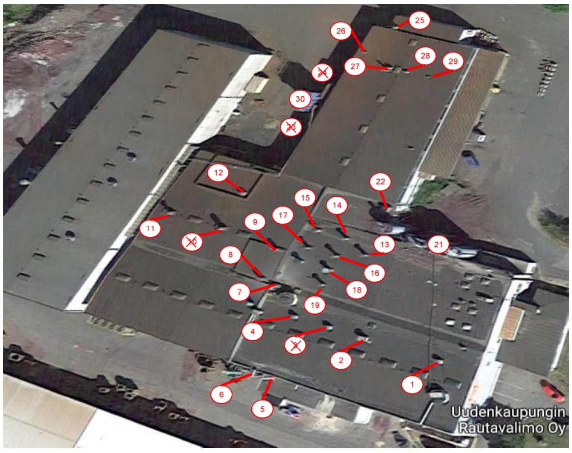
12.11.2019 and Valumehaanika foundry was approved in the email from Agency received on 6.9.2021.

List of **5 pilot foundries** where the emission and indoor air quality measurements were carried out during the project according to the GA. All measurements were completed by 13.5.2022:

- **Karhula foundry**, Finland: steel foundry (organic phenolic Alphaset binder system). Both emission and indoor air quality measurements.
- **URV foundry**, Finland: iron foundry (organic phenolic Alphaset binder system). Only emission measurement.
- **Valumehaanika foundry**, Estonia: iron foundry (organic phenolic Alphaset binder system). Emission and indoor air quality measurements from organic Alphaset binder system and two inorganic binder systems.
- **KSM Castings**, Germany: aluminium foundry (inorganic binder system). Emission and indoor air quality measurements.
- **Stavanger Steel**, Sweden: steel foundry (water glass inorganic binder system). Both emission and indoor air quality measurements.

B2.1 Emission measurements in 3 inorganic and 2 organic pilot foundries

URV foundry (organic binder system): Emission measurement was carried out at URV iron foundry in 29-30th of January 2019. *URV uses organic binder and they have phenolic Alphaset sand system.* There are several odour emission sources in foundries and the emissions were measured from all process stages (moulding shop, pouring, casting hall, shake-out, finishing line, painting hall and sand regeneration, see figure 5).



Nr	Measuring point	Use	Measurements 2019
1	Molding shop, roof fan 99TK01 PF02	on use	measured
2	Molding shop, fire hood	on use	measured
3	Molding shop, roof fan 99TK01 PF03	not on use	
4	Molding shop, roof fan99TK01 PF03	not on	
5	Core cannon, amine scrubber	on use	measured
6	Sand silos Gietart-filter	on use	measured
7	Exhaust air from the induction furnace	on use	measured
8	Exhaust air from the induction furnace	on use	taking into account in calculation
9	Hood on top of the induction furnace	on use	taking into account in calculation
10	General exhaust air	not on use	no production
11	General exhaust air	not on	no production
12	Roof fan	not on	no production
13	General exhaust air from the casting hall	on use	taking into account in calculation
14	General exhaust air from the casting hall	on use	measured
15	General exhaust air from the casting hall	on use	taking into account in calculation
16	General exhaust air from the casting hall	on use	taking into account in calculation
17	General exhaust air from the casting hall	on use	measured
18	General exhaust air from the casting hall	on use	measured
19	General exhaust air from the casting hall	on use	taking into account in calculation
20	General exhaust air from the casting hall	on use	taking into account in calculation
21	Removal place hood and sand regeneration Wiser-filter	on use	measured
22	General exhaust air from the removal place	not on	
~~23~~	~~Sinkopuhdistin, suodatin~~	not exist	
~~24~~	~~Puhdistamo, suodatin~~	not exist	
25	Finishing, Ionblast-filter	on use	measured
26	Paint storage, roof fan 5 PK	on use	no production
27	Exhaust air from the paint storage 1PK2	on use	measured
28	Painting hall, roof fan 1PK3	not on	
29	Painting hall, roof fan 1PK4	on use	
30	Filter from finishing and sandblasting	on use	measured

Fig 5. Emission measurement points at URV

Results: In this measurement the emission limit values set in the environmental permit are followed. The result conclusions have been made in accordance with ILAC-guide (ILAC-G8:03/2009 Guidelines on the Reporting of Compliance with Specification). Results are in a line with the environmental permit regulations:

- Average particle concentration from exhaust air of induction furnaces (20,1 mg/Nm³) is within the limit value. Particle concentrations from other places are under the limit value.
- Average NO_x and CO concentrations from exhaust air of induction furnaces is clearly below the limit value.
- Average amine concentration from amine scrubber of core cannon is clearly below the limit value.
- PCDD/F-concentration from exhaust air of induction furnaces exceeds the limit value.

Deliverable: ***DeB2D Results of total emission measurements in organic binder system pilot foundry in URV in Finland.*** Delivered in Midterm report on 16.6.2020.

Karhula Foundry (organic binder system): Emission and indoor air quality measurements were carried out at Karhula foundry on 24-25th of July 2019 (Fig 6). *Karhula foundry uses organic phenolic Alphaset binder sand system*. Karhula Foundry Oy is ferrous foundry that produces demanding cast components for process industry, mining, marine, energy and general engineering. The production began at Karhula in 1880's. Foundry produces high alloyed steels such as duplex, martensite, ferritic and austenitic stainless steel, super-austenitic steel, heat, wear and corrosion resistant steels and low alloyed steel. The cores are made by using Alphaset, Betaset or Cold-Box binder systems. All these methods are based on phenolic resin binders.

Fig 6. Emission and odor measurements at Karhula foundry in April 2019.

Results: There are only particle concentrations set in the environmental permit for Karhula foundry. But all other compounds were still measured during the Green Foundry LIFE emission and indoor air quality measurements.

Based on the emission measurements, the particle concentrations did not exceed the limit values. Particles from melting shop, vibrator, core making, cooling line/pouring line and sand reclamation were under the limit values. Highest particle concentration was measured in the sand reclamation 14,1 mg/Nm^3 (Table 5).

There are no limit value set for VOC emissions. VOC concentrations varied between 0,7-16,3 mg/Nm^3 in different measurement points. The highest VOC concentration was measured in cooling/pouring line (16,3 mg/Nm^3). Results presented in table below.

Table 5. Summary of the emission measurements at Karhula foundry.

Measuring points		Sand reclamation	Vibrator	Core making, before amine gas scrubber	Core making, after amine gas scrubber	Cooling line, pouring	Melting shop	**Total sum**
Date		24.4.2019	24.4.2019	24.4.2019	24.4.2019	24.4.2019	25.4.2019	
Flow rate	*Nm³/h*	48 577	35 759	8 747	8 747	23 337	54 782	
Particles								
Concentration	*mg/Nm³*	14,1	0,09	1,00		0,74	3,9	
Hourly emission	*kg/h*	0,68	0,0032	0,01		0,02	0,21	0,93
TVOC								
Concentration	*mg/Nm³*	2,4	1,3	0,7	0,7	16,3	0,2	
Hourly emission	*kg/h*	0,12	0,0	0,0	0,01	0,4	0,01	0,6
Formaldehyde								
Concentration	*mg/Nm³*	0,22	0,26	0,24	0,25	0,31	0,17	
Hourly emission	*kg/h*	0,01	0,01	0,00	0,00	0,01	0,01	0,04
Other aldehydes								
Concentration	*mg/Nm³*	<0,32	<0,41	<0,33	<0,87	<0,55	<0,19	
Hourly emission	*kg/h*	<0,015	<0,01	<0,00	<0,01	<0,01	<0,01	0,06
Phenol								
Concentration	*mg/Nm³*	0,02	<0,01	0,03	0,05	0,12		
Hourly emission	*kg/h*	0,001	<0,0002	0,0002	0,0004	0,003		0,005
Creosols								
Concentration	*mg/Nm³*	<0,02	<0,03	<0,02	<0,01	0,2		
Hourly emission	*kg/h*	<0,001	<0,001	<0,0001	<0,0001	0,005		0,01
SO_2								
Concentration	*mg/Nm³*	0,000	0,000	0,000	0,000	<0,35	0,32	
Hourly emission	*kg/h*	0,00	0,00	0,00	0	0,008	0,02	0,03

Table 6. Odor measurement results from Karhula foundry.

Measuring point	Odor consentration	air flow	Odor emission
	ou_E/m^3	m^3/s	ou_E/s
Vipration	28	9,9	278
Amine scrubber	40	2,43	97
Core makeing	38	6,48	246

Odors were measured from main sources, the vibration, amine scrubber and core making. Odor concentrations were rather low (Table 6).

Deliverable: ***DeB2C Results of total emission measurements in organic binder system Karhula Foundry in Finland.*** Delivered in Midterm report on 16.6.2020.

Valumehaanika (organic and inorganic binder systems measured for comparison): Emission and indoor air quality measurements were carried out at Valumehaanika foundry on 19-24.9.2021. Valumehaanika AS is a small iron foundry locating in Tartu, Estonia. The foundry has been established in 1966 and it has been recently renovated (Fig 7).

Fig 7. Overview of the foundry. At the back is the induction furnace and on the right the sand mixer.

The sand system at Valumehaanika is the organic phenolic Alphaset binder system. The moulds and cores are made by hand. Typical casting size varies between 5…100 kg, and the products are used in machines, generators, furnaces and other heating equipment.

Emission measurements were carried out with different binder systems (one organic phenolic binder and two inorganic binder systems) in order to compare the results between different binders. Same production volumes, products and process conditions were used for each of these three emission measurements. Each binder system was used for castings for the whole day and emission were measured. Same was repeated with other tested binder systems in following days. The aim of the measurements was to find out the concentration of components, emissions and concentrations in indoor air.

Following binder systems were tested and emissions measured:

1) Alphaset = organic phenolic Alphaset binder
2) Peak = inorganic Cast Clean S 27 binder and Cast Clean K4…K6 hardeners, made by Peak Deutschland GmbH and
3) Geopol = inorganic Geopol 618 binder and SA73 hardener, made by SandTeam.

Results: The weight of the iron castings was 800 kg in each measurement and the sand amount was about 5000 kg. Measurement arrangements were principally same in all three measurements. However, it has to be noticed that there were background concentrations in the foundry hall which effected the results. All unit process emissions were mixed in the room air because the foundry processes were in the same hall. The ventilation system was very primitive containing only a general ventilation (roof fans only). The binder system influence in the indoor air quality was affected by the unit processes (shake-out or demolishing activities) carried out in the same hall, and therefore the results were unillustrative and unclear.

Based on the results of the tests carried out with iron castings and using inorganic binder system, the total emission measurements demonstrated about 50% less emission concentrations compared to the organic binder. Emission measurement results from both the tested inorganic binders were similar. As a conclusion, emissions in the foundry were clearly reduced when implementing inorganic binders.

Deliverable: ***DeB2A Results of total emission and indoor air quality measurements in Valumehaanika foundry in Estonia.*** Delivered in Final report, ***Appendix 1***. This report replaces the original DeB2A Results of total emission and indoor air quality measurements in two inorganic binder system foundries in France. The other inorganic binder system foundry is KSMCasting which is presented below.

Emission and indoor air quality measurements at KSMCastings Hildesheim, Germany.
The KSM Castings Group manufactures components and systems made of aluminum and magnesium for the automotive industry in modern casting and manufacturing processes and under the observance and being conscious of the strictest environmental standards.

KSM Castings in Hildesheim has a gravity die casting foundry using sand moulds and cores (Fig. 8). The foundry products are aluminium castings for automotive, eg. engine exhaust manifolds and engine cover blocks. The sand binder system is *inorganic: Cordis + Anorgit, produced by Hüttenes & Albertus*. Cordis is a binder system based on a silicate solution and is used in conjunction with the inorganic Anorgit additive (two-component system). Hardening takes place by heating to a temperature of 150...200 ^{o}C either by hot gas blowing or by using ovens.

KSM Hildesheim's casting line consists of an automatic 8-seater carousel (Fig 9). The cores are installed into the mould halves by robots and the moulds are assembled before casting. Robots dispense the required amount of melt for each mould into the pouring ladle and pour the melt into the moulds. After solidification, the moulds are broken and the castings are moved to the finishing area.

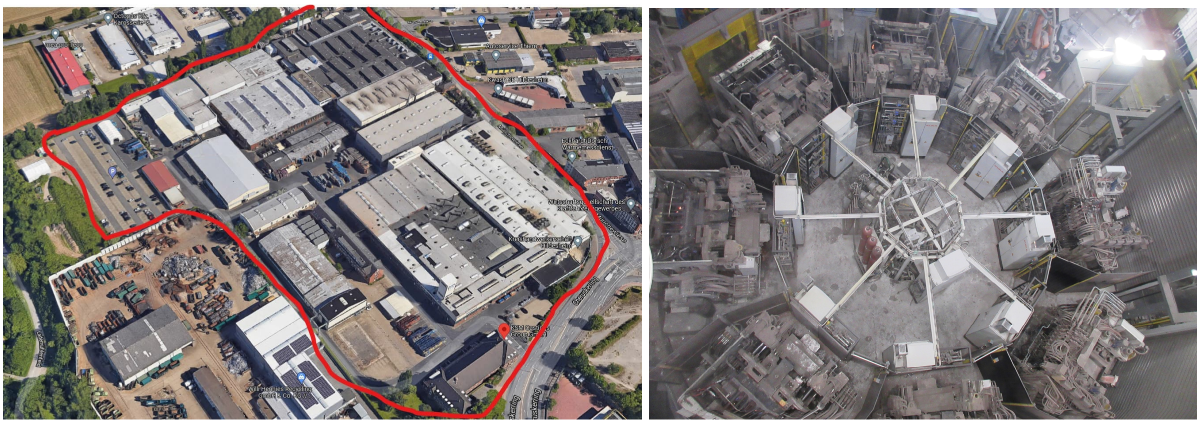


Fig. 8-9. KSMCastings in Hildesheim, Germany and the automated carousel.

Results:
Emission and indoor air quality measurements were carried out on 8-10th of March 2022 by AX and Meehanite. The emissions were measured from the roofs, Fig. 10


Fig 10. Measurements on the roof.

As a conclusion, it can be stated that all gaseous emissions were very low. Main reason for low gaseous emissions is the inorganic binder system used in KSM, Hildesheim.

The majority of emissions are released into the outside air through sunroofs. Particulate emissions are calculated from the concentrations measured in front of the filter and in order to find out the degree of filtration, also after the filter. The cleaning efficiency of the Donaldson fiber filter installed in the exhaust air of the discharge site was found to be excellent 99.97%. Summary of the results are presented in the Table 7.

Table 7. Results of the emission and indoor air quality measurements at KSMCastings, Hildesheim.

Measuring point		Vibration	Roof openings
Binder type		Inorganic	Inorcanic
Emissions per casting quantity (mg/kg)	Particles	58.1	7.3
	Total VOC	0.2	3.4
	BTEX	0.01	0.4
	Ethanol	0.00	0.2
	2-Propanol	0.00	0.1
	Phenols	0.01	0.1
	Cresols	0.01	0.1
	Asetaldehyde	0.001	0.1
	Formaldehyde	0.001	0.4
	Carbon monoxide		73
	NOx		18.0
	SO2		6.1
Emissions per sand quantity (mg/kg)	Particles	11.3	1.4
	Total VOC	0.05	0.66
	BTEX	0.002	0.07
	Ethanol	0.001	0.04
	2-Propanol	0.001	0.03
	Phenols	0.002	0.01
	Cresols	0.002	0.01
	Asetaldehyde	0.0001	0.02
	Formaldehyde	0.0003	0.07
	Carbon monoxide		14.2
	NOx		3.5
	SO2		1.2

Deliverable: ***DeB2A Results of total emission and indoor air quality measurements in inorganic binder system foundry in Germany, Appendix 2.*** Delivered in Final report.

Stavangel Steel (inorganic water glass binder system):
Stavanger Steel AB is a steel foundry located in Norrhult, Sweden. Stavanger Steel is a small steel foundry employing some 30 employers. The production of the foundry has recently been 300 - 500 ton a year, the technical capasity of the fasilities is some 1.000 ton per year. The steel qualities of the foundry are ferritic steel, austenitic and martensite steel, duplex and superduplex steel, in addition to tempered steel. The weights of castings varies from 5 to 1500 kg.

The casting is based on hand forming using quartz, chromite and recycled sand. The recycling rate was about 70 %. The bonding agent used was based on natrium silicate water glass Na_2SiO_3

that can be regarded as inorganic binder. Emission and indoor air quality measurements were carried out on 10-12.5.2022.

Results:
During the measurements the production took place in one shift with amounts of melting 2 500 ton and of good castings 1 700 ton. The melting, pouring and cooling were made in the melting shop where the emissions were measured as well.

All exhaust air from the foundry was collected into one fiber filter, fig 11.
The shake out site and fettling are in separate buildings and each has its own exhaust air filter (fig 12). The particle cleaning efficiency rate of the shake-out filter was measured and fettling shop particle concentration after filter was measured too.


Fig. 11-12 Foundry fiber filter and shake-out fiber filter.

Based on the results as inorganic resin was used, all gaseous emissions were low. Aldehydes, phenols and cresols were not measured because they do not occur in inorganic resins (Table 8). Foundry fibre filter cleaning efficiency was very high 99,8 %.

The carbon monoxide concentration in the exhaust air always increased during casting and varied between 5...30 ppm. VOC concentrations remained low due to the inorganic resin used. The VOC compounds contained a little ethanol, which probably comes from the coating.

Table 8. Summary of the concentrations and emissions in exhaust air at Stavanger Steel foundry.

Measuring point		Before Foundry filter
Binder type		Inorganic
Emissions per casting quantity (mg/kg)	Particles	412
	Total VOC	10.0
	BTEX	0.3
	Ethanol	4.5
	2-Propanol	4.0
	Carbon monoxide	326
	NOx	26.1
	SO2	28.2
Emissions per sand quantity (mg/kg)	Particles	82
	Total VOC	2.00
	BTEX	0.06
	Ethanol	0.89
	2-Propanol	0.80
	Carbon monoxide	65
	NOx	5.2
	SO2	5.6

Deliverable. ***DeB2B Results of total emission and indoor air quality measurements in water glass foundry in Sweden.*** Delivered in Final report, ***Appendix 3***.

<u>Conclusion of the total emission measurements carried out in 5 pilot foundries:</u>
The table 9 has been calculated from the specific emissions of different compounds proportionately to the use of foundry sand. The results have been calculated for the organic binders from three measurements carried out at URV, Karhula foundry, Valumehaanika foundries and for the inorganic binders from three measurements carried out at Valumehaanika (two different inorganic resins), KSMCastings and Stavanger Steel foundries.

From the results can be concluded, that emissions are thousands of times higher for organic binders for several components.

Table 9. Average specific emissions calculated from the emission measurement results in relation to the use of sand.

Binder	organic	inorganic
	Emission per sand	
Compound	mg/kg sand	
Particles	3 084	74,1
TVOC	1 232	3,1
Formaldehyde	88,7	0,14
Other aldehydes	139	0,08
Phenol	9,9	0,05
Creosols	15,8	0,08
CO	26 078	107
SO_2	56,7	7,3

To make any comparison between the results is difficult, because the foundry processes and ventilation systems are very different. Yet, the difference is still significant.

B2.2 Indoor air quality measurements in pilot foundries in 3 inorganic and 1 organic pilot foundries

Occupational hygiene:
According to the International Occupational Hygiene Association, the term occupational hygiene refers to the discipline of anticipating, recognizing, evaluating and controlling health hazards in the working environment with the objective of protecting worker health and well-being and safeguarding the community at large. Occupational Hygiene can also be defined as the practice of identifying hazardous agents; chemical, physical and biological; in the workplace that could cause disease or discomfort, evaluating the extent of the risk due to exposure to these hazardous agents, and the control of those risks to prevent ill-health in the long or short term.

Exposure agents can be examined by measurements and the health risks are evaluated in respect, in this case, to guideline values presented in the current Finnish legislation, such as HTP (*Haitalliseksi Tunnettu Pitoisuus* i.e. "*Known Harmful Concentration*") values provided by the Finnish Ministry of Social and Health Services. The Finnish reference values, as well as the Finnish legislation concerning occupational hygiene in general, are aligned with EU legislation (for example IOELV and BOELV). The occupational hygiene measurements were executed and evaluated according to SFS-EN:689 (2018)[1], SFS-EN 481:2001[2] and SFS 3861:2000[3] -standards.

Karhula (organic binder system): Occupational hygiene measurements were carried out on 24-25th of April 2019 during the normal foundry production (fig 13). Measurements were done in the production area of the foundry's Cold-Box -method core making unit, the pouring/cooling line and the large vibrator/shake-out machine. Measurement staff selected the most suitable and representative measurement points in co-operation with the foundry staff.

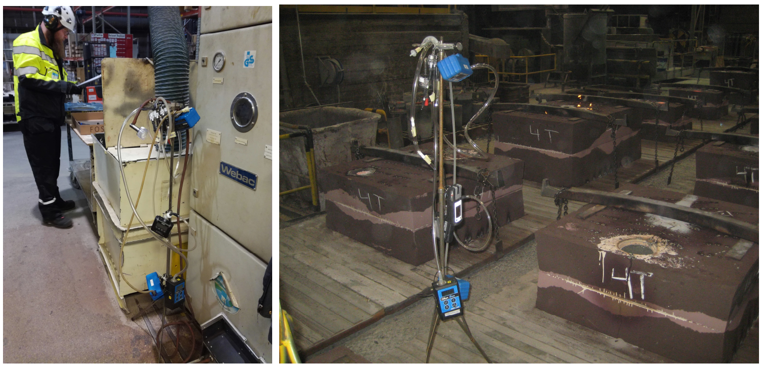


Fig 13. Indoor air quality measurements at Karhula foundry.

Results: In most parts, worker exposure levels are relatively low, with levels below 10% of HTP values. The exception is formaldehyde, the HTP value of which is exceeded by vibrating and carbon monoxide with an HTP value exceeded in casting. The particle concentration in the formula is also moderately high at 35 % of the HTP. Inorganic dust concentrations were measured in core making/cold-box and large vibrator/shake-out -machine working stations. Inorganic dust is not significantly present in pouring/cooling line. Measurement results are presented in Table 10.

Table 10. Measured organic dust concentrations.

Measurement Point	Measurement			Measured concentration	Percentage of HTP(8h)-value
		start	stop		
	date	*time*	*time*	*mg/m³*	*%*
Core Making/Cold-box	24.4.2019	8:19	14:50	0,4	4
Vibrator/Shake-out	25.4.2019	7:44	12:04	1,5	15

Measurement Point	Measurement			Measured concentration	Percentage of HTP(8h)-value
	date	start *time*	stop *time*	*mg/m³*	*%*
Core Making/Cold-box	21.1.2020	7:46	14:35	0,49	5
Vibrator/Shake-out	21.1.2020	7:49	14:36	0,48	5

Fine quartz dust concentrations were measured in core making area during the making of large cores as part of previous occupational hygiene measurements done on February 19th 2019 by AX-Consulting. Measurement results are presented in Table 11.

Table 11. Measured fine quartz dust concentrations

Measurement point	Measurement			Measured concentration	Percentage of HTP(8h)-value
	date	start	stop		
		time	*time*	*mg/m³*	*%*
Core making	19.2.2019	8:09	14:49	0,0075	15
Core making, area	19.2.2019	during active work		0,0177	35

Measurement Point	Measurement			Measured concentration	Percentage of HTP(8h)-value
	date	start	stop		
		time	*time*	*mg/m³*	*%*
Core Making/Cold-box	21.1.2020	7:46	14:35	0,0069	14
Vibrator/Shake-out	21.1.2020	7:49	14:36	0,0069	14

Valumehaanika foundry (both inorganic and organic binder systems measured for comparison):
Organic phenolic Alphaset binder system particle concentrations in indoor air was two times higher than on the two inorganic binders. BTEX compounds emissions were approximately three times higher on organic Alphaset binder than on inorganic binders. VOC concentrations were almost the same with inorganic Geopol binder and with organic Alphaset binder and lowest with inorganic Peak binder. This is mainly due to ethanol and 2-propanol, which come from the coating not from binders.

Formaldehyde concentration was three times higher on Alphaset resin than inorganic resins. Also fine quartz dust concentrations were exceeded by Alphaset binder waste sands (limit value for 8 hours is 0,1 mg/m3), Table 12.

Table 12. Measured fine quartz dust concentrations in indoor air at Valumehaanika (organic and 2 inorganic binder systems).

Binder	Measurement			Measured concentration	Part of limit(8h)-value
	date	start *time*	stop *time*	*mg/m³*	%
Alphaset	21.9.2021	11:00	12:49	0,18	358
Peak	22.9.2021	11:14	12:48	0,07	135
Geopol	23.9.2021	12:09	13:39	0,08	152

KSMCastings foundry (inorganic binder system):
Indoor air measurements were not made at ground level, because the large outer doors of the foundry were mostly open. In this case, the measurement result would have reflected the concentration of the outdoor air. In addition to emissions, the concentration measured from the roof hatches describes also the worst possible indoor air concentrations.

The need for personnel in casting area is minimal, and the exposure to possible emissions is very low. Therefore, the exposure measurements for individual workers were not made.

Results are described under subaction **B2.1 Emission measurements in 3 inorganic and 2 organic pilot** foundries, Table 7. Results of the emission and indoor air quality measurements at KSMCastings, Hildesheim.

Stavanger Steel foundry (inorganic binder system):
As an inorganic resin was used in the foundry all gaseous emissions were low, see Table 8 Summary of the concentrations and emissions in exhaust air. Also particle and fine dust quartz concentrations were quite low, table 13 and 14.

Table 13. Measured indoor air particle concentration.

Measuring Point	Measurement			Measured concentration
	date	start *time*	stop *time*	*mg/m³*
Foundry	11.5.2022	8:10	13:49	1,02

Table 14. Measured indoor air quartz dust concentrations.

Measurement Point	Measurement			Measured concentration
	date	start *time*	stop *time*	*mg/m³*
Foundry	11.5.2022	8:16	13:49	0,06

The carbon monoxide (CO) concentration during casting were quite high. On average, the concentration was about 30 ppm. During casting, the CO concentration rose up to 90 ppm (fig

14).

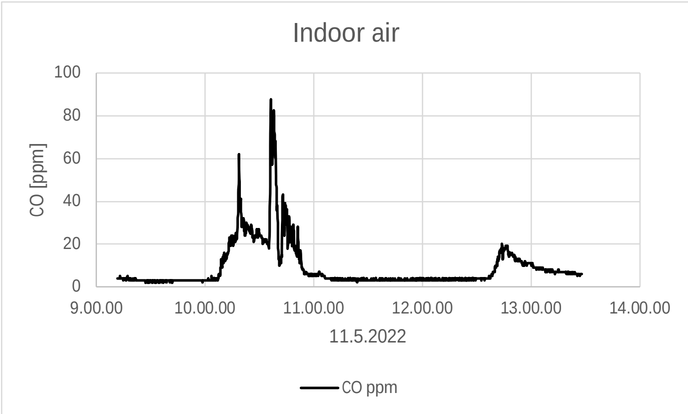


Fig 14. CO concentration in indoor air.

<u>Conclusions of the indoor air quality measurements carried out in 4 pilot foundries</u>:

The most significant compound of organic binders, which are polluting the indoor air in foundries, is formaldehyde. It origins from the organic binder itself.

Other significant compounds are carbon dioxide, quartz, and particulates, but they are a problem for all foundries, regardless of binder.

Table 15. Measured indoor air concentrations of pilot foundries.

Compound	Karhula		URV		Valumehaanika		Valumehaanika		Valumehaanika		KSM		Stavange Steel		HTP(8h)-value
	organic Alphaset	Percentage of HTP(8h)-value	organic Alphaset	Percentage of HTP(8h)-value	organic Alphaset	Percentage of HTP(8h)-value	inorganic Peak	Percentage of HTP(8h)-value	inorganic Geopol	Percentage of HTP(8h)-value	inorganic	Percentage of HTP(8h)-value	Inorganic	Percentage of HTP(8h)-value	
	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3
Particles	0,71	7		-	3,95	39	1,70	17	2,20	22	0,42	4	1,02	10	10
TVOC	22,7	-		-	4,30	-	3,17	-	4,43	-	0,19	-	0,79	-	
BTEX	0,24	-		-	1,54	-	0,36	-	0,38	-	0,02	-	0,02	-	
Formaldehyde	0,32	87		-	0,18	49	0,00	0	0,00	0	0,02	6		0	0,37
Other aldehydes	0,17	-		-	0,99	-	0,38	-	0,23	-	0,01	-		-	
Phenol	0,00	0		-	0,12	1	0,08	1	0,05	1	<0,004	0		0	8
Creosols		-		-	0,28	-	0,16	-	0,08	-	<0,004	-		-	
CO	23,4	102	25,2	110	55,5	241	62,5	272	56,9	247	4,19	18	35,7	155	23
SO2		-		-	0,2	15	2,74	211	2,69	207	0,35	27	2,22	171	1,3
Quarts	0,03	51		-		-		-		-		-	0,06	117	0,05

It is difficult to make a comparison between the binders because the foundry processes and ventilation systems are very different. Yet, the difference is significant.

For some foundries, where applicable, concentrations measured at emission points have been used, if it can be assumed that they are the same as in the indoor air otherwise.

There is not any HTP value for the total VOCs, but in general the HTP values of various hydrocarbons are high, and not any of these compound concentrations exceede the HTP value (table 16).

Table 16. A set of HTP values for VOC compounds.

Volatile Organic Compound (VOC)	HTP (8h) -value	HTP (15 min) -value
	mg/m³	mg/m³
Ethyl acetate	730	1470
Ethanol	1900	2500
Acetone	1200	1500
Styrene	86,0	430,0
Toluene	81	380
Butanes	1900	2400
Ethyl benzene	220	880
2-Ethyl-1-Hexanol	5,4	
Xylene	220	440
Methyl acetate	610	770
2-Butanone		300
2-Propanol	500	620
Other VOCs (heptane)	1200	2100

Deliverables:
DeB2C Results of indoor air quality measurements in organic binder system Karhula Foundry in Finland. Delivered in Midterm report on 16.6.2020.
DeB2A Results of total emission and indoor air quality measurements in Valumehaanika foundry in Estonia, Appendix 1 (inorganic and organic binders measured). Delivered in Final report. ***(***Replacing the deliverable of DeB2A Results of total emissions and indoor air quality measurements in two inorganic binder system pilot foundries in France).
DeB2B Results of total emission and indoor air quality measurements in water glass foundry in Sweden. Delivered in Final report, ***Appendix 3.***
DeB2A Results of total emission and indoor air quality measurements in inorganic binder system foundry in Germany. Delivered in Final report, ***Appendix 2. (***Replacing the deliverable of DeB2A Results of total emissions and indoor air quality measurements in two inorganic binder system pilot foundries in France).

There were delays in this Action B2. All planned 5 pilot foundry emission measurements were completed by 13.5.2022. All planned 4 indoor air quality measurements were completed by 13.5.2022.

6.1.5. B3. Test series of mould, cores and casts produced by inorganic and organic binder systems

Foreseen start date: 1.1.2019 Actual start date: 1.11.2018
Foreseen end date: 30.6.2022 Actual end date: 15.4.2022

In this action test moulds and cores were made with different inorganic binder systems at Karhula Foundry in Finland, Valumehaanika foundry in Estonia and FOM Tacconi foundry in Italy. Tests moulds and cores were used for the producing production scale series of test castings representing typical products of the foundries.

Karhula: The aim in Karhula was to produce in production scale steel casting with different inorganic binders. **Three inorganic binder systems were demonstrated**. According to GA it was promised to carry out 3 series of 4 tons, 15 tons and 20 tons of test castings with organic and inorganic binders. With the first tested inorganic binder system it was not possible to produce this size of test castings as planned because it requires drying in a furnace at elevated temperature of ca. 160…200 °C, to achieve the strength levels needed. Due to the small size of the furnaces available, the size of the moulds and cores was limited, and test castings with weight only up to 500 kg could be produced. It was decided more sensibly to make many tests series with smaller

castings to obtain more statistically significant results and experiences. Therefore, several test series with smaller sizes (max. 2500kg/piece) were produced also with two other inorganic binder systems. These inorganic binder systems are “self-setting”, it is they harden at ambient temperature without any need for heating or gas blowing. The hardener in these self-setting binder systems is organic ester solution.
Preliminary tests were made with all three inorganic binder systems to find the right contents of binder and promotor/hardener. Sand test pieces with different binder and promotor/hardener contents were produced and studied, and test blocks mould were made and cast with stainless steel. The production scale test castings were normal products of Karhula, Fig 15-16 are the typical test moulds and pouring arrangements.

Figure 15. Stainless steel test castings made by inorganic binder moulds and cores in Karhula.

Figure 16. Typical test moulds, left and pouring arrangements, right.

It was found gaseous emission formation was much smaller from the moulds made with all inorganic binders than moulds made with organic Alphaset, Fig. 17

Figure 17. Organic Alphaset mould, left, inorganic binder (nr. 3) mould, right

The quality of the castings was assessed both in Karhula Foundry and in CTIF and compared with the reference castings made by current organic binder system, phenolic Alphaset.
Surface quality was assessed by comparison test pieces and possible gas pinhole defects were inspected by dye penetrant method. No gas pinholes were detected in test casts made by inorganic binders, thanks to the very low gas emissions.

The sizes and total volumes of the test castings were:

- Test casts with inorganic binder system nr. 1: 30…500 kg, total volume 8,9 tons
- Test casts with inorganic binder system nr. 2: 15…1800 kg, total volume 13,9 tons
- Test casts with inorganic binder system nr. 3: 28…2500 kg, total volume 19,8 tons

Moreover, 39,2 tons reference test castings with current organic Alphaset binder system were produced. Lessons learnt and experiences are gathered below from all tests carries out. Names of the inorganic binders are not used since this information is classified upon the request of inorganic binder system suppliers.

Conclusions and lessons learnt from the tests at Karhula Foundry*:*

- It is possible to produce the moulds by the tested inorganic binder systems having the equal quality properties compared to the current organic phenolic Alphaset method
- The quality of the castings was as good as with the current products made by organic binder system moulds
- Inorganic binder systems which require heating to elevated temperature are not feasible for the current production, due to the risk of damaging of wooden or plastic core boxes and patterns, and prolonged production
- Self-setting inorganic binders can be applied in mould and core making with the current patterns and core boxes
- The implementation of inorganic binders in full scale production would require investment of separate mixer line because run-in on the inorganic binder line takes time and the entire production cannot be interrupted.

Withdrawal of Karhula Foundry*:* Karhula had to withdraw from the project 23.10.2020, due to financial reasons caused by Covid-19. Due to very promising results and to gain more experiences from inorganic binders a new pilot foundry, ***Valumehaanika*** in Estonia, was involved in the project. Amendment request nr. 2 was prepared for the change (together with one year prolongation of the project period**)** and accepted by Commission.

Valumehaanika: The aim in Valumehaanika foundry was to continue the missed tests in Karhula. Their current binder system is the same as in Karhula, phenolic Alphaset system. Modern continuous production mixer and hand moulding was used for the demonstrations (fig 18).

Figure 18. Moulding line in Valumehaanika, left and test moulds, right.

Valumehaanika had no equipment for heating or hot gas blowing of moulds and cores. Therefore, only self-setting or “no-bake” systems and the same binder systems as in Karhula (inorganic binder system nr. 2 and nr. 3) were used. **Two inorganic binder systems were** tested in the continuous mixer without any need for eg. pump changes.

Preliminary tests using with different recipes were carried out with both binder systems. Several small-scale test series were produced to find optimal recipes of binder and hardener for Valumehaanika production. Low ambient temperature in the foundry, 8..12 ^{o}C, slows the hardening and the “fastest” available hardeners were finally used.

Test casting were normal products of Valumehaanika. Cast material was grey cast iron, and casting temperature ca. 1450 ^{o}C (fig 19).

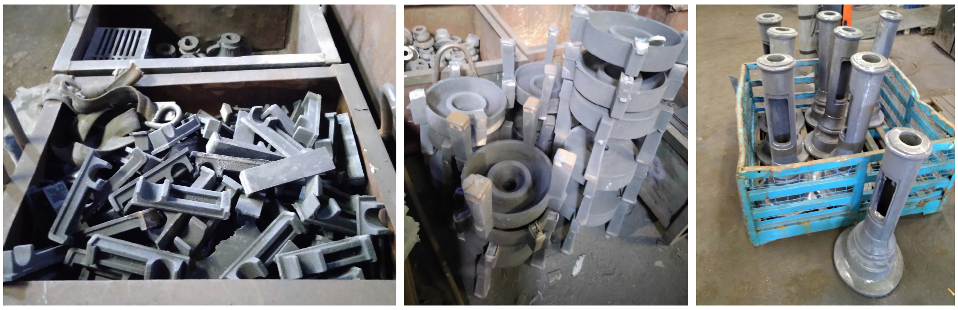


Fig. 19. Test castings made by inorganic binder systems in Valumehaanika.

Totally 19,7 tons of test castings with weight range of 20…550 kg were made by using inorganic binders and 16,5 tons of comparison castings made by using organic Alphaset binder system. The number of production-scale test series was significantly higher than planned at the GA due to smaller castings produced. In our experience, during the demonstrations, it made sense to do several sets of tests with smaller castings in order to obtain more statistically significant results and much more practical expertise.

Conclusions and lessons learnt from the tests at Valumehaanika:

- Self-setting inorganic binders can be used instead of organic Alphaset in continuous mixer lines
- The feasible recipe of the binders and hardeners is dependent on circumstances, eg. ambient temperature, in the foundry
- The quality of the castings was comparable with the casings made by current organic binder system
- Some stronger sticking of sand was experienced with inorganic binder systems. Longer shot blasting times solved the issue, but testing of different coatings is recommended
- Valumehaanika plans to invest separate moulding line for inorganics

FOM Tacconi (now Fonderie di Assisi):
FOM Tacconi produces both iron and steel castings for automotive industry, mainly parts for engines. **FOM Tacconi tested two inorganic binders in core making**. The cores were made by the sub-supplier, 2V srl which is a small factory making cores, including inorganic binder system cores for aluminium foundries. This company makes also classics cores with organic binders using shell moulding techniques for FOM Tacconi foundry. In this action they produced 320 inorganic cores for test purposes. Test cores were produced with 2 inorganic binder systems; with the same binder systems as tested in Karhula. For tests a very challenging product in term of complexity was chosen, to see better the results in difficult conditions (concerning small particular and turnings). During the core making, the cores were dried by gas and second time by the electric oven. Finally, cores were painted by immersion (Fig 20).

Fig. 20 Core making machine, left, coating of the cores, middle, and coated inorganic binder system cores, right.

The cores were transported to FOM Tacconi, and some of them were tested in foundry's chemical laboratory by lost of ignation method. The temperature was 900ºC and time 2 hours. Inorganic binder cores showed much lower gas formation than traditional organic binder system cores. For casting demostrations the cores were placed in green sand moulds and the moulds were casted in automatic GF Disa line. Casting material was gray cast iron GLJ 250 and casting temperature 1389°C (=standard process temperature), (Fig 21).

Figures 21. Test cores in green sand mould, left. Casting line and NOTICE BOARD during the test casts, right

Decoring operations and control check of casted parts were done by visual verification of the products just after knocking out. The scapping rate is normal for this complex casting with the organic binder system cores.

Conclusions and lessons learnt from the tests at FOM Tacconi:

- It is possible to produce same quality of cores with two tested inorganic binder systems as with traditional organic core making binder systems, even very complex form cores
- Inorganic binder system cores showed much reduced gas formation than organic binder cores. This it important, because up to 80% of gas formation in moulds are coming from cores
- The tested 100% inorganic binder systems require core shooters with heating equipment
- FOM Tacconi is considering investing in a separate core production line

Once the steel parts casted by the different partners, CTIF carried out several analyses and tests for Action B3, concerning the impact of tested inorganic binder system sands on the quality of steel castings. following tests were carried out:

- Determination of roughness indices of the castings by the different partners,
- Measurement of gas contents (on parts) that can be generated by the sand and

- Structural investigations on samples taken from the parts to check the absence of defects due to exogenous gas generated by the sand.

As a summary of all the tests carried out, the behaviour of the inorganic sands used by the project partners does not have a negative impact, as far the quality of the steel castings produced is concerned. Detailed results describe in deliverable *DeB3D Quality analyses of test casts carried out in the pilot foundries _ CTIF, attached the Final report.*

Deliverables in this Action:
DeB3A Test casts produced by inorganic binder systems at Karhula Foundry and Valumehaanika, Appendix 4. Combined reports with Karhula Foundry and Valumehaanika test casts results in the Final report.
DeB3B Test cores produced by inorganic binder systems in Italian pilot foundry, Appendix 64. Delivered in Final report.
DeB3C FOM Tacconi and Karhula Foundry implementing the inorganic binder system in everyday practices*, *Appendix 5. Combined reports with Karhula Foundry and FOM Tacconi evaluations. Delivered in the Final report.
DeB3D Quality analyses of test casts carried out in the pilot foundries _ CTIF, Appendix 6 (ADDITIONAL). Delivered in the Final report.

This action was completed successfully in spite of the withdrawal of Karhula foundry.

6.1.6. B4. Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dust

Foreseen start date: 1.1.2019	Actual start date: 1.10.2018
Foreseen end date: 31.12.2020	Actual end date: 31.5.2022

This action was successfully completed in spite the delays.

B4.1. Cleaning by composting method

The aim in the composting method was to degrade the harmful organic substances of surplus foundry sand (*PAHs, phenols, BTEX, DOC, TOC and fluoride)* and produce clean Fertiliser Product (soil material) suitable for green construction and landscaping purposes.

Currently natural sand is mixed with the composting material in the end of the composting process. By adding the foundry waste sand in the beginning of the composting process the harmful organic substances will be degraded by microbiological activity during the process. This is a win-win situation for foundries to avoid paying high deposit fees and for composting companies to replace the natural sand by using foundry sand in the soil material.

The clean soil material must meet the limit values set in the *Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011): Substrate – Mixture soil material (5A2).* This regulation sets limit values and demands for heavy metals, pathogens (Salmonella and E. coli) and impurities (weeds, garbage). When using foundry waste sand instead of natural sand, the end product must also meet the limit values set for heavy metals according to the *Government Decree of landfills (331/2013).*

Composting tests were carried out in Finland and Spain with different inorganic and organic binder system foundry waste sands and dust specimens.

Finland: Composting tests at Tarastenjärvi waste treatment center (fig 22). In the GA no composting heap size or waste sand amount was written but it was planned that each composting

test heap will be average 20 tons and sand /dust proportion 20-30%. In the GA it was written that in total 6 composting test heaps will be tested in Finland.
IN Tarastenjärvi site the first two test heaps were constructed of phenolic waste sand and tests started on 24th of July 2019 and ended on 11th of June 2020. The size of test heaps were app. 20 tons and waste sand proportion was 25% and 30%. Organic additives like manure and wood chips were added to the heaps. Third test heap was constructed on 11th of June 2020, using inorganic binder system waste sands transported from Karhula foundry. Size of the test heap was 11 tons and inorganic binder system waste sand proportion 16%. Because the concentrations of harmful substances of the inorganic waste sand were very low already in the beginning the tests, the composting period of 6 months was enough to degrade and clean the harmful substances. Composting tests ended on 30th of November 2020 because the permit was granted only for 12 months and also because Karhula Foundry withdrawed from the project and no waste sand was received.

Figures 22. Composting test heaps in Tampere site and sampling procedure.

The progress of the composting process was controlled by measuring temperature regularly. Composting material and wastewater analyses were collected in the beginning and end of the each test period.

The results from Tarastejärvi composting tests demonstrated that the end-product material met the limit values set in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011). Clean soil material was reused for landscaping purposes at the waste treatment center.

Eurofins was responsible for all the analyses. Eurofins consulted Meehanite throughout the project of the composting test results, composting progress and activities to be done to meet the limit values. The harmful substances were well degraded within 5-6 months.

Deliverable: ***DeB4.1A Composting method result of organic and inorganic surplus foundry sand and dust specimens in Finland (first pilot site in Tampere).*** Delivered in Midterm report on 16.6.2020.

Composting tests in new site in Northern Finland: Remaining composting tests were carried out in a new location in Iisalmi where also the permit for tests from local authority was applied 12.6.2019 and renewed on 24.8.2021.
First two small scale composting heaps were tested in June-December 2019 (fig 23). These tests were carried out at the **Peltomäki waste treatment center, Iisalmi**. Organic binder system furan sand system dusts were used in the composting tests. Size of the first two small scale test heaps were 20 tons and proportion of waste dust included was 25% and in second heap 30%.

Fig 23. Composting test heaps in a new site in Northern Finland.

The progress of the composting process was controlled by measuring temperature regularly and mixing the heaps during the composting period (fig 24). Composting material analyses were collected during the test period and mixed regularly to ensure the accurate oxygen level.

Temperatures increased rapidly above 60 degrees and stayed well above 50 degrees until September 2019 in both test heaps. This showed that the composting process was successful and the material fulfilled hygiene demands.

Fig 24. Temperature measurement and sampling procedure.

Results from two small size test heaps: The harmul substances of the foundry dusts were well degraded during the composting tests. There were challenges with the furan sand system low pH level of 3,5-3,6 and high content of sulphate. High Sulphate is origin from the hardener (toluene sulphone acid) which is used for hardening the sand moulds or cores in the foundry. Sulphate is a salt of sulphuric acid and it degreases during the composting process when accurate oxygen is present. Therefore the aeration and mixing of the heaps are needed. The results were promising and the harmful substances were well degraded. All limit values were met.

Industrial size composting test heaps:
Based on the good results the pilot foundry wanted to continue with industrial scale composting tests. Tests started in 11/2020 and ended in 05/2022. The size of these composting heaps were 91 tons and 182 tons. Dust proportion was about 25% (figures 25).
Aeration and heating system with pipelines were installed in the bottom of the composting heaps. Heaps were regularly mixed to ensure the adequate oxygen level needed for successful composting. All wastewaters from the composting field were collected into a container to avoid any leaks to environment. There were challenges with the low pH level and high amount of sulphates present in the size of the industrial scale composting heaps. Harmful substances were degraded but the high amount of sulphates present slowed down the maturing process. More tests were made in order to follow the progress of the composting process and aeration was increased. Due to the prolonging of the composting tests by 19 months, more analyses and tests were made than was planned (composting end date in the GA was 10/2020, actual end date 05/2022). This was unforeseen but necessary to complete the tests according objectives and actions in the GA. Eurofins made more work and analyses than planned and they exceeded their budgeted costs.

Fig. 25 Industrial scale composting test heaps in Northern Finland.

Results of industrial size composting heaps demonstrated that harmful substances as TOC, DOC, BTEX, fluoride and sulphate were well degraded and the end materials met the limit values. The degradation of the harmful substances is presented in the Table 17. The material was clean and mature and was used in landscaping of the noise embankment nearby.
Composting process has been found a cost-efficient option for degrading the harmful substances of foundry waste sands/dusts and reusing the clean soil material in new applications. The new pilot foundry is interested in treating and cleaning the waste dusts by composting method in future.

Table 17. Degradation of harmful substances of the organic binder system foundry surplus dusts in the industrial size composting heaps.

	Dust	Limit value for non-hazardous inert waste	Compost heap 1 (25%) START	Compost heap 2 (30%) START	Compost heap 1 (25%) END	Compost heap 2 (30%) END	Compost heap 1 (25%) Degradation efficiency	Compost heap 2 (30%) Degradation efficiency
TOC, % dm	12	3	23	25	20	20	13 %	20 %
DOC, mg/kg dm	2700	500	10000	9800	970	930	90 %	91 %
BTEX, mg/kg dm	7,38	6	2,60	2,50	0,30	0,29	88 %	88 %
Fluoride, mg/kg dm	36	10	17	12	8,9	8,9	48 %	26 %
Sulphate, mg/kg dm	3200	1000	3700	3500	2000	2000	46 %	43 %

Results of the composting tests in the new site in Northern Finland are reported in the deliverable: ***DeB4.1A Composting method results with organic binder system dusts in Finland*** (updated), ***Appendix 7***. Delivered in Final report.

According to the GA 6 test heaps will be tested in Finland and 4 test heaps in Spain. There were no volumes of the composting heaps nor the sand amounts used in the GA.

In total, 7 composting test heaps with the total volume of 480 tons of composting material were treated and cleaned **in Finland. In Spain 6 test heaps** were tested with the total volume of 120 tons. **In total of 114 tons of waste foundry sands and dusts were cleaned in composting process during the project in Finland and Spain**. All composting tests were successful and the soil materials met the national regulations and limit values. Tests were carried out according to the GA.

Spain: **Composting tests in Spain** were subcontracted by TECNALIA and all composting tests were carried out between March 2019 to February 2020. The composition of the heaps was as follows: from 4th March 2019 to 6th July 2019, two heaps with inorganic waste sand (from silicate moulding process) and two heaps with organic waste sand (from washed green moulding sand*). From 24th October 2019 to 21st of February 2020 two heaps with ecological inorganic binder system waste sand from cores from aluminium foundry. The weight of each test heap was approx. 20 tons, giving a total weight for the three pairs of heaps of 120 tons. Waste sand proportion was 20%. Note, in Spain no foundry uses ecological inorganic binder system sand for moulding making, only in core making.

*This sand was the last sand washed and supplied by Ecofond, a collaborator in the project, before they closed down as a business in 2018.

Separate composting heaps (sand plus organic matter) were formed with unwashed inorganic waste sand (from silicate moulding process), washed organic waste sand (from green moulding sand), and ecologic waste sand (from cores formed with ecological inorganic binder from moulding green sand for aluminum foundry). All sand types were mixed with organic material typically used in compost production (forest waste, wood chips from waste pallets, and in this particular case, animal manure) in specific proportions.

The composting tested were carried out at a compost plant named Composgune, in Ormaiztegui, in The Basque Country, northern Spain (fig 26). Composgune was there all permits, the test heaps were managed in accordance with pertinent legislation; Law 22/2011 and Law 5/2013 on waste and contaminated soil and Government Instruction AAA/661/2013 on waste landfill.

Chemical and biological analyses were carried out by Tecnalia and Tecnalabaqua (ENAC nº1116 LE2210) and Phytotoxicity tests were by Neiker.

Fig 26. Launch day of Green Foundry project and 4 heaps constructed in 2019.

Results: Three types of sand were analysed, green, silicate and eco, representing organic and inorganic processes. The sand came from three types of foundry; green sand used for automotive iron casting (organic), silicate sand used for railway steel casting (inorganic) and eco sand used for automotive and machine tool aluminium casting (inorganic).

The different types of sand behaved similarly throughout biodegradation. Eco sand (inorganic) and silicate sand (inorganic) are equally suitable for composting, as they give similar results. This means that regarding environmental matters foundries should choose any inorganic sand over organic sand. Both sand types are equally suitable for producing compost for use as fertilizer (both within pathogen limits). Washed green sand (organic) is suitable for use as a component of compost for use as fertilizer. There were no difference in the final results obtained from this washed sand compared to previous studies with equivalent unwashed green sand.

Deliverable: ***DeB4.1B Composting method results inorganic, organic surplus foundry sands and dusts specimens in Spain.*** Delivered in Midterm report on 16.6.2020.

This subaction was delayed by 19 months, but all composting tests were successfully completed according to the GA.

B4.2. Cleaning by thermal reclamation method

Technology Industries was responsible for test arrangements of thermal reclamation tests. These were carried out at Finn Recycling Ltd in Iittala, Finland which was originally planned and was according to the GA. According to the GA different types of organic (furanic, phenolic and green sand) and inorganic binder system waste sand from Karhula foundry test casts will cleaned by thermal reclamation method. In the project 2 inorganic waste sand specimens from Karhula foundry was tested and three organic binder systems. In total of 10 tons of waste sands were treated by thermal reclamation method.

Reclamation of foundry sands is a combination of techniques used to recycle the used sand back into the moulding process. A mechanical reclaimer is often used to break down the cast moulds and bound sand back into easily flowable form. While mechanically reclaimed sand can be used partially in the moulding process, another technique is needed when maximum circulation and usage of waste sand is desired. In thermal reclamation high heat is used to combust the remains of the binding agents surrounding the sand grains.

Thermal reclamation tests were done at Finn Recycling's existing thermal reclamation process plant in Urjala, Finland. The reclamation plant is commercially used for ester cured phenolic resin no-bake sands (APNB). The reclamation temperature i.e. the temperature of the sand leaving the thermal process was set to 650^{o} C, which is the set temperature used with APNB sands. The process line consists of the feeder, thermal reclamation oven and a cooling screw. See figure 27. Sand quality tests conducted were the Loss on Ignition (LOI) test and the 3-point bending strength test.

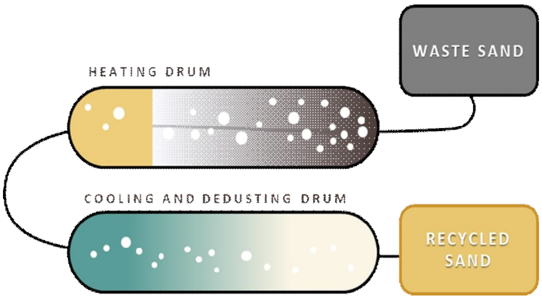


Figure 27. Principle of the thermal reclamation process.

Results:

Ester cured phenolic resin no-bake sand (APNB) (fig 28). APNB organic sands were certain kind of reference sands in this study. Loss of ignition is clearly under the set limit value 0,3 % and 3-point bending strength test results are in good level, about 200 N/cm2.

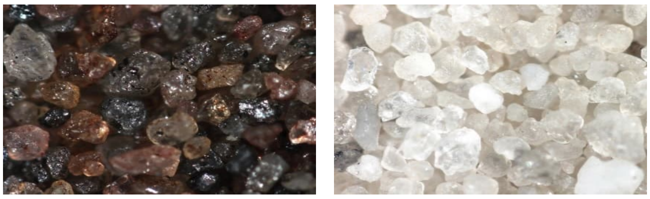


Figure 28. Stereomicroscopy photos of unreclaimed vs. reclaimed APNB sand.

Inotec inorganic sand. LOI values after reclamation were in the level of 0,2-0,3 %. The bending strength test results show that with only thermal reclamation no significant regeneration of the used sand with Inotec takes place if the process consists only of thermal reclamation.

Peak inorganic sand. LOI values after reclamation are in the good level of 0,03 %. Lower strength levels in the start of the hardening was noticed, but after 24 h hardening time the strength levels were in acceptable level.

Furan bonded organic sand. The reclamation results were good as expected, but the process needs a little more adjusting so that the bench and hardening times of the resulting reclaimed sands are equal to those of new sands.

Green sand. Green sand by its nature is problematic for thermal reclamation as its bonding system is based on bentonite clay. The loss on ignition of the sand was bit over 0.3% which is not perfect, but usable. Some cold-box cores were made with reclaimed green sand. The green sand thermal reclamation process needs further development.

In addition, wet attrition test was carried out which was not included in the original project actions but was necessary when testing and treating inorganic binder system waste sands. The used treatment method is specific combination of wet treatment and mechanical attrition. These tests were made to find possible interaction effects of this method and thermal reclamation treatment on the quality of reclaimed inorganic waste sand.

Summary:

The results of thermal reclamation on the different sand systems are summarized in the table below, table 18.

Table 18. Results of thermal reclamation on the different sand systems.

Binder system	**Results of thermal reclamation**
Peak	Small improvement
Inotec	Small improvement
APNB	Good results, in commercial use
Furan	Promising results as expected
Green sand (bentonite)	Thermal alone is not enough

The thermal reclamation method is most suitable for phenolic and furanic sand systems. Small improvements were only noticed with inorganic binder system waste sands, since there are less organic compounds present. In the future Finn Recycling will develop and rent small thermal reclamation units which are transported to foundries and they can treat the waste sands at the site. This way the foundries can save in transportation costs.

Deliverable: ***DeB4.2 Thermal reclamation test results with inorganic and organic surplus foundry sand specimens (updated), Appendix 8.*** Delivered in the 2nd Progress report (9.1.2021). Updated on 31.11.2021 with wet attrition test results, attached in the Final report.

The final thermal reclamations were delayed because of the Corona pandemic and because of waiting inorganic binder system samples from Karhula Foundry in 2020. There were also delays in reporting the wet attrition test results. Figure 29 of the test arrangements.

Figure 29. Project worker Kalle Kekäläinen during the reclamation tests in Finn Recycling production plant and thermal reclaimed Inotec inorganic sand after the cooling phase.

This subaction was delayed but completed as planned. Results of the tests carried out were good. Finn Recycling is negotiating with potential European investors and they are marketing the small unit plants to foundries e.g. in Germany.

B4.3. Cleaning by washing method

According to the grant agreement inorganic surplus foundry sands from Spanish aluminium foundries would have been transported to Ecofond plant and cleaned by washing method. Due to the closure of Ecofond company in September 2019, the washing tests were subcontracted by Tecnalia and planned chemical washing tests were carried out in Tecnalia laboratory. The tender procedure was carried out by ARABA partner according to the LIFE Grant agreement guidelines and Tecnalia was chosen to carry out the washing tests and to assist ARABA personnel in the composting tests. The tender procedure was attached the 1st progress report in 31.3.2019 (Annex 10).

The starting point for the formula and process were based on previous Tecnalia studies, however, for this method to be viable at an industrial level, Tecnalia focused on using readily available low-cost materials and equipment. In the GA it was written that 3 inorganic waste sand specimens from inorganic aluminium foundries will be tested by washing method. In these washing tests Tecnalia carried out washing tests with 4 waste sand specimens. ARABA was responsible for delivering the waste sands for washing test purposes.
Inorganic sands were able to get only from one steel foundry in Spain (point 1.). Therefore ARABA hade to make inorganic waste sand specifically dedicated to the project washing test purposes (point 2). Araba is an aluminium foundry and it does not normally use inorganic binders. ARABA uses green sand system usually. To obtain 500 kg inorganic waste sand for test purposes, specific work was carried out for the project (not usual work in the foundry) for which all products necessary to cast parts with inorganic binders were purchased. The sand residues were obtained and used for the tests and aluminium parts were made, as most of them were found to be defective. ARABA made several tests to produce good moulds with the inorganic binder sand. These additional costs are reported in their prototype costs. Parallel the inorganic waste sand washing tests, 2 organic green sand specimens were tested (points 3 and 4) as comparison according to the GA (specimens from an aluminium foundry and from the closed Ecofond company).

Four sand specimens tested in Tecnalia's washing tests:

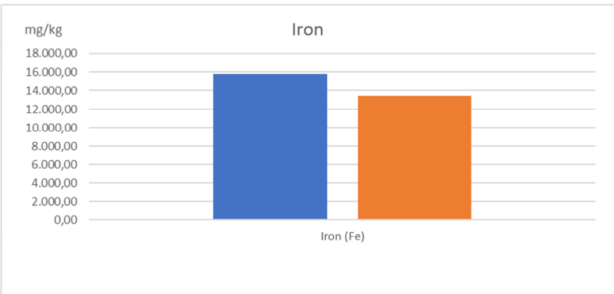
1. **Inorganic** binder system waste sand from a steel foundry casting for railway pieces
2. **Inorganic** binder system waste sand made by Fundiciones Araba foundry (ARABA does not normally use inorganic binders). ARABA produced moulds and cast parts with this type inorganic binder system sand for the project and made several tests with this type of sand in order to produce good moulds and good quality castings.
3. **Organic** from a green sand foundry from an aluminum foundry which cast for automotive pieces.
4. **Organic** from green foundry from the sand stored at Ecofond.

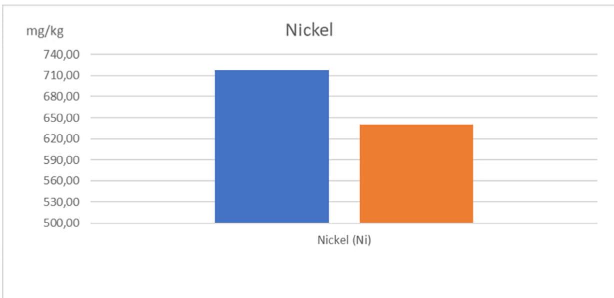
The principle of the washing method was that by using basic chemical products (5M hydrochloric acid and distilled water), the contaminated moulding sand could be washed cost-effectively and made reusable back in foundry processes. The quantities of unwashed sand started at 30 grams, and as the experiments progressed, the scale was up to 450 grams. In total, approx. 100 kilos of unwashed sand was used.

Test arrangements: Step one was to wash the sand with distilled water. This was then analyzed for pH and rewashed using fresh water until the level obtained by washing in water stabilized, i.e. no further reduction (fig 30). Once pH showed no further change, step two was to add the damp sand to an Erlenmeyer flask containing HCl. This was then mixed with a magnetic agitator for eight hours. The solution was then filtered to separate the surplus foundry sand from the acid, and the pH level of the sand was checked. The sand was then returned to an Erlenmeyer flask containing fresh HCl to repeat the washing, agitation and analyzing process until the desired pH range was obtained twice, i.e. no further change.

Fig 30. Washing sand test arrangements (washing and filtering the waste sands).

The final stage was to dry the sand using either a Mufla furnace or a microwave oven for 90 minutes (both giving the same result). The dry sand was then ready for full chemical analysis.





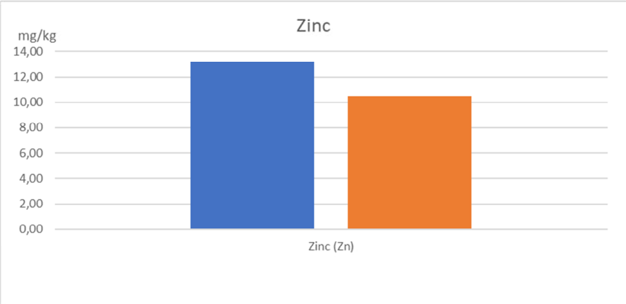


Fig. 31. Iron, nickel and zinc concentrations of inorganic binder system sands before and after the washing process.

Results: The diagrams above (fig 31) demonstrate the elements (iron, nickel and zinc) which were most reduced by the washing process of inorganic waste sand samples. The test results of washed green sand samples (organic binder system waste sands) demonstrated the reduction of DOC, TOC and BTEX compounds between 15-25%.
The process designed for this experiment proved to be successful in reducing residual metal contents in surplus foundry sands. In addition, pH was transformed to alkaline. Washing the foundry waste sands could extend its useful lifetime and the washed sand could be reused in foundry processes and reduce the need of virgin sand.
While the metal residuals were removed effectively, the high consumption of distilled water and the use of HCl (hydrochloric acid) as well as treatment of wastewaters reduces the ecological credibility of this option. High water consumption and costs of neutralizing system needed in the washing method would not be a wise solution on economical way. Also the environmental impacts as the treatment of process wastewaters must be taken into account. Technically this method is effective for cleaning the foundry waste sands. Further industrial scale tests are needed but based on the cleaning efficiency results obtained this method is proposed as Emerging Technique in the BAT evaluation.

Deliverable: ***DeB4.3 Washing test results of inorganic foundry surplus foundry sand specimens in Spain*****.** Delivered in Midterm report on 16.6.2020, updated with 450 g test results in 11/2020 as requested by Commission Midterm letter on 22/7/2020. ***Updated report attached as Appendix 66 in Final report.***

This subaction was successfully completed.

B4.4. Conclusion of the results of the waste sand cleaning methods

In this report the results of the three waste sand cleaning methods which were demonstrated in the Action B4 Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dusts are summarized. The cleaning methods in question were

- B4.1 Cleaning by composting method
- B4.2 Cleaning by thermal reclamation method
- B4.3 Cleaning by washing method

Cleaning by composting method: In the composting method the harmful substances are well degraded during the process due to the microbiological activity. In the end the clean mixture soil material is produced which can be reused as a green construction material. The results and experiences of the composting tests in this project demonstrated efficient degradation of harmful substance e.g. BTEX, DOC, phenols, fluoride and PAH compounds were degraded by 70..80%. The composting process needs a lot of room. As an example, to treat about 7000 tons of waste sand annually you need app. 1 ha (hectar) composting site. Also the wastewater treatment system has to be constructed or waste waters are conducted to municipal wastewater treatment center. During these tests the wastewaters were analysed and collected into a separate container and transported to local waste treatment center. There were no remarkable high concentrations in the wastewaters. Odours exist mainly in the beginning of the composting process and while mixing the heaps. The composting method is economically and environmentally viable method for cleaning the foundry waste sands and producing new side products as fertiliser soil material suitable for green construction method. This method is ready for uptake after the end of the project but pretests must be carried out in order to find suitable recipes for each waste sand type.

Cleaning by washing method: The washing tests were carried out on laboratory at Tecnalia Research&Innovation in Spain. There was a company in Spain that commercially cleaned foundry sands by washing method but this company was closed in 2019 due to economical issues. In general, the results of washed sand specimens of the laboratory tests were good. The cleaning efficiency varied from 17 % (copper), 53% (zink), 53% (chromium) to 65% (barium). But the high water consumption and costs of neutralizing system needed in the washing method would not be a wise solution on economical way. Also the waste waters have to be treated or conducted to municipal waste water treatment plant. This method needs more studies even though the cleaning efficiency results were promising.

Cleaning by thermal reclamation method: Reclamation of foundry sands is a combination of techniques used to recycle the used sand back into the moulding process. A mechanical reclaimer is often used to break down the cast moulds and bound sand back into easily flowable form. While mechanically reclaimed sand can be used partially in the moulding process, another technique is needed when maximum circulation and usage of waste sand is desired. In thermal reclamation high heat (650^{o}) is used to combust the remains of the binding agents surrounding the sand grains. The results of the tests were promising. This treatment method is more suitable for some sand types than to others. As a summary, this method is most feasible for organic Alphaset phenolic sand system and also for furan sand system. A full-size thermal reclamation plant itself is very expensive, and the transportation costs can be rather high for foundries. There will be also small treatment units available in the future in the market which can be transported from foundry to foundry. This reduced the transportation costs of the waste sands and could be a cost effective treatment solution for foundry using certain types of binder systems.

Deliverable: ***DeB4.4***. ***Conclusions of the results of waste sand cleaning methods, Appendix 65.*** Delivered in Final report.

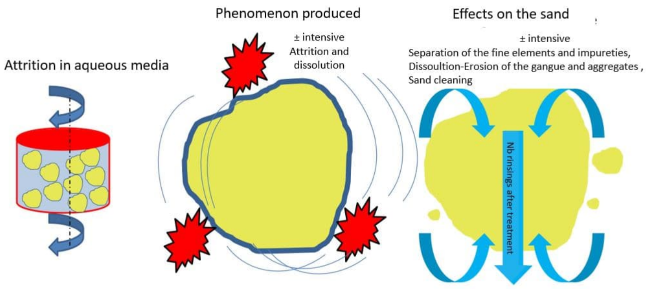
This subaction was completed as planned.

B4.5. Re-use options of inorganic waste sand in core making

The treatment processes selected for the Green Foundry Life project are those capable of cleaning inorganic waste sand to obtain the quality of treated sand to be sufficient for the reuse in foundries in moulding making and or core making, or for external reuse (geo-construction purposes).

In the GA it was planned that CTIF will conduct reclamation studies of inorganic waste sands by *combining ultrasonic and microvawe thermomechanical technologies* in aqueous media to make sand reusable in foundry for coremaking. The planned technology was not used because the test results carried out in another project were not promising. The planned tests were replaced by *hydromechanical and ultrasonic technologies* being the most efficient emerging technologies. From 2017 till 2019, CTIF developed a new platform dedicated to R&D and recycling tests of chemically bonded sands, with modules using mechanical, thermal, hydromechanical, ultrasonic and microwave technologies. At the end of 2019, the results of the work carried out by CTIF identified two effective emerging technologies for cleaning inorganic sand waste in order to reuse the treated sand in core making (hydromechanical and ultrasonic treated HA Cordis process). The comparison of the effects generated by the different treatments carried out in 2019 showed that microwave technology (used alone) is not effective. Based on this experience, CTIF decided in early 2020 to carry out the inorganic sand waste treatment tests for the Green Foundry Life project using hydromechanical and ultrasonic technologies to compare the results obtained with a conventional mechanical technology ***DeB4.5B Clarifications for withdrawing from the microwave and ultrasonic tests, Appendix 36.*** All planned tests were carried out according to the GA.

The processes of *hydromechanical and ultrasonic technologies* were selected and tested for comparison with a conventional *mechanical technology* which is currently used in the foundry industry (attrition mechanical process) (fig 32). Following inorganic binder system waste sand specimens were tested: GEOPOL, PEAK, INOTEC and one inorganic binder, IE.



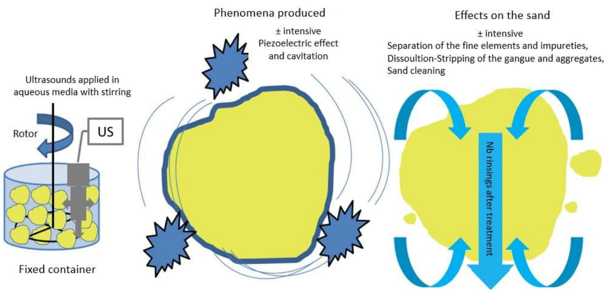


Fig. 32 Principle of **hydromechanical treatment** process Principle of **ultasonic treatment process**

Findings:
- No breakage of the sand grains in all cases,
- The sand is well cleaned in all cases,
- Only Inotec sand has a slightly higher acid demand.

Explanations:
- Phenomena produced and the effects generated by the treatment are particularly effective in cleaning inorganic sands,
- Slightly high acid demand for Inotec sand can be reduced by optimising the settings of the treatment module (rotation speed, treatment time, number of rinses).

Findings:
- No breakage of the sand grains in all cases,
- The sand is well cleaned in all cases,
- Only Inotec sand has a slightly high acid demand and a low quantity of clear unstained grains.
- Acid demand of one inorganic binder IE sand is also a bit high.

Explanations:
- Phenomena produced and the effects generated by the treatment are particularly effective in cleaning the inorganic sands (with however poor characterisation results of the treated sands, compared to the hydromechanical treatment process),
- Acid demands that are still somewhat high for Inotec and IE sands, can be reduced by optimising the settings of the treatment module (treatment time and number of rinses).

Results of the inorganic binder system waste sand treatment methods: Treatment trials were carried out with three technologies: hydromechanical technology, ultasonic technology and conventional mechanical technology (Tables 19-21).

Table 19. Results of the sand characterisation after *mechanical treatment*.

Laboratory checks on the sand samples	Ref SN BE01	INOTEC	CTIF IE	GEOPOL W37-20	PEAK W37
Fineness index	46	50	49	52	55
Distribution 50-70-100 (%)	95,03	92,00	94,68	90,27	90,75
Distribution 200-270-bottom (%)	0,18	0,92	1,04	1,89	2,28
Absence of residual aggregate (%)	0,00	0,00	0,00	0,08	0,04
Theoretical specific surface (cm2/g)	159	176	170	184	195
Breakage of sand grains observed under the light microscope (high/low/no)	no	low	low	significant	significant
Aggregate removal observed under optical microscope (yes/no)	no	yes	yes	yes	yes
Amount of fines produced by the treatment (no/low/significant)	no	significant	significant	significant	significant
Grain shape observed under light microscope (general trend: spherical/angular)	Spherical	Sph+Ang	Sph+Ang	Sph+Ang	Sph+Ang
Appearance of grains observed under the light microscope (general trend: smooth/rough)	smooth	smooth+Rug	smooth	smooth	smooth
Amount of black grains (general tendency: not/low/significant)	no	significant	low	low	low
Quantity of light-coloured grains with black spots (general tendency: not/low/significant)	no	significant	significant	significant	significant
Amount of light-coloured unstained grains (general trend: not/low/significant)	significant	no	low	low	low
Electrical conductivity of treated sand (µS/cm)	500 - 520	863	1262	997	842
pH of the treated sand	8,30 - 8,40	10,01	10,17	9,57	9,44
Acid demand of treated sand (ml HCL)	1,2 - 2,0	27,5	35,9	20,9	17,1
Samples retained for leaching test		X	X	X	X
Updated on 26/11/2021					

Table 20. Results of the waste sand characterization after *hydromechanical treatment*

Laboratory checks on the sand samples	Ref SN BE01	INOTEC	CTIF IE	GEOPOL W37-20	PEAK W37
Fineness index	46	49	47	48	49
Distribution 50-70-100 (%)	95,03	92,64	95,42	94,68	93,94
Distribution 200-270-bottom (%)	0,18	0,14	0,04	0,00	0,06
Absence of residual aggregate (%)	0,00	0,04	0,00	0,04	0,08
Theoretical specific surface (cm2/g)	159	172	160	169	172
Breakage of sand grains under the light microscope (significant/low/no)	no	low	low	low	low
Aggregate removal observed under optical microscope (yes/no)	no	yes	yes	yes	yes
Amount of fines produced by the treatment (no/low/significant)	no	low	low	low	low
Grain shape observed under the optical microscope (general trend: spherical/angular)	Spherical	Sph+Ang	Sph+Ang	Sph+Ang	Sph+Ang
Appearance of grains under the optical microscope (general trend: smooth/rough)	smooth	smooth	smooth	smooth	smooth
Amount of black grains (general trend: no/low/significant)	no	low	low	low	low
Quantity of light-coloured grains with black spots (general trend: no/low/significant)	no	significant	low	low	low
Amount of clear unstained grains (general trend: no/low/significant)	significant	significant	significant	significant	significant
Electrical conductivity of treated sand (µS/cm)	500 - 520	523	516	507	511
pH of treated sand	8,30 - 8,40	8,78	8,73	8,72	8,45
Acid demand of treated sand (ml HCl)	1,2 - 2,0	5,8	2,2	0,6	1,5
Samples retained for leaching test		X	X	X	X
Updated on 26/11/2021					

Table 21. Results of the waste sand characterization after *ultasonic treatment*

Laboratory checks on the sand samples	Ref SN BE01	InoEC	CTIF IE	GEOPOL W37-20	PEAK W37
Fineness index	46	50	47	49	50
Distribution 50-70-100 (%)	95,03	93,02	96,10	94,14	93,98
Distribution 200-270-bottom (%)	0,18	0,18	0,06	0,04	0,10
Absence of residual aggregate (%)	0,00	0,04	0,04	0,06	0,12
Theoretical specific surface (cm2/g)	159	176	162	171	175
Casse grains de sable observée au microscope optique (significant/low/no)	no	low	low	low	low
Sand grain breakage observed by optical microscope (significant/low/no)	no	yes	yes	yes	yes
Aggregate removal observed under optical microscope (yes/no)	no	low	low	low	low
Amount of fines produced by the treatment (no/low/significant)	Spherical	Sph+Ang	Sph+Ang	Sph+Ang	Sph+Ang
Appearance of grains under the optical microscope (general trend: smooth/rough)	smooth	smooth	smooth	smooth	smooth
Amount of black grains (general trend: no/low/significant)	no	low	low	low	low
Quantity of light-coloured grains with black spots (general trend: no/low/significant)	no	significant	low	low	low
Quantity of clear unstained grains (general trend: no/low/significant)	significant	low	significant	significant	significant
Electrical conductivity of treated sand (µS/cm)	500 - 520	525	521	515	518
pH of treated sand	8,30 - 8,40	8,76	8,77	8,79	8,58
Acid demand of treated sand (ml HCL)	1,2 - 2,0	7,5	4,5	1,5	1,6
Samples retained for leaching test					
Updated on 26/11/2021					

Treatment trials carried out with inorganic binder system waste sands demonstrated that hydromechanical and ultasonic technologies can be regarded as effective techniques in allowing the cleaned sand to be reused in foundry processes or geo-construction and road engineering purposes. However, the ultasonic treatment method is less efficient than the hydromechanical treatment method (comparing the values of acid demand, electrical conductivity and pH measured on the samples of treated sand: see the values in tables 20 and 21). Yet, the ultrasonic treatment method has a positive impact and is more efficient than the mechanical treatment, it's the reason why this method is also proposed as an emerging technology.
Nevertheless, these hydromechanical and ultrasonic treatment processes are not yet commercially available and they need to be tested on an industrial scale to verify whether these emerging technologies would be viable, compared to solutions using conventional technologies (mechanical, thermal, thermomechanical).

In order to verify if the cleaned inorganic binder system waste sands fulfilled the quality criteria for core making process, tests with "7 kg baches of waste sand" cleaned by hydromechanical process were used in core making processes since this treatment method gave the best results (fig 33).

Fig. 33 Coremaking tests with the inorganic binder system waste sands.

Results of coremaking tests: The strength of the cores made with the hydromechanically treated "CTIF IE" sand and the service life of the prepared sand are similar to those obtained with the new reference sand (BE01). The tests confirmed that the hydromechanical treatment process of inorganic waste sands was particularly effective for the reuse of treated and cleaned waste sand suitable in moulding or core making processes.

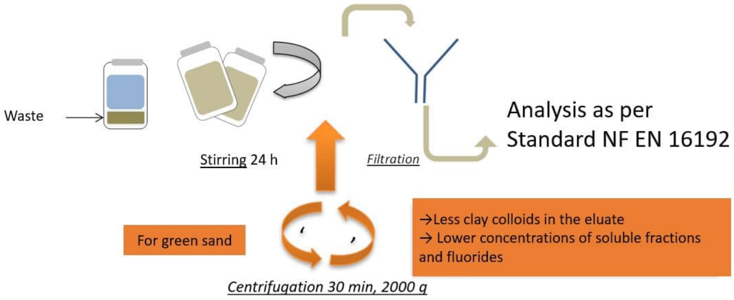
B4.6. Re-use of inorganic waste sand in geo-construction

According to the GA the application of the inorganic foundry waste sand in geo-construction will be demonstrated by leaching tests and evaluations will be compared with national regulations. This has been carried out according to the GA.
Once the steel parts were casted by the partners in the Green Foundry Life project, CTIF carried out leaching tests with the waste sand specimens from Karhula foundry and tests carried out at CTIF with different inorganic binders for clarifying the applicability of different inorganic waste sand types in geo-construction purposes in different countries.

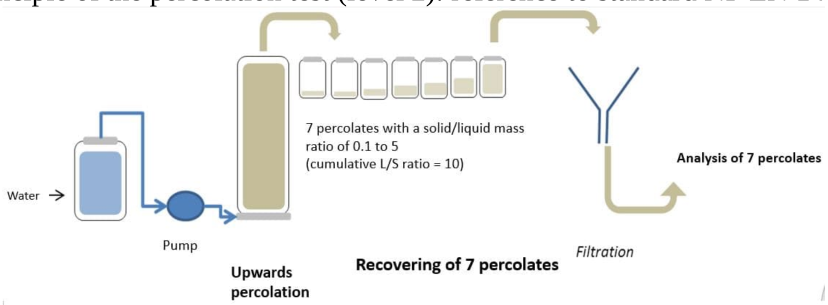
Leaching tests were carried out with 12 sand samples:

- Four samples of *untreated* inorganic waste sands (waste sands from CTIF test casts: IE, waste sands from Karhula Foundry test casts: GEOPOL W37, Inotec and PEAK W37)
- Four samples of treated inorganic sand, with the lowest results obtained after characterisation (batches from the *mechanical treatment process*)
- Four treated inorganic waste sand samples with the highest results after characterisation (batches from the *hydromechanical treatment process*).

The principle of the leaching test (level 1): reference to standard NF EN 12457-2



The principle of the percolation test (level 2): reference to standard NF EN 14405



Results of leaching tests: Based on results of the leaching tests carried out on the inorganic binder system waste sands (waste sands from CTIF test casts: IE and waste sands from Karhula Foundry test casts: INOTEC, GEOPOL W37-20 and PEAK W37) and taking into account the limit values provided by the project partners, the table below summarises all the possible reuse options for all the samples tested (tables 22-23).

In Finland there are different use categories for foundry waste sands as:

- Roadway, covered
- Roadway, paved
- Field covered
- Field paved
- Embankment
- Floor structure of industrial or storage building

In France there are three categories in the CEREMA guide “Environmental acceptability of alternative materials in road techniques – Foundry waste sand, in the case of reuse of waste sand as alternative material in road techniques.

- Type 1: Road uses of type 1 are uses up to three metres high in the sub-base of pavements or shoulders of the paved riad structures: backhill under structures; subgrade; sub-base course or base course and binder course
- Type 2: Road uses of type 2 are uses up the six metres in height in technical embankments associated with the road infrastructure (e.g. noise protection or landscape barriers) or in shoulders, provided that they are used within covered road construction.
- Type 3: Road uses of type 3 are those uses: as a roadway or shoulder sub-base, as a technical fill associated with the road infrastructure (e.g. noise protection or landscape barriers); in pre-fill backfill necessary for the construction of a road

infrastructure; in drainage systems (e.g. drainage trench or spur); construction roads;forestry roads; farming roads and haulage roads.

From other countries there were no options nor limit values available for foundry waste sands to be reused in geo-construction purposes. Only limit values for inert waste (foundry waste sands to be landfilled) were set for foundry waste sands.

Table 22: Possible reuse options for inorganic sands tested during the project in Finland.

Process	Options	Accepted in center	Use of the material in geo-contruction (document from Finlande)						
	Samples tested	waste inert	Roadway covered[1]	Roadway paved[1]	Field covered[1]	Field paved[1]	Embankment	Floor structure of industrial or storage building	Crushed stones and ash[2]
Untreated sands	INOTEC	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	CTIF IE	No	No	No	No	No	No	No	No
	GEOPOL W37-20	No	No	No	No	No	No	No	No
	PEAK W37	No	No	Yes	No	No	No	Yes	No
Mechanical processing	INOTEC	No	Yes	Yes	No	Yes	Yes	Yes	Yes
	CTIF IE	No	No	No	No	No	No	No	No
	GEOPOL W37-20	No	No	No	No	No	No	No	No
	PEAK W37	No	No	Yes	No	No	No	Yes	No
Hydro mechanical processing	INOTEC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	CTIF IE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	GEOPOL W37-20	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	PEAK W37	Yes except in Italie	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MAJ du 12.01.2022									

Table 23: Possible reuse options for inorganic sands tested during the project in France.

Process	Options	Accepted in center	Use of the material in road ingeneering (2019 Cerema guide France)		
	Samples tested	waste inert	Alternative material for type 1 use	Alternative material for type 2 use	Alternative material for type 3 use
Untreated sands	INOTEC	No	Yes	Yes	Yes
	CTIF IE	No	Yes	Yes	Yes
	GEOPOL W37-20	No	No	No	No
	PEAK W37	No	No	No	No
Mechanical processing	INOTEC	No	Yes	Yes	No
	CTIF IE	No	Yes	Yes	Yes
	GEOPOL W37-20	No	No	No	No
	PEAK W37	No	No	No	No
Hydro mechanical processing	INOTEC	Yes	Yes	Yes	Yes
	CTIF IE	Yes	Yes	Yes	Yes
	GEOPOL W37-20	No	Yes	Yes	No
	PEAK W37	Yes except in Italie	Yes	Yes	Yes
MAJ du 12.01.2022					

The above results showed that the waste from the inorganic sand "INOTEC" can be reused in all geo-construction and road engineering options. The waste sand from the inorganic sand "PEAK" is only reusable for two geo-construction options, and the waste from the inorganic sand "INOBAKE" (CTIF IE) can be reused for all road engineering options.

After mechanical treatment of these inorganic sand wastes, there are fewer options for reuse in geo-construction and road engineering. This showed that the mechanical treatment is inefficient.

Instead of cleaning the sand grains, the mechanical treatment has "released" pollutants captured by the new sand during the steel manufacturing process (these pollutants are contained in the residual gangue and in the fine elements of the sand).

The presence of these pollutants in too large quantities was the cause of poor leaching results (e.g. fluorides, soluble fraction, DOC, Cr, Ni).

On the contrary, it appeared that all the options of reuse in geo-construction and road techniques are possible for inorganic sand wastes treated by hydromechanical technology, except for the option of reuse in road technique of type 3 in the case of the "GEOPOL" sand where the phenol index and fluorides are slightly above the acceptance limits in the partner countries.

This showed that hydromechanical technology was effective in treating inorganic sands.

To conclude, at this stage of the development of the different inorganic binders tested during this project, we cannot deduce that such or such process of inorganic sand is the best placed for a reuse in geo-construction or in road techniques, because it is the parameters of production and the industrial history of the sand which have an important impact on the quality of a waste sand.

Deliverable: ***DeB4.5 Feasibility studies of the reuse of inorganic surplus foundry sand in core making and geo-construction, Appendix 9.*** Delivered in the Final report.

Life Cycle Assessment:

Life Cycle Assessment was carried out to assess the environmental impacts of the technologies and methods tested in the Green Foundry LIFE project in the *Action B4 Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dusts*. This included monitoring both positive and negative environmental impacts at all steps of the process.

Composting method

Positive environmental impacts:

- The harmful substances as DOC, BTEX, phenols, fluoride, PAH will be reduced by 40-90% during the composting process.
- The amount of foundry waste sands transported to landfills will be reduced.
- Different organic waste raw materials can be reused and cleaned locally in composting process instead of landfilling.
- Producing clean and hygienised mixture soil material suitable for green construction purposes (MMM 24/11).
- There are already existing composting companies producing composting material and mixture soil material. They have all the environmental permits existing for composting process and wastewater treatment system. Such companies can introduce cleaning of foundry waste sand by composting method in their existing business.
- The positive environmental impact for constructing a composting field is that different local waste materials can be reused in composting process and transformed into a valuable new products and materials. This will enhance the circular economy and reduce the need of long distance transportations.
- In case a new area is needed the environmental and construction permits must be applied from regulatory bodies. Composting field will be constructed in a way that there will not be negative environmental impacts in the environment.
- Environmental impacts will be regularly monitored (e.g. wastewaters, odors).

Negative environmental impacts:

- In case the composting site will be constructed from the beginning, there will be some temporary negative environmental impacts during the construction work. Such as
    - composting field construction work
    - noise from lorries and construction machines
    - dust from ground construction work
    - increased traffic
- Environmental impacts will be regularly monitored (e.g. wastewaters, odors).

Washing method

Positive environmental impacts:

- Through washing, the hazardous elements present in foundry waste sand (WFS) are reduced or eliminated at 36% to 100% efficiency.
- The chemical washing of WFS would remove hazardous elements that would otherwise remain active in landfill, potentially coming into contact with other reactive materials.
- Valuable landfill space would be freed up for highly toxic materials that have no other alternative.
- The best washing efficiency is found in the most commonly used WFS – organic sand from green moulding (source: FEAF), potentially having a wide impact.
- Washed WFS contains 80% fewer fines than raw sand and 50% fewer RCS (residual crystalline silica <0.05 mg/m3). In view of forthcoming regulations ((UE) 2017/2398) this reduces health risks and improves foundry worker efficiency (reduced use of restrictive PPE).
- The adoption of this method would reduce the need for new extraction as washed WFS can be reused to make cores, and, in optimal circumstances, new moulds.
- By locating a plant strategically close to several foundries, transport related emissions could be minimized and reduced against transportation to landfill.
- Chemical washing plants would operate without combustion processes and would be CO2 neutral.

Negative environmental impacts:

- The process requires large quantities of HCI – 140 litres per 100 kilos WFS. This cleaning agent itself requires neutralizing.
- The process requires large volumes of distilled water – 300 litres per 100 kilos WFS (75% recoverable by use of a closed circuit).

Thermal reclamation

Positive environmental impacts:

- Reduces the need of new sand at foundries by 70-95 % as some sand always turns o dust
- Reduces the net lifecycle greenhouse gas emissions from foundry sand by 50-70 %
- Reduces shipping and transportation for sands as those can be circulated locally
- Reduces amount of sand which needs to be landfilled by 70-95 %
- Instead of ending up into the ground from landfilled sand, the resins are burned in the thermal treatment into less harmful substances.

Negative environmental impacts:

- Uses a fossil fuel as energy source, though his can be mitigated in the future by use of biogas
- Thermal reclamation causes GHG-emissions at the reclamation site
- Depending on the resin, thermal reclamation can cause sulfur oxides as flue gases, which have to be treated with appropriate filters.

Hydromechanical treatment

Positive environmental impacts:

- Reduces the need of new sand at foundries by 95-96%, the 4-5% correspond to processing losses
- Reduces the net lifecycle greenhouse gas emissions from foundry sand by 50-70%
- Reduces shipping and transportation for sands as those can be circulated locally
- Reduces the amount of sand which needs to be landfilled by 95-96%
- The hydromechanical treatment process makes it possible to recycle the sand treated internally, or to reuse it in geo-construction or road engineering
- Modern means that limit the impact on the environment can be integrated into the hydromechanical process to carry out the filtration of the rinsing water
- Rinsing operations can be done in a closed loop to reduce the amount of water consumed per ton of sand processed

Negative environmental impacts :

- The sand rinsing operations carried out in an open loop during the hydromechanical treatment generate a quantity of wastewater that must be filtered (5.5 to 8 m^3 per ton of treated sand, depending on the number of rinses carried out)
- Sand must be dried after the rinsing operations
- Wastewater filtration treatment generates 4 to 5% waste (not analyzed to date)
- Hydromechanical treatment requires a minimum of 4 rinses, otherwise the pH of the wastewater must be regulated

Ultrasonic treatment

Positive environmental impacts:

- Reduces the need of new sand at foundries by 95-96%, the 4-5% correspond to processing losses
- Reduces the net lifecycle greenhouse gas emissions from foundry sand by 50-70%
- Reduces shipping and transportation for waste sands as those can be circulated locally
- Reduces the amount of sand which needs to be landfilled by 95-96%
- The ultrasonic treatment process makes it possible to recycle the sand treated internally, or to reuse it in geoconstruction or road engineering
- Modern means that limit the impact on the environment can be integrated into the ultrasonic process to carry out the filtration of the rinsing water
- Rinsing operations can be done in a closed loop to reduce the amount of water consumed per ton of sand processed

Negative environmental impacts:

- The sand rinsing operations carried out in an open loop during the ultrasonic treatment generate a quantity of wastewater that must be filtered (6 to 8,5 m^3 per ton of treated sand, depending on the number of rinses carried out)
- The sand must be dried after the rinsing operations
- Wastewater filtration treatment generates 4 to 5% waste (not analyzed to date)
- Ultrasonic treatment requires a minimum of 4 rinses, otherwise the pH of the waste water must be regulated

Deliverable ***DeB4.6 Life Cycle Assessment report on tested methods, Appendix 10.*** Delivered in the Final report.

This subaction was completed successfully in spite of the delays due to COVID pandemic and travelling restrictions in Europe. Foundry sand specimens and inorganic binder system test casts were transported to CTIF in Paris for test purposes in July 2021 by Meehanite.

6.1.7. B5. Replication and transfer of the project results

Foreseen start date: 1.10.2020 Actual start date: 1.10.2020
Foreseen end date: 30.6.2021 Actual end date: 30.6.2022

This action was to ensure the replicability and transferability of the project results after the end of the project. This included Workshops, BAT report and contribution to IED Directive revision work.
This action was divided in three sub-actions:

- B5.1 Outcomes of the Green Foundry Workshops: "latest experiences of environmental and occupational hygiene improvements"
- B5.2 Conclusions and project outcomes "the methods and procedures for future greener foundry"
- B5.3 Business plan and replication and transferability plan

Subaction B5.1 Outcomes of the Green Foundry Workshops: "Latest experiences of environmental and occupational hygiene improvements":

Due to the COVID pandemic and delays in the project the planned two Workshops were also delayed and also decided to be arranged as Webinars. This was discussed with the Agency in the TEAMS monitoring meeting on 3.12.2020 and presented in the Amendment request Nro 2, delivered on 1st of April 2021.

- The **Public Webinar** was arranged on 22nd of April 2022. Partners and 75 other relevant invited stakeholders participated the webinar. Total number of participants (whole time or part time) was ca. 100. 297 invitations were delivered by using email, and invitation was also placed on project website, Linkedin, Facebook and delivered by using other relevant national foundry industry lists of partners and their websites. Directly after the Public Webinar, 15 foundries contacted partners from Spain, France, Poland, Turkey, Finland, Italy for further tests in the potential follow-up LIFE project or related to testing inorganic binders in future or waste sand problems and composting tests.

  Main discussions and outcomes of the public webinar are presented in the Deliverable ***DeB5.1A Content of the Public Green Foundry LIFE project public Workshop, Appendix 11** (Final report).* E.g. a member of the Technical Working Group of BREF, Mr Nicolas Creon, participated the project webinar and we got valuable information related to the BAT technique requirements to be presented in in the BAT report. During the BAT report preparation partners were in contact with the TWG members Juhani Orkas from Aalto University, Finland and Mrs Elke Radke, CAEF, Germany.

- After the Public Webinar, participants comments and feedback were discussed in the **Private Workshop** arranged on 3rd June 2022 with partners, and the BAT report was finalised.

- Submission of final BAT report was delivered to the BREF TWG on 22th of June 2022 (JRC-B5-EIPPCB@ec.europa.eu). Deliverable ***B5.4. BAT report feedback request from the BREF TWG, Appendix 12.*** Delivered in the Final report.

- Final BAT report of the Green Foundry LIFE project is attached as ***Deliverable DeB5.1B BAT publication, Appendix 13.*** Delivered in the Final report.

- BAT report content was divided in following categories based on the requirements set for BAT technologies. The suggested BAT and Emerging Technologies were discussed with TWG member Mrs Elke Radke, CAEF and Dirk Lehmhus, IFAM during the BAT report preparation. The following technologies fulfil the requirements set for the BAT/ET technologies.

  Best Available Techniques (BAT) suggestions by Green Foundry LIFE. The following techniques are deemed sufficiently mature to be considered as BAT:
  1) Thermal reclamation of foundry sands (P*rimarily for organic binder WFS, unnecessary for inorganic binders, of interest for hybrid systems and mixed waste foundry sand, e.g. organic moulds/inorganic cores. Commercially available both as a service and for in-house installation in foundries.)*
  2) Composting of waste foundry sands (*Mostly not required for purely inorganic systems. Commercial availability through regular composting plants where natural sand is used in the of the composting process)*

  Emerging Techniques (ET) suggestions by Green Foundry LIFE. The following techniques have been proven on lab scale within Green Foundry LIFE, but are either not yet commercially available, or are currently not available on in this scale.

  1) Use of inorganic binders for moulds in iron and steel casting *(As shown within Green Foundry LIFE, suitable binder systems are commercially available)*
  2) Use of inorganic binders for cores in iron and steel casting *(As shown within Green Foundry LIFE, suitable binder systems are commercially available)*
  3) Washing of foundry waste sand (*Temporarily not available on commercial level in Spain, provider currently out of business).*
  4) Ultrasonic treatment of foundry waste sand (*Proven on lab scale in the course of Green Foundry LIFE, scale-up pending).*
  5) Hydromechanical treatment of foundry waste sand (*Proven on lab scale in the course of Green Foundry LIFE, scale-up pending).*

- Totally **7 seminars arranged in Finland, France and Spain** (according to the GA: 4 seminars in FI, SP, IT, FR):
  - Finland on 5-6.5.2022: "SVY opintopäivät", Green foundry presentation (foundry engineers and foundrymen)
  - Finland 25.3.2021: "Valty webinar" for foundry engineers, casting users, suppliers
  - France 28.2.2022, 25.3.2022, 21.4.2022 and 16.5.2022: CTIF national webinar, Green Casting presentation (foundrymen, suppliers, engineers, sales engineers).
  - 12-17.6.2022: BIEMH 2022 Trade fair, Spain: Dissemination of Green Foundry LIFE project results (Foundry industry, engineers, mechanical industry)

  - Following 4 national seminars to be arranged in autumn 2022: In October-November national foundry seminars will be arranged in Spain, Italy, Germany and Poland where the project partners AGH, UNIPG, IFAM, Tecnalia /ARABA will participate and give oral presentations of the Green Foundry LIFE project activities and outcomes (e.g.Polish annual Foundrymen´s Day 2022 in Krakow). These will be carried out by partners as dissemination actions in the new Green Casting LIFE project beginning on 1st of September 2022.

    Due to the COVID pandemic practically all foundry seminars and annual events were postponed and cancelled in 2020-2021 and therefore all planned national foundry seminars in the decided countries could not be arranged. These were postponed until 2022.

After LIFE Communication activities. National seminars to be participated by project partners in autumn 2022 as listed above (Deliverable DeE1.3 After LIFE Communication plan, Appendix 31):

- BDG German Foundry Industry Association 10/2022
- FEAF Spanish Foundry Industry Association 09/2022
- ”Valun käytön” seminar in Tampere to be arranged on 3-4.11.2022, Finland
- 36 Congresso Tecnico di fonderie organized by Assofond in 11/2022, Italy
- ISM 2022 The International Conference on Industry 4.0 and Smart manufacturing on 2-4.11.2022, Austria.

Subaction B5.2 Conclusions and project outcomes “the methods and procedures for future greener foundry”.

Main results and outcomes of the project are collected and presented in the project Conclusion report, ***DeB5.2 Conclusions and outcomes of the Green Foundry LIFE project, Appendix 14.*** Delivered in the Final report.

In this report following issues are discussed:

- Results of the test casts carried out in the pilot foundries in the Green Foundry LIFE project and applicability of inorganic and organic binder systems in in different sand foundry types:

  The results in production scale test casts with inorganic binder systems ferrous foundries were promising, the quality of the castings was comparable with the castings made by organic binder systems. The project, however, learned that the extensive use of inorganic binders in ferrous foundries requires vast knowledge about different inorganic binder systems and their proper implementation into current or new production lines. Much more extensive production-scale piloting is needed.

  Results of the small-scale chamber test emission measurements carried out in this project with organic and inorganic binding systems:
  The results showed that the total gas formation and harmful emissions of PAHs and BTEX are remarkably reduced with all inorganic binder systems, both fully inorganic and “semi” inorganic (=inorganic binder + organic hardener) systems compared to all types of tested organic binder systems (=phenolic, furanic and bentonite systems).

- Solutions to improve foundry ventilation systems will be presented. Practical prevention systems for the most emitting foundry unit processes (e.g. shake-out and sand reclamation) that cause main hygienic and air borne emission problems as well as local and general ventilation systems are described:

  Ventilation uses heating energy in the heating of supply air and electricity in operation of fans. The use of inorganic binders reduces gaseous emissions and the need of ventilation. The annual cost savings can be 12..17 k€ and by applying efficient local ventilation systems the savings can be even more remarkable.

- Solutions for inorganic and organic surplus foundry sand cleaning and reuse methods are presented. Feasibility of cleaning and reuse technologies demonstrated in this project are evaluated and assessed on environmental and economic aspects:

  Based on the project results related to the waste sand cleaning and treatment demonstration actions, the composting and thermal reclamation methods were the most promising and feasible techniques, and they are already commercially available.

Composting method is most efficient for cleaning the organic binder system waste sands and producing clean fertilizer soil material suitable for green construction purposes. In composting method there is no difference what kind of organic or inorganic binder system waste sands are used in the composting process. The recipes are modified based on the waste sand type used. The process itself is space demanding which is why existing composting companies are recommended. In case the composing site will be constructed the costs are higher but after constructing the running costs are rather low.
Thermal reclamation method is not a new treatment method and it is very effective way to clean the waste sands and then recycle back to foundry processes. Based on the test carried out with 3 organic and 2 inorganic binder system waste sand types, this method is most suitable for Alphaset phenolic organic binder system waste sands and also for furanic waste sands. The investment and energy costs are high as well as the waste sand transportation costs for the foundries far away. There will small scale prototype units commercially available in the future by Finn Recycling Ltd and these units can be rented and transported to foundries for cleaning the waste sands.
The cleaning efficiency results from the washing tests which were carried out on laboratory scale were promising, but this treatment method should be studied more and tested on industrial scale. Also the need for additional chemicals and high water consumption may turn out to be economically not sustainable.
Treatment trials carried out with inorganic binder system waste sands demonstrated that hydromechanical and ultrasonic technologies are effective in allowing the cleaned sand to be reused in foundry processes or geo-construction and road engineering purposes. But these hydromechanical and ultrasonic treatment processes are not yet commercially available and they need to be tested on an industrial scale to verify whether these emerging technologies would be viable, compared to solutions using conventional technologies (mechanical, thermal, thermomechanical).

B5.3 Business plan and replication and transferability plan

The Business plan was produced by Meehanite Technology Ltd as deliverable ***DeB5.3A Business plan, Appendix 15.*** Delivered in Final report.

Current situation: The European ferrous foundry industry is the third largest in the world for ferrous casting (CAEF, 2020), after China and India, and are responsible for 15% of the global production. Iron and steel industries belong to the Energy intensive industries (EIIs) groups which are considered to be highly energy intensive. In 2020, the European ferrous foundry sector was composed by 1652 ferrous foundries which produced 9,1 million tons of casting (CAEF, 2020).

Needs of the customers: Potential customers, ferrous foundry branch, is among the most polluting industries. Majority of the ferrous castings are produced by using sand moulds. Sand moulds are currently hardened by using organic binder systems, by green sand (bentonite) binder system or by furan or phenolic resin binder systems.
There are many factors influencing the need of ferrous foundry branch to decrease the polluting in future:

- EU has set targets in “Green Deal” to decrease the harmful emissions and to improve the indoor air quality in major industries
- End customers such as automotive industry are increasingly environmentally conscious and will favour in future the suppliers which have cleaner production processes
- Waste sand disposal is problematic, and sand reuse is impossible without costly treatments
- It is more and more difficult to get employees to unhealthy workplaces in EU
- Best Available Technology (BAT) Reference Document (BREF) is currently being prepared for the smitheries and foundries industry according to the Sevilla process: The requirements for the limit values for impurities will decrease.

The solution by Meehanite Technology Ltd:
The application of inorganic binder systems instead of current organic binder systems provides a solution to remarkably reduce harmful emissions and improve indoor air quality in ferrous foundries. Waste sand problem will be also improved because inorganic binder system surplus foundry sand will contain less harmful substances such as DOC, BTEX and phenols than organic binder system surplus foundry sand, which often must therefore be landfilled. Inorganic binder system waste sand can be reused in e.g. geo construction purposes, and landfilling can be avoided. Meehanite Technology can provide foundries, which are interested to change to inorganic binders, a full package of knowledge including:

- Recommendations for suitable inorganic binder types for the foundry
- Recommend recipes of binders and hardeners
- Recommendations for the process changes and devices needed to change the binding system
- Solutions for foundry sand reclamation methods and possible waste sand reuse application
- Solutions for other means to improve indoor air quality, eg. by designing local ventilation
- Investments plans, including cost and pay-back time calculations

The Replication and Transferability Plan includes the measures to ensure that the results of the project are utilized to the greatest extent possible for the benefit of the European foundry branch. The plan involves activities aimed at increasing the adoption of the innovative solution of the project. Replicability strategy begins within the framework of this project by focusing on the replicability of the solution in other companies in the ferrous foundry industry, by looking in partner countries for other companies with similar processes as the pilot foundries of the project. Subsequently, the consortium will look for the possibility of the replication to other countries. In addition, the transferability strategy envisages the application of the same solutions to other sectors with similar characteristics to the sectors studied in the Green Foundry LIFE project (e.g. bronze foundries).

The plan includes the means to find and contact potential candidates for replication and transfer, as well as methodologies and database to convince candidates about the use of inorganic binders in everyday practice. The plan will be updated during the activities carried out by partners after the end of the project and during the new LIFE project.

Deliverable: ***DeB5.3B Replication and Transferability Plan, Appendix 16.*** Delivered in Final report.

This action was completed successfully in due time.

6.1.8. C1. Project monitoring

Foreseen start date: 1.7.2018	Actual start date: 1.7.2018
Foreseen end date: 30.6.2022	Actual end date: 30.6.20212

This action is in progress.

The project included monitoring actions to measure the impacts of the project. The main focus is on improvements in environmental and climate performances.

This action was divided in three sub-actions:

C1.1. Environmental impacts
The environmental impact monitoring was regarded to air quality measurements, emission

measurements from the casting process and surplus foundry sand purification methods demonstrated and the environmental impact assessment of the composting tests. The lists of compounds to be monitored and analysed were based on national regulations set for foundry waste sands (Government Decree of landfills, 331/2013) and for composting material analyses based on the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011): Substrate – Mixture soil (5A2). Emissions to be measured in the chamber tests and from pilot foundries were decided in the beginning of the project and those are based on the national limit values set for foundries and based on the experiences of AX, Meehanite and AGH personnel.

<u>Action B1 Emissions of different binder systems during the small-scale test casts</u>. Chamber tests were carried out to measure the environmental emissions and hazardous compounds from test casts made with organic and inorganic binder systems and the results were compared. Chamber test measurement results are presented in project deliverable (*Action B1 deliverables from Finland and Poland).* Tests were carried out with commonly used organic and 5 different inorganic binder systems. Based on the chamber test measurement results at Karhula and URV foundries, the emission reductions of 67-99% can be expected when exchanging from organic binders to inorganic one, table 24.

Table 24. Emission measurement results from organic and two inorganic binder system chamber tests

	Test	URV	Karhula	Karhula	Emission
		chamber	chamber	chamber	reductions
	Resin	phenolic Alphaset	Inorganic Peak	Inorganic Inotec	%
Emission per casting [g/ton casting]	dust	211	56,10	7,40	96,50
	CO	10 129	361	128	98,74
	SO_2	203,31	6,51	3,30	98,38
	VOC	3 256	111,6	35,2	98,92
	BTEX	665	8,50	1,05	99,84
	asetaldehyde	81,3	8,76	0,72	99,11
	formaldehyde	1,92	6,23	0,63	67,22
	phenol	109	0,89	0,13	99,88
	o-cresol	152	<1,50	<0,08	99,95
	p-cresol	74,1	<1,50	<0,05	99,93
Sum		14 883	563	177	

AGH chamber test results demonstrated that moulding sand with organic binder generated 2 to 3 times more gas volume than inorganic. Emissions of PAHs, as well as BTEX in case of moulding sands with organic binders were several dozen higher than the emissions of these compounds from moulding sands with inorganic binders. In the Hardkop pilot foundry conditions in Poland, the moulding sands with inorganic binders (Geopol, Cordis and Inotec) characterised by lower harmfulness for the environment and employees than moulding sands with organic binders.

These chamber test results are utilised when expressing the potential emission reduction for the pilot foundries involved in the project and for new foundries interested in introducing the inorganic binder system in the process.

<u>Action B2 Total emission and indoor air quality measurements of pilot foundries</u>. Total emissions and indoor air qualities were measured from 5 pilot foundries representing both organic and inorganic binder systems. The aim with these emission and indoor air quality measurements was to determine *current emissions and indoor air qualities* in pilot foundries representing both organic and inorganic binder systems. Measurement results from 5 pilot foundries are reported *in Action B2 Deliverables.* E.g. in Valumehaanika foundry both the inorganic and organic binder systems wre tested and emissions and indoor air qualities were measured. The total emission measurements demonstrated about 50% less emission concentrations compared to the organic binder. As a conclusion, emissions in the Valumehaanika foundry were clearly reduced

when implementing inorganic binders.

Action B4 Recycling options and sand purification or inorganic surplus foundry sand and high concentration organic waste sands and dusts. The cleaning efficiencies of purification methods were monitored by the degradation of harmful substances. Purification methods tested were composting, washing method and thermal reclamation. Degradation of harmful substances are presented in the deliverables of each tested method and results are evaluated on environmental, economic and cleaning efficiency wise in the DeB4.4 Conclusions of the results of waste sand cleaning methods.

In the thermal reclamation tests the sand quality was analysed by the Loss Ignition (LOI) test and the 3-point bending strength test. Based on the test results this reclamation method is most efficient for ester cured phenolic resin no-bake sand system but good results were also monitored for furan sand system and small improvements for inorganic binder sands. The aim of the thermal reclamation was to recycle the cleaned sands back to foundry processes and reduce the need of new sand.

The aim of the washing tests was to demonstrate that harmful residual substances of surplus foundry sands can be removed sufficiently. Degradation of harmful substances were monitored in the beginning and in the end of the tests. Results demonstrated that hazardous elements of the green sand (bentonite) and inorganic binder system was sands were washed away and broken down by processes involving distilled water and hydrochloric acid. Cleaning efficiencies of phenol were 38%, fluoride 36%, DOC 65%, TOC 89% and BTEX 100%.

The progress of the composting tests was monitored regularly by sample analyses. The end product (soil material) must be clean of harmful substances and also mature and hygienized. Degradation of harmful substances during the composting process was analysed in the beginning and end of the composting tests. Based on the results the degradation of DOC concentrations in different test heaps varied between 64-73%, phenol 93-98% and fluoride 17-46%. In Finland, totally 360 tons of composting material were cleaned by composting method and all soil materials fulfilled the limit values and requirements set for the Fertiliser Product (24/11).

Environmental impacts of the composting tests were analysed from the wastewaters which were collected from the composting site. Composting sites were constructed by using waterproof materials as asphalt surface or a watertight film to avoid any leakages to environment. Wastewaters from the test sites were collected either to a separate container and transported to local waste treatment centre or the composting site had already an existing wastewater treatment system and wastewaters were conducted to the municipal wastewater treatment plant. Based on the results, there were no remarkable high concentration of harmful substances and there were no negative environmental impacts to surrounding area. Analyse results are presented in the B4.1 deliverables. Composting test progress and results were delivered and discussed with local authorities. The nearest settlement in Finland was about 1,5-2 km from the composting field and there were no complains or reclamations of odours to the authorities during the tests. In Spain, totally 120 tons of composting materials were cleaned by composting tests in a local composting site and all the cleaned end materials fulfilled the limit values and requirements set for the Fertiliser Product.

The environmental impacts of the project actions have been updated in the KPI indicator webtool and the table is attached as ***DeC1.1C Performance indicators Final report, Appendix 17*** in the Final report.

This sub-action completed as planned.

C1.2. Socio-economic impacts

Socio-economic impacts of the project on the local economy and population were assessed. This included the impacts on the wider population and its well-being. The socio-economic impact was assessed in regards to economic, environmental and health aspects and estimated the market uptake and replication of the Green Foundry project results.

Deliverable: ***De.C1.2 Assessment of the socio-economic impacts of the project actions, Appendix 18.*** Delivered in Final report.

This sub-action completed as planned.

C1.3. LIFE KPI Webtool
The KPI webtool has been updated in the start of the project, in the Midterm report and Final report and the final excel table is attached as ***DeC1.1C Performance indicators Final report, Appendix 17.***

The comments of indicator values which differ remarkably at the end of the project:

1.5. Project Area/Length and 1.6. Humans to be influenced by the project:
The application of inorganic binders in ferrous foundries turned out to be much more complicated than expected before the project. At the end of the project 3 ferrous pilot foundries (FOM Tacconi, Karhula and Valumehaanika) were ready to start using inorganic binders in near future (original goal was 150). In addition, 6 other ferrous foundries currently use inorganic binders in everyday practice. The project has not been directly involved in their processes, but the dissemination of promising results and cooperation with the inorganic binder producers have indirectly influenced the change to inorganic binders. Indicators 1.5 and 1.6 at the end of the project are respectively clearly below. The new project "Green Casting LIFE" will start in September 2022. The goal of this project is to widely demonstrate inorganic binders on an industrial scale, in min. 20 iron foundries, and thus the target of 300 foundries using inorganic binders is believed to be achievable after 5 years of the project.

13. Jobs:
No new persons have been hired to Meehanite at the end of the project (original goal was 4), because the project is not yet ready for marketing. New demonstrations in pilot foundries are needed to convince foundries to change to inorganic binders. New project "Green Casting LIFE" will provide that lacking information and experience and will make it possible to hire new personnel into Meehanite. The hired persons will act as technical experts and as office workers. KPI value 5 years after the project is expected to be met (12 jobs).

Other KPI indicator values are met or exceeded.

3.1. Waste management:
The promised amounts of the treatments for waste sand by composting tests (6 heaps in Finland and 4 heaps in Spain representing ca 40-50 tons of waste sand to be cleaned) and thermal treatment tests with inorganic sands from Karhula and 3 organic sands were reached and KPI indicators in were met**.** In total 7 composting test heaps were tested in Finland and 6 in Spain. In total of 114 tons waste sand /dust were treated. In thermal reclamation tests 2 inorganic waste sand specimens from Karhula foundry and 3 typical organic binder system waste sand types (furanic, phenolic and green sand) were treated and tested. In total of 10 tons of waste sands were treated and cleaned during the project.

10.2. Involvement of non-governmental organisations (NGOs) and other stakeholders in project activities and 12.1. Networking:

Indicator values were met or exceeded. In the GA the original goal of 20+5+11+8=44 organisations were written and during the project 30+6+8+12=56 organisations were achieved.

11.1. Website:
KPI indicator values in have been exceeded. In the GA the original goal was 5,000 visitors. In the end of the project there were 82,200 visitors in the project website.

14.1. Running cost/operating costs during the project.
In the GA the project budget was 2 027 998 €. In the end the project eligible total costs were 2 065 710 €.

This sub-action completed as planned.

6.1.9. D.1. Dissemination planning and execution

Foreseen start date: 1.7.2018 Actual start date: 1.7.2018
Foreseen end date: 30.6.2021 Actual end date: 30.6.2022

This action is divided in two subactions.

D1.1. Networking with other projects
According to the GA it was planned that at least 30 contacts of fa-to-face meeting will be arranged during the project. Due to the COVID pandemic there were only few face-to face meeting before the pandemic (7/2018-06/2020). **6 face-to face meetings before the COVID pandemic were arranged** (listed in the ***DeD1.2 Dissemination plan updated/section 3, Appendix 19****)*. Face-to-face meetings were arranged with:

1) Finn Recycling Ltd (thermal reclamation) (11/2018),
2) IFAM/Finn Recycling (test arrangement planning) (11/2018),
3) LUX Oy (binder system supplier) (11/2018),
4) Ekokumppanit Oy (networking with other national and international project) (1/2019),
5) GIFA 26-27/2019 face-to-face meetings with: Hüttenes Albertus (binder system supplier), ASK Chemicals (binder system supplier), PEAK International (binder system supplier), Institute für Giessereitechnik (foundry institute), CAEF (European Foundry Association), IFAM (representatives from other departmens e.g. testing of casts), 3D printer manufacturer, etc.). Can be regarded in total of 7 arranged meetings at GIFA.
6) Meeting with project partners at GIFA on 26.6.2020.

In addition to the face-to-face meetings other **networking activities were carried out. Emails with seven (7) relevant LIFE projects** were carried out (**listed in the Appendix 19, section 4**). During these networking activities (emails, teleconferences, TEAMS meetings) a new project proposal idea was created and a project proposal was prepared in November 2021. New relevant foundries were introduced and contacted during these networking activities in EU countries. New contacts with 300 relevant stakeholders (foundries, organisations, system suppliers, manufacturers, universities) were made while inviting the participants to project Webinar on 22nd of April 2022 and project data was delivered. Throughout the LIFE networking activities and former contacts in previous LIFE projects 16 partners among institutes, SMEs, universities, foundry institutes and foundries in EU were found for the new LIFE project. The networking activities and LIFE projects are listed in the table of DeD1.2 Dissemination plan, *Appendix 19.*

This subaction was completed successfully even though not so many face-to face meetings were not arranged as planned due to the COVID.

D1.2. Dissemination planning and development of the dissemination pack
All dissemination activities during the project are updated in the DeD1.2 Dissemination plan

(Appendix 19) and summarized here.

- Website (opened in 11/2018)
  - The main project results and activities are informed on the project website (www.greenfoundry-life.com). For private site the username: visitor and password: Greenfoundry
  - Calculation of the visitors started in March 2018:
    - 2018: 9,000
    - 2019: 16,000
    - 2020: 24,000
    - 2021 20,000
    - 2022: 6,000 (January-March)
    - 2022: 7 200 (March-June)

In total 82,200 visitors during the project. In the GA 5,000 visitors were written.

- Layman´s report was produced in paper version (100 pieces) and as electric version and will be placed on project website and delivered to relevant stakeholders as Webinar participants (300 participants) by project partners, ***DeD1.2D Layman's* report, *Appendix 20.*** Delivered in Final report. Report produced in English.
- **6 notice boards** were placed on composting sites in Spain and Finland and at the thermal reclamation plant during the tests in Nuutajärvi, Finland, and during the test casts in pilot foundries in Karhula, FOM Tacconi and Valumehaanika and chamber tests in Karhula Foundry. Delivered in the 1st progress report (fig 34).

Fig. 34 Notice boards e.g. on composting site in Spain and Finland and chamber tests at Karhula foundry, Finland.

- **12 technical publications** were published during the project (GA: 5 technical publications). Publications listed in the updated DeD1.2 Dissemination plan. Publications delivered in progress reports. No new publications in Final report.
  - AX magazine 2018-2021: Green Foundry articles of project activities AX-Uutiset (4 publications). ***Appendices 21 A, B C, D.*** Delivered in Final report.
  - Foundry Journal of the Polish Foundrymen´s Association 2018: Green Foundry article. ***Appendix 22.*** Delivered in Final report.
  - An poster presentation: S. Saetta, F. Di Maria, V. Caldarelli, S. Tapola "*Improve the use of natural resources: inorganic binders in iron and steel foundries – Case of the Green Foundry LIFE project*", transactions SARDINIA 2019 - 17th International Waste Management and Landfill Symposium. ***Appendix 23.*** Delivered in Final report.
  - The scientific publication on ScienceDirect 2019: "S.Saetta, V. Caldarelli, "*Lean production as a tool for green production: the Green Foundry case study*" Procedia Manufacturing. Open access. https://www.sciencedirect.com/science/article/pii/S2351978920305916.

Appendix 24. Delivered in Final report.
    - Article in Metalblog 2018: New inorganic silicate-based binders, ***Appendix 25.***
    - MetalNews (CTIF's newletter) 2018 and 2021: Inorganic binders at the heart of the new Green Foundry project. CTIF-MetalNews. ***Appendices 26-27.***
    - Other Moulding and Core Sands with Inorganic Binders. Mould and Core Sands in Metalcasting: Chemistry and Ecology by Mariuzs Holtzer and Angelilka Kmita 2020) ***Appendix 28.*** Delivered in Final report.
    - MDPI 2020: Environmental impact of the reclaimed sand addition to moulding sand with furan and phenol-formaldehyde resin – a comparison. https://www.mdpi.com/1996-1944/13/19/4395/pdf. ***Appendix 29.*** Delivered in Final report.
    - MDPI 2021: Research on the release of dangerous compounds from the BTEX and PAHs groups in industrial casting conditions. https://www.mdpi.com/1996-1944/14/10/2581/pdf. ***Appendix 30.*** Delivered in Final report.
  - **11 project roll- ups** for each partner (GA: roll-up per partner). DeD1.2B Project leaflets and roll-ups (delivered 12/2018). Delivered in 1st Progress report (29.3.2019)
- **2,500 leaflets** (November 2018: 1500 pieces, second edition 2019: 1000) (GA: 1,500 leaflets). DeD1.2B Project leaflets and posters. Delivered in 1st Progress report (29.3.2019)
- **DeD.1.2E Dissemination plan** (delivered 03/2019 and updated during the project until 06/2022.). ***Appendix 19.*** Updated version delivered in Final report.
- **43 relevant events, seminars, congresses participated** by partners, DeD1.2 Dissemination plan updated (GA: 20-30 events).
- Totally **7 seminars arranged in Finland, France and Spain** (GA: seminars in FI, SP, IT, FR). Updated in the Dissemination plan:
    - Finland on 5-6.5.2022: "SVY opintopäivät", Green foundry presentation (foundry engineers and foundrymen)
    - Finland 25.3.2021: "Valty webinar" for foundry engineers, casting users, suppliers
    - France 28.2.2022, 25.3.2022, 21.4.2022 and 16.5.2022: CTIF national webinar, Green Casting presentation (foundrymen, suppliers, engineers, sales engineers).
    - 12-17.6.2022: BIEMH 2022 Trade fair, Spain: Dissemination of Green Foundry LIFE project results (Foundry industry, engineers, mechanical industry).
- **The State of Art** (preparatory) **seminar was merged with the project kick-off meeting on 15th November 2018** in Finland, where project partners and relevant inorganic binder system suppliers were invited (DeA1 Preparatory Workshop delivered in 1st Progress report 29.3.2019).
  It was challenging to get competitive binder system suppliers to participate in same meeting in the beginning of the project. Therefore relevant 2 binder system suppliers participated the meeting, but 5 relevant ones were invited. During the project cooperation and networking activities were carried out with partners and binder system suppliers and Green Foundry LIFE project got the permission to use their commercial brand names in project deliverables.
- **The Public (open) Webinar was arranged on 22nd of April 2022**. Partners and 75 other relevant invited stakeholders participated the webinar. In the webinar project partners presented all project activities carried out and the outcomes and BAT technologies to be presented for the ongoing revision of the BREF Document.
  Total number of participants (whole time or part time) was ca. 100. 297 invitations were delivered to relevant stakeholders.
- **Private Webinar** was arranged with project partners **on 3rd of June 2022.** Comments and feedback from the Public Webinar were discussed and the draft version of the BAT report was modified. It was decided that 2 BAT techniques (Best Available Techniques) and 5 ET techniques (ET) were suggested and delivered to the BREF documentation Technical Working Group in a form of formal BAT templates.

- **Project seminar was arranged by Technology Industries of Finland on 5-6.5.2022 in Tampere** parallel the foundry annual seminar where the conclusions of the Green Foundry LIFE project were presented and the new draft of the BREF document were presented and discussed with foundrymen. AX also presented the BAT techniques how to meet the new draft BREF limit values set in the new draft of the BREF revision (February 2022).

This subaction completed successfully.

6.1.10. E.1. Project management

Foreseen start date: 1.7.2018 Actual start date: 1.7.2018
Foreseen end date: 30.6.2022 Actual end date: 30.6.2022

This action was completed successfully and was divided in three subactions.

Subaction E.1.1 Project management by Meehanite

This action was described in section **5. Administrative**.
Project progress reports were delivered as follows with clarifications and documents requested during the monitoring meetings or in the progress report letters. Also project deliverables were delivered with the progress reports.
DeE1.1A 1st progress report delivered 29.3.2019
DeE1.1B Midterm report delivered 16.6.2020
DeE1.1C 2nd progress report delivered 9.1.2021
DeE1.1D Final report within 3 months after the project has ended.

In the Final report the new or updated project deliverables after Midterm report are attached.

The Agency letters related to the monitoring visit/progress reports are attached in the Final report provided with the clarifications and documents from partners. Since the coordinator can not be sure if all the issues raised in the Commissions letters are clarified and data well received in progress reports and raised during the monitoring visits, the coordinator has provided the requested clarifications and documents also in the Final report.

Subaction E.1.2 Project auditing
According to the Annex X to the Model LIFE Grant Agreement Financial and Administrative Guidelines; XI Certificate on the financial statements and accounts, there is no need for the project auditing for any of project partners.

Subaction E.1. After -LIFE Plan
In the After LIFE Communication plan the future communication and dissemination activities were presented. The deliverable ***DeE1.3 After LIFE Communication plan*** is attached as ***Appendix 31.*** Delivered in the Final report.

Updated list of project deliverables is attached as ***Appendix 60.***

6.2 Evaluation of Project Implementation

Action	Foreseen in the revised proposal	Achieved	Evaluation
A1 Preparatory actions for pilot foundries and foundry sand recycling activities A1.1 Visiting pilot foundries	Objectives: To visit 5 pilot foundries and making plans for emission measurements in Action B2. Expected results: Plans ready for the emission measurements in pilot foundries.	Completed with modifications.	3 pilot foundries visited (Karhula Foundry and URV foundry in Finland and Valumehaanika foundry in Estonia). TEAMS meetings arranged with KSMCasting, Germany and Stavanger Steel foundry, Sweden (this foundry was familiar for Foundryteam partner).
A1.2 Preparation of small scale pilot castings	Objectives: To plan the chamber test arrangements to be carried out in FI and PL. Expected: Plans ready for chamber tests in 2 pilot foundries in Finland and chamber tests in AGH-UST laboratory and pilot foundry in Poland.	Completed as planned.	Chamber tests were carried out in Finland by AX and in Poland by AGH. Test arrangements were prepared after the kick off meeting on 16th of November 2018 in Tampere. Some small changes in the budget of AGH for subcontracting the analyses from external laboratories because their own laboratory was under renovation. Tender procedure carried out and documents delivered in Midterm report (Appendix 17).
A1.3. Preparatory seminar about sand binder technologies	Objective: To arrange a preparatory seminar and to evaluate the current state of art of inorganic binders in partner countries. Expected: Preparatory seminar was arranged on 15th November 2018 in Tampere, Finland. The current use of inorganic binders in partner countries were presented by partners.	Completed as planned.	In the beginning of the project the binder system suppliers were very unwilling to exchange their experiences in front of other competitors. Only two inorganic binder system suppliers participated in the project preparatory seminar project activities were planned. During the project actions (chamber tests B1 and test casts B3) 5 inorganic binder system suppliers available in the market were tested and the project also got the permission to use their brand names and test results in the project deliverables. So, the cooperation during the project was very fruitful and the experiences were exchanged and binder system suppliers got information from the pilot foundries for further development work. Very successful cooperation with binder system suppliers and foundries started during this project.
A1.4 Environmental permits delivered to national authorities for surplus foundry sand purification tests in FI and SP	Objectives: To apply the needed environmental permits for sand purification tests. Expected: All permits were received for composting tests.	Completed as planned.	Permits for composting tests applied and received in Finland and Spain. No need for a permit for washing tests because these were carried out in lab scale at Tecnalia laboratory. No need for a permit for thermal reclamation tests because tests were made in the existing full scale thermal reclamation plant in Nuutajärvi, Finland which had the environmental permit for its operation.
B1 Emissions of different binder systems during small scale test casts	Objectives: To carry out chamber tests with inorganic binders in Karhula Foundry and URV foundry in Finland and chamber tests with inorganic and	Completed as planned.	Finland: Emissions from chamber tests with organic phenolic binder system at URV foundry. Emissions from chamber tests with two inorganic binder system at Karhula foundry.

	organic binders at AGH-UST laboratory and pilot foundry in Poland. Expected: One organic and one inorganic binder system tests carried out in Finland. In Poland 12 samples tested in laboratory scale and 12 samples tested in chamber tests in pilot foundry.		Additional chamber test was carried out because Karhula Foundry was interested in one "self-setting" inorganic binder and the emissions of this binder type was measured and compared with other binder systems. Poland: AGH carried out laboratory scale chamber tests and pilot foundry chamber tests at HARDKOP foundry in Poland as planned. Some changes with the subcontracting work was needed because the laboratories of AGH were under renovation. Tender procedure was attached in midterm report (App. 17). Results were very promising. The emissions from moulding sands with organic binders were several dozen higher than emissions from moulding sands with inorganic binders.
B2 Total emissions of indoor air quality measurements of pilot foundries B2.1 Emission measurements in pilot foundries	Objectives: To measure total emissions in 5 pilot foundries using both organic and inorganic binder systems. Expected: 5 completed emission and indoor air quality measurements in pilot foundries: -Karhula foundry, FI (organic binder system) -URV foundry, FI (organic binder system) -Valumehaanika foundry, EE (both organic and inorganic binder systems were measured) -KSMCastings, DE (inorganic binder) -Stavanger Steel, SE (inorganic binder system, water glass)	Completed as planned in spite of delays caused by COVID pandemic.	There were changes with the pilot foundries during the project. Due to the withdrawal of French 2 foundries in the beginning of the project and due to the COVID pandemic and travelling restrictions in Europe, there were delays in this action. Final measurements were carried out in Sweden on 13.5.2022. In spite of delays in this action the measurements were carried out in 5 pilot foundries as planned. Because of the changes with foundries, looking for new suitable foundries, visiting them, carrying out many negotiations and making new measurement plans, personnel costs in this action were higher than planned for AX, Foundryteam and Meehanite personnel. This also increased the travelling costs because of travelling to meet new foundries and due to the COVID because one trip was cancelled, so more travel costs occurred in this action than planned.
B2.2 Indoor air quality measurements in pilot foundries	Objectives: To measure indoor air quality measurements in 4 pilot foundries using both inorganic and organic binder systems. Expected: Indoor air qualities were measured in 4 pilot foundries, as planned, in spite of changed with foundries: -Karhula foundry, FI (organic binder system) -Valumehaanika foundry, EE (both organic and inorganic binder systems were measured) -KSMCastings, DE (inorganic binder) -Stavanger Steel, SE (inorganic binder system, water glass)	Completed as planned in spite of delays caused by COVID pandemic.	Same evaluation as above related to the pilot foundry changes because indoor air quality measurements were carried out in same pilot foundry (excluding URV foundry).
B3 Test series of mould,	Objectives:	Completed as	Karhula foundry, Finland: Three inorganic

cores and casts produced by inorganic and organic binder	Karhula: In total of 117 tons of test casts made by inorganic and organic binder systems. Size range of 4-20 tons. FOM Tacconi: In total 300 pieces á 3 kg test cores of inorganic binder system. Expected: Karhula: In total 81 tons of test casts with three inorganic and current organic phenolic binder systems were produced during the project. Size range of 15..2500 kg. The maximum size of the test casts planned in Karhula according to the GA was not achieved because of the limitations of the tested inorganic binder systems. But much more test series were carried out than planned, to find the suitable recipes and parameters for different inorganic binders. In the end of the project, the total amount of test casts produced in Karhula and Valumehaanika (representing the same foundry type and using same organic phenolic Alphaset binder system) was as approx. the amount mentioned in the GA (117 tons). New foundry, Valumehaanika: Remaining test casts were produced at Valumehaanika foundry. 36 tons of test casts with two inorganic and current organic phenolic binder systems were produced during the project. Size range of 20..550 kg. FOM Tacconi: In total 320 pieces á 3 kg test cores with two inorganic binder systems were produced.	planned in spite of the delays due to the COVID pandemic.	binders and current organic phenolic binder were tested. First inorganic binder system needed heating/drying and the foundry had only small preheating furnace and this limited the size of the test casts up to 500 kg. Also the wooden patterns used at Karhula were not suitable for this purpose (risk for deformations and breakages at temperatures 160-200 degrees). Suitable inorganic binder systems were found and different recipes and process parameters were tested. The “self-setting” inorganic binders were most suitable for Karhula foundry. The size of the test casts was up to 2500 kg. Results and experiences were very promising and the quality of the test casts were comparable to the casts produced with moulds of organic binder system. Unfortunately, due to the COVID pandemic and financial problems, Karhula withdrawed from the project on 23.10.2020. A new pilot foundry was found and remaining tests were carried out at Valumehaanika foundry in Estonia in September-December 2021. Valumehaanika foundry, Estonia: Two inorganic binder systems and the current organic phenolic binder system were tested. The foundry was very pleased with the results and experiences and they are interested in continuing the testing and hopefully within few years to exchange completely to inorganic binders or building a new line for inorganic binders. FOM Tacconi, Italy: Test cores with two inorganic binder systems were produced. The formation of gases was less than with organic binders which affect the cast surface quality in a positive way. The tests were successful and results promising and the foundry is interested in exchanging to inorganic binders in the full scale production in near future. The challenges with the foundry sand reclamation must be tested and solved.
B4 Recycling options and sand purification of inorganic surplus foundry sand and high concentration organic waste sand and dusts B4.1 Cleaning by composting method in Finland and Spain	Objectives: 6 test heaps will be tested in Finland and 4 in Spain. Expected: 7 test heaps in Finland and 4 in Spain.	Completed as planned in spite of delays caused by COVID pandemic.	Finland: First 3 composting tests were carried out in Tampere in 2019-2020 with inorganic and organic waste sands/dusts. Due to the COVID Karhula foundry withdrawed from the project and we were not able to get waste sand to our test purposes. Therefore a new composting site and new pilot foundry were looked and the remaining 2 small size and 2 industrial size composting tests were constructed and completed successfully in Iisalmi. Composting tests were successfully

			completed and the end product material as mixture soil material was clean of harmful substances and mature and fulfilled the national limit values. In total 360 tons of composting material (waste sand/dust proportion of 25-30%) was cleaned during the project in Finland. Cooperation will continue after the project, and the new foundry was very interested of the results and they are currently applying a new environmental permit in cooperation with Meehanite/AX for the composting process and for reusing the cleaned composting material in the noise embankment landscaping purposes in industrial scale in future. Spain: 6 composting test heaps were constructed with total of 120 tons of composting material (waste sand proportion of 20%). The end product was clean and mature and fulfilled the national regulations and limit values.
B4.2 Cleaning by thermal reclamation method	Objectives: To clean inorganic waste sand and three most typical organic sand types by thermal reclamation method. Expected: 2 inorganic binder system waste sand specimens from Karhula foundry and 3 organic binder system sand types were cleaned and results compared.	Completed as planned.	Inotec and PEAK inorganic binder system waste sands (3 tons) were transported from Karhula foundry and cleaned by thermal reclamation method. As a comparison three organic binder system waste sand types were cleaned by same method: Alkaline phenolic no-bake waste sand (3 ton reclamed), furan waste sand (3 ton reclamed) and green sand (bentonite) waste sand (1 ton reclamed). Organic binder system sand types were delivered from Finnish pilot foundries. In total of 10 tons of waste sand were treated by thermal reclamation system by FinnRecycling Oy in Finland. Results were good and the method is very efficient for cleaning organic phenolic and furan sand system waste sands and small improvements with both the inorganic waste sands were reported.
B4.3 Cleaning by washing method	Objectives: Washing tests with 3 inorganic binder system foundry sand specimens. Expected: 2 inorganic binder system waste sand specimens and 2 organic green sand specimens were cleaned by washing method in small scale tests in Tecnalia laboratory.	Completed but tests were carried out in lab scale not on industrial scale.	Tests were planned to be made by Ecofond, in Spain. Ecofond company closed down business and a substitute washing company did not exist. ARABA made a tender procedure and Tecnalia Research&Innovation was chosen (1st progress report, Annex 10). Tecnalia carried out the washing tests on laboratory scale with 100 kg inorganic and organic binder system waste sands. Inorganic silicate sand samples from three Spanish pilot foundries were washed in Tecnalia washing process. For a comparison also organic binder system green sand (bentonite) samples were washed and results compared. In general, the results of all washed sand specimens are good. But the consumption of the additive materials needed in the washing method would not be a wise solution on environmental or economical way, at least, at

			laboratory scale, it could be that at industrial scale this anomaly could be rectified.
B4.4 Conclusion of the results of the waste sand cleaning methods	Objectives: DeB4.4 Conclusions of the results of waste sand cleaning methods. Expected: Conclusions of the composting method, thermal reclamation method and washing method demonstration actions presented.	Completed as planned.	In this report the results of the waste sand cleaning methods as composting, thermal reclamation and washing methods, were discussed and the results and experiences were presented by following categories: cleaning efficiency, construction, operation and costs and capacity.
B4.5 Re-use options of inorganic waste sand in coremaking	Objectives: To carry out reclamation studies with 4 types of inorganic sands by combining ultrasonic and microwave thermomechanical technologies. Expected: Mechanical, hydromechanical and ultrasonic treatment tests were carried out with 4 inorganic binder system waste sand types.	Completed as planned in spite of delays due to the COVID pandemic.	Based on the studies carried out by CTIF in 2019, the results demonstrated that the planned “microwave technology” alone is not effective for cleaning the inorganic waste sand. It was decided to carry out the inorganic sand waste treatment tests by using “hydromechanical” and “ultrasonic technologies” to compare the results obtained with a conventional “mechanical” technology. The results demonstrated that these technologies are effective in obtaining inert waste sand limit values after treatment and allowing the reuse coremaking processes. The rest results of coremaking tests were comparable with the “new” sand coremaking tests. These technologies were tested in lab scale but based on the promising results, industrial scale demonstration tests are needed. Inorganic waste sands were transported from Karhula foundry to CTIF, Paris in July 2021.
B4.6 Re-use options of inorganic waste sand in geo-construction	Objectives: To carry out leaching tests with 4 inorganic binder system waste sands. Expected: Leaching tests carried out with 4 inorganic binder system waste sands.	Completed as planned in spite of delays due to the COVID pandemic.	Three were delays in this action because of COVID and travelling restriction in Europe. Inorganic waste sand samples (400 kg) from Karhula foundry were transported to CTIF for test purposes in July 2021. In these leaching tests 4 inorganic binder systems were tested. Comparison of the tested inorganic binder system waste sands were carried out based on the leaching test results. Results: there are option for reusing inorganic binder system waste sands in geo-construction purposes, but not all limit values set in different countries are fulfilled. Some treatment methods are therefore recommended.
B5 Replication and transfer of the project results	Objectives: To arrange two Workshops, 4 national seminars (FI, IT, FR, SP), prepare the BAT report, Conclusion report, Business plan, and Replicability and Transferability plan. Expected: Two Workshops arranged (public and private), 7 national seminars (2*FI,4*FR, 1*SP), BAT report, Conclusion report, Business plan and Replication and Transferability reports ready.	Completed as planned in spite of delays due to the COVID pandemic.	Due to the COVID pandemic the two Workshops were arranged as Webinars. The COVID caused that many annual foundry seminars were cancelled in 2021 and they were postponed in autumn 2022. Therefore seminars were not possible to arrange in all countries as planned. By the end of the project, 7 seminars were arranged as follows: 2 in Finland, 4 in France and 1 in Spain. Partners are committed to participate the national seminars in autumn 2022 in the listed events (section 6.1.7. B5 Replication and transfer of the project results).

C1 Project monitoring	Objectives: To update the Performance indicators (1st progress report, Midterm report and Final report) and produce the assessment of the socio-economic impacts of the project actions Expected: As planned.	Completed as planned.	Due to the COVID and prolonging the project with 12 months, the monitoring activities were continued until the end of the project.
D1 Dissemination planning and execution	Objectives: Notice board, Project leaflets and roll-ups, 5 technical or magazine publications, Layman´s report and dissemination plan, 20-30 events. Expected: 6 notice boards, 2500 leaflets, 10 roll-ups, Layman's report, 12 publications, Dissemination plan, 43 events.	Completed as planned in spite of COVID pandemic.	Due to the COVID many relevant and planned events, conferences, seminars, fairs, etc were cancelled in 2020-2021. Therefore the planned dissemination events were not participated. Partners participated very actively in relevant Webinars arranged during the COVID and in events that were arranged in 2022. So the objectives in this action were successfully fulfilled.
E1 Project management	Objectives: To prepare partnership agreements, produce 1st progress report, midterm, report, final report, audit report and After LIFE Communication plan Expected: as planned but one additional progress report was delivered on 9.1.2021 due to the prolonging of the project.	Completed as planned.	Progress reports and the After LIFE Communication plan produced as planned. Due to the prolonging of the project with 12 months one additional progress report was delivered on 9.1.2021. No audit report was needed. According to the *Annex X to the Model LIFE Grant Agreement Financial and Administrative Guidelines; XI Certificate on the financial statements and accounts* there is no need for the project auditing for any of project partners. This was also verified from the monitoring team member Mrs Sonja Jaari in emails on 27.4.2022.

Immediately visible environmental impacts of the project.

- Cleaning by composting method: **In total 7 test heaps were constructed in Finland and 6 in Spain**. The cleaning efficiency of harmful substances e.g. phenol, BTEX and DOC was 90-98%. In total **480 tons of composting materials were treated and cleaned** in the composting tests. The foundry waste sand and dust proportion varied between 20-30%. In total, **114 tons of foundry waste sand/dust were cleaned in the composting process**. The cleaned foundry waste sands and dusts represent both organic and inorganic binder systems. **Cleaned sands composting materials were used in landscaping purposes** because all materials fulfilled the national limit values. In the GA it was written that 6 test heaps will be tested in Finland and 4 in Spain. The expected cleaning efficiency for certain harmful compounds is expected to be 90%. The volumes of the test heaps were not written in the GA, but it was expected that these 6+4 test heaps would be about 20 tons each with the sand proportion of about 20%. This would result in total 200 tons of composting material (10 heaps*20 ton) with the sand amount of 40 tons in total (200 tons of composting material * 20% sand proportion). All the expected results related to the number of test heaps, waste sand amounts, clean composting material volumes and cleaning efficiency rates were exceeded.
- Cleaning by thermal reclamation method: **2 inorganic binder system waste sand types from Karhula Foundry and 3 organic binder system sand types** were treated and cleaned by thermal reclamation method. In total **10 tons of inorganic and organic**

binder system waste sands were tested and cleaned by thermal reclamation method in the project. **The cleaned sands were transported back to foundries** in mould making process. In the GA it was written that inorganic waste sand samples are delivered from Karhula Foundry and 3 most typical organic sand types (furan, phenol and green sand) are tested. The expected results were exceeded.

- Cleaning by washing method: In the GA the washing tests were planned to be carried out at Ecofond company but as the company was closed in 2019. Tecnalia carried out these tests in their laboratory. According to GA, 3 inorganic waste sand specimens would be treated by washing method. In total 4 washing tests were made: 2 inorganic waste sand specimens from steel and aluminium foundries in Spain and 2 organic green sand specimens from aluminium foundry in Spain and Ecofond company green sands. 100 kg of waste sands were cleaned by washing process at Tecnalia laboratory scale tests. The expected tests were achieved and results were promising.
- Hydromehanical, ultrasonic and mechanical treatment tests at CTIF experimental foundry: In the GA it was written that CTIF will conduct reclamation of inorganic sands by combining ultrasonic and microwave thermomechanical technologies in aqueous media. Additionally they will analyse the sands from test trials in the project. In studies carried out by CTIF in 2019 in the RECSAND project **CTIF found out that the microwave is not effective method.** Therefore CTIF decided in early 2020 to carry out the inorganic sand waste treatment tests for the Green Foundry Life project using **hydromechanical and ultrasonic technologies** and to compare the results obtained with a conventional **mechanical technology**. In total 3 different treatment methods for cleaning the inorganic waste sand specimens were tested. Treatment tests were carried out with 4 inorganic binder system waste sands from test trials from Karhula foundry (PEAK, GEOPOL, Inotec) and CTIF experiments (IE). In total **5 tons inorganic binder system waste sand were treated by different treatment methods.** Without treatment these sands would have been transported to landfills. The expected results were achieved and more treatment methods were tested than written in the GA.
- **Without Green Foundry LIFE project cleaning and treatment tests 129 tons of waste sand/dusts would have been transported to landfills.**

Environmental impacts after the end of the project.
The expectations of the inorganic binders to be implemented in iron and steel foundries have not fully answered one´s expectations while preparing the proposal and based on the test casts produced in this project so far. More R&D work is needed from the binder system manufacturers especially related to the drying demands of moulds and waste sand reclamation methods to be tested. In case these technical problems are tackled, and the ferrous foundries and other suitable iron and steel foundries in Europe will introduce the inorganic binders in production scale, then the environmental impacts will be remarkable in relation to waste sand reuse applications instead of landfilling, and in relation to the emission reductions and indoor air quality improvements.

Based on the Green Foundry project emission measurement results in small scale chamber tests (tests carried out in lab scale and in pilot foundries, Action B1), the **harmful emissions** as phenols, VOC, BTEX, PAH, formaldehyde **can be reduced by 80-98%** and **indoor air quality can be improved by 70-80%** by exchanging to inorganic binders. The recycling of inorganic binder system foundry sand will increase because the used sand can be recycled longer, and the amount of waste sands to be transported to landfills will reduce. Also the inorganic binder system waste sand will contain much less harmful organic substances and instead of landfilling it can be reused in other applications as in road- and geo-construction application.

Despite the excellent environmental benefits, the introduction of inorganic binders in ferrous foundries is still in the early stages, and only a few ferrous foundries have adopted them for everyday use. The project's production-scale demonstrations have shown that, in most cases, foundries have to make large investments to use inorganic binders in their daily use. Much larger full-scale demonstrations are needed to convince foundries of the expensive investment. **In**

addition, recovery of the used inorganic binder sand is still partially under development. This has to be solved before full-scale production is viable.

Replication efforts of the project. Results from the test casts carried out in three pilot foundries in the project were promising. Different inorganic binders were tested and suitable ones were found for the pilot foundries. Project pilot foundries are very interested in applying the inorganic binders, but there are challenges to tackle before major investments can be made. As discussing the foundries, foundry institutes, binder system suppliers and BREF Document technical working group members the foundries need more successful demonstrations before applying the new inorganic binder system and making big investment decisions. The message has been that min. 15-20 production scale demonstrations in Europe are needed in order to show that this method can be referred as BAT technique.
The application of inorganic binders requires various investments. New moulding and core lines and new sand reclamation equipment suitable for a specific type of inorganic binder (self-setting or hot cured) must be built. Sand reclamation methods for various inorganic binders are currently being further developed. But the achievable emission reductions are so huge and the quality of the castings is comparable to current organic binder technologies that ferrous foundries will be ready to introduce inorganic binder systems step by step within 3-5 years. In the long term, it is expected that approx. 7% savings can be achieved by changing from organic to inorganic binders. Potential cost savings are based on the reduced costs of waste sand disposal (recycling and/or reuse instead of landfilling) and the lower need for ventilation due to lower emissions.

Effectiveness of the dissemination activities and comment on any major drawbacks. Partners participated in **43 relevant events**, **exhibitions and seminars during the project**, in spite of the COVID pandemic. From those 21 were international events and big exhibitions. In the GA 20-30 were written.
Due to the COVID-19, many big exhibitions and seminars were cancelled in 2020-2021. This also effected in the planned dissemination activities of Green Foundry project. Some of these planned events were arranged as Webinars where project partners actively participated or arranged them themselves (e.g. CTIF seminars in 2022, AXtober video releases in 2020 (among other Green Foundry project video presentation). Here are some of the relevant international events where partners disseminated the project results: e.g. The GreenWeek 2021 virtual conference, II International Conference Engineering Materials. Safety – Environment – Technology (EMSET 2021, video conference in Krakow), 61st Slovenian Foundry Conference Portoroz 2021 in Slovenia (face-to-face meeting), Euroguss 2020 and 2022 Trade Fair in Nurnberg, ISM The International Conference on Industry 4.0 and Smart manufacturing, Italy 2019, Euromat conference in Stockholm in 2019, etc.
One major drawback was that due to the COVID pandemic the planned project **public Workshop was arranged as Webinar on 22.4.2022.** 297 invitations were emailed plus invitation was disseminated via social media: LinkedIn, Facebook, on companies website, foundry association member lists etc. Around 100 participants were present in the webinar and partners got several contacts after the webinar from foundries interested in participating as pilot foundry in future activities if possible. Also the **private Workshop was arranged as webinar on 3rd of June 2022** where the feedback from the BAT report which was discussed in the public webinar was now discussed with partners.
6 Notice boards were produced and placed on project demonstration sites. **10 roll-ups** were delivered to project partners which were used in dissemination events. **12 publications were released** in relevant magazines during the project. **The Layman´s report was produced in electric version and also in paper version** and it will be actively distributed to interested stakeholders and pilot foundries to be invited to the follow up project. Layman's report will be used as a summary report of the Green Foundry project results/experiences/actions carried out so far and it will be widely distributed by partners in the new LIFE project to all relevant and interested pilot foundries in Europe and to other relevant stakeholders. It will be placed on project website which are updated regularly after the end of the project. Layman's report will be

distributed also to all participants invited and contacted during the Green Foundry LIFE project Public Webinar.

In **the After LIFE Communication Plan** future dissemination actions are presented and future events are listed in 2022. The Green Foundry project results will be widely disseminated after the end of the project to invite new follower foundries to participate in the project activities.

During the project, while preparing the new LIFE project application in 2021 and while inviting participants to the project public Webinar in April 2022, partners carried out wide dissemination activities by contacting 75-90 potential ferrous foundries in partner countries and other relevant stakeholders as regulatory bodies, binder system suppliers, informing the event in their website, using facebook and other social media.

The COVID pandemic caused delays in Green Foundry LIFE project dissemination actions and many planned dissemination events were cancelled. In spite of this, the partners succeeded to participate in 43 relevant events for disseminating, presenting the results. So the 30 disseminations events planned in the GA were fulfilled, and in total 43 events were participated. **No major drawbacks occurred.** The virtual way of disseminating info may have reached even more contacts in more countries than originally anticipated by the traditional way.

Policy impacts. The project results related to the inorganic binders in ferrous foundries were collected in a form of BAT report and delivered to the **Technical Working Group of the BREF Document**. The revision of BREF has started in 2019 and is continuing in 2022. 1st draft of BREF document was released in February 2022 Best Available Techniques (BAT) Reference Document for the Smitheries and Foundries Industry, draft 1 (europa.eu). The project outcomes have been delivered to the TWG in a form of official BAT/ET templates. 2 BAT and 5 ET technologies were delivered to the TWG. Feedback was received in the Public Webinar in April 2022 from a member of the TWG group and the BAT content was discussed with the member of CAEF (also member of the TWG), Mrs Elke Radtke and Prof Juhani Orkas from Technology Industries (also partner of the project) and he is a member of the TWG group, too. National contact person of TWG group in Finland has requested comments for the draft. AX, as an expert in emission measurement in different industry sectors, was requested for comments on the BAT draft, in relation to the planned monitoring activities and increased emission measurements for foundries. Comments from each country were delivered to TWG in May 2022.

Project emission and indoor air quality measurement results from the pilot foundries and chamber tests can be utilized in the discussions of **IED directive (Industrial Emission Directive)** regulations and limit values. Coordinator (Sara Tapola and Markku Tapola) participated in the **EU Green Week virtual conference in June 2021** where the Green Foundry LIFE project results were presented and the current **IED Directive (Industrial Emission Directive)** regulations and emission abatement technologies were discussed. As a continuation for this discussion, the project coordinator and partner, Dirk Lehmhus (IFAM), were invited to present the Green Foundry LIFE project results during **CINEA session on sustainable industries on 7th October 2022:** "This session is one of the seven organized by CINEA in order to gather together policy officers from relevant DGs (DG ENV, CLIMA, ENER, etc) and projects to present the latest policy updates and activities on the field on a specific topic, sustainable and clean industry in this case."

EU waste policy aims to contribute to the circular economy by extracting high-quality resources from waste as much as possible. **The European Green Deal** aims to promote growth by transitioning to a modern, resource-efficient and competitive economy. As part of this transition, several EU waste laws will be reviewed.
Particularly interesting for this project was the specific policy related to **landfill waste** (Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste). The Landfill Directive aims to protect both human health and the environment. In particular, it aims to prevent, or reduce as

much as possible, any negative impact from landfill on surface water, groundwater, soil, air and human health. It does this by introducing rigorous operational and technical requirements.
In addition, according to the Commission decision 2014 amending decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council the waste sands are listed under following waste categories: 10 09 wastes from casting of ferrous pieces. i) 10 09 07* casting cores and moulds which have undergone pouring containing hazardous substances ii) 10 09 08 casting cores and moulds which have undergone pouring other than those mentioned in 10 09 07.
One of the project objectives was to reduce sands wasted from casting procedure. These sands are currently landfilled and are categorized as hazardous waste. By introducing inorganic binders there will be much less harmful substances in the foundry sands and sands can be reused in new applications. This would directly benefit waste policy by reducing as much as possible landfill waste.

Other activities related to policy impacts are related to the discussions or presentations by the partners with relevant stakeholders e.g. policy makers, authorities, foundry associations and local foundries, binder system suppliers. One of the main forums for dissemination of the project results will be **national and international foundry associations**. Partners have presented project activities with following stakeholders:

- Finland: Suomen Valimotekninen Yhdistys
- CAEF annual meeting in Croatia 1.6.2019. Representatives of CAEF foundry associations. presentation by Juhani Orkas.
- Germany: BDG –German Foundry Association
- Italy: Assofond foundry association informed and present in the project activities at FOM Taconi foundry.
- Italy: Sardinia 2019 – 17th International waste management and Landill Symposium 30.9.-4.10.2019 by UNIPG. Meetings with decision makers, universities, waste management companies and associations.
- Spain: Spanish Federation of Foundry Associations - FEAF
- France: French Foundry Association - Fondeurs de France
- Poland: Polish Foundrymen’s Association and presentation at the annual meeting by Prof Rafal Danko, 2018 (in November-December 2022)
- Europe: CAEF Environmental Group (member Prof. Juhani Orkas from TI). Updating project activities in the CAEF meetings. Project outcomes are of great interest at CAEF.
- International Foundry Fair Trade GIFA: Presentation by Pekka Kemppainen, CEO of Karhula foundry, at the GIFA for foundrymen, foundry associations and policy makers. Meetings with inorganic binder system suppliers and project partners (all relevant system suppliers were met at GIFA).
- Germany: BDG (German Foundry Industry Association) Technical Committee 5.3.2020 (in autumn 2022). Presentations by Dirk Lehmhus, IFAM
- Germany: Euroguss 2020 (March) and 2022 (June) Trade fair. Presentation by IFAM.

EU Policy on the Urban Environment. The European Commission has, in recent years, been increasing its focus on urban issues, as a response to the fact that by 2020 it is estimated that almost 80% of EU citizens will be living in cities. The political importance of the issue is demonstrated by its inclusion in the **7th Environmental Action Programme (7EAP) under Priority Objective 8, entitled, Sustainable Cities**: "Working together for Common Solutions". The overall objective of this policy drive is to enhance the sustainability of EU cities to achieve by 2050 that all Europeans are "living well, within the limits of the planet".
Casting process represents one of the major sources of dust and harmful VOC and gas compounds which significantly impact on the urban air quality and working atmosphere environment. The project results demonstrated that by introducing the inorganic binders, this impact will be reduced, and it will facilitate urban objectives.

EU added value of the project and its actions.
The Green Foundry LIFE project results demonstrated the **huge potential that inorganic binder systems have as an emission-free system alternative to organic core and mould binders in ferrous foundries.** As a matter of fact, the project has found that harmful emissions of PAHs, VOCs, SO2, BTEX and CO decreased by more than 80% when using new inorganic binder systems instead of the organic binder systems. What is more, indoor air quality has been demonstrated to improve by 70-80% when using inorganic binder systems, while increased recycling of foundry sand and waste foundry sand, and dust cleaning and reuse methods have also been successfully demonstrated.

In the last decades, the pressure on companies from authorities, investors, consumers and the society as a whole to adopt environmentally friendly practices has increased significantly. Most equipment manufacturers, which make a significant part of the demand of products produced by foundries, are expected to consider green values as their main marketing tool in the near future. This has already been seen regarding energy suppliers – cupolas operating by coke are replaced by electric melting furnaces, which must use green electricity made by nuclear, hydro, solar or wind. What is more, companies belonging to all sectors and not just those in the energy industry are also starting to face increasing pressure to focus on climate action. In this vein, ferrous foundries, being responsible for the emission of a relevant amount of harmful volatile and gas compounds emitted in Europe, are also facing significant pressure to adopt environmentally friendly practices, and this is expected to become even more important in the future. Thus, it is reasonable to anticipate that EU customers will insist on green processes in foundries, so that foundries will need to implement these solutions and transform their processes. When ferrous foundries in Europe have ready solutions to go into this, the European Foundries will become more competitive and win market share from Asian foundries.

It is worth mentioning that the steel industry is already undergoing a transformation towards more environmentally friendly production processes. As a matter of fact, green steel will be made by deoxidizing iron ore by hydrogen instead of carbon and in this way minimize CO2 output. It thereby seems inconsistent to use castings made by organic binders causing toxic emissions and at the same time going to green steel. This makes it sensible to assume that ferrous foundries will end up substituting totally or partially organic binders.

Given that the implementation of inorganic binder systems will bring significant benefits to iron and steel foundries in Europe, these types of foundries are expected to be willing to carry out the investments necessary for their implementation. Besides, since this process is also aligned with the interests and priorities of public authorities and a significant number of private investors, it is sensible to foresee that public and private investors and funders will be also be willing to finance these investments. E.g. the European Investment Bank (EIB) has expressed their interest towards the treatment technologies demonstrated in the project.

Reduction of foundry waste sand to be landfilled. It has been studied in this project, that inorganic binder system waste sands contain much less harmful substances compared to organic binder waste sands, and the inorganic waste sands can be recycled in the foundry process for longer time. This case the need for new sand decreases and also less waste sand will form. Because the inorganic binder system waste sands are cleaner, they can be reused in new applications e.g. geo-construction purposes (**The Government Decree on the Recovery of Certain Wastes in Earth Construction in Finland (843/2017**).

Green Foundry LIFE project demonstrated different cleaning and recycling options to reduce the amount of waste sand to be landfilled in Europe. The composting method demonstrated that the harmful organic substances of the foundry waste sand and dusts were effectively degraded by microbiological activity. The clean end-product as soil material fulfilled the limit values set in the **Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011): Substrate – Mixture soil (5A2)**. Soil material can be reused in landscaping and green construction purposes which reduced the amount of foundry waste sand to be landfilled. Thermal reclamation tests demonstrate that certain sand types can be effectively recycled back to foundry processes which decreases the need of new sand and decreases the amount of waste sand to be landfilled. In all the tested techniques the aim was to reduce the amount of waste sand to be landfilled in Europe. Based on the project results, two BAT (Best Available technique) and two ET (Emerging Technique) were delivered to TWG group in relation to the foundry waste sand cleaning and recycling methods, aiming to reduce the total amount of waste sand to be landfilled.

Based on the demonstration actions and results received the composting and thermal reclamation methods are economically viable and also commercially available. These can be recommended as good options for treating the waste sands and reuse in new applications or recycle back to foundry processes compared to the increasing costs of the landfilling.

6.3 Analysis of benefits

In this section please discuss the project's progress focusing on the results achieved. Justify any anticipated significant deviations from the targets set initially, and comment on targets already met or exceeded. In the case of the Final report, where relevant, refer to the final actual values of the Key Project-level Indicators (KPI):

1. **Environmental benefits**
   a. Direct / quantitative environmental benefits

      The highlights of the project are:

      - Cleaning by composting method: About **114 tons of waste foundry sand and dust** were cleaned in 7+6 composting test heaps during the project (In Finland 90 tons waste sand and in Spain 24 tons of waste sand). (*GA: 6+4 test heaps and ca 40-50 tons of waste sand/dust to be treated, when sand proportion is 20-25% per heap).*
      - Composting tests: **Producing 480 tons of clean and mature soil material** suitable for landscaping and green construction purposes during the project.
      - Thermal reclamation tests: **10 tons of waste sands** (2 inorganic and 3 organic binder system waste sand types) were cleaned in the thermal reclamation tests in Finland and transported back to foundries. (*GA: Inorganic waste sand specimens are delivered from Karhula Foundry and three most typical organic sand types; furanic, green sand and phenolic are delivered from Finnish foundries*).
      - Without Green Foundry LIFE project cleaning tests these **129 tons (114+10+5) of waste sand/dusts would have been transported to landfills.**
      - Cleaning by washing method: 100 kg waste sands (2 inorganic waste sands and 2 organic binder system waste sands) were cleaned at Tecnalia laboratory tests *(GA: 3 inorganic binder waste sands from Spanish aluminium foundries).*
      - **Emission measurements in 5 pilot foundries** representing both organic and inorganic binder systems *(GA: emissions of 2 organic and 3 inorganic binder system foundries).*
      - **Indoor air quality measurements in 4 pilot foundries** representing both organic and inorganic binder systems *(GA: indoor air quality of 2 organic and 2 inorganic binder system foundries).*
      - **117 tons of test casts and cores** representing both inorganic and organic binder systems at Karhula Foundry and Valumehaanika foundries were produced. **3 inorganic binder systems** were tested (*GA: ca 117 tons of test castings with 3 inorganic and current organic binder systems tested in Karhula Foundry*).
      - **320 pieces test cores** (á 3 kg) were produced with **2 inorganic binder systems** at FOM Tacconi foundry in Italy (GA: 300 test cores produced with inorganic binder system).

- **5 tons inorganic waste sand treated by hydromehanical, ultasonic and conventional mechanical treatment methods (3 treatment methods)** at CTIF laboratory *(GA: inorganic binder system waste sand treated with combining ultrasonic and microwave thermomechanical technologies in adequous media on laboratory scale).*

b. Qualitative environmental benefits (long-term)

<u>The highlights of the project are:</u>

- Project partners and binder system suppliers will actively continue developing the inorganic binder systems. One of the goals of the project was to form an active information exchange group around the knowledge of inorganic binders. Close development cooperation within this group continues in the new LIFE project, where the key suppliers of inorganic binders are also partners.
- In the new Green Casting LIFE project, withing next 3,5 years the use of inorganic binder systems will be demonstrated in full scale production in 6 flagship partner foundries and tested in 15 follower pilot foundries in Europe.
- This extensive demonstration in the new LIFE project will create such a knowledge and experience base that 300 foundries are expected to adopt an inorganic binder system five years after the end of this project.
- Project has shown that improving indoor air quality is possible by changing to inorganic binders, which reduces the need for ventilation and emission abatement technologies and saves costs.
- Project has shown that the amount of foundry waste sand to landfills will be reduced and foundries can avoid to pay the high deposit fees.
- Project has shown that inorganic waste sands contain less harmful substances and therefore it can be re-used in other applications e.g geo-engineering construction, road construction, green field construction purposes.

2. Economic benefits

The economic benefits targeted in the project were not achieved since no pilot foundry adopted the inorganic binders in the full scale production during the project. But there are potential for remarkable economical benefits in future after adapted the techniques:

- By introducing the inorganic binders the end-of pipe solutions and ventilation systems can be reduced. In Foundrybench project, (IEE/07/585/SI2.500402), it was calculated that the electric consumption of the ventilation in ferrous foundries is of 0,9 MWh per produced ton of castings. The reduction in the need of the ventilation was estimated in the project to be 60% for foundries using inorganic binder systems, ie. the reduction of 0,54 MWh per produced ton of castings. The price of electricity in the EU is now 250… 500 € / MWh. A ferrous foundry producing annually 5,000 tonnes can save € 675,000 / € 1,350,000 per year by changing to inorganic binders.
- Deposit fees for waste sands will be reduced. Landfill fees for waste sand are in the EU as high as € 60 to € 100 per tonne. A ferrous foundry, which produces 5,000 tonnes per year, produces also an average of 5,000 tonnes of waste sand per year. The cost savings with inorganic binders by which landfilling of waste sand is avoided can be € 300,000 to € 500,000 / year.
- Instead of landfilling the waste sands can be reused in composting process and produce clean soil material. Normally composting soil materials include sand (e.g. ridge sand) and inorganic waste sand can replace this and reduce costs accordingly.

3. **Social benefits** (e.g. positive effects on employment, health, ethnic integration, equality and other socio-economic impact etc.).

- To improve the indoor air quality for a safer work environment. Organic binders emit hazardous casting fumes and fine particles like binder aerosols. By accelerating the uptake of inorganic binders, the Green Foundry project will have a significant impact on improving the working environment for foundry workers. During the project, 280 employees have benefited from the improvement of indoor air quality.
- To improve the image of foundries as “dark, dusty and dirty” workplaces for new workers.
- Average number of employees in ferrous foundries in the EU is ca. 133. In case 300 ferrous foundries changing to inorganic binders it is potential to positively affect the health of 40,000 workers.
- In the EU an average of 3,000 people live in an area affected by emissions from a ferrous foundry. In case 300 ferrous foundries change to inorganic binders, it is potential that the health of the 900,000 inhabitants around the foundries will be positively affected.

4. Replicability, transferability, cooperation:

Project results from testing inorganic binders and experiences so far have been discussed with ferrous foundries and foundry associations in Europe. About 100-150 foundries were directly contacted with emails and discussions during the project or arranged webinars, meetings and exhibitions. The interest towards this topic and Green Foundry project results have greatly attracted attention. The uptake of the inorganic binders in iron and steel foundries still depends on the technological readiness and development work needed.

For some foundries and their processes it could be rather easy to introduce the inorganic binder system already but in majority of iron and steel foundries it would require big investments, at least if those inorganic binder systems are introduced, which need to be dried. To solve these technical problems and to develop also inorganic binders which do not need additional drying will foster the market access of the inorganic binders in iron and steel foundries and increase the replication potential. The need for inorganic binders in iron and steel foundries is real and therefore more development work and tests are needed in cooperation with foundries and inorganic binder system suppliers. It is already potential to introduce inorganic binders in some foundry processes e.g. in core-making where the formation of gas created problems and the change in inorganic binders would improve the quality of the cast. So step-by-step solutions in foundries are most relevant options in near future.

In the Project Public Webinar the foundries hoped to have at least 15-20 successful demonstration cases and experiences of different types of foundries and products before they are ready to make changes in their production. Foundry processes are very sensible, so all technical problems and all processes must be well tested and proven before the foundries can make these big investment decisions.

Project results have been widely disseminated in 12 relevant publications and 43 relevant events, webinars, exhibitions and meetings. Active dissemination activities will continue after the end of the project by project partners. Future networking and new development project are planned. Experiences, results and guidelines for implementing the inorganic binders including also foundry waste sand cleaning and treatment methods are provided in project deliverables in a practical manner for presenting the tested technologies on environmental, economic and technical way.

5. Best Practice lessons:

- The expectations of the inorganic binders to be implemented in iron and steel foundries have not fully answered one´s expectations while preparing the proposal and based on the test casts produced in this project so far. The implementation of inorganic binders is more complex than anticipated and some costly investments must be often made. Therefore, much more industrial scale demonstration is needed to ensure that inorganic binders and investment equipment works as expected.

- More R&D work is needed from the binder system manufacturers especially related to the drying demands of moulds and sand reclamation methods which were not the subject of this Green Foundry LIFE project.
- The technical development of inorganic binders was not as advanced as it had been promoted by the manufacturers
- Concerning the goals regarding environmental impact the results are excellent – much less odorous gases and smoke is coming out from moulds during the casting. On environmental and emission reduction wise the results are as good as expected.
- Results regarding casting quality seem to be good, too. Less gases mean less internal gas defects and better working feeders reduce shrinkage defects.
- Most inorganic binders on market seem to work reasonably or very well with aluminum and other non-ferrous casting metals, but results with iron and especially steel are still limited.
- While testing different inorganic binders in Action B3 it became obvious that some inorganic binders need drying in furnaces in temperatures up to 180-200 C.
- Such inorganic binders can be used only in foundries which already have on-line drying furnaces in their core and mould production lines.
- In those temperatures it is possible to use only metallic core boxes and metallic moulds, which will cause huge cost increase or a process suits only for high volume
- For example in Karhula foundry the existing core drying furnace was small in size and therefore the size of moulds was limited so that castings up to 300 kg could be produced by these inorganic binders.
- Breaking of moulds also occurred. The reason for breakages was unproper drying.
- When using resin core-boxes, they were damaged because of heat and when using wooden ones they were too good isolators and drying was incomplete
- When the drying was complete, the strength of the moulds was good enough and surface quality of the castings was good even if the mould were not coated.
- Test casts demonstrated that the formation of gaseous emissions from the moulds made by inorganic binders is minimal compared to the mould made of organic binders.
- Surface defects caused by gas formation can be practically avoided. This is a major benefit, quality wise.
- Because of this drying demand of the moulds the size of the test casts at Karhula foundry could not be as big as expected (4 tons, 15 tons and 20 tons). But small moulds were made in many series to gain more experiences and find suitable recipes and process parameters.
- Promising tentative results were achieved with one inorganic binder where also organic compounds are used as hardener. The hardener content is 12… 18% of the binder content.
- Small organic component creates enough strength to get the core or mould out from tooling and then final hardening can happen at ambient temperature without need of heating of gas blowing. This kind of binder system is called “self-setting” or “self-curing”Tentative results of these semi-inorganic binder systems were very promising and the test cast quality aspects were also good.
- As a conclusion, with the use of inorganic binders, it is possible to obtain not only indoor air and product quality benefits but also cost benefits. Sand costs can be reduced primarily due to lower disposal costs and air conditioning can be reduced due to lower emissions.

To implement inorganic binders in full scale production in ferrous foundries, the following must be taken into account:

- Vast knowledge is needed about different inorganic binder systems and their proper implementation into current or new production lines.
- Individual implementation plan for each foundry must be prepared including suitable inorganic binder systems for the foundry’s production lines and products, and technical and economic information about possibly needed investments

- In most cases investments for moulding, core making and sand regeneration methods are needed and broad preliminary testing should be carefully carried out before commitment.
- Traditional nature of the branch opposes reforms: there should be successful example cases of replacing the organic binder systems by inorganic binders, so that new ferrous foundries would have sufficient and latest information to start the introduction of inorganic binder systems in full production scale.
- Suitable sand reclamation system should be tested for inorganic binder system waste sand. This is one the main goals in the new Green Casting LIFE project.

The current standard for casting industry is still the application of organic binders. It has been widely used for years in mass production especially in small-sized products and more complex multi-core shapes. Organic binders are mostly used for their technical properties. With a more conscious approach towards environment, the metal industry has started to look towards greener solutions in foundries. A recent advancement has been the development of eco-friendly inorganic binders. An inorganic binder makes it possible to perform a curing process at a low temperature and does not generate a toxic substance, and, thus, a working environment is kept in a good condition. In addition, just a small amount of a gas is generated during a manufacturing process of a core and a casting process. Thanks to this defects in casting are reduced, and there is no need to install an anti-environmental pollution system ultimately leading to lowered manufacturing costs. The main drawback of inorganic binders is the lack of wider demonstration actions in at least 20 ferrous foundries and utilization on commercial scale. There are good examples of using inorganic binders however these are mainly restricted to non-ferrous foundries, i.e. only for aluminum production in high volume production. The uptake in ferrous foundries, i.e. for steel and iron casting, several problems remain due to the higher pouring temperature of iron and steel. Due to that, the durability of the moulds and cores needs to be higher. The quality of inorganic binder moulds and cores have not been good enough for such high temperature castings. Based on the project results inorganic binders emits less harmful components indoors, to the environment and via foundry sand. In addition to environmental impact, the inorganic binders focuses also on the physical properties and quality of the moulds, cores and casts, by reducing the formation of the gases in the cores which affects the quality of the casts in positive way. Even though there are some technical issues to be solved also after the end of this project, **the potential and possibilities of the inorganic binders are undoubted.**

6 Policy implications are described in the section **6.3 Evaluation of project implementation under Policy Impacts.**

7 Key Project-level Indicators

Here is assessed the project’s progress towards achieving the Key Project-level Indicator (KPI) targets. The main goals of the project were:

- To reduce hazardous airborne emissions from given ferrous foundries by 80-95%
- To improve indoor health approximately 70-80% for a given ferrous foundry
- To reduce waste problem of hazardous surplus foundry sand by recycling up to 75 %
- To boost about 300 ferrous foundries in applying inorganic binder systems instead of present organic binder systems in everyday practice within 5 years after the project.

Attainments of these targets are monitored by relevant Key Project Indicator values given in KPI Webtool. The indicator values representing the present situation in the project are updated. Until now, the measured results of the project actions indicate that there should not be major problems to achieve the given KPI values at the end of the project.

Small scale emission tests made by AGH in Poland and chamber emission tests made by AX in Finland and AGH in Poland in Action B1 indicate that the hazardous airborne emissions are reduced by more than 80 %, when inorganic binder systems are applied instead of organic binder systems. The total emissions and indoor air quality measurements in foundries applying inorganic binder systems, in Action B2, have been completed successfully by 13.5.2022. in spite of the of delay due to the Covid-19. **The KPI values 6.1 Air - Emissions and 6.2 Air – Quality** will be reached when inorganic binder systems are applied in everyday practice in the given foundries.
The results in action B3. “Test series of mould, cores and casts produced by inorganic and organic binder systems” show both promising results and some practical problems, which have to overcome before everyday practice of inorganic binder systems in many ferrous foundries can be applied. Some of the tested inorganic binder systems need drying at elevated temperatures, up to 160…200 ^{o}C, in heating furnaces, to reach the needed strength levels. This is a problem for foundries which do not have on-line heating facilities for moulds and cores, and big investments would be needed, to be able to apply these kind of binder systems. On the other hand, promising results have been achieved from test cores which have been made by Italian core maker having online heating facilities. The properties of cores and quality of the test casts have been equal to those produced by organic binder systems. Some of tested inorganic binder systems do not need drying at elevated temperatures. The results from tests with these kind of “self-curing” binder systems in Karhula Foundry were promising. The use of self-curing inorganic binders will be most probably the solution for the drying problem. After the withdrawal of Karhula Foundry from the project due to economic reasons on October 23, 2020, the demonstrations with self-curing inorganic binder systems were carried out in Valumehaanika in September 2021. The results were also there promising, the quality of the castings was comparable with the castings made using current organic binder system, phenolic Alphaset.
However, demonstrations have shown that in most cases foundries have to make large investments to use inorganic binders in their daily practice. Much wider full-scale demonstrations are needed to convince foundries of costly investments. In addition, the recovery of used inorganic binder sand is still partially under development. Therefore, the introduction of inorganic binders in ferrous foundries is still in the early stages. The original goal at the end of the project was for 150 ferrous foundries to use inorganic binders in daily use. During the project, 3 pilot foundries demonstrated inorganic binders on a production scale. In addition, there are 6 ferrous foundries in the EU that use inorganic binders currently for daily use. The project has not been directly involved in their processes, but the dissemination of the promising results and cooperation with producers of inorganic binders have indirectly influenced the transition to inorganic binders. **Project KPI indicators 1.5. Project area/length and 1.6. People affected by the project** were changed accordingly (only 3 pilot foundries were considered in KPI values). The follow-up measures set out in the business plan and in the new LIFE project, which will probably start this autumn, will include large-scale demonstrations of inorganic binder systems and practical answers to open sand recovery questions. Therefore, it is believed that 5 years after the project, the target of 300 ferrous foundries using inorganic binders will be achievable. The results achieved in Action B.4 “Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dust” show the targets set for the reduction of the hazardous foundry waste were achieved. The promised amounts of the treatments for waste sand by composting (10 test heaps in Finland and Spain: ca 40..50 tons of waste sand to be composed) and thermal treatments (3 inorganic waste sands from Karhula and 3 organic sands) are already reached, and the results are good. Original **KPI indicators in 3.1. Waste management** were accordingly met**.**
The Actions B5.” Replication and transfer of the project results” and D4 “Dissemination planning and execution” were somewhat influenced by Covid-19. In total 43 events were participated by partners and 7 national seminars were arranged in FI, SP and FR. Before Covid-19 started, the mentioned actions proceeded as planned. Especially it must be brought up, that most of the project partners participated to GIFA Fair in June 2019, in Germany. GIFA is the biggest Fair in foundry branch in the world. Project meeting was arranged there, and partners met numerous relevant stakeholders in the branch. Covid-19 changed the situation so that all project workshops and meetings in 2020-2022 were held through video conferencing. However, thanks to the easier arrangement, their numbers were much larger than planned.

The public seminar was also held as a Webinar on April 22, 2022. It aroused great interest and there were up to 100 participants present, at least part-time. There were 15 ferrous foundries in the public that are interested in applying inorganic binders and are potential pilot foundries in the possibly upcoming new LIFE project. There was a lively discussion during the Public Webinar. The planned national seminars in some partner countries were postponed due to Covid-19 and will be held in the autumn of 2022. 7 national seminars have been already arranged in SP, FI and FR. Presentations at these future seminars will be given by designated project partners.
During the autumn of 2021, a new LIFE project proposal was prepared together with 15 other participants, including 6 flagship pilot foundries. Several other ferrous foundries, other stakeholders and NGOs were contacted during the preparation of the proposal. Letters of support were received from nine foundries, eight NGOs and three other stakeholders.
KPI indicators in **10.2. Involvement of non-governmental organisations (NGOs) and other stakeholders in project activities** (the original goal was 44 organisation, achieved 56) and **12.1. Networking** (the original goal was 30 members of interest groups, achieved 220) **were reached or exceeded.**
The project website was constructed as planned. The interest was large, and the target for nr. of individuals and the target for nr. of visits has exceeded. KPI indicators in **11.1. Website was 82 200 individual visits during the project** and objective was exceeded (the original goal was 5,000 individual visits).
No new employees have been hired. The results of the project so far are promising, and it is possible to reach the KPI indicator values beyond 5 years after the project in **13. Jobs**.
No major changes have been happened in actual costs compered to budget. KPI indicators in ***14.1.*** Running cost/operating costs during the project were in total of 2,065,721 € (according to the GA 2,027,998 €). Small deviations between cost categories and partners existed.
Calculations about the cost savings to be achieved when changing from organic binder systems to inorganic binder systems in ferrous foundries has been calculated in Section 6.4.2. Based on project results, it is expected that significant cost reductions can be seen in handling of waste foundry sand and in preventing hazardous emissions from foundries as well as in costs related to workers health issues. The KPI indicator values in **14.2.4. Cost reduction expected in case of continuation/ replication/transfer** after the project end are possible.
Future funding will depend on the possible launch of a new LIFE project. If the project is launched, funding will be secured for the next 3.5 years. Otherwise, the financing is self-financing. KPI indicator value in **14.3. Future funding** will be met.

In spite of the delays and problems occurred in project actions due to the COVD-19 (clarified action by action in section *6.2 Main deviations, problems and corrective actions implemented*), and a need for 12 months prolonging, all project actions were finally successfully carried out as planned, objectives and expected results were fulfilled as planned in the Grant Agreement. Thanks to good cooperation with project partners and wide contacts in relevant stakeholders and European foundries.

8 Comments on the financial report

Overview of the actual incurred project costs. **In the end of the project the eligible costs were 2,065,710 € (total costs 2,116,426 €)**. In the Grant agreement the total eligible costs were 2,027,998 € (total costs 2,088,998 €).

9. Appendices

1	DeB2A Results of total emission and indoor air quality measurements in Valumehaanika foundry in Estonia. *(This deliverable replaces the DeB2A Results of total emission and indoor air quality measurements in one of the inorganic binder system pilot foundries in France)*
2	DeB2A Results of total emission and indoor air quality measurements in an inorganic binder system pilot foundry in Germany. *(This deliverable replaces the DeB2A Results of total emission and indoor air quality measurements in the second inorganic binder system pilot foundries in France).*
3	DeB2B Results of total emission and indoor air quality measurements in water glass pilot foundry in Sweden
4	DeB3A Test casts produced by inorganic and organic binder systems at Karhula Foundry and Valumehaanika (combined report)
5	DeB3C FOM Tacconi and Karhula Foundry implementing inorganic binders in everyday practices
6	DeB3D Quality analyses of test casts carried out in the pilot foundries _ CTIF (ADDITIONAL)
7	DeB4.1A Composting method results with organic binder system dusts in Finland (updated)
8	DeB4.2 Thermal reclamation test results with inorganic and organic surplus foundry sand specimens (updated with wet attrition test results 31.11.2021)
9	DeB4.5 Feasibility studies of the reuse of inorganic surplus foundry sand in core making and geo-construction
10	DeB4.6 Life Cycle Assessment on tested methods
11	DeB5.1A Content of the public Green Foundry project Workshop
12	B5.4 BAT report feedback request from the BREF TWG
13	DeB5.1B BAT publication
14	De.B5.2 Conclusions and outcomes of the Green Foundry project
15	DeB5.3A Business plan
16	DeB5.3B Replication and transferability plan
17	DeC1.1C Performance indicators (Final report)
18	De.C1.2 Assessment of the socio-economic impacts of the project actions
19	DeD1.2 Dissemination plan (updated until 06/2022)
20	DeD1.2D Laymans report
21A-D	Technical publications: Green Foundry LIFE (LIFE17 ENV/FI/173) articles at AX magazine in 2018-2021 (4 articles)
22	Technical publication: Inorganic binder investigations at Foundry Journal of the Polish Foundrymens Association 2018 by AGH.
23	Technical publication: An poster presentation: S. Saetta, F. Di Maria, V. Caldarelli, S. Tapola "*Improve the use of natural resources: inorganic binders in iron and steel foundries – Case of the Green Foundry LIFE project*", transactions SARDINIA 2019 - 17th International Waste Management and Landfill Symposium.
24	Science Direct 2019 Saetta Caldarelli UNIPG
25	Technical publication CTIF MetalBlog 2021

26	Technical publication CTIF 2018
27	Technical publication CTIF MetalNewsDecember2021
28	Technical publication: Other Moulding and Core Sands with Inorganic Binders. Mould and Core Sands in Metalcasting: Chemistry and Ecology by Mariuzs Holtzer and Angelika Kmita 2020)
29	Technical publication MDPI 2020 Materials-13-04395
30	Technical publication MDPI 2021 Materials-14-02581
31	DeE1.3 After LIFE Communication plan
32	Contract of employment Mariusz Holtzer (AGH UST)
33	Karhula Foundry financial cost statement, withdrawed on 23.10.2020
34	Tender procedure and invoices with payment proofts of Meehanite related to prototype costs at new composting site
35	Contract of employment as project assistant Valentina Caldarelli (UNIPG)
36	DeB4.5B Clarifications for the withdrawing from the microwave and ultrasonic tests by CTIF (ADDITIONAL)
37-46	Financial cost statements of all beneficiaries (pdf forms)
47-57	Financial cost statements of all beneficiaries (excel form)
58	Payment request (signed), Cost Summary (signed), Income Summary (signed), Consolidated cost statement (signed), Funds distribution (signed)
59	Consolidated cost statement (excel format)
60	Updated list of deliverables
61	DeB1A Results of emission measurements of chamber test cast carried out in Karhula foundry, Finland. Delivered in Midterm report 16.6.2020, *updated with second inorganic binder system test results*, attached in Final report.
62	DeB1C Results of emission measurements of inorganic and organic mould sands in testing foundry at AGH laboratory.
63	DeB1D Results of emission measurements of inorganic and organic mould sands in pilot foundry HARDKOP in Poland.
64	DeB3B Test cores produced by inorganic binder system in Italian pilot foundry.
65	DeB4.4 Conclusions of the results of waste sand cleaning methods.
66	DeB4.3 Washing test results of inorganic surplus foundry sand specimens in Spain