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LAYMANS REPORT

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LIFE PROJECT NAME or Acronym
“Green Foundry LIFE”
Inorganic binder system to minimise emissions, improve indoor air quality, purify and reuse of contaminated foundry sand

Data Project

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Data Beneficiary

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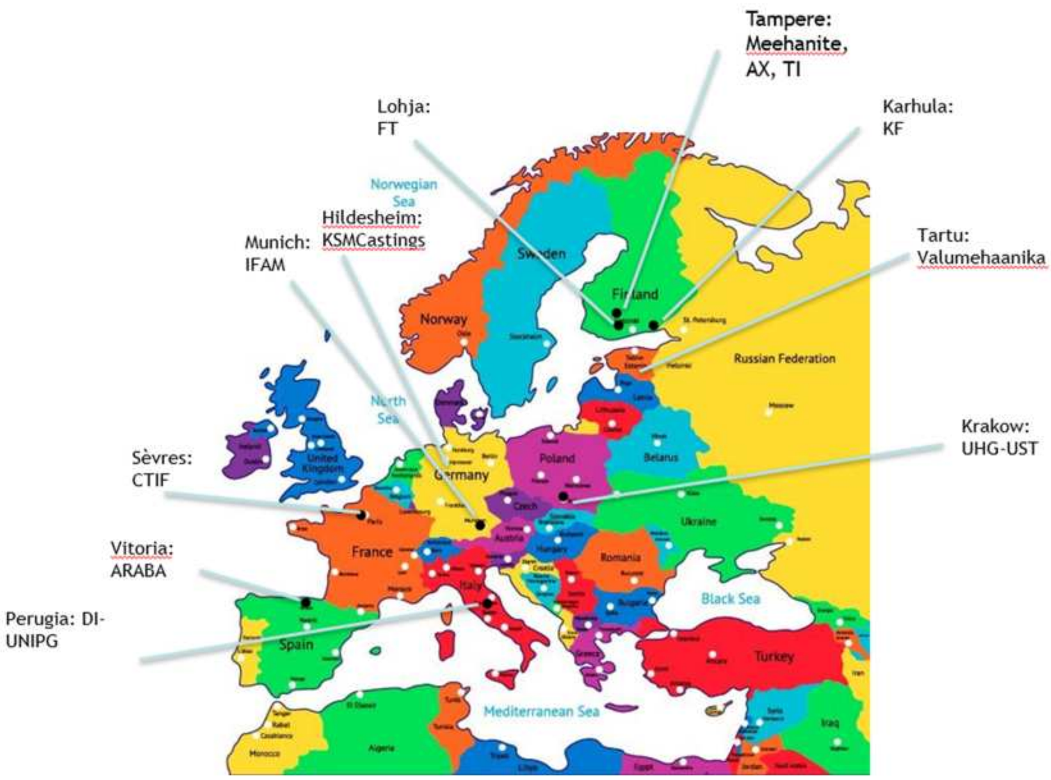
	AGH University of Science and Technology, Poland
	Centre Technique des Industries de la Fonderie, France
	Dipartimento d´Ingegneria, University of Perugia, Italy
	Eurofins Viljavuuspalvelu Oy, Finland
	Foundryteam Ltd, Finland
	Fundiciones Araba SL, Spain
	Fraunhofer IFAM, Germany
	Technology Industries of Finland
	Karhula Foundry Ltd, Finland

Partners and pilot foundries involved



1. Laymans report (English)

1.1. Environmental problem targeted

Industrial sector plays an important role in the economic well-being of EU, generating 25% of all the EU GDP. Although the 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. It is-one of the most environmentally polluting sectors, due to high gas emissions and waste generation. The environmental problems have been set as a priority to be solved.

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 ºC. 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 main objective of the Green Foundry project was to decrease the environmental impact of the European foundry industry by introducing novel technologies for sand molding systems. 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.

So far new silicate based inorganic binders have been established in few aluminium foundries which have demonstrated to contribute to a decrease in hazardous air emissions and an improvement of indoor air conditions at the workplace when compared to organic binder systems. Besides, the reduction of harmful substances in foundry sand that goes with the use of these types of binder systems has a major influence on the possibilities for treatment of such wastes and accordingly reduces the amount of foundry sand to be landfilled.

In the Green Foundry LIFE project the use of various inorganic binder systems were experimentally tested in three pilot foundries and the impact on product quality as well as the integration in established process chains were evaluated. Dedicated emission measurements were performed in small scale chamber tests and foundry conditions with different organic and inorganic binder systems to measure the emission reduction and improvement in indoor air quality when exchanging to inorganic binder systems.

Furthermore, the treatment of inorganically and organically bound waste sands were demonstrated with composting and thermal reclaiming methods on industrial scale. Mechanical, hydromechanical, ultrasonic and washing methods were tested on laboratory scale tests. For the implementation of the inorganic binder system in ferrous foundries one of the critical issues is to find a suitable treatment method or reuse applications for the waste sand. The findings of the project are fed into the currently running process of developing a new best available technology reference document (BREF) for the smitheries and foundries industry.

2. Emissions of different binder systems during small scale test casts

The aim was to measure total emission from different inorganic and organic binder systems and compare the results.

Small scale chamber tests were carried out at lab scale tests at AGH University in Poland and in pilot foundry conditions in Finland and Poland. Under lab scale tests AGH University measured emissions from six binder systems used in sand moulds as:

- Organic binders: furan resin and phenol-formaldehyde resin.
- Inorganic binders: Inotec and Cordis and Geopol.
- Green sand: activated bentonite.

Fig. 1 Chamber tests and emission measurements at UGH University in Poland.

Main conclusions of the laboratory and Hardkop pilot foundry tests:

- ***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 emission of these compounds from moulding sands with inorganic binders.
- Green sand 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.
- In the pilot foundry conditions the moulding sands with inorganic binders (Geopol, Cordis and Inotec) were characterised by lower harmfulness for the environment and employees than moulding sands with organic binders.

Main conclusions of the test results at Karhula and URV pilot foundries:
Chamber tests were carried out with phenolic binder and two inorganic binders and results are compared in the table below. ***Emission reductions of 96-99% were measured*** when using inorganic binders compared to the organic phenolic binder (Table 1).

Fig. 2 Chamber tests and emission measurements at Karhula foundry in Finland.

Table 1. Chamber test results with different binding systems at Karhula Foundry and URV foundry.

	Test	URV chamber	Karhula chamber	Karhula chamber	Emission 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	

3 Results of test casts and cores in pilot foundries

The aim was to demonstrate the feasibility of inorganic binders in production scale in the manufacture of moulds and cores in ferrous pilot foundries.

Karhula Foundry in Finland and Valumehaanika foundry in Estonia use currently organic phenolic Alphaset binder and FOM Tacconi in Italy foundry uses bentonite sand (green sand) binder.

Demonstrated inorganic binders:

- InotecTM from ASK Chemicals GmbH
- Cordis from Hüttenes-Albertus Italy S.p.A.
- Cast Clean from Peak Deutschland GmbH
- Geopol® from Sandteam spol s.r.a.

Inotec TM and Cordis binder systems consist of fully inorganic binders and hardeners. The hardening processes in these systems need drying at elevated temperature at 150…200°C. Geopol® and Cast Clean binder systems consist of fully inorganic binders and organic hardeners (ester solutions). These binder systems harden at ambient temperature, and they are therefore called as “self-setting”.

3.1 Fonderie di Assisi in Italy

Fonderie Assisi (former FOM Tacconi) is located near the centre of Assisi, which is one of the Unesco’s world heritage towns. For this foundry the emission reductions are necessary to continue production in future at its current location.

Fonderie Assisi produces both iron and steel castings for automotive industry, mainly parts for engines, such as castings for turbos and exhaust manifolds. **Fonderie Assisi demonstrated Cordis and InotecTM inorganic binders in core making**. The cores were manufactured by the sup-supplier, 2VI S.r.l., producing test cores with both tested inorganic binder systems. The core shooting equipment used was equipped by hot air blower, enabling the heating to 150…200 ºC. Most of the cores were painted by alcohol-based zirconium coatings. Before casting, the cores were placed into the green sand moulds. The casting material was grey cast iron, and the casting temperature was ca. 1390 ºC.



Fig. 3. Cores with inorganic binders were produced at FOM Tacconi foundy.

Experiences from the inorganic binder system test cores:
The cores of inorganic binder system had the equal quality properties, as well as the quality of the test castings, compared to the current organic phenolic Cold-Box method cores and castings. The gas formation, measured in laboratory by loss of ignition method, was significantly reduced compared to Cold-Box cores, resulting less emissions and better indoor air quality in the foundry.

FOM Tacconi is satisfied with the results, and they are planning to proceed in application with inorganic binders. The implementation of core making by the demonstrated inorganic binder systems at the foundry requires investment of core shooting device equipped with heating or hot air blowing possibility. The foundry has made preliminary studies on suitable devices.

3.2 Karhula Foundry in Finland

Karhula Foundry produces demanding middle to large size special castings for global casting markets. The cast materials include wide variety of cast irons and steels, with the special emphasis on duplex, martensite, ferritic, austenitic and super-austenitic stainless steels.

Karhula Foundry demonstrated InotecTM, Clean Cast and Geopol® inorganic binders in mould and core making by using separate test mixer and hand moulding. Several full production scale series of tests with all three inorganic binder system moulds and cores were made. Typical foundry’s products with casting weight range of 15…2500 kg were produced.

Most of the moulds were painted by alcohol-based zirconium coatings. Casting materials were different types of stainless steels, and casting temperatures varied between 1500…1540 ºC.

Fig. 4. Castings with three different inorganic binders were prodced at Karhula foundry.

Experiences from different inorganic binder system test casts and cores:
It is possible to produce the moulds and cores by the tested inorganic binder systems having the equal quality properties with the moulds and cores made by the current organic, phenolic Alphaset, method. The quality of the castings was as good as with the current products made by organic binder system. The harmful emissions from the moulds were greatly decreased by all the tested inorganic binder systems, compared to the moulds made by fully organic Alphaset binder system.

The inorganic binders which require heating to elevated temperatures are not feasible for the current production. There is a risk that in high temperatures wooden or plastic core boxes and patterns would deform and be destroyed. The patterns and core boxes should be made of metallic materials, which would be very expensive. The production times would also be extended, especially with bigger moulds. Necessary investment for heating equipment would increase costs, too.

The self-setting inorganic binder systems are better suited for the current production and product range. The implementation of these inorganic binders in full scale production would, however, require high investments for a separate mixer line.

3.3 Valumehaanika foundry in Estonia

Valumehaanika AS is an iron foundry locating in Tartu, Estonia.The current organic binder system is phenolic Alphaset system. **The self-setting Clean Cast and Geopol® inorganic binders were demonstrated**, by using the current modern continuous mixer line. Several production scale test series were made by both binder systems with different recipes of binders and hardeners, to find the most feasible ones for the prevailing production conditions and the produced castings. The moulds and cores were painted by alcohol-based zirconium coatings. The size range of the castings was 5…200 kg. Casted material was the grey cast iron EN GJL-250 and casting temperature was ca. 1450 ^{o}C.

Fig. 5. Test casts with two different inorganic binders were produced at Valumehaanika foundry.

Experiences from different inorganic binder system test casts:
The self-setting inorganic binders could be used instead of organic Alphaset in the continuous mixer line, without any need to change the existing equipment. The feasible recipes of the binders and hardeners are dependent on circumstances in the foundry, especially ambient temperature, in the foundry. The cooler the temperature was, the slower was the hardening, and faster hardeners must be used.

With the proper recipes, the properties of inorganic binder moulds and cores were comparable with current organic binder moulds. The quality of the castings was also good and comparable with the casings made by current organic Alphaset system.

Valumehaanika was satisfied with the results. For the full-scale production, it would require high investments for a separate inorganic binder system moulding line.

4. Recycling options and sand purification of inorganic surplus foundry sand and high concentration organic waste sand and dusts

In addition to the undesirable emissions described, casting processes produce a huge amount of undesirable waste. 90% of ferrous foundries are using sand casting, making and intensive use of sand as an inert primary material, and generating more than 6 million tons of spend foundry sand in Europe per year, being most of them landfilled. Thus, the regeneration and reuse of sand are crucial. In the Green Foundry LIFE project different surplus foundry sand purification, regeneration and reuse methods were demonstrated with different binder system waste sands to recycle the cleaned foundry sand back to process or to create new reuse applications for the foundry sand. **The aim is to reduce the total amount of waste sand to be landfilled.**

4.1. Cleaning surplus foundry sand by composting method

The aim in the composting process is to degrade the harmful organic substances of surplus foundry sand (*PAHs, phenols, BTEX, DOC, TOC and fluoride)* and produce clean soil material 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 surplus sand in the beginning of the composting process the harmful organic substances will be degraded during the process, resulting clean soil material suitable for green construction purposes. 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 surplus 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).*

In Spain inorganic and organic binder system foundry waste sands were cleaned by composting method. End-products met the national limit values set for the *Fertiliser Product.*

Fig. 6. Composting tests in Spain

In Finland organic and inorganic binder system foundry waste sand and dust specimens were cleaned by composting method. 360 tons composting material were cleaned and the end-products met the limit values and it can be reused in landscaping purposes. The degradation of harmful substances is illustrated in the Table 2. The composting process takes app. one year to be clean and mature.

Fig. 7. Composting tests, sampling procedure and sieving the clean end-product in Finland.

Table 2. Degradation of the harmful substances during the composting tests and the cleaning efficiency rates.

	Organic dust	**Organic waste sand**	Limit value for non-hazardous inert waste	Compost heap 1 (organic dust) START	Compost heap 2 (organic waste sand) START	Compost heap 1 (organic dust) END	Compost heap 2 (organic waste sand) END	**Compost heap 1 (organic dust) Degradation efficiency**	**Compost heap 2 (organic waste sand) Degradation efficiency**
DOC, mg/kg dm	4500	1600	500	7800	4700	2100	1700	**73 %**	**64 %**
Phenol index, mg/kg dm	1,20	2,10	1	5,5	1,4	<0,10	<0,10	**98 %**	**93 %**
Fluoride, mg/kg dm	180	23	10	39	6	21	<5,0	**46 %**	**17 %**

4.2 Foundry sand cleaning and regeneration methods

The aim of the cleaning and regeneration treatments of the surplus foundry sand is to recycle the cleaned sand back to foundry processes, reduce the need of virgin sand and reduce the total amount of waste sand to be transported to landfills.

4.2.1 Thermal reclamation of surplus foundry sands

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 carried out 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° C, which is the set temperature used with APNB sands. The process line consists of the feeder, thermal reclamation oven and a cooling screw (Fig 8). Sand quality tests conducted were the Loss on Ignition (LOI) test and the 3-point bending strength test.

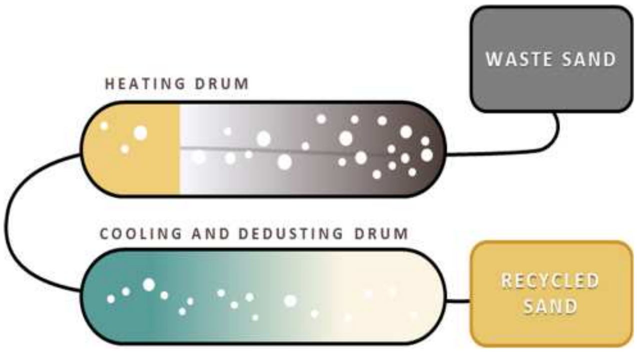


Fig. 8. Principle of the thermal reclamation process.

Results:
<u>Ester cured phenolic resin no-bake sand (APNB)</u>
APNB organic sands were certain kind of reference sands in this study. LOI 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 9. 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 were 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.

Summary:
Results of thermal reclamation on the different sand systems are summarized in the Table 3.

Table 3. Results of the reclamation tests with 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	Thermal alone is not enough

4.2.2. Washing of surplus foundry sands

The aim of the washing tests was to demonstrate that the residual substances of the surplus foundry sands can be removed sufficiently, and that the cleaned sand has the necessary physical characteristics, and it can be reused e.g. in core making.

Washing tests were carried out on laboratory scale by Tecnalia Research&Innovation in Spain. Organic binder system surplus sand (bentonite sand) and inorganic binder system surplus sands were cleaned by washing method. Main agents were distilled water and hydrochloric acid. Over several cycles, the surplus foundry sand specimens were washed, filtered and rewashed, progressing from distilled water to hydrochloric acid. In the end the washed sand was dried in a Mufla furnace.

As shown in the Table 4, the hazardous elements were washed away and broken down by processes involving distilled water and hydrochloric acid.

Based on the results from these tests, the treatment method could be recommended as an emergency technology for the future BREF revision. Environmental impact assessment related to the process wastewaters should be clarified.

Table 4. Washing test results of the organic binder system green sand before and after the washing.

Total metal (mg/kg)	Before washing	After washing	Washing efficiency
Barium (Ba)	7.85	4.55	42
Chromium (Cr)	335.00	163.00	51
Iron (Fe)	15,800.00	13,400.00	15
Molybdenum (Mo)	3.24	<2.00	38
Nickel (Ni)	718.00	640.00	11
Zinc (Zn)	13.20	10.50	20

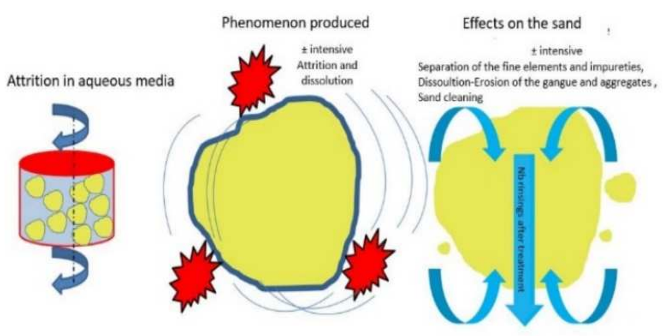
Hazardous elements (mg/kg)	Before washing	After washing	Washing efficiency
Fluorides	7.80	<5.00	36
Phenol	0.80	<0.50	38
DOC	480.00	169.00	65
TOC	8,900.00	<1,000.00	89
BTEX	0.22	<0.04	100

4.2.3. Cleaning tests of inorganic binder system waste sands

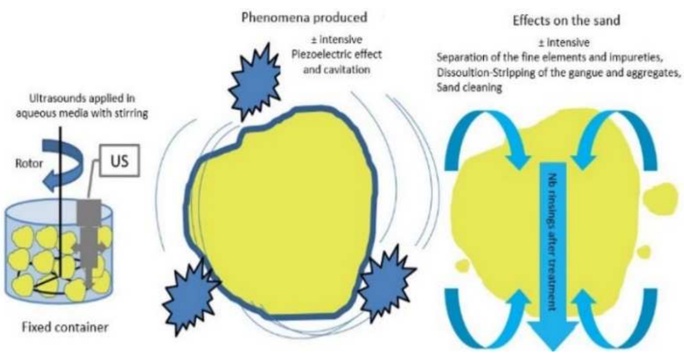
The treatment processes selected for the Green Foundry Life project are those capable of cleaning inorganic waste sand to obtain the quality of treated sand to be sufficient for reuse in foundries (moulding, core making), or for external reuse.

The processes using the emerging hydromechanical and ultrasonic technologies being the most efficient were selected for comparison with a conventional mechanical technology currently used in industry (attrition mechanical process). Following sand inorganic sand systems were tested: GEOPOL, PEAK, INOTEC and one inorganic binder, IE.

Principle of the hydromechanical treatment



Principle of the ultrasonic treatment



<u>Findings</u>:
- 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.

<u>Explanations</u>:
- 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).

<u>Findings</u>:
- 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.

<u>Explanations:</u>
- 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

Results:
Treatment trials carried out with inorganic waste sands demonstrated that hydromechanical and ultrasonic technologies are particularly most effective in allowing the cleaned sand to be reused in foundry processes or geo-construction and road engineering purposes.

Nevertheless, these hydromechanical and ultrasonic treatment processes 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).

4.2.4 BAT report for the BREF revision:

As a conclusion, a Best Available Technologies (BAT) report will be published of the project outcomes. The Best Available Technology Reference Document (BREF) for the smitheries and foundries industries is currently in preparation through the established Seville process. The BAT report will be delivered to BREF revision technical working group for analysing.

Based on the results of the project, the concrete proposals for uptake of the respective technologies and processes in the updated version of as either Best Available Technology (BAT) or Emerging Technology (ET) candidates:

Designation of technology	**Status**
Use of inorganic binders for moulds in iron and steel casting	BAT
Use of inorganic binders for cores in iron and steel casting	BAT
Thermal reclamation of foundry sand	BAT
Composting of waste foundry sand	BAT
Washing of foundry sand	ET
Ultrasonic treatment of foundry sand	ET
Hydromechanical treatment of foundry sand	ET

5. Benefits and impacts

Lessons learnt and sustainability of test casts with inorganic binders in three pilot foundries:

The results in production scale test casts with different inorganic binder systems in ferrous pilot foundries were promising - emission were significantly reduced and the quality of the castings was comparable with the castings made by organic binders. The project, however, learned that the extensive use in these and other ferrous foundries requires:

- Vast knowledge about different inorganic binder systems and their proper implementation into current or new production lines.
- Individual implementation plan for each foundry including suitable inorganic binder systems for the foundry's production lines and products, and technical and economic information about possibly investments needed.
- 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: there should be successful example cases of replacing the organic binder systems by inorganic binders, so that new ferrous foundries would dare to start the change and introduction of inorganic binder systems in full production scale.
- Suitable sand reclamation system for inorganic binder system waste sands should be tested.
- In case foundries take inorganic binders in use in part of the production or for some products, it is necessary to solve the sand reclamation system because organic and inorganic waste sands should not be mixed together.

Cost benefit discussion on the project results:
Currently inorganic binder systems are 10…20% more expensive than widely used organic binder systems. The usage of inorganic binders is much less, only 1 % of European foundries use inorganic binders and most of them are casting light metals. When the production volume of inorganic binders grows, the price difference is expected to narrow.

The need of environmental investments in European ferrous foundries will increase in future for many reasons:

- Proposed new BREF document will set stricter limit values for emissions
- Monitoring of emission will be much more extensive
- Many customer sectors are flagging for green values (eg. automotive industry)
- European workers oppose unhealthy workplaces

The use of inorganic binders brings environmental benefits that can have also cost implications. Harmful emissions will decrease, and indoor air quality improves, which means less need for emission abatement and ventilation. The cost of ventilation is high, especially in cold weather countries. The recent drastic increase in energy prices worsens the situation.

Organic binder waste sands contain many harmful impurities which prevent reuse in many applications. Big part of organic waste sands must therefore be landfilled or cleaned by expensive methods. Landfilling fees have increased, being now eg. in Finland up to 100 €/ton. Inorganic binder waste sands contain much less harmful impurities, and majority of them can be reused in many applications without any treatment.

In near future, when the usage of inorganic binders starts to increase and stricter emission limits are mandatory, the total costs of inorganic binders are expected to be same or cheaper.

Transferability of the project results:
The project results are promising. Emission reductions are remarkable when change from organic binder systems to inorganic binder systems is done. Waste sands with inorganic binders are much cleaner and can be reused in many applications, when organic binder waste sands are still mainly landfilled.

Some demonstrated methods in the project are ready for wider industrial use, such as composting and thermal reclamation of waste sands. The results in three pilot foundries proved that there are available many feasible inorganic binder systems for producing good quality ferrous castings. Wider implementation of ferrous foundries still requires much more production scale industrial demonstrations. Often the change means investments on moulding and core making lines and sand regeneration. Successful examples of the transition to inorganic binders are needed to persuade the foundries to make the necessary investments. Some open issues, such as recovery of mixed inorganic and organic binder waste sands need also to be addressed. One option of starting use inorganic binder is to make only the cores by inorganic binders and use current organic binder system for mould making.