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Spend Foundry Sand valorisation in Construction sector through the validation of high-performance applications (LIFE ECO-SANDFILL).

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Deliverable D3

Diagnosis of surplus sand generation in EU and its demand among construction sector

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1. EXECUTIVE SUMMARY

The present deliverable report gathers available figures about Spent Foundry Sand generated across Europe, as well as amounts reported to be landfilled and valorised. It also presents data about aggregates demand in construction applications

The sources used in the study have been annual statistics from European industry associations about sand consumption data in foundry and construction sector, metal casting production statistics, search results in databases of European and national PRTRs and European waste statistics (Eurostat, EAA, Environmental Dept. of Spanish and Basque Governments) by economic activity and waste category, reports and surveys evaluating sand demand and waste in casting processes, interviews to industry associations and environmental agencies.

Given the lack of specific entries in Eurostat and E-PRTR databases and the variability of the foundry sand waste estimates at European level from the various sources consulted, ranging from 18 Mt to 4 Mt (and referred to varying geographical scopes), new estimations have been carried out, to try to calculate the amount of foundry sand waste generated which could be available for valorisation. Two computation procedures have been followed: on the one hand, EU-wide data have been extrapolated from detailed waste generation and valorisation data reported on regional (Basque Country) and national (Spain) scale, by linking them to corresponding metal casting production figures (CAEF area). On the other hand, EU-wide SFS generation estimates have been worked out by using the sand-to-liquid metal ratios and the metal yield data compiled from several surveys and the annual EU-wide net casting production data. The values obtained by those calculation methods for SFS from ferrous casting activities in the CAEF area have been in the range 3.5-4.5 Mt and 4.5-9 Mt (ca.6 Mt mean value), respectively. A sensibility analysis has been conducted to assess the impact of calculation assumptions on the results.

From reported information on waste management routes and valorisation rates in several EU countries, it has been assumed that around 60% of the SFS from EU ferrous foundries is sent for disposal and therefore available for exploring new valorisation options, as the reclamation solution proposed in LIFE ECO-SANDFILL for secondary fine aggregates.

The references consulted show that production of natural fine aggregates (sand & gravel) amounted to 1,061 Mt in EU-28 in 2014. The predictions made by Euroconstruct for years 2016 and 2017 expect a growth for construction sector of 2% each year. Thus, it can be affirmed that the potential market of reclaiming of SFS has a wide field of possibilities abroad Europe.

2. NOMENCLATURE

BREF	Best available techniques Reference document developed under the IPPC Directive and the IED
CAEF	European Foundry Association
CH	Switzerland
CSM	Chemically bonded sand moulding
DE	Germany
DOE	Department of Energy (US)
EIPPCB	European IPPC Bureau
EPS	Expanded Polystyrene
ES	Spain
EU	European Union
EWC-Stat	European Waste Classification for Statistics
FEAF	Federación Española Asociación Fundidores
FR	France
GSM	Green sand moulding
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control
LOI	Loss on Ignition
LoW	List of Wastes
NACE	*Nomenclature générale des Activités économiques dans les Communautés Européennes* (General Industrial Classification of Economic Activities within the European Communities)
PRTR	Pollutant Release and Transfer Register
SFS	Spent Foundry Sand
SI	Slovenia
UK	United Kingdom
US	United States

3. INTRODUCTION

Deliverable D3 "Diagnosis of surplus sand generation in EU and its demand among construction sector" is associated with the Action A2. *Solution impact assessment within the European foundry and construction industry*.

In the framework of Action A2, the Action leader (IK4-AZT), supported by ACCIONA and with the information provided by the stakeholders TABIRA and PTEC, have estimated the types and amounts of spent foundry sand (SFS) being generated annually in Europe, as well as the SFS volume destined for disposal to landfill and the volume valorised. Actual and potential valorisation routes for the surplus sand are evaluated also in this task, focusing on the feasibility of using SFS -appropriately treated- into construction applications. Also in the scope of this task are the estimation of demand of natural aggregates by the construction sector, the identification of technical and regulatory constrains for using reclaimed SFS as alternative fine aggregates in construction and the policies addressed by the valorisation of SFS as secondary raw material.

3.1. OBJECTIVES

The aim of the action A2 is to determine the diagnosis of the current situation addressing two main areas:

(1) Waste generation check-up: The amounts of foundry sand and types discharged in Europe, trying to estimate consistent data about waste generation, from the various current estimates available, ranging from 5 to 18 Mt, depending on the information source. Review of current waste management practices and trends.
(2) Market check-up: The demand for silica sand in construction applications. Assessment of the sand that can be potentially recycled in the construction industry (e.g. correction sand in concrete sector, mortars, flowable fills, asphalt concretes, etc.) in order to obtain global figures of sand use and demand and potential markets.

The final goal of the task consists of the evaluation of the potential solution that the LIFE ECO-SANDFILL might represent for the European Foundry industry.

The present deliverable deals with the analysis of spent foundry sand statistics (waste generation, valorised and landfilled amounts) and the market demand for natural aggregates in construction. The analysis of waste sand valorisation trends and the discussion of the boundary conditions for using SFS as alternative fine aggregates in the construction sector in EU will be included in deliverable report D4 "Analysis about the upcoming changes concerning SFS valorisation in EU".

3.2. DELIVERABLE OUTLINE

This preparatory action covers the state-of-art and prospective analysis not only from a theoretical point of view, but also collecting all relevant information about the actual SFS management situation and international best practices.

In this sense, deliverable D3 aims at working out the most reliable estimates possible about waste foundry sand generation and demand of aggregates in construction sector in the EU — constituting a potential market outlet for reclaimed SFS.

The study is structured in two main survey areas, waste foundry sand generation and sand demand in construction. As for sand waste generation in the foundry industry, the following subjects are examined:

- Overview of types of sand used in sand casting of metals.
- Amounts of Spent Foundry Sand (SFS) generated in the EU, from ferrous and non-ferrous industries. Sorted by type of moulding system sand.
- Waste management routes for SFS: tonnes of SFS sent to landfill, tonnes of SFS valorised or reclaimed in foundry and in other industry sectors.

On the other hand, the market analysis of aggregate demand in construction sector includes

- Total amount of natural aggregate used for construction applications, by source (quarry, deposits, marine).
- Tonnes of intermediate products manufactured with this natural aggregate (ready mix-concrete, mortars, flowable fills, asphalt products...etc).

4. SAND CASTING OF METALS

Foundries melt ferrous and non-ferrous metals and alloys and reshape them into products through the pouring and solidification of the molten metal or alloy into a mould. The solidified part (also known as a casting) is ejected or broken out of the mould to complete the process. Casting is most often used for making complex shapes that would be difficult or uneconomical to make by other methods. Cores are used to produce internal features within the part.

The process varies depending on the type of metal, size of series and type of product to be manufactured. Generally, the main division within the sector is based on the type of metal (ferrous or non-ferrous) and the type of moulding used (expendable or permanent moulds). Those main categories can be further broken down according to the mould material and moulding and core-making system used, type of furnace employed for melting, the casting (pouring) method and the finishing techniques applied [1] [2].

4.1. MOULDING SYSTEMS

Moulds may be classified in two large families:

- Expendable (single-use moulds): These are specially made for each casting and are destroyed for removing the part. The moulds are generally made of sand, which can be chemically bonded, clay-bonded, or even unbonded. Investment casting can also be included in this family.
- Permanent moulds (multi-use moulds): These can be used to make many successive castings and are employed in gravity and low-pressure casting, pressure die-casting and centrifugal casting. Typically those moulds are metallic.

Sand casting is the most widely used casting process, accounting for a significant majority of total tonnage cast. Nearly all alloys can be sand casted, including metals with high melting temperatures, such as steel, nickel, and titanium.

Ferrous foundries generally apply sand mould techniques, whilst non-ferrous foundries often apply die-casting techniques —which allow a better surface finish, and sand casting techniques tend to be reserved for those products that are not produced in large series. According to estimates in the 2005 edition of *IPPC - Reference Document on Best Available Techniques in the Smitheries and Foundries Industry* by the EC [1], for non-ferrous casting, about 30% of copper alloys are cast in sand moulds and only about 10% of light non-ferrous metals are cast in single-use moulds.

The cores used for ferrous castings are practically always made of sand.

For sand moulding, the mould may be produced from a model by manual or mechanical ramming actions, such as by jolt, squeeze, air impact, vibration, etc. Generally, cores are produced by the same techniques as moulds, although small or medium sized cores are often blown or shot into wooden, plastic or metallic core-boxes.

4.1.1. Raw materials for sand moulding

Moulding sands, also known as foundry sands, are defined by eight characteristics: refractoriness, chemical inertness, permeability, surface finish, cohesiveness, flowability, collapsibility and availability/cost. To achieve the required specifications multicomponent systems are used. The sand mixture can be naturally occurring sand or a specifically formulated mix of different ingredients to get certain desired properties not possessed by natural sand. [1] [2] [3] [4]

Main components of moulding sands are refractory materials (which make up 95 to 99%), binders, additives and other chemicals (e.g. parting compounds). The different types of base sands (refractory materials) used for foundry purposes are silica sand, chromite sand, zircon sand and olivine sand.

The physical and chemical properties of the refractory material used to make the moulds or cores affect their characteristics and their behaviour during pouring. The choice of binder technology used depends on factors such as the size of the casting, the production rate, the metal poured, the shake-out properties, etc.

Binders can be either inorganic or organic substance. Binders included in the inorganic group are clay sodium silicate and Portland cement. In foundry shop, the clay acts as binder which may be Kaolinite, Ball Clay, Fire Clay, Limonite, Fuller's earth and Bentonite. Binders included in the organic group are dextrin, molasses, cereal binders, linseed oil and resins like phenol formaldehyde, urea formaldehyde etc. Binders of organic group are mostly used for core making. Among all the above binders, the bentonite variety of clay is the most commonly used. However, this clay alone cannot develop bonds among sand grains without the presence of moisture content in moulding sand and core sand.

Additives are added to the moulding components to improve surface finish, dry strength, refractoriness, and "cushioning properties". Up to 5% of reducing agents, such as coal powder, pitch, creosote, and fuel oil, may be added to the moulding material to prevent wetting, improve surface finish, decrease metal penetration, and burn-on defects. These additives achieve this by creating gases at the surface of the mould cavity, which prevent the liquid metal from adhering to

the sand. Reducing agents are not used with steel casting, because they can carburise the surface layer of the metal during casting.

Up to 3% of "cushioning material", such as wood flour, saw dust, powdered husks, peat, and straw, can be added to reduce scabbing, hot tear, and hot crack casting defects when casting high temperature metals. These materials are beneficial because burn-off when the metal is poured creating voids in the mould, which allow it to expand. They also increase collapsibility and reduce shakeout time.

4.1.2. Methods of sand moulding

4.1.2.1. MOULDING WITH NATURAL SAND

Some foundries use naturally bonded sand. This is sand which contains a natural percentage of clay. Only water needs to be added in order to activate the binding capacity. The approximate composition of natural sand is 80% Quartz sand, 15% clay and 5% water. If needed, some additives may be mixed as well. The mineralogical constituents of the clay may belong to the kaolinite group or the secondary mica group. When it contains a greater amount of clay, it is blended with river sand, dune sand or any other variety of sand which is relatively clay-free so as to get the optimum properties desired in the sand mixture [5].

It is mainly used in small-sized non-ferrous (e.g. copper) foundries and is not used in foundries casting iron and steel.

4.1.2.2. GREEN SAND MOULDING

Green sand moulding is the most common moulding process. This method is generally not used to make cores. Cores are formed using a chemical binding system.

Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85 to 95% silica (or olivine or zircon) sand; 5 to 10% bentonite clay; 3 to 9% carbonaceous materials such as powdered (sea) coal, petroleum products, corn starch or wood flour; and 2 to 5% water. The clay and water act as the binder, holding the sand grains together. The carbonaceous materials burn off when the molten metal is poured into the mould, creating a reducing atmosphere which prevents the metal from oxidising as it solidifies. In the case of cast steel, the moulding sand only contains bentonite, cereal binder and water (no introduction of carbonaceous materials to avoid carburisation).

4.1.2.3. MOULDING WITH UNBONDED SAND (V-PROCESS)

This process uses dry sand, rammed by vibration without any binder addition, with the sand held between two polyethylene sheets by partial vacuum.

4.1.2.4. MOULDING AND CORE MAKING WITH CHEMICALLY-BONDED SAND

Core-making uses primarily chemical binding systems. Cores require different physical characteristics than moulds; therefore, the binding systems used to make cores may be different from those used for moulds. The binding system used must produce strong, hard cores that will collapse to allow removal after the casting has hardened. Therefore, cores are typically formed from silica sand (and occasionally olivine, zircon or chromite sand), and strong chemical binders.

The sand and binder mix is placed in a core-box where it hardens into the desired shape and is removed. Hardening, or curing, is accomplished with a chemical or catalytic reaction or by heat. A wide variety of resin binder processes are currently used, which can be classified into three general categories, according to the hardening method:

- Cold-setting processes (No-bake systems): The curing of cold-setting sands is effective at ambient temperature. The process begins when the last component of the formulation has been introduced into the mix. Cold-setting processes include the following processes: phenolic-acid catalysed, furan-acid catalysed, polyurethane (phenolic isocyanate), resol-ester (alkaline phenolic ester hardened), alkyd oil-unbaked, ester silicate, cement.
- Gas-hardened processes (Cold-box system): In these processes, curing takes place by injecting a catalyst or a hardener in a gaseous form. The following processes are included among them: cold-box (amine hardened phenolic urethane), resol-ester (alkaline phenolics methyl formate hardened), SO_2 hardened furan resins, SO_2 hardened epoxy/acrylic (free radical curing), CO_2 hardened sodium silicate (water glass), CO_2 hardened alkaline phenolic.
- Hot curing processes: In these processes, curing takes place by heating the sand resin mix or, more often, by allowing it to come into contact with the heated pattern equipment. Hot-curing processes comprise: Hot-box, phenolic and/or furan based, warm-box, Shell (Croning), linseed oil, alkyd oil-baked.

Another way of categorising the binders, as mentioned in section 4.1.1, is by the elementary classification of "organic" and "inorganic." For example, the ester catalysed silicate no-bake and the CO_2-gassed systems listed above are classic foundry examples of inorganic core binders.

The selection of the process and type of binder depends on the size and number of cores or moulds required, production rates, and equipment.

4.1.2.5. EXPENDABLE PATTERN CASTING

In expendable pattern casting, the pattern is not removed from the mould before pouring. The pattern, which is made of expanded polystyrene (EPS), is a single-use one, which is destroyed when poured. These expandable patterns may be embedded either in chemically-bonded sands or in binderless sand, hardened by vibration.

As stated in the *Reference Document on Best Available Techniques in the Smitheries and Foundries Industry* produced in the EIPPCB workplan in May 2005, this process, commonly called "Lost Foam casting", was developed over 30 years ago and its commercial growth was initially rather slow. However, during the last 15 years, it has become used more often, primarily for the mass production of automotive parts or similar products, in spite of significant set-up difficulties.

4.1.2.6. INVESTMENT CASTING AND CERAMIC SHELL

This process is used to produce intricate, thin section parts with high dimensional accuracy, fine details, and very smooth surfaces.

The process begins with the manufacture of expendable wax patterns, by injecting molten wax into an aluminium or epoxy die to form a pattern that is virtually an exact replica of the desired casting. The wax may contain fillers. The wax patterns are cleaned with water or organic solvent and coated with a wetting agent, which helps the ceramic slurry to adhere to the wax. The cluster is then dipped in a liquid ceramic slurry, stuccoed with granular silica, zircon or alumina/silica refractories and then dried before the application of the next coat. The coating process is continued until a sufficiently thick shell is established. The dried mould is then de-waxed by inserting it into a steam autoclave in which the wax patterns are melted out, or into a "flash-furnace", in which the wax may be partially burnt out. After this, the shell is fired in a furnace at a high temperature. This burns out the residual wax and hardens the ceramic, leaving a one piece ceramic shell mould, into which the molten metal is poured to form the casting.

4.1.3. Types of Moulding Sand by use

Moulding sands can also be classified into various types according to their use, e.g.: backing sand, core sand, dry sand, facing sand, loam sand, parting sand, system sand [4].

- FACING SAND

Facing sand forms the face of the mould. It is next to the surface of the pattern and it comes into contact with molten metal when the mould is poured. Initial coating around the pattern and

hence for mould surface is given by facing sand. Facing sand has high strength refractoriness. Facing sand is made of silica sand and clay, without the use of already used sand. Different forms of carbon are used in facing sand to prevent the metal burning into the sand. A facing sand mixture for green sand of cast iron may consist of 25% fresh and specially prepared and 5% sea coal. They are sometimes mixed with 6-15 times as much fine moulding sand to make facings. The layer of facing sand in a mould usually ranges between 20-30 mm. From 10 to 15% of the whole amount of moulding sand is the facing sand.

- BACKING SAND

Backing sand or floor sand is used to back up the facing sand and is used to fill the whole volume of the moulding flask. Backing sand is sometimes called black sand because of old, repeatedly used moulding sand is black in colour due to addition of coal dust and burning on coming in contact with the molten metal.

- SYSTEM SAND

In mechanised foundries where machine moulding is employed, system sand is used to fill the whole moulding flask. In mechanical sand preparation and handling units, facing sand is not used. The used sand is cleaned and reactivated by the addition of water and special additives. This is known as system sand. Since the whole mould is made of this system sand, the properties such as strength, permeability and refractoriness of the moulding sand must be higher than those of backing sand.

- CORE SAND

Core sand is used for making cores and it is sometimes also known as oil sand. Core sand is highly rich silica sand mixed with oil binders such as core oil which composed of linseed oil, resin, light mineral oil and other bind materials. Pitch or flours and water may also be used in large cores for the sake of economy.

- PARTING SAND

Parting sand without binder and moisture is used to keep the green sand not to stick to the pattern and also to allow the sand to the parting surface the cope and drag to separate without clinging. Parting sand is clean clay-free silica sand which serves the same purpose as parting dust.

- DRY SAND

Green sand that has been dried or baked in suitable oven after making the mould and cores is called dry sand. It possesses more strength, rigidity and thermal stability. Dry sand is mainly used for larger castings. Moulds prepared in this sand are known as dry sand moulds.

- LOAM SAND

Loam sand contains many ingredients, like fine sand particles, finely ground refractories, clay, graphite and fibre reinforcements. Loam sand contains as much as 30-50% of clay and 18% of water. When mixed with water, the materials mix to a consistency resembling mortar and become hard after drying. Patterns are not used for loam moulding and shape is given to mould by sweeps. Loam sand is particularly employed for loam moulding used for large grey iron castings.

4.2. YIELD OF CASTING OPERATIONS

4.2.1. Sand-to-liquid metal ratios

According to a survey conducted by AEA Technology through ETSU on UK foundries using green sand in year 1995 [6], the distribution of sand-to-liquid metal ratios found for green sand moulding in the iron and copper sectors was as shown in Table 4-1. Information was gathered from a representative sample of companies, using a confidential questionnaire, for an Environmental Performance Guide presenting data on efficiencies of greensand use and reclamation in UK foundries.

Table 4-1. Frequency distribution of green sand-to-liquid metal ratios among respondents to UK foundry sector survey (*Source: ETSU, 1995* [6])

Type of foundry	Sand-to-liquid metal ratio	% respondents
Iron	2:1 to 5:1	21%
Iron	5:1 to 10:1	36%
Iron	10:1 to 20:1	21%
Copper	less than 2:1	22%
Copper	2:1 to 5:1	44%
Copper	5:1 to 10:1	22%

The average sand-to-liquid metal ratio in the iron sector was 9:1, yet some foundries were operating either considerably above or below this figure. The range [5:1 to 10:1] was the most frequent. The lower ratios are generally associated with certain types of metal moulds or single-product foundries where box size/casting combinations are more easily optimised.

In the copper sector, the average total mixed (green) sand-to-liquid metal ratio was about 4:1. The reason this value is lower than that for the iron sector is largely because most copper foundries are product orientated with an optimised box size.

The *BREF on Smitheries and Foundries Industry* [1] presents the data gathered by the ETSU survey on chemically-bonded sand-to-liquid metal ratios for various metal types (see Table 4-2). From the survey results, two-thirds of iron foundries answering the questionnaire used a chemical sand-to-liquid metal ratio in the range [1:1 to 4:1].

Table 4-2. Frequency distribution of chemical sand-to-liquid metal ratios among respondents to UK foundry sector survey (*Source: SF BREF, 2005* [1])

Type of foundry	Sand-to-liquid metal ratio	% respondents
Iron	1:1 to 2:1	20%
Iron	2:1 to 3:1	22%
Iron	3:1 to 4:1	22%
Steel	3:1 to 4:1	23%
Steel	4:1 to 5:1	23%
Aluminium	5:1 to 10:1	28%
Aluminium	over 20:1	22%
Copper	1:1 to 2:1	38%

Other figures available in literature for sand-to-metal ratios are the following:

- Ratio of used sand per casting tonne of 1:1 [7] derived from the statement by the authir that typically, about one ton of foundry sand is required for each ton of iron or steel casting produced (US data). The green sand constitutes over 90% of the moulding materials used in the process.
- As mentioned by Dalquist [8], in the US around 0.5 ton sand/ton cast metal is landfilled annually from foundries (each ton of cast metal requires about 5.5 tons of sand, of which approximately half a ton is disposed of; after each run, 10% of the green sand is removed from the foundry cycle). That translates into a ratio of used sand-to-cast metal of 5.5:1 in the US. The same industry in the UK disposes of 0.27 tons sand for each ton of cast metal.
- According to a DOE report on the environmental profile of the US metal casting industry [9], 800 pounds of spent sand per ton of casting are handled annually, which means a ratio SFS-to-cast metal of 0.4:1.
- In [10] the author report as casting inputs 999.75 kg ductile iron, 5810 kg green sand mould and 3125 kg core (shell (Croning)), for outputs of 500 kg good casting and 8319 kg of waste sand from casting process. Those figures implied a sand-to-liquid metal ratio of about 6:1 and a metal yield of 50%.

In 2015, IK4-AZTERLAN, in cooperation with IHOBE, conducted a survey in the foundry sector in the Basque Country (which makes up over 50% of the total Spanish foundry industry), in the framework of the activities of the *Working Group of the Foundry Sector – Basque Government for the Prevention and Valorisation of Moulding Sands and Fines (2015-2016)*. Yearly data were gathered about waste generation and valorisation routes of SFS, as well as plant production (tonnes of liquid metal) of active foundries in the region for three years (2012-2014). Considering the answers from the 15 major ferrous foundries, responsible for more than 85% waste foundry sand generated, the following ratios of waste sand-to-liquid metal have been estimated.

Table 4-3. Frequency distribution of waste sand-to-liquid metal ratios among respondents to Basque Country foundry sector survey (*Source: IK4-AZT, 2015*)

Type of foundry & moulding	SFS-to-liquid metal ratio	% respondents 2012	% respondents 2014	Avg. ratio
Ferrous (industry avg.)	0.1:1 or less*	7.1%	7.1%	0.4:1*
Ferrous (industry avg.)	0.1:1 to 0.4:1*	71.4%	64.3%	
Ferrous (industry avg.)	over 0.4:1*	21.4%	28.6%	
Ferrous (industry avg.)	0.35:1 or less	69%	62%	0.34:1
Iron (industry avg.)	0.25:1 or less	89%	89%	0.18:1
Steel (industry avg.)	0.35:1 to 1:1	75%	75%	0.72:1
Iron (green sand moulding)	0.2:1 or less	86%	100%	0.13:1

* *sand & fines included in waste amounts used for ratio calculation*

On average, about 0.4 t waste sand were generated per tonne of liquid metal. However, some plants are operating considerably above that ratio and generating approximately 1 t waste per tonne of liquid metal. The ratio of moulding waste generation of half the installations is in the range 0.15-0.30 t waste per tonne of liquid metal. That waste figure comprises moulding sand and the fines, which are not separated for waste management in some cases. Further segregation of responses into steel and iron foundries and green and chemical sand moulding has been carried out. More over, since quantities of waste sand and fines generated were reported separately, ratios of waste sand-to-liquid metal have been calculated on a sand exclusive basis. In such cases, the average amount of waste sand per tonne of liquid metal is about 0.34 t (with half the number of foundries reporting ratios below 0.2:1) and 0.13 t per tonne of molten iron for iron foundries using green sand moulding.

Previous figures about waste sand ratios are available from a study conducted in 1997 on five Basque ferrous foundries by IHOBE and the regional association of the foundry industry (*Asociación de Fundidores del País Vasco y Navarra*, AFV) [11]. Amount of SFS generated was

estimated at 200 kt/yr in the Basque Country and the foundries surveyed reported ratios of 0.30-0.57 t of waste per tonne of net casting for iron castings and 1.50 for steel castings, together with ratios of 0.20-0.40 t of new sand (cores incl.) per tonne of net casting (0.80 for one steel foundry in the survey).

4.2.2. Metal yield

The metal yield is the ratio of the amount of metal melted to the weight of the finished good castings. Five main factors affect metal yield, i.e.:

- quality requirement
- choice of mould-box size
- the extent of runner and feeder systems
- metal shrinkage
- scrap casting rate.

Metal yield does not have a direct effect on sand use. However, an increase in yield may result in fewer moulds being produced, which means that less sand is consumed overall. Lower metal yields are generally associated with higher integrity products, where superior quality standards may be required, necessitating a more extensive feeding system. Lower yields, however, may also be indicative of higher scrap rates and excessive feeding systems. In these circumstances, foundries need to review their process control and mould production methods. The average metal yields for the main alloy sectors, obtained from the answers to a survey in the UK foundry industry and from the Portuguese steel foundry association, are given in Table 4-5. Values in Table 4-5 show the reported average metal yields, depending on the type of sand moulding.

Table 4-4. Average metal yield in the main alloy sectors (*Source: SF BREF, 2005* [1])

Sector		Average yield	Range of yields reported
Iron	lamellar	68%	40%-90%
	nodular	63%	40%-90%
Steel		45%	N.A.
Aluminium		57%	40%-80%
Copper		58%	30%-90%

Table 4-5. Average metal yield in the main alloy sectors (*Source: GG119, 1998 UK* [12])

Sector		Chemically bonded sand	Green sand
Iron	lamellar	69%	68%
	nodular	64%	63%
Steel		51%	N.A.
Aluminium		71%	57%
Copper		63%	58%

4.3. USED FOUNDRY SAND: REGENERATION, RECYCLING, RE-USE AND DISPOSAL

Since foundries make intensive use of sand as an inert primary material, the regeneration of this sand is a major point of consideration as part of its environmental performance [1]. Reducing new sand addition rates reduces the amount of sand sent to landfill. A clear distinction must be made between green sand and chemically-bonded sand. Green sand can be easily reconditioned after use. Indeed, recirculated green sand shows a better technical quality than new sand. Most green sand foundries perform primary regeneration.

Primary regeneration, also known as attrition or particulation, involves breaking down the sand from moulds or cores back to its original grain size. This includes screening the sand, removing tramp metal, and separating and removing fines and over-sized agglomerates. The sand is then cooled before being sent for storage, returned to the sand system or blended with new sand. At this stage, the sand grains are likely to retain a partial coating of spent binder. This affects the amount of reclaimed sand that can be used to make moulds and, more particularly, cores. New sand therefore has to be added to ensure that the sand mix produces adequate mould and core strength and subsequenty aids good casting quality. Primary reclaimed sand is not generally of sufficient quality to be used for core-making, without further processing to remove residual binder materials, and is therefore used principally for moulds. The main primary regeneration techniques are vibration, rotating drum or shot blasting.

Secondary regeneration involves the further processing of the previously particulated sand to remove residual binder. The sand is returned to a quality similar to, or better than, that of new sand. Foundries using secondary regeneration have, in some cases, virtually eliminated the need for new sand. To remove residual binder, more aggressive techniques are needed than for primary regeneration. The main secondary regeneration techniques are:

- cold mechanical treatment:
  - low energy attrition: friction, impact (for cold-setting resins)

- high energy attrition: pneumatic chafing, grinding, centrifugal friction

- thermal treatment (usually in a fluidised bed)
- wet scrubbing.

Sands bonded with cold-setting resins may be regenerated using simple treatment techniques, due to the fragility of the binder layer. Mechanical regeneration systems (e.g. fluidised bed systems) are based on interparticle friction or impact.

Sands bonded with gas-hardened and thermosetting resins need more intensive treatment to remove the binder layer. These include grinding, pneumatical chafing and centrifugal friction.

Silicate sands can only be regenerated mechanically using pneumatical treatment.

Thermal treatment involves the burning of the organic binder. Bentonite is inactivated by the high treatment temperature. For sand flows containing green sand, any thermal treatment should therefore be combined with a mechanical treatment.

Wet regeneration involves binder removal through interparticle grinding. This technique applies only for green sand and silicate or CO_2-bonded sands and is not widely applied.

Secondary regeneration of green sand as a monosand flow finds limited implementation. For chemically-bonded sands, mechanical regeneration is most widely applied. The most important monosand flows for secondary regeneration are the core sands in nonferrous foundries. Due to the low thermal load they are easily separated from the green sand.

Further more monosands are produced from mould and core-making with purely organic systems such as croning, furan resin and urethane cold-box. A smaller monosand stream is non-cured core sand, arising from broken or rejected cores in the core-making shop and the residual sand of core-making machines.

Mixed sands generally contain bentonite-bonded sand as well as chemically-bonded sand. They are mainly generated in iron foundries and represent some 75% of the total waste sand production.

An overall reclamation ratio of 92% is a normal value for mixed green sand - chemically bonded sand systems. Regeneration ratios of up to 98% have been reported. The actual ratio depends on the volume and chemical composition of the used cores. For furan cold setting monosands, values around 78% are reported.

Sand recycling is common in the EU, as it is in the US. For instance, in a study sponsored by Biffa (waste management group in the UK) found a wide range of sand recycling rates —anywhere from 0% in the smallest foundries which could not afford to treat their sand to 95% in large foundries which had equipment dedicated to the process. 82% of sand is recycled overall, and in disposal it represents 54% of the total foundry waste stream [8].

4.3.1. Regeneration of green sand (primary regeneration)

The sand from the moulds in green sand moulding can be reconditioned after pouring for multiple re-use. This internal recirculation of green sand with minimal treatment, referred to as primary regeneration, has three aims: (1) to break the sand into its original grain size or small particles, (2) to remove the fines, and (3) to cool the sand before blending with new sand.

The addition of a minimum percentage of new sand is performed in order to maintain the quality of the moulding-sand. The amount of new sand added is determined by the input of core sand and the losses in the process. For coreless moulding, the average sand renewal ratio is 2-5%. In casting processes using cores, sand renewal occurs through the introduction of the core sand into the loop. In systems using chemically-bonded cores, the mixing of the core sand may have a negative effect on the sand quality, depending on the binder type and the amount of core sand mixed. In any case, surplus sand is removed from the sand circuit after the shake-out screen or from the storage silos.

The level of new sand addition is governed by a number of factors; the usual range is 10-20% of the poured metal weight. However, it is more convenient to consider new sand additions as a percentage of sand throughput. For most foundry processes, a 5% addition is considered sufficient, but many foundries work at lower rates. For a green sand monosystem, regeneration ratios of 98% may be achieved. Systems with a high degree of incompatible cores, may achieve a regeneration ratio of 90-94%.

4.3.2. Simple mechanical regeneration of cold-setting sand

Simple mechanical techniques are used for the regeneration of cold setting monosands (e.g. furan sand) and uncured core sand. These techniques include the breaking of lumps, segregation of the sand grains and cleaning by intergranular friction, with consequent dedusting and cooling down to operational temperature. They can be used for

- All cold-setting sand, excluding silicate sand. The regenerated sand can be re-used in the same moulding cycle, with small additions of new sand to level-off quality losses.

- Uncured core sand with organic binders. The regenerated sand may be re-used for core-making using the same binder type, after mixing with new sand, and it may also be used, within certain limits, for the renewal of moulding-sand.

For furan cold setting monosands regeneration ratios around 78% are reported.

4.3.3. Cold mechanical secondary regeneration

Cold mechanical regeneration is mainly applied for removing bentonite layers from green sand and for removing chemical binders in no-bake systems. The grinding technique is the most widely applied cold mechanical treatment. Vibration and impact systems are also used for chemically-bonded sands but produce sand of only low or average quality.

For clay-bonded sand, the maximum regeneration rate using a grinding system is 65-75%. This corresponds to the quartz grain content of the material. In general, waste green sand consists of about 80% quartz sand grains and about 20% fines (bentonite, coal dust, etc.). Out of 100% waste sand, about 70% is transferred back to the core-making as reclaimed sand. The degree of efficiency with regard to quartz is about 88%. For a chemically-bonded sand, the amount of recyclable quartz sand is 90-95%. The total sand circuit flow and the need for new sand depends on the amount of cores (and core sand) used. Therefore, data on the sand circuit are very process-specific.

The technique of cold mechanical regeneration using an impact drum is based on intergranular grinding of the sand and gives the best results for chemically bonded monosand. The regeneration system allows the introduction of a limited amount (15%) of uncured core sand (core breaks from production). When applied on a mixed bentonite-organic sand, the regeneration is preceded by a magnetic separator, to remove green sand. The combination of magnetic separation and impact drum cleaning allows an optimised chemically bonded sand regeneration from a mixed sand flow, with re-use of the regenerated sand in core-making. Cores made with 100% regenerated sand have acceptable properties. In practice, 10-70% of regenerated sand is used for new cores, the actual amount depending on the core type.

In a pneumatic system for cold mechanical secondary regeneration, binders are removed from the sand grains using abrasion and impact. The pneumatic system can be used for the regeneration of organic mixed and monosands and mixed sand containing bentonite.

A waste sand mix of green sand with chemically-bound core sand having the following characteristics: 8-12% fines content, 3-5% LOI, <2% humidity; produces a regenerate yield of 70-80%, based on SiO_2 content of waste sand.

The technique may be applied also for the regeneration of core sand of the CO_2-water glass type from aluminium foundries (60% regeneration ratio).

4.3.4. Thermal regeneration

Thermal systems are normally used for chemically bonded sand systems and mixed sand systems, provided that the share of chemically bonded sands (cores) is high enough. Thermal regeneration uses heat to combust binders and contaminants. All thermal processes need an initial mechanical step in order to bring the sand to the correct grain size and to screen out any metallic contaminants.

Regeneration ratios, based on used sand throughput, of about 95% are reported for thermal systems in several foundries. Regenerated sands are mostly applied in core-making, but mould making application has also been reported.

4.3.5. Combined regeneration (mechanical–thermal-mechanical) for mixed organic-bentonite sands

In mixed organic-bentonite sands, cured bentonite and organic binders are present on the sand grains. The dust is composed of active and cured bentonite, coal dust (only for iron foundries), quartz fines and organic binder residues. Mixed sands occur mainly in iron foundries and represent some 75% of the total used sand production. The regeneration can be performed using mechanical, pneumatic, thermal or combined systems.

From operational data of several regeneration systems active in foundries, efficiency of the installations is estimated at 70-80%. The regenerated sand is used for mould making (100%) and core-making (70-80%). The applicability for core-making is related to the initial amount of chemically-bonded sand. The regenerated sand can be used for core-making in the original process, for cores with low or medium geometrical demands. The applicability in other binder systems must be tested in each case. Furthermore, these sands may be applied without restrictions for the replacement of losses in green sand moulding cycles.

4.3.6. Wet sand regeneration

The wet regeneration system can only be applied to green sand and silicate- or CO_2-bonded sands. Regeneration from these types of processes allows full re-use of the regenerated sand in both moulds and cores. Tests on regenerated green sand showed the possibility of producing good quality cold-box cores with an acceptable binder quantity.

4.3.7. Internal re-use of uncured core sand

Core production generates sand residues in the form of broken cores, cores with small mistakes and excess sand from the core-making machines. The excess sand can be hardened in a specific unit. Afterwards, the various unused core sand flows are fed to a breaking unit. The resulting sand may be mixed with new sand for the production of new cores. This technique applies for polyurethane (cold-box) and furan resin-bonded sands. Other binders do not allow this technique. Internal re-circulation of 5-10% of the core sand (which otherwise would be disposed of) is achieved.

4.3.8. Re-use of dusts from the green sand circuit in mould making

The dust collected through the exhaust filtration, from the shake-out installation and from the dosing and handling stations, for dry green sand contains active binder (bentonite) and additives (carbonaceous materials) compounds and may be recycled into the green sand circuit.

4.3.9. Valorisation of used foundry sand and fines from sand circuit in non-foundry applications

Used sand and undersize sand from the sand circuit may find some external applications. Due to its high quartz content and appropriate granulometry, used sand may be applied as a virgin sand substitute, with the main areas of application being construction (road bases, filling material, drainage material, permanent landfill covers…) and building materials industry (cement, concrete, bricks, tiles, etc.). The limits of these applications are given by either technical criteria for construction materials and/or environmental criteria for the given application.

Other fields of application are secondary copper smelting and zinc recuperation.

Deliverable report D4 "Analysis about the upcoming changes concerning SFS valorisation in EU" discusses in depth waste foundry sand valorisation trends and the boundary conditions for using SFS as alternative fine aggregates in the construction sector in EU.

5. WASTE FOUNDRY SAND

5.1. STATISTICS ON FOUNDRY SAND WASTE AT EUROPEAN LEVEL

Official Europe-wide statistics about amounts of waste foundry sand generated, landfilled and valorised, annually, are difficult to find.

Waste foundry sands fall into the following *List of Waste codes* (Commission Decision 2014/955/EU), depicted in Table 5-1. For the purposes of the LIFE ECO-SANDFILL project only non-hazardous waste categories shall be considered.

Table 5-1. EU List of Waste (LoW) codes applicable to waste sand from casting metals.

LoW code	Description	Chapters of list of wastes
10 09 05*	casting cores and moulds which have not undergone pouring containing dangerous substances	wastes from casting of ferrous pieces
10 09 06	casting cores and moulds which have not undergone pouring other than those mentioned in 10 09 05	
10 09 07*	casting cores and moulds which have undergone pouring containing hazardous substances	
10 09 08	casting cores and moulds which have undergone pouring other than those mentioned in 10 09 07	
10 10 05*	casting cores and moulds which have not undergone pouring containing dangerous substances	wastes from casting of non-ferrous pieces
10 10 06	casting cores and moulds which have not undergone pouring other than those mentioned in 10 10 05	
10 10 07*	casting cores and moulds which have undergone pouring containing hazardous substances	
10 10 08	casting cores and moulds which have undergone pouring other than those mentioned in 10 10 07	

Eurostat waste database and the European Pollutant Release and Transfer Register (E-PRTR) have been searched, but no specific entries for waste foundry sand streams have been found.

Community statistics (substance oriented) on the generation, recovery and disposal of waste are regularly produced, according to the rules set in Regulation (EC) No 2150/2002 and its amendments. Statistics on the aggregate waste category item No.42 "Other mineral wastes (W122+W123+W125) – Non-hazardous", *Eurobase code W12B* comprising EWC-Stat 12.2, 12.3, 12.5 waste categories, are available (Comm. Reg. (EU) No 849/2010). LoW codes applicable to SFS from casting ferrous pieces (10 09 06/10 09 08) are reported grouped with non-ferrous counterparts (10 10 06 / 10 10 08) and many other waste streams within that consolidated entry. The equivalence between the statistical nomenclature and the list of waste is shown below.

Table 5-2. Table of equivalence between EWC-Stat Rev 4 (substance oriented waste statistical nomenclature) and the European list of waste (LoW) for relevant mineral waste categories (0 non-hazardous) for foundry sand wastes within "12 Mineral Wastes" entry

	EWC-Stat Rev4		LoW included in EWC-Stat Rev4 (sub-) categories, [0 Non-hazardous]
Eurobase code W12B: Other mineral wastes = W122+W123+W125 (non-hazardous)	12.2 Asbestos wastes		-
	12.3 Waste of naturally occurring minerals		01 01 01, 01 01 02, 01 03 06, 01 03 08, 01 03 09, 01 04 08, 01 04 09, 01 04 10, 01 04 11, 01 04 12, 01 04 13, 01 05 04, 01 05 07, 01 05 08, 02 04 01, 08 02 02, 10 11 10, 10 12 01, 10 13 01, 19 08 02, 19 09 01, 19 13 02, 20 02 03
	12.5 Various mineral wastes	12.51 Artificial mineral wastes	02 04 02, 06 09 04, 06 11 01, 08 02 03, 10 03 05, 10 09 14, 10 11 03, 10 11 05, 10 11 14, 10 12 08, 10 12 12, 10 13 04, 10 13 06, 10 13 10, 10 13 11, 10 13 14, 12 01 17, 12 01 21
		12.52 Waste refractory materials	**<u>10 09 06</u> Casting cores and moulds which have not undergone pouring other than those mentioned in 10 09 05**
			<u>10 09 08</u> casting cores and moulds which have undergone pouring other than those mentioned in 10 09 07
			<u>10 10 06</u> Casting cores and moulds which have not undergone pouring other than those mentioned in 10 10 05
			<u>10 10 08</u> casting cores and moulds which have undergone pouring other than those mentioned in 10 10 07
			16 11 02 carbon-based linings and refractories from metallurgical processes others than those mentioned in 16 11 01
			16 11 04 other linings and refractories from metallurgical processes other than those mentioned in 16 11 03
			16 11 06 linings and refractories from non-metallurgical processes others than those mentioned in 16 11 05
	12.1 Construction and demolition wastes		17 01 01, 17 01 02, 17 01 03, 17 01 07, 17 05 08, 17 08 02, 17 03 02, 17 06 04, 17 09 04
	12.4 Combustion wastes		10 01 05, 10 01 07, 10 01 19, 10 02 08, 10 02 14, 10 03 20, 10 03 24, 10 03 26, 10 07 03, 10 07 05, 10 08 16, 10 08 18, 10 09 10, 10 10 10, 10 11 16, 10 11 18, 10 12 05, 10 12 10, 10 13 07, 10 13 13, 06 09 02, 10 01 01, 10 01 02, 10 01 03, 10 01 15, 10 01 17, 10 01 24, 10 02 01, 10 02 02, 10 03 16, 10 03 22, 10 03 30, 10 05 01, 10 05 04, 10 05 11, 10 06 01, 10 06 02, 10 06 04, 10 07 01, 10 07 02, 10 07 04, 10 08 04, 10 08 09, 10 08 11, 10 09 03, 10 09 12, 10 10 03, 10 10 12, 10 12 03, 11 05 02
	12.6 Soils		17 05 04, 20 02 02
	12.7 Dredging spoil		17 05 06
	12.8 Waste from waste treatment		19 01 12, 19 01 14, 19 01 16, 19 01 18, 19 01 19, 19 12 09

Waste of moulding sands for ferrous and non-ferrous castings are just part of 4 LoW categories out of the 48 included under the non-hazardous "W12B: Other mineral wastes" and of the 116 LoW categories within the overall "W12 Mineral Wastes" reported in waste statistics tables in Eurostat. If waste W12B generation data are filtered by NACE code corresponding to "Manufacture of basic metals and fabricated metal products, except machinery and equipment", one can achieve the narrowest waste generation data value (EU-wide) enclosing generated foundry sand waste [13]: 10.5 Mt in year 2014 for the EU28. Anyway, with no indication of the % that SFS accounts for in those sub-total amounts. Data about waste treatment refers to "W12B - Other mineral wastes" from all sources (including household) and cannot be used straightforwardly to infer amounts of foundry sand waste to recovery or disposal.

Table 5-3. Waste generation & treatment. Other mineral wastes (W122+W123+W125) – Non-hazardous (*Source: Eurostat [codes env_wasgen, env_wastr]*)

Year	GEO	Waste generation from metal manuf., Mt [(1)]	Waste generation from all NACE+hh, Mt	Total waste treatment, Mt	Landfill / disposal (D1-D7, D12), Mt	Recovery other than energy recovery, Mt
2012	EU28	10.36	784.14	777.66	662.90	114.55
	EU15	7.21	340.75	331.86	287.34	44.31
	CAEF[(2)] countries, CH excl.	7.49	1319.63	1283.88	859.97	392.59
	Spain	0.338	26.39	26.39	20.07	6.32
2014	EU28	10.52	824.86	592.57	492.54	99.80
	EU15	6.92	354.55	346.96	314.26	32.47
	CAEF countries, CH excl.	7.29	395.27	393.23	266.54	87.59
	Spain	0.273	22.13	22.13	18.27	3.87

[(1)] *NACE activity: Manufacture of basic metals and fabricated metal products, except machinery and equipment*

[(1)] *CAEF: European Foundry Association. Country members: Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Lithuania, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom*

In the case of the E-PRTR register, the online database allows to filter waste transfer data by industrial activity or economic sector (NACE codes), classifying waste transfer amounts per type of waste (hazardous/non-hazardous) and end-route (recovery/disposal/unspecified). For non-hazardous waste from metal casting activities the database gathers data from over 400 facilities from 22 European countries (CAEF countries except Turkey, Croatia and Lithuania, plus Bulgaria, Romania, Slovakia and, in year 2014, also Serbia). [14]

Table 5-4. Non-hazardous waste transfers per metal casting activity (*Source: E-PRTR register*)

Year	GEO	Industrial activity/economic sector	Total waste, Mt	recovery, Mt	disposal, Mt	No. Facilities
2014	All countries reporting (22) [1]	NACE 24.5 metal casting	5.927	4.294	1.633	443
		NACE 24.51 iron casting	*4.273*	*3.005*	*1.267*	*296*
		NACE 24.52 steel casting	*1.087*	*0.807*	*0.280*	*72*
		NACE 24.53 light metals casting	*0.462*	*0.401*	*0.060*	*51*
		NACE 24.54 other NF metal casting	*0.106*	*0.080*	*0.026*	*24*
		Production & processing of metals: ferrous metal foundries	4.986	3.396	1.591	389
	Spain	NACE 24 basic metal manuf.	2.421	1.449	0.972	82
		NACE 24.5 metal casting	0.826	0.540	0.287	43
		NACE 24.51 iron casting	*0.345*	*0.119*	*0.226*	*26*
		NACE 24.52 steel casting	*0.468*	*0.414*	*0.054*	*14*
		NACE 24.53-54 light & other NF metals casting	*13.3 kt*	*6.8 kt*	*6.5 kt*	*3*
		Production & processing of metals: ferrous metal foundries	0.398	0.138	0.260	39
2012	All countries reporting (21) [2]	NACE 24.5 metal casting	9.245	7.567	1.678	429
		Production & processing of metals: ferrous metal foundries	7.647	6.058	1.589	378
	Spain	NACE 24 basic metal manuf.	2.395	1.321	1.074	76
		NACE 24.5 metal casting	0.872	0.587	0.285	39
		Production & processing of metals: ferrous metal foundries	0.376	0.143	0.233	33

[1] *Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom, Bulgaria, Romania, Slovakia*

[2] *countries listed in (1) above plus Serbia*

Although reported data on non-hazardous waste in E-PRTR can be narrowed down to waste transfers from metal casting activities (even per metal type: iron, steel, light metals, other non-ferrous metals), it is not possible to break down data beyond, by waste category, to find out how much waste sand from casting cores and moulds contributes to those non-hazardous waste

amounts. Therefore, sand moulding waste will be included in the ca. 6 Mt of non-hazardous waste from metal casting quantified for 22 European countries in 2014, together with other wastes such as slags, refractories, dust, binders, etc. For that total amount, 72.5% recovery and 27.5% disposal ratios are reported. Iron and steel casting amount for 82% and 18%, respectively, of the total non-hazardous waste from metal casting. In year 2012 total non-hazardous waste transferred amount was noticeably higher (9.3 Mt), in spite of having one less country reporting.

Data from a study conducted by CAEF – The European foundry Association in 2007 on foundry sand waste management status in Europe (geographical coverage: Austria, Finland, Hungary, Italy, Norway, Poland, Portugal, Spain, Sweden) reveal that SFS generated in the listed countries in 2007 amounted to 2.2 Mt approximately. According to CAEF [15], the production figures have decreased on average by approx. 20% in the past 10 years and the waste data could be adapted in the same extent. CAEF estimates generation of waste in Germany (the EU country where more foundries are located) at 2.1 Mt of used sand per year and reports the following disposal/recovery paths: 65% landfill covering, 15% landfill disposal as waste, 7.5% brick industry, 6% backfill to underground, 5% road construction. In the 2007 study, distribution of SFS by waste management routes was screened, including amounts valorised as secondary aggregates in roads and construction sector. Rough data are summarised in the table below.

Table 5-5. Used foundry sand generation and management routes in Europe (*Source:CAEF* [15])

GEO	2007 SFS generated, t	2007 Waste management routes	2016 SFS estimates*, Mt
Austria	100000-150000	Landfill; cement industry, asphalt; co-cementing	0.100
Finland	130000	Sec. aggregates in construction sector (40000 t); raw material in cement industry; fluxing material in copper/steel industry; mineral liner in landfills; bulk material in composting	0.104
Hungary	59000	landfill	0.047
Italy	500000	cement production; production of hydraulic lime; brick industry; cement and bitumen conglomerates for building; glass industry; ceramic industry; roadbed baking	0.400
Norway	25000 *(yr.2004)*	soil improvement (1 foundry), thermal reclamation (2 foundries)	0.020
Poland	750000-800000	40-50% reprocessed; sec. aggregates in construction (10%); rest in landfills	0.620
Portugal	80000	reprocessing (mainly chemical bonded sand); landfills (mine pits); clinker manufacture	0.064
Spain	300000	cement (clinker); 60000t; in Basque Country limited to green sand mould and fines; 16000t of green sand in brick making; in Catalonia re-use as compost (since 2001)	0.240

GEO	2007 SFS generated, t	2007 Waste management routes	2016 SFS estimates*, Mt
Sweden	200000	landfill	0.160
Germany	N.A.	15% landfill, disposal as waste 65% landfill covering 7.5% brick industry 6% backfill to underground 5% road construction	2.100
Total 10 CAEF countries			3.855

* *IK4-AZT estimates from 2007 CAEF's study data and '20% drop in waste generation' assumption.*

More recent reliable EU-wide data on foundry waste generation and management have not been obtained from European agencies or industry organisations, although several figures are available from the literature. In the web summary of project LIFE-FOUNDRYSAND - *Re-use of surplus foundry sand by composting* (LIFE13 ENV/FI/000285), it is stated that in Europe, around 18 million tonnes of foundry waste sand is produced every year [16]. Two other LIFE projects offer apparently disparate SFS estimates at European level, of some twenty years ago. According to the abstract of project *The processing of current waste foundry sand and sand previously discarded to landfill sand as a total recycling service to the foundry industry and other users* (LIFE98 ENV/UK/000588), 9.15 Mt of surplus foundry sand were landfilled each year throughout Europe (ca.1998), with some 15% of that total being generated in the UK [17]; whereas 1996 LIFE project *Regeneration and recycling by mechanical treatment of all sept fons foundry sand* (LIFE96 ENV/F/000373) estimated that tonnage of waste sand amounted to 950,000 tonnes in 1995 in France and to more than 5 million tons for the entire European Community [18].

5.2. ESTIMATION OF SFS GENERATION IN EUROPE

Given the variability of the foundry sand waste estimates at European level from the various sources consulted, ranging from 18 Mt to 4 Mt, and referred to varying geographical scopes, new estimations have been carried out in the present project, to try to calculate the amount of foundry sand waste generated which could be available for valorisation. Two computation procedures have been followed: on the one hand, EU-wide data have been extrapolated from reported waste generation data on a smaller scale by linking them to corresponding metal casting production figures. On the other hand, EU-wide production figures can be used as a basis for a rough estimation of foundry sand waste, using the sand-to-liquid metal ratios and the metal yield data compiled from several surveys (see section 4.2).

The evolution of metal casting production by foundries located in the CAEF member countries in the last years can be outlined from yearly statistics of the Association on ferrous and non-ferrous casting [19] [20].

Table 5-6. Total yearly production (in 1000 t) of ferrous and non-ferrous metal castings in CAEF country members, 2008-2015 statistics (*Source: CAEF*)

Foundry	GEO	2008	2012	2013	2014	2015	Avg.%
Iron, Steel and Malleable iron castings, kt	CAEF Total	13629.6	11487.4	11361.7	11574.9	11393	100.0%
	France	*2060.7*	*1436.4*	*1419.2*	*1393.6*	*1328.5*	*12.9%*
	Germany	*4785.4*	*4267.4*	*4122.7*	*4150.9*	*4085.4*	*36.7%*
	Italy	*1655.7*	*1115.4*	*1146.3*	*1164*	*1130.7*	*10.4%*
	Poland	*750.2*	*688*	*700*	*700*	*709*	*5.0%*
	Spain	*1221.7*	*985.5*	*976.3*	*1006.2*	*1065.6*	*8.9%*
Non-ferrous metal castings, kt	CAEF Total	3485.4	3487.4	3590.2	3809.9	4005.6	100.0%
	France	*327.4*	*362.3*	*328.9*	*335.8*	*356.9*	*9.7%*
	Germany	*981.6*	*988.2*	*1007.1*	*1134.2*	*1221.3*	*29.2%*
	Italy	*982.3*	*844.3*	*825.4*	*860.9*	*900.5*	*24.7%*
	Poland	*252.4*	*348*	*358*	*358*	*353*	*7.6%*
	Spain	*137.5*	*133.4*	*131.3*	*135.6*	*146*	*3.8%*
TOTAL CASTING PRODUCTION – CAEF, kt		17115	14974.8	14951.9	15384.8	15398.6	100.0%

The six countries that dominate the industry in terms of weight, namely Germany, France, Turkey, Italy, Spain and Poland, account for 85% of the production of ferrous metal castings. The average production per foundry in Germany (16.5 kt), Spain (14 kt) and France (11 kt) is considerably higher than in the rest of countries (average CAEF output: 6 kt per foundry).

The non-ferrous metal sector is dominated by Germany, Italy, France and Poland; the first two countries hold a share of over 50% in the production total. The plant production in non-ferrous foundries in Germany is again above the average in the CAEF (more than 3 kt per foundry, versus 1.4 kt on average).

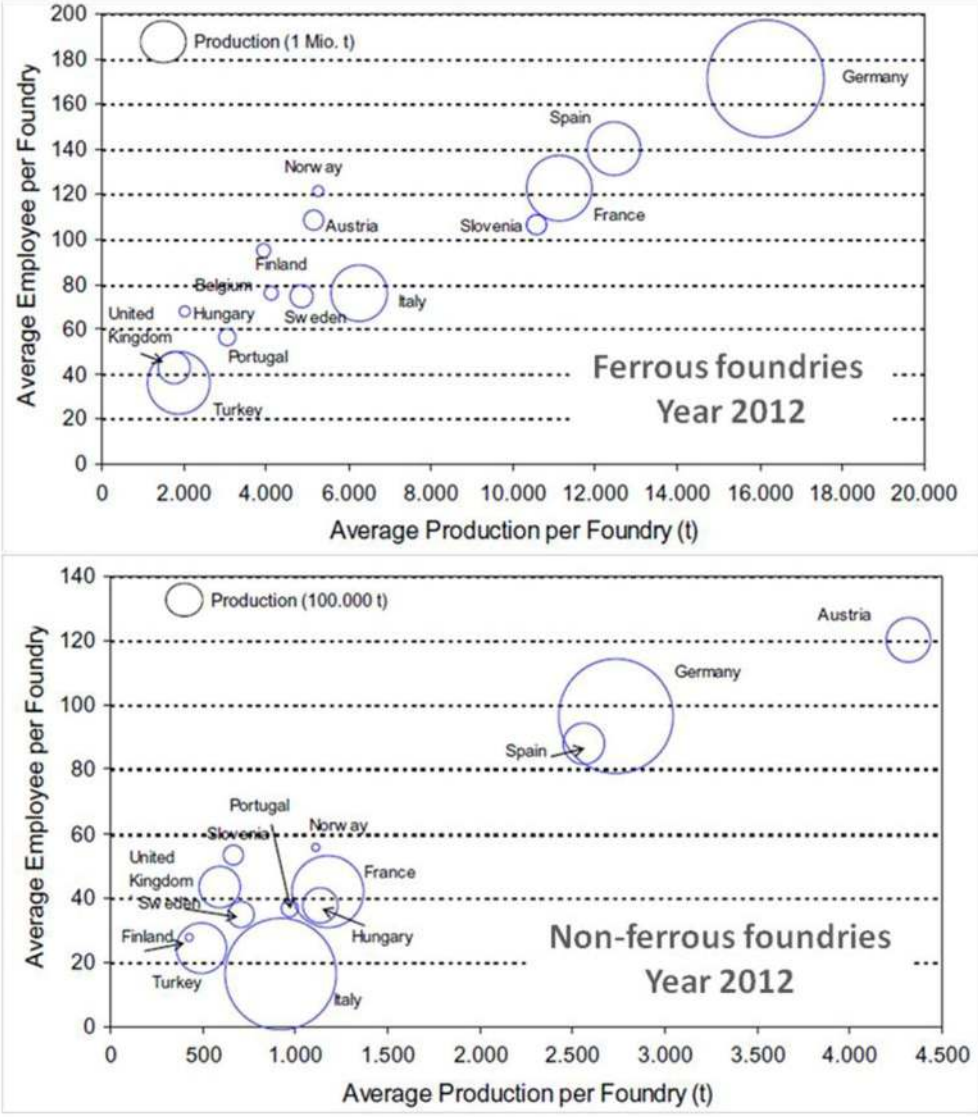

Figure 5-1. Average Production per Foundry in the CAEF member countries. Top: Iron, Steel and Malleable Iron Castings. Bottom: Non-ferrous metals castings (*Source: CAEF* [19])

Detailed data on casting production and moulding sand waste generation in year 2015 is available for the Spanish foundry industry, and at a local level for the Basque Country region, through statistics and environmental reports produced by the Spanish national foundry association (*Federación Española Asociación Fundidores*, FEAF) [21]. An environmental questionnaire to compile detailed data about waste management of the different waste streams arising in metal casting, differentiating green sand and chemically bonded sand moulding processes waste has been addressed to FEAF associates accounting for over 95% of total Spanish net production. 33 out of 39 iron casting foundries and 21 out of 27 steel casting foundries have taken part in the survey, plus 3 non-ferrous foundries.

In the case of the Basque Country region, surveyed foundries represent 97% of total net production in that geographical area. 32 out of the 57 Spanish foundries surveyed by FEAF are located in the Basque Country.

Table 5-7. Spanish foundry industry status, 2015 – production and waste management (*Source:FEAF*)

Data per sub-sector		Iron	Steel	Non-ferrous	Total
No. active foundries		39	27	44	110
Net production, t		856,034	64,838	128,567	1,049,439
FEAF Environmental Questionnaire*	No. foundries	33	21	3	57
	Net production, t	841,053	61,908	510	903,471
	GSM sand & cores waste, t	207,746	16,734	124	224,604
	GSM sand & cores waste valorisation	*43.21%*	*56.58%*	*62.33%*	*44.20%*
	GSM fines waste, t	35,628	4,259	1	39,888
	GSM fines waste valorisation	*71.26%*	*49.17%*	*100.00%*	*68.90%*
	CSM sand waste, t	19,506	29,458	174	49,138
	CSM sand waste valorisation	*52.16%*	*47.39%*	*22.12%*	*49.29%*
	CSM fines waste, t	7,497	4,967	4	12,468
	CSM fines waste valorisation	*0.00%*	*4.93%*	*47.17%*	*1.97%*
	Moulding sand total waste, t	**227,252**	**46,192**	**298**	**273,742**
	Moulding sand & fines total waste, t	**270,377**	**55,418**	**303**	**326,098**
	Others, t	16,007	2,795	0	18,802
	Others, valorisation	*2.39%*	*37.77%*	*0%*	*7.65%*
	Sand & fines - total waste, t	**286,384**	**58,213**	**303**	**344,900**
	Sand & fines - total waste valorisation	***43.89%***	***46.08%***	***39.11%***	***44.26%***

* Survey results for *57 foundries (54 ferrous + 3 non-ferrous, equiv.96.97% production of FEAF associates). GSM = Green Sand Moulding || CSM: Chemically bonded Sand Moulding*

Table 5-8. Basque Country foundry industry status, 2015 – production and waste management (*Source:FEAF*)

	Data per sub-sector	Iron	Steel	Non-ferrous	Total
FEAF Environmental Questionnaire*	No. foundries	17	12	3	32
	Net production, t	286,680	41,204	510	328,394
	GSM sand & cores waste, t	67,147	5,350	124	72,621
	GSM sand & cores waste valorisation	*30.78%*	*66.21%*	*62.33%*	*33.44%*
	GSM fines waste, t	16,788	4,259	1	21,048
	GSM fines waste valorisation	*64.42%*	*49.17%*	*100.00%*	*61.34%*
	CSM sand waste, t	11,702	18,865	174	30,741
	CSM sand waste valorisation	*44.78%*	*37.54%*	*22.12%*	*40.21%*
	CSM fines waste, t	4,287	2,589	4	6,880
	CSM fines waste valorisation	*0.00%*	*9.46%*	*47.17%*	*3.59%*
	Moulding sand total waste, t	**78,849**	**24,215**	**298**	**103,362**
	Moulding sand & fines total waste, t	**99,924**	**31,063**	**303**	**131,290**
	Others, t	1,317	1,698	0	3,015
	Others, valorisation	*0.00%*	*29.23%*	*0.00%*	*16.46%*
	Sand & fines - total waste, t	**101,241**	**32,761**	**303**	**134,305**
	Sand & fines - total waste valorisation	***36.27%***	***41.09%***	***39.11%***	***37.45%***

* Survey results for *32 foundries (29 ferrous + 3 non-ferrous, equiv.97% production of FEAF associates in Basque Country). GSM = Green Sand Moulding || CSM: Chemically bonded Sand Moulding*

Additionally, reported industrial waste data can be searched by type of activity (industrial activity and/or NACE codes) and LoW codes in the Basque PRTR Register [22] [23] [24] [25] and filtered by waste treatment operation. By doing so, data on waste generated and send to disposal from casting moulds and cores (i.e., SFS) used in the Basque ferrous foundry industry have been extracted.

Table 5-9. Generation and disposal of waste from casting moulds & cores from ferrous metals foundries in the Basque Country (*Source: EPER Euskadi / E-PRTR*)

Year	Industrial activity/economic sector	LoW 10 09 06 waste, kt	LoW 10 09 08 waste, kt	Generation SFS, kt	Disposal SFS from foundries, kt
2012	All activities	64.13	92.82	156.95	
	2(b) Production of pig iron or steel including continuous casting 2(d) Ferrous metals foundries	44.11	46.73	90.84	
	NACE 24.51 iron casting & NACE 24.52 steel casting	44.11	40.72	84.83	54.55
2014	All activities	71.34	97.80	169.14	
	2(b) Production of pig iron or steel including continuous casting 2(d) Ferrous metals foundries	39.91	54.75	94.66	
	NACE 24.51 iron casting & NACE 24.52 steel casting	39.45	52.61	92.05	68.08
2015	All activities	72.20	81.86	154.06	
	2(b) Production of pig iron or steel including continuous casting 2(d) Ferrous metals foundries	34.93	44.46	79.39	
	NACE 24.51 iron casting & NACE 24.52 steel casting	34.38	40.96	75.34	58.55

Similarly, a refined search in the Spanish PRTR register [26] produces the corresponding values of waste of casting cores and moulds generated and disposed of in ferrous foundry activities.

Table 5-10. Generation and disposal of waste from casting moulds & cores from ferrous metals foundries in Spain (*Source: PRTR-ES*)

Year	Industrial activity/economic sector	LoW 10 09 06 waste, kt	LoW 10 09 08 waste, kt	Total mould & cores waste, kt	SFS from foundries disposal, kt
2012	2(b) Production of pig iron or steel including continuous casting 2(d) Ferrous metals foundries	85,10	147,05	232,15	142,25
2014	2(b) Production of pig iron or steel including continuous casting 2(d) Ferrous metals foundries	82,31	148,52	230,83	158,63
2015	2(b) Production of pig iron or steel including continuous casting 2(d) Ferrous metals foundries	75,04	135,11	210,14	130,93

When analysing waste data from PRTR registers one should take into account that the E-PRTR thresholds are designed to capture 90% of all European industrial releases. Not all active foundries might be reporting to the registers. Under Regulation (EC) No 166/2006 *concerning the establishment of a European Pollutant Release and Transfer Register* (E-PRTR Regulation.), only foundry installations with a production capacity exceeding 20 tonnes per day are obliged to report off-site waste transfers if these are in excess of specific threshold values (2t/yr for hazardous waste and 2 kt/yr for non-hazardous waste). Moreover, in the *Report from the Commission to the European Parliament and the Council on progress in implementing Regulation (EC) 166/2006* (COM(2013) 111 final) it is stated that the analysis has made clear that the thresholds set by the E-PRTR Regulation only allow the reporting of about 39% of hazardous waste and 17% of non-hazardous waste, with large differences between different economic sectors. Those circumstances may explain that data extracted from PRTR registers for a region differ from data reported by casting industry statistics and surveys in the same region, especially when small companies populate the sector.

Extrapolating the FEAF's survey data of SFS generation in ferrous foundries (Table 5-8) to 100% foundries in the Basque Country in 2015, an estimated value of 105 kt is obtained. That is about 25% over the amount reported for ferrous casting activities in the *EPER Euskadi* register (Table 5-10). The same ratio is found for Spain wide data: reported waste value for 2015 in the PRTR-ES register accounts for 25% of the extrapolated value for 100% Spanish ferrous casting industry

(280 kt). Since Spain is one of the CAEF countries with higher average production per foundry, it is expected that reported data in the European E-PRTR for other countries are not including waste from many installations with lower capacity and that representativeness is below that estimate 75% for Spain.

Therefore, FEAF's survey data on sand waste generation and ferrous casting net production in 2015 for the Basque Country and Spain have been preferred over PRTR data to be taken as basis for extrapolation of EU-wide data.

The average ratio of generation of SFS to net casting production in ferrous foundries, according to FEAF's survey data is 0.31 t waste per net tonne casting for the Basque Country and 0.30 for Spain. Sand and cores waste from green sand moulding represents 70% of total SFS generated in the Basque Country foundries and 82% in Spain. Those figures vary among iron and steel casting installations: the ratio of SFS tonnes generated per tonne of net iron casting is 0.28 in the Basque Country and 0.27 in Spain as a whole, whereas SFS tonnes per net steel casting are 0.59 in the Basque Country and 0.75 for Spain. The share of steel casting in the ferrous foundry industry is 7% in Spain and 13% in the Basque Country.

In 2015, 9.35% of the 11.39 Mt of ferrous casting production in the CAEF countries was produced in Spain. Split data of iron and steel casting production in the total ferrous foundry production in the CAEF member countries have not been gathered for year 2015, but according to available 2008-2012 series [19], the share of steel in the total output of iron, steel and malleable castings was around 8% on average. No data about the share of sand moulding use in the total casting statistics are available and 100% is assumed for ferrous casting.

Under those assumptions, extrapolated figures for CAEF countries show 3.5 Mt of waste sand and cores from ferrous foundries, of which approximately 2.5 Mt would be generated in the five major European producer countries (Germany, France, Italy, Spain, Poland). For green sand moulding ranging between 70% and 85% of total sand casting of ferrous metals, SFS are computed to be 2.4 to 3 Mt, respectively.

Considering the same geographical scope as in the 2007 study by CAEF [15] discussed in section 5.1, 2.3 Mt of SFS might be generated from ferrous foundries in that subset of CAEF countries. If extrapolated data for SFS generated in non-ferrous foundries[1] of those countries are added, the total generated quantities of waste sand would amount to 2.9 Mt. For the whole CAEF area, 4.2 Mt waste foundry sand can be reckoned.

[1] 0.58 t SFS per tonne of net non-ferrous casting. Ratio estimated from data reported by 3 non-ferrous foundries in FEAF's survey in Spain [21]. Assumption: 30% sand casting in non-ferrous metals

Those figures have been calculated using the average 2015 Spanish ratio waste sand-to-net casting production. As explained in section 4.2, the yield of casting operations and ratio of waste sand generated depend on many factors (type and size of parts being casted, moulding technology, scrap casting rate, metal alloy, larger/smaller capacity of foundry, new sand addition rates in the process, sand recycling equipment…). Values of SFS-to-cast metal ratios ranging from 0.27 up to 0.57 are provided in the references consulted. Hence, the projected SFS values with the 0.30 waste sand-to-net ferrous casting Spanish ratio are almost certainly underestimated. The use of the ratio 0.57, for example, would produce the waste sand value for ferrous casting in the CAEF area to increase up to 6.5 Mt. If a ratio=0.30 is used to extrapolate waste amounts for countries with national average production per plant >10 kt/year (DE, ES, FR, SI) and a ratio=0.50 for the rest of countries (with smaller installations predominating), SFS from ferrous casting remain at a guess value of 4.5 Mt.

The effect of metal yield and sand consumption rates on SFS estimates for the CAEF area is illustrated in Table 5-11. As a basis for the calculations the following values have been taken:

- net ferrous casting production (2015 CAEF total) = 11.39 Mt
- average steel share in ferrous casting production = 8%
- metal yield for iron casting: range 40%-90%, average 65%
- metal yield for steel casting: average 50%, minimum 30%
- average ratio SFS-to-liquid metal for ferrous casting: 0.34
- ratio SFS-to-liquid metal for iron castings: 0.08-0.75 (mean value 0.18)
- ratio SFS-to-liquid metal for steel casting: 0.35-1.1 (mean value 0.72)

Table 5-11. Sensibility analysis: impact of metal yield and SFS:metal ratio variables in waste generation scenarios of ferrous foundry sand for net production = 11.39 Mt

kt of waste sand from ferrous casting (CAEF total) for several [yield, ratio] hypotheses	SFS:liq. metal (avg) = 0.34	SFS:liq. metal (iron) = 0.18 (steel)= 0.72	SFS:liq. metal (iron) = 0.08-0.75 (steel)= 0.72	SFS:liq. metal (iron) = 0.18 (steel)= 0.35-1.10
Metal yield (iron): 65%	-	2903	1290-12094	2903
Metal yield (steel): 50%	-	1313	1313	638-2005
Metal yield (avg.): 63.8%	**6102**	**4215**	**2603-13407**	**3541-4908**
Metal yield (iron): 40%	-	4717	-	-
Metal yield (steel): 30%	-	2187	-	-
Metal yield (avg.): 39.2%	**9942**	**6904**	**-**	**-**
Metal yield (iron): 90%	-	2096	-	-
Metal yield (steel): 30%	-	2188	-	-
Metal yield (avg.): 85.2%	**4993**	**4284**	**-**	**-**
Metal yield (iron): 90%	-	2096	-	-
Metal yield (steel): 50%	-	1313	-	-
Metal yield (avg.): 86.8%	**4580**	**3409**	**-**	**-**

As proved, depending on the assumptions, computed SFS amounts from ferrous foundries can increase by a factor of ten. However, most likely total CAEF area values fluctuate between 4.5 and 9 Mt, around mean values of 6 Mt.

Valorisation levels of SFS across EU countries, and even by region, are quite different, according to information conveyed in the surveys by CAEF and FEAF (see Table 5-5, Table 5-7 and Table 5-8) and PRTR registers. In some cases, valorisation rates are around 50%, in other cases landfill is the only waste management option reported. Assuming that in some of the main producer countries high valorisation rates of spent ferrous foundry sand take place, a guess of overall 60% landfill of the SFS generated from ferrous casting in the CAEF area would lead to disposal estimates of 2.7-5.4 Mt, which could offer an opportunity to seek new valorisation alternatives and divert non-hazardous sand waste from landfill and deposit.

6. MARKET ANALYSIS OF AGGREGATE DEMAND IN CONSTRUCTION SECTOR

6.1. INTRODUCTION TO AGGREGATES

Aggregates are granular material used for construction activities. Among them, there can be different natural aggregates (from mineral deposits, such as sand, gravel and crushed rock), artificial aggregates (by-products or wastes of industrial processes, such as slags and flying ashes) and recycled aggregates (predominantly Construction and Demolition wastes), addressing to the use percentages in the constructive activities shown in the figure below.

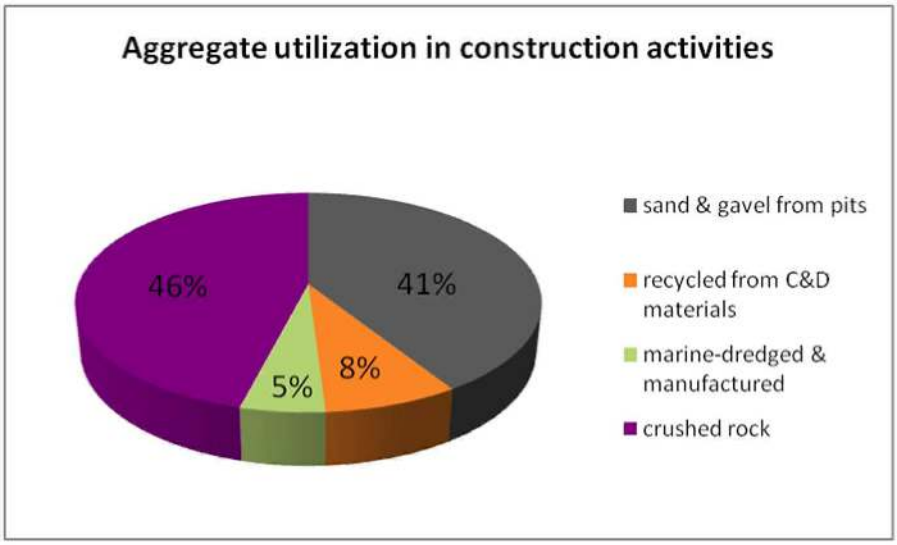

Figure 6-1. Construction applications of aggregates

It can be stated that aggregates are the base material of the construction activities, and its extraction is one of the activities with a greater environmental impact in the constructive chain. Therefore, their utilization and the study of the implementation of recycled aggregates one of the elements to have into account to develop the business in a sustainable and cost-effective way, as well as.

For this reason, European policies and legislation are moving towards a more sustainable resource model that increment the reutilization of recycled aggregates, decrease deposition in landfills and the extraction of natural aggregates.

6.2. AGGREGATE PRODUCTION IN EUROPE/CONSTRUCTION PRODUCTS IN EUROPE

The average European aggregates demand is close to 2.6 billion tonnes per year, representing an annual turnover of an estimated €15 billion. Natural aggregates produced in the 25,000 existing quarries and pits represent the 87% of them. The remaining 10% comes from recycled aggregates (8%), being the rest marine and manufactured aggregates (5%).

According to data provided by the European Aggregates Association, in year 2014 the total production of aggregates was of 2.65 billion tonnes, being this value in concordance with the average value of aggregate demands per year in Europe. Production of natural aggregates in the EU28 plus EFTA countries was of 2.36 billion tonnes, from which 1,061 Mt correspond to sand & gravel, 1,241 Mt to crushed rock and 56 Mt to marine aggregates.

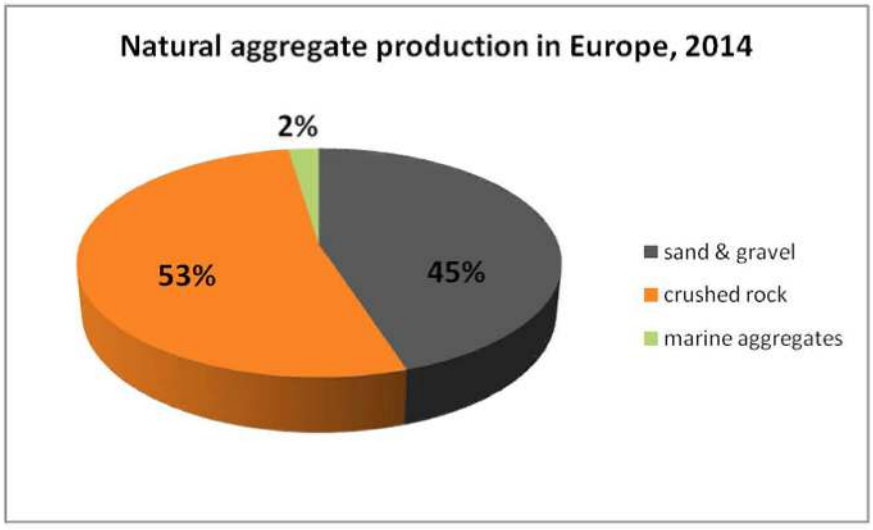

Figure 6-2. Natural aggregate production in 2014 (*Source: European Aggregates Association*)

According to Eurostat data [27], domestic extraction of sand and gravel in the EU28 has dropped from 2,092 Mt in 2012 to 1,983 Mt in 2014. Domestic consumption of the same materials was 2,104 Mt in 2012 and 1,991 Mt in 2014.

In addition, the predictions made by Euroconstruct for years 2016 and 2017 expects a growth for construction sector of 2% each year. Thus, it can be affirmed that the potential market of reclaiming of SFS has a wide field of possibilities abroad Europe.

Regarding to the materials manufactured with natural aggregates, they are represented mainly by:

- structural unbound materials (40% of total)
- ready mix concretes (25% of total)
- precast concrete (15% of total)
- asphalt products (10% of total)
- architectural concrete products (5% of total)
- armour stone (3% of total)
- railway ballast (2%)

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