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Project Acronym: REUSteel

Project title: Dissemination of results of the European projects dealing with reuse and recycling of by-products in the Steel sector

Deliverable 2.1

List of projects of interest for valorisation and dissemination

Table of Content

1. Project Summary and purpose of the present document

The project will develop dissemination and valorisation of the most important results achieved in the EU research projects (ECSC, RFCS, FP3, FP4, FP5, FP6 and Horizon 2020) on the reuse and recycling of by-products, deriving from the steel production cycle, as well as the exploitation of by-products coming from other industrial sectors outside the steelmaking cycle, such as alternative Carbon sources (e.g. biomasses and plastics). To the list contained in the proposal new and ongoing EU-funded projects (including ECSC/RFCS projects as well as other EU funded projects) have been added in the present document. The project aims at performing an integrated critical analysis to improve the effectiveness of the achieved results in the previous projects, to establish a road map for future research in the topic as well as to promote the synergies with other industrial sectors, according to the concepts of Circular Economy (CE) and Industrial Symbiosis (IS).

Over the past few decades great efforts have been made in European research to exploit by-products recovery as well as their quality, through the improvement of existing technologies and the development of new sustainable solutions. These have led the steel industry to save natural resources and to reduce the environmental impact, resulting in being closer to its "zero-waste" goal. Most of the related projects dealt with these topics.

In recent years, the concept of CE has been strongly emphasized at European level as an opportunity to improve the environmental sustainability of the production processes as well as to achieve considerable savings in both consumption of primary raw materials and costs related to landfilling and disposal of by-products and wastes. This concept is also highlighted in the Strategic Research Agenda (SRA) of the European Steel Technology Platform (ESTEP), which participates in the project as a subcontractor of the coordinator.

The aim of the project is to review, analyse and organise the most important achieved results on the reuse and recycling of by-products coming from the steelworks inside and outside the steelmaking cycle. In addition, it aims at exploiting the reuse and recycling of by-products deriving from other activities outside the steelworks, for instance alternative carbon sources (e.g. biomasses and plastics). The dissemination and valorisation actions of the most relevant results will provide a global vision of the state-of-the-art to promote both the exploitation of the outcomes and the synergies with other industrial sectors. This will allow organizing project results in a more organic form in order to present the research results to a wider audience.

A joint critical analysis, carried out by all the partners, belonging to different institutions, will provide new insights and guidelines for future research topics in this field, in order to promote the dissemination and, consequently, the implementation of the achieved results.

Further aims of the project will be focused on the re-organisation of the results, in order to present selected groups of topics at planned workshops and seminars. This will provide a clearer vision of the outcomes to stakeholders and new audiences, in order to get new and deeper indications for a new roadmap, future synergies with other sectors and industrial trends.

The present document provides the list of the selected projects, according to the aim of the REUSteel project. In the list, each project is summarized with a short description. Compared to the proposal, new European projects, relevant for REUSteel, have been included.

Along the list of the selected projects, the document also includes a separate section with a list of the criteria that will be adopted for the selection in D2.2, such as: relevance for the project, time of completion, real implementation of the results, etc. In addition, other criteria concerning the most important aspects in terms of innovation have been added, according to the aim of the REUSteel project. Finally, the list of the projects relevant for valorisation and dissemination has been obtained.

2. Preliminary list of previous and ongoing EU-funded projects

In this section a list is provided of closed and ongoing EU-funded projects (listed in chronological order), which are related to the topic of reuse and recycling of by-products. The list is considered preliminary as the consortium reserves the right to add any additional projects that will come to the knowledge of the beneficiaries during the project and are deemed relevant.

2.1 List of ECSC/RFCS projects

[P1] ECSC-STEELDEM 3C 7215-AA/403: Economic advantages of integrated processing of steelworks EAF wastes, mainly containing Zn, Pb, Cd, FeOx, Zn ferrite and others, with total recovery 01/07/1995-31/12/1998. The project aim was to determine the optimum conditions for the total recycling of EAF dusts. A hydro-metallurgical extraction system wherein the flue dusts coming from EAF (Iron oxides plus Zn, Cu, Pb oxides) are extracted and separation has been implemented. Nearly pure metallic Zn was collected at cathodes, whereas lead and heavy metals were separated in the form of cements. A ferrous residue has also been obtained. Once dried, converted into pellets and mixed to reductants, this residue has been introduced into EAF to recover iron. The recycling feasibility of the residual fraction has been proved by trials carried out at the EAF since no process or product anomalies have been remarked.

[P2] CSC 7215-AA/903 The in-plant by-product melting (IPBM) process 1/07/1996-30/06/1998. The project aimed at developing a flexible process outside the main metallurgical line for the transformation of steel slags and other by-products (such as dust and millscale) into value-added products, in order to achieve "zero-waste" in the steel plant. Two processing variants using a smelting vessel was evaluated, slag reduction where mineral products and hot metal is produced and vitrification where the molten steel slag is utilized as a neutralization mass for noxious waste and valuable products was produced. The study was carried out through mathematical modelling, pilot plant tests and slag products of satisfactory quality were produced.

[P3] ECSC-STEEL C 7210-AA/425: Development of technologies for treatment of dusts and sludges containing zinc and lead to improve their recycle reuse (TREATDUST) 01/07/1996-30/06/1999. The project carried out an investigation aimed at

the assessment of the optimum combination of treatments for recovering the metals contained in dusts coming from BOF and EAF. The work has mainly been done through laboratory investigations including different treatments as acid/basic leaching/washing, coagulant oxidation, purifying treatments and electrolysis. Dust mixing and palletisation followed by proper treatments (reducing heat treatment, magnetic separation, melting of magnetic fraction, steel cutting in an induction furnace, and treatment of effluents) have also been evaluated. In addition, the treatment of BOF dust after having been continuously recycled under the form of briquettes into the converter has been investigated in a laboratory furnace designed according to the model of the rotary hearth. The results of each type of different treatment investigated gave indications on the possible conversion of EAF and BOS dusts into different types of useful by-products, pointing out also critical point, according to the different treatment route.

[P4] ECSC 7215-AA/803 Improved cleaning of waste gases and recycling of BOF dusts 1/07/1996-31/12/1999. The project aimed at using results from previous research work on the use of X-ray fluorescence (XRF) techniques to measure dust concentrations in gas streams, and to improve the effectiveness of the waste gas cleaning system. By monitoring zinc levels, the maximization of recycling potential of low-zinc slurry solids to a sinter plant was achieved.

[P5] ECSC 7210-PR/005 Briquetting of self-reducing blendings of waste iron oxide mixtures 1/07/1997-31/12/2000. This project aimed at developing a technically and economically acceptable recycling process for residues with a high iron content to avoid their landfill destination. A low temperature briquetting process of self-reducing blendings was developed to process oily mill scales and sludges.

[P6] ECSC 7215-PP/012 High purity zinc and ferroalloys recovery from EAF dusts through a combined pyro-hydrometallurgical treatment 01/07/1998-30/06/2001. A combined pyro-hydrometallurgical technology for the treatment of dusts generated in the Electric Arc Furnace (EAF) has been developed and successfully tested. The pyrometallurgical treatment is run on a 1.5 MW single electrode electric arc furnace (D.C.), equipped with a water cooled feed duct. Reducing conditions have been obtained through the feeding of carbonaceous species so to enhance the generation of powders enriched in zinc oxide. The process is run continuously, charging the furnace containing liquid metals and slag with a mixture of EAF dust, flux as slag modifier and coal. These conditions favour the reduction of reducible oxides (the non-reducible ones are collected in slag); volatile metals such as Zn, Pb and Cd evaporate and are gathered as oxides in the gas cleaning plant. The products of this process are ZnO enriched powders, ferro-alloy and inert slag. The ZnO content in the powders is higher than 80%. A hydrometallurgical treatment of these powder is done in order to recover the Zn. The whole treatment involves an acid leaching followed by purifying treatments and eventually an electrolytic treatment. This last process step is done on a pilot scale for a series of 10 cathodes (1.2 m2/each) where the Zn is deposited (total of 640 kg Zn produced; the exhaust electrolyte solution recovered from this treatment was 7500 litres). The Zn obtained (separated from the cathode surface by means of mechanical means) has a purity level of 99.96%. A techno-economical evaluation of this so-called Full-Rec technology including both pyro and hydro-metallurgy processes rescaled to an industrial scale for 65000 t/y EAF dust treatment, shows an investment Internal Return Rate over 20%.

[P7] ECSC 7215-PP/028 Innovative use of iron and steel making by-products for the sealing and securing of steel industry deposits 1/07/1999-30/06/2002. The project was focused on the recycling and use of different by-products as secure sealing materials to cover iron and steel deposits. According to the environmental regulations and after detailed characterization of by-products and residues, the most suitable materials were investigated in laboratory tests and in pilot/demonstration field tests. The investigated materials include LF slag, EAF slag, dust residue from processing slags and BF sludges. The test fields created to compare efficiency of the alternative sealing systems to those available on the market showed that substitution of natural clay by BF sludge or a mixture of BF and LF sludge shoed comparable or better sealing efficiency.

[P8] ECSC 7215-PP/026 Foaming of slag and recycling of steel dust by injection into the electric arc furnace 1/7/1999-30/7/2002 The main objectives of this project were the demonstration of the recycling of the stainless steelmaking dust in combination with foaming slag operation in stainless steelmaking. This was done by injection of zinc rich dusts together with carbon. This led to very important improvements on the technical and economical performances of the EAF stainless steelmaking process, on the treatment and valorisation of the by- products, EAF dust, slag and strongly reduced the disposal of hazardous dusts.

[P9] ECSC 7210-PR/203 Efficient utilisation of waste products from secondary steelmaking as flux materials for electric arc furnace 1/07/2000-30/06/2003. The project aimed at increasing the use of waste products (slag and spent refractory) as flux material in the electric arc furnace. Different ways of recycling were investigated with the aim to improve the internal material recycling both in the carbon and stainless steel production. This can lead to decrease wastes from steelmaking, to improve the electric arc furnace metallurgy and to reduce raw materials.

[P10] ECSC 7210-PR/195 Characterization, modelling & validation of the impact of iron and steelmaking slags used in road construction on groundwater 1/07/2000-30/06/2003. The main goal of this project was to develop a method for the elaboration of a technical guide for using slags in road construction, by taking into account the quality of groundwater. The following areas were addressed, in order to elaborate a technical guide for the use of slags in various contexts: characterisation of iron and steelmaking slags and slag mixtures and their behaviour to water, application of pollution transfer models, considering the hydro-geological and weather conditions of the site used.

[P11] ECSC 7210-PR/271 In situ, quick sensing system for measurements of process-critical components in steelmaking slags (INQUISSS) 1/07/2001-30/06/2004. The project aim was the adaptation and optimisation of laser-based sensing (LIBS) in plant processing conditions, to develop a quick/on-line, in situ, integrated inference system for the measurement of process-critical components of molten slags. Different metallurgical slags (EAF, Converter and Ladle) were considered. The operative parameters of slag processing, such as oxidation potential, basicity, recycling capacity, were determined through integrating sensing and advanced process modelling, to ensure representativity of measurements and transferability of results.

[P12] ECSC 7210-PR/267 Sustainable agriculture using blast furnace and steel slags as liming agents 1/07/2001-30/06/2004. Fertilisers from BOF steel slag can be used as liming agents on acidic soils as substitutes for natural liming materials. This project aimed at

showing that steel slags are good liming materials with no harmful effects to the soil and to the groundwater. Test fields treated with iron and steel slag as liming material on long-term test fields were investigated in order to show the effects of the use of iron and steel slags in agriculture.

[P13] RFSP-CT-2003-00007 Hydrometallurgical continuous treatment of ZnO enriched powders for metal zinc production (FULL-REC 2) 01/09/2003-31/08/2005. This project is the logical continuation of a previous demonstration project, (agreement 7215PP/012), conceiving a new integrated pyro-hydrometallurgical process, the Full-Rec technology developed and tested at demonstrative plant scale. The previous project demonstrated the feasibility and the related economic advantages of the pyrometallurgical section. Concerning the hydrometallurgical process, the relevant results from batch operation proved its technological feasibility, even though additional experimentation appeared necessary to design an industrial plant, define the most appropriate annual capacity, explore financial needs and economic return. The efforts of the present project are then addressed to the demonstration of the industrial feasibility of a continuous hydrometallurgical process for metallic Zn recovery from ZnO enriched EAF dust. The activities that have been carried out concerned the design and realisation of the needed modifications of the hydro-metallurgical plant in order to make it suitable for continuous operation in the solution purification section and the execution of the subsequent experimental campaigns in fully operation mode. In parallel, the collection and preparation of the EAF dusts to be used in the experimental campaign has been done. The results demonstrated the possibility to produce metallic Zn at high purity grade (>99.98%). No accumulation phenomena of the impurities in the solution have been observed. The residue coming from sulphuric leaching, rich in PbO, can be charged in the pyro-metallurgical furnace as well as the residue from coagulant oxidation, rich in FeO. A techno-economical evaluation has been done for the process treatment. This evaluation has then been rescaled to the industrial scale plant.

[P14] ECSC 7210-PR/326 Alternative processing of sinter plant recycling materials 01/07/2002-31/12/2005. The project was focused on investigation of briquetting of sinter plant recycling materials like BF dusts or mill scale and utilisation of the briquettes as additional charging material for ironmaking in the blast furnace. For briquetting that vibration densification process was selected that was used for the well-known concrete brickmaking.

[P15] ECSECSC 7210-PR/327 Hearth protection in BF operation by injection of TiO_2-materials 01/07/2002-31/12/2005. This project focused mainly on investigations into the injection of titanium-rich materials, in order to assist BF operators and optimise their hearth protection measures. Thermochemical calculations were carried out pointing out the most favourable conditions for the formation of protective TiCN layers for hearth protection. Furthermore, a simplified melt flow pattern using a statistical reactor model evaluation method was developed in order to investigate the residence time distribution (RTD) of titanium in the BF and to evaluate different injection regimes. The results of the theoretical investigations built the base for the injection campaigns at the various steelworks. Numerous injection campaigns were carried out at blast furnaces with only one tap hole as well as at blast furnaces with alternating tapping at two or more tap holes. Based on the results of the injection campaigns, practical recommendations are given for BF operators for the efficient injection of TiO_2 materials for hearth protection. Favourable conditions for titanium injection

are defined, for example by high temperatures of HM and slag. Furthermore, a discontinuous injection with high injection rates during tapping is recommended for efficient hearth protection. Additional injection campaigns with a TiO_2-rich waste material and ilmenite sand as well as campaigns with an injection of coal and TiO_2 material through one tuyere were also carried out within this RFCS project. Scaffold formations were detected and analysed after injection campaigns at the EBF of MEFOS, as well as after excavation of BF A of voestalpine for relining, and excavation of BF 2 of Ruukki for the mid-campaign repair.

[P16] RFSR-CT-2005-00001 Short term CO_2 mitigation for steelmaking (SHOCOM) 01/07/2005-31/12/2008. The objective of the SHOCOM project was to provide the European steel industry with technologies and processes capable of cutting CO2 emissions by using secondary raw materials. The evaluated secondary raw materials were charcoal and plastic residues. Charcoal was investigated as CO2 neutral source of C which enhance coke reactivity in order to lower the reserve zone temperature of the blast furnace. Furthermore, the injection into BF tuyeres was studied, especially charcoal reactivity in and outside the raceway. Also, the reducing gas generation from waste/secondary raw material as plastic residues for iron ore reduction in Midrex or BF was evaluated. The quality requirements and sources of secondary raw material were evaluated. Additional the feasibility of using plastic wastes of various compositions as additives to coal blends for the production of blast-furnace coke was studied, paying special attention to the effects of plastic wastes on: coal thermal behaviour; coking pressure ; and quality of cokes produced in movable wall ovens at two scales.

[P17] RCFS-CT-2007-00003 Alternate carbon sources for sintering of iron ore (ACASOS) 01/07/2007-31/12/2010. The project investigated new alternate carbon sources for sintering, to the aim of substituting coke breeze. Biomass, deposited carbon rich dust, BF-dust and alternate sources as petroleum coke and anthracite were identified, characterized and economically evaluated for replacing coke breeze.

[P18] RFSR-CT-2007-00010 Upgrading and utilisation of residual iron oxide materials for hot metal production (URIOM) 01/07/2007-31/12/2010. For reuse of residual iron oxides from stainless steelmaking within the steelworks itself, two new technologies have been developed. The residues included dusts, millscale, EAF and argon oxygen decarbonization (AOD) slag, refractory material and oily residues. One technology was the inductively heated coke bed reactor and the second technology was a new briquetting technology using vegetable binders for briquette utilisation in the EAF. During the investigations the suitable residual iron oxide materials to be processed by the new technologies were characterised and selected. For both technologies comprehensive process concepts have been developed based on laboratory- and technical scale trials.

[P19] RFSR-CT-2007-00006 Energy and productivity optimised EAF stainless steel making by adjusted slag foaming and chemical energy supply (EPOSS) 1/07/2007-31/12/2010 Main aim of the project was to increase the energy efficiency and productivity during EAF high alloyed stainless steelmaking by innovative slag foaming (based on CaC_2 injection carbon/oxygen/FeSi addition) and adjusted use of all available energy sources. Resulting EAF slag after the new process was analysed for environmental and physical properties.

[P20] RFSR-CT-2008-00001 Flexible injection of alternative carbon material into the blast furnace (FLEXINJECT) 1/07/2008-31/12/2011. The aim of the project was to achieve a sustainable use of carbon resources by reaching high injection levels of ACM (Alternative Carbon Materials) (plastics, dusts, sludge etc.) and thereby decrease the coke and coal demand. A new method for pre-treatment of ACM to make them suitable for BF injection was evaluated. Within the project, physical and chemical characterisation, pre-treatment of materials in the Tornado process, fluidisation and conveying, operational injection tests at experimental and industrial BF, as well as theoretical calculations and CFD modelling were carried out. The project concluded that there are no limits in ACM addition to PC up to 25 %. It was shown through theoretical calculations that injection of ACM in mixtures or separately are both feasible methods for implementation on industrial scale. Separate injection offers flexibility but requires large investments while mixed injection limits the investment costs but have larger effects in case of damage where the injection of supplementary reducing agent is stopped. Modelling shows that it is more efficient to inject ACM and PC in separate lances.

[P21] RFSP-CT-2009-00028 Using slag as sorbent to remove phosphorus from wastewater (SLASORB) 01/07/2009 - 30/06/2012. The project was focused on the development of the use of slag in full-scale filters designed to remove phosphorus from wastewaters. Taking into account the recent evolution of EU legislation on P removal from wastewaters, this project aimed at defining the technical and economic feasibility of field-scale filters filled with slag and how to handle slag after P-saturation, including rejuvenation and valorisation as fertilisers.

[P22] RFSR-CT-2009-00004 Sustainable electric steel production (GreenEAF) 01/07/2009 - 30/06/2012. In an EAF more than 40% of energy comes from chemical sources by fossil fuels. Natural gas is used in dedicated burner during the melting of the scrap while coal (mainly anthracite), lump in the basket and pulverised by wall injector, is used as foaming agent. The project aim was to investigate the possible partial or total substitution of coal and natural gas with charcoal and syngas produced from pyrolysis of biomass. Different aspects have been evaluated including the availability of biomass in the areas around the steelworks participating in the project, the definition of the pyrolysis conditions, the definition of the yield and quality of the char produced and, lastly, the testing phase both at pilot and industrial scale of charcoal in substitution of coal for both charging and injection. In parallel, syngas utilization for EAF burners has been simulated by means of CFD calculations. The results indicated the feasibility of the substitution of coal by char both for charging and injection despite some problems have been observed mainly due to char reactivity.

[P23] RFSR-CT-2010-00001 Innovative carbon products for substituting coke on BF operation (INNOCARB) 01/07/2010 - 31/12/2013. The main focus of the project was to reduce the coke consumption at the BF. At the first measure nut coke was activated by activation agents to increase reactivity with aim to lower the thermal reserve zone temperature in the BF shaft. At the second measure coke was substituted by cold bonded carbon briquettes made of carbon materials like coke breeze and dust which are usually not usable for the blast furnace. The properties of carbon materials were evaluated and recipes for

carbon briquette making were developed which fulfil the requirements of a blast furnace coke.

[P24] RFSR-CT-2010-00005 Increased yield and enhanced steel quality by improved deslagging and slag conditioning (OPTDESLAG) 1/07/2010-30/06/2013. The project aimed at improving the deslagging process during two steps of liquid steelmaking (after hot metal desulphurisation and before secondary steelmaking). The goal was to increase the yield by minimising the metallic losses, and to minimise the amount of remaining slag after deslagging. In addition, thanks new information achieved from image analysis about the efficiency of deslagging, a dynamic control of the following slag conditioning process was developed, in order to ensure optimal conditions in the subsequent metallurgical processes.

[P25] RFSR-CT-2010-00004 Processes and technologies for environmentally friendly recovery and treatment of scrap (PROTECT) 01/07/2010-31/12/2013. This project developed an innovative method to promote the use of low-value energy rich waste combined with cleaning and preheating of zinc-containing steel scrap to allow Zinc recovery and "purification" of the scrap to be fed in electric steelmaking industries. Different technologies were developed and evaluated for separation and treatment of energy containing waste streams, thermochemical conversion of solid waste fuels, scrap preheating and gas treatment facility with recovery of valuables. The main conclusions from the project were: different fractions of complex and non-complex waste streams can be separated into useful products and recycling rate can be improved; gasification and pyrolysis are suitable techniques for thermochemical conversion of waste streams; Cl rich materials (e.g. pure PVC) are needed for a successful thermochemical conversion of waste streams; the operability of a scrap preheating concept has been shown but more work is needed to verify zinc removal efficiency; a recovery system for valuables based on the EZINEX setup was designed, the concept is positive from both environmental and economic view points; further development of the concept is advised.

[P26] RFCS-CT-2011-00037 Impact of long-term application of blast furnace and steel slags as liming materials on soil fertility, crop yields and plant health (SLAGFERTILISER) 01/07/2011-30/06/2015. The project investigated the effects of Cr and V from iron and steel slags on soils and plants as a basis for further environmental discussions on liming agents in the EU. The use of the fine-grained steel slag as liming/fertiliser material in agriculture is advantageous for both the steel industry and the farmers in Europe and worldwide. The steel industry has a problem with fine slag which it cannot seell to the building industry while farmers get a positive yield from using slag as a liming/fertiliser material. The effects of iron and steel slag on soil and crop yields in different conditions throughout Europe were assessed. Also, possible negative effects of trace elements such as Cr and V were investigated on the soil and plants. Very positive outcomes were achieved by the project, which deepened the benefits of the exploitation of these slags as liming agents on soils from both Northern and Southern Europe

[P27] RFCS-CT-2012-00039 Efficient use of resources in steel plants through process integration (REFFIPLANT) 01/07/2012-31/12/2015. The project aimed at improving the efficiency of resources (materials, water, energy) in integrated plants. This aim was achieved by developing alternative design solutions for the minimization of resources at source and improved recycling, reuse, treatment of wastewater, slag, sludge and dust by considering the

site-wide interactions between the processes and related factors. The project showed how to exploit PI methods and techniques together with multi-criteria optimization in order to identify overall solutions minimizing the steelmaking ecological footprint.

[P28] RFSR-CT-2012-00006 Control of slag quality for utilisation in the construction industry (SLACON) 1/07/2012-31/12/2015. The project aimed at ensuring and increasing the utilisation of steelmaking slags in the construction industry by improving the quality of the slag. New techniques were developed to immobilise the critical elements and separate remaining leachable substances (e.g. fluoride, molybdenum, chromium and vanadium) from the washing/cooling water and to condition these separated substances for disposal or reuse. The elimination of leachable substances helped to avoid negative environmental impacts and to support the efficient use of steelmaking slags.

[P29] RFCS-CT-2013-00030 Environmental impact evaluation and effective management of resources in the EAF steelmaking (EIRES) 01/07/2013-31/12/2016. The project aimed at reducing the environmental impact of EAF steelmaking by providing plant managers and technicians with a consolidated and understandable metric to quantify and monitor the overall environmental impact of the production cycle. Some metrics (Key Performance Indicators and LCA-based eco-indicators) were defined evaluating different categories of environmental impact. An integrated decision support tool (detailed process modelling + metric tool) was developed to access and track the environmental impact of the present process, to evaluate through simulations the potential effect of alterations/modifications of process parameters and of the equipment on the environmental footprint of the production cycle. By exploiting the process simulation tools, several cases study were investigated also dealing with the reuse of by products in the electric steelmaking route, such as, for instance, the reuse of LF and EAF slag to partially replace lime and dolime and the use of rolling mill scale in EAF as scrap substitute.

[P30] RFCS-CT-2013-00037: Removal of Phosphorous from BOF Slag (PSP-BOF) 01/07/2013-31/12/2016. The project sought to separate useable substances (Fe-rich and P-rich fractions) from BOF slag for utilisation in different application. Different separation techniques have been investigated based on either liquid slag (partial) or on solidified slag. Also, treatment of liquid slag with sewage ash high in phosphorus was tested. Fractions rich in phosphorus and calcium can be used as fertiliser or in cement and V-rich fraction as raw material for vanadium production. Remaining slag will result in high iron content and low phosphorous content and hence should be appropriate for internal recycling in sinter plant or BF. The process showed promising results and could lead to significant savings of iron ore, limestone, CO2 and energy. Further research is however necessary. The goal of the PSP-BOF project was to add knowledge and value by investigating the entire chain by innovative methods and carry out operational tests.

[P31] RFSP-CT-2014-00003 Biochar for a sustainable EAF steel production (GREENEAF2) 1/07/2014 - 30/06/2016. The project is a logical continuation of the previous GREENEAF project. The activities have been focused on the aspects that need a further clarification. These lasts concerned a more accurate control of char reactivity with subsequent optimization of EAF operating practices and the improvement of the injection system for the use with biochar. Following this approach, industrial trials (plus related theoretical/laboratory activities) concerning both the biochar charging in the bucket and the

use of a purposely designed injection system able to promote the slag foaming using biochar injection have been done. The effects of biochar utilization on productivity, costs, environmental emissions, materials handling, and storage were also considered in order to make biochar utilization a standard and applicable practice. Moreover, a Life Cycle Assessment study allowed the evaluation of biomass use the impact on the environment. Positive results and energy saving (about 6%) found for specific process conditions. The injection trial gave controversial results. Lastly, a global techno-economical evaluation of the use of char in substitution of coal has been done.

[P32] RFCR-CT-2014-00006 Developing uses of alternative raw materials in cokemaking (ALTERAMA) 01/07/2014-31/12/2017. In order to substitute higher proportions of expensive coking coals with alternative raw materials and maintain coke quality and safe oven operation, suitable pre-carbonisation technologies need to be developed to increase oven charge density, and the feasibility of using them in existing coke oven plants needs to be assessed. ALTERAMA aims at developing a novel methodology based on hydrous pyrolysis to maximise the introduction of biomass in coking blends and minimise non-renewable carbon emissions. This has been done by studying different types of carbon materials, e.g. lignins high density polyethylene and coal tar, as well as organic binders, such as thermolysed waste plastics, waste ion-exchange resins and waste hydrocarbons from the coking plant, to provide a suitable briquette. The highest char yields in briquettes were obtained with torrefied sawdust with coal tar or coal tar sludge as binder. Biomass containing briquettes could be added up to 10 wt. % with good coke quality results. Surfactants were shown to increase charge density without adverse effects on coke properties. The studied surfactants were better than oils from an environmental perspective and for the health and safety of workers. This makes them attractive replacements for oil in briquettes. The increased density is positive for coke yield but also enables use of poorer coals and alternative materials while maintaining coke quality.

[P33] RFSR-CT-2014-00008 Recycling of industrial and municipal waste as slag foaming agent in EAF (RIMFOAM) 1/07/2014-30/06/2017. This project aimed to partly substitute carbon and oxygen with industrial and/or municipal waste (ASR, rubber tyres, plastics, biomass waste and by-products, EAF dust and mill scale) for slag foaming in the EAF. During the project cost- and energy-effective alternative slag foaming agents were explored with the requirements that the slag foaming intensity should be maintained or improved, the liquid steel quality should be preserved, and emissions should be kept at a low level. The experimental approach adopted involved material characterization, pre-treatment, lab- and pilot testing and industrial trials. Technical feasibility, the economical perspective, emission levels and energy consumption were considered when the result was evaluated. This can lead to a competitive and more environmentally sustainable European steelmaking industry. The final report is not yet available.

[P34] RFCS-CT-2017- 749809 New Activation Routes for Early Strength Development of Granulated Blast Furnace Slag (ACTISLAG), 1/07/2017- 31/12/2020. This project aims at creating an efficient route to create ground granulated blast furnace slag (GGBS) that can be used for concrete or dry-mix mortar. The goal is to increase GGBS value by improving short-term reactivity and develop new products containing more than 80 wt.-% of GGBS with at least as good mechanical performance as CEM II class products. Two main

topics were addressed so far; (1) the fundamental understanding of the relation between structure, reactivity and performance of industrial slags and (2) modification of the slag chemical and physical properties in liquid state.

[P35] RFCS-CT-2017-754197 Cement-free brick production technology for the use of primary and secondary raw material fines in EAF steelmaking (FINES2EAF), 01/07/2017-31/12/2020. The project aims at increasing the value of steelmaking residues by using the material in cement-free bricks that can be internally recycled and (re)used in the EAF. In the project a production technology, for the cement-free bricks, that can be used directly in the steel plant will be developed. The expected results are improved residue utilization, internal recovery of metals and reduction of dumped materials. In a lab-scale production of bricks different binders and agglomeration parameters are tested, for example drying conditions and pressing force and time. In order to obtain the cement-free bricks technology more acceptable for the steelworks, also operational tests will be performed.

[P36] RFCS-CT-2018-800762 Eco-friendly steelmaking slag solidification with energy recovery to produce a high quality slag product for a sustainable recycling (ECOSLAG), 1/06/2018-30/11/2021. The project deals with aspects of heat recovery from EAF, BOF and LF slag such as transportation, utilization of the recovered heat as well as utilization of the remaining slag. Due to the complexity of different steelworks, the project is currently testing three different solutions that are customized to given circumstances but will be able to be exploited by different steelworks: (1) direct recovery of heat from LF slag to EAF, (2) air/water granulation of EAF slag while recovering heat and (3) RecHeat recovery system. An advanced solidification process of LF slag with heat recovery by charging the hot LF slag as a lime substitute in the EAF is being developed with a major constraint being the lack of direct access of the LF to EAF. The solidification of EAF slag by air/water granulation and the generation of electricity by thermoelectric technology and of a hot medium (e.g. air or steam) from waste heat of the hot is being developed. The goal is to design an open "box" where the slag will be able to be cooled while heat will be recovered. The RecHeat (heat recovery from slag) is a new innovative and simple heat exchanger solution for slag heat recovery, the technology is based on the metal structure with a large heat transfer area, on which the liquid slag is poured on. The recovered heat will be utilized by the ModHeat® (Modular Heating) technology, which is an innovative industrial dryer, as a mobile, container construction, and enabling technology for e.g. steel industry sludge drying and reutilization. At all three steelworks in the project the EAF slag is currently used (e.g. earthwork, road construction, civil engineering, and in some cases deposited) while all the LF slag is deposited. The only successful solution for heat recovery will be one where the resulting slag will be able to be used as a product like it is currently.

[P37] RFCS-CT-2019-846260 Reuse of slags from integrated steelmaking (Slagreus) 1/06/2019-30/11/2022. The aim of the project is the internal recycling of a Fe-enriched BOF slag fraction as a substitute for raw material as iron ore fines for the sinter plant and the external use of a Ca- and P enriched BOF fraction as high valuable cement additive and fertilizer. A new processes chain will be developed to increase the reuse. The route comprises a primary liquid Fe-enrichment by slag recirculation and secondary solid and dry Fe-enrichment processes. The enrichment processes take benefit from differences of physical and chemical slag properties as density, viscosity, solidification properties, magnetic

susceptibility, hardness and thermal expansion. The secondary Fe-enrichment consists of a microwave assisted comminution of the BOF slag, selective grinding and dry magnetic separation. The secondary Enrichment step will multiply the Fe-concentration in the substitute of the primary step and further reduce the P-content. Simultaneously the quality of the Ca-rich non-magnetic fraction will be improved. Due to the dry processing of the BOF slag the produced Ca-rich fractions will keep the hydraulic properties. On this basis the Ca-rich fractions will be evaluated for an external use in the cement industry as a raw meal in clinker production and as alternative reactive cement main constituent. Also, the external use of the CaO-rich fraction from magnetic separation as lime fertilizer will be evaluated.

2.2 List of other EU-funded projects

[P38] FP3-BRE20116 - Recycling of zinc and lead containing dusts from the electric arc furnace 1/01/1993 – 31/12/1995 Typically 15-20 kg of dusts per ton of steel are collected in bag house filter system of the EAF. These dusts contain important quantities of iron, zinc and lead. The recovery of Zn and Pb from EAF dusts in non-ferrous smelters becomes profitable with the increase of Zn in the treated dusts. The objective of the project is to evaluate the possibility to enrich the EAF dust in Zn adopting a dust recycling by melt injection in the EAF. Tests have been carried out in two EAF steel shops (Krupp and DET). These tests demonstrated that by recycling about 60% of the total dust, an average of 10% of Zn increase in the powder has been obtained. Furthermore, dust recycling with the subsequent iron recovery in the melt allowed to obtain a significant reduction by about 30% of the amount of dust to be transported to non-ferrous smelter. This implies an obvious ecological benefit due to the reduction of the amount of dust to be delivered and, lastly, processed. Concerning the impact of the tested procedures on the process and products, no negative effects could be observed.

[P39] FP4-INCO: A new treatment process to recover magnetite, zinc and lead from iron and steel making dusts and sludges (Ref.IC15970704) 01/09/1997-30/11/1999. Steelmaking dusts contain heavy metals like zinc, lead and cadmium in their compositions in forms that are easily leachable by water or slightly acidic or alkaline media, hence these are hazardous residues due to their eco-toxicity characteristics. In this project, a new process is developed in order to recover valuable metals and products from steelmaking dusts and sludges. Two different process routes are evaluated, both from the technical and from the economic points of view. A pre-treatment stage, based on water leaching of the dusts, is, in both cases, studied, to remove alkalis and chloride present in the wastes. This step is of relevance for the further treatment of dusts in order to recover metals. The first procedure is based on the previous reduction of zinc and lead oxides to the metallic state, followed by its separation by vaporisation and physical means. Then, a magnetic separation step allows the recovery of magnetite. The remainder of iron oxide phases, partially reduced, are then re-oxidised by controlled means to produce magnetite, that is again enriched by magnetic separation means. The second procedure consists in a full oxidation of all the ironish phases to trivalent iron. Then, the controlled reduction is done until an important amount of magnetite may be easily separated by magnetic means. The final residue, containing

concentrated amounts of lead and zinc is treated by hydrometallurgical means, employing ammonium chloride reagent. The dusts treated are both from BOF and EAF.

[P40] FP4-BRPR970446 – Treatment of liquid steel slag with sand and oxygen in order to improve their volume stability and their environmental behaviour This project aimed at finding ways to improve the volume stability in steel making slags increasing its usability. Within the project a process concept where developed to treat liquid slag with SiO_2 containing material and oxygen to overcome the problem with insufficient stability. The slag can be used as raw material for road construction as aggregates as well as aggregates for asphalt layers

[P41] FP5-G5RD-CT-2002-00652 – Elimination of zinc ferrite (REZIN). 1/04/2002 – 31/03/2005 This project focused on development of a method to transform the unleachable zinc ferrite in dust into a leachable zinc oxide and no waste. The method can be combined with alternative methods for pre-treatment utilising excess heat. Three concepts were tested and patents have been filed in Italy; concept A – low temperature treatment with lime of zinc ferrite into leachable zinc oxide, concept B – recirculation of EAFD combined with a by-pass filter and concept C – on-line recording of zinc in EAFD coupled to separation of the low- and high-zinc fractions. All proposed concepts were verified and improved by thermodynamic modelling, laboratory and pilot tests and plant trials. Concept A resulted in the production of metallic zinc and a residue that by melting gives iron and a sale-able slag. Concept B was tested both in pilot scale and in full scale steel plant. The high-grade zinc dust achieved in the pilot tests could not be confirmed in the plant tests. On the other hand, it was discovered that an upgraded dust product easily can be achieved by re-injecting the low zinc fraction achieved from a cyclone underflow in the gas stream. Concept C showed about the same positive effect in the steel plant as concept B. The project shows a savings potential of both CO2 emissions, energy consumption and cost compared to conventional routes at the time of the study. At the end of the project, possibilities to scale up the pilot plant to develop and demonstrate the full technology were discussed.

[P42] FP6-SME: Recycling of EAF dust by an integrated leach-grinding process (REDILP-Ref.508714) 01/11/2004-30/04/2007. The objective of this project was to develop a "cold" process to remove the heavy metals, as well as the zinc oxide, from the dust and to use of the remaining inert material as e.g. construction material. A breakthrough was made by a process consisting of simultaneous mechanical graining combined with a high selective leaching. The 98% of zinc and lead recovery was reached and, due to the highly selective leaching process, the zinc oxide produced is uncontaminated with iron from the raw dust.

[P43] Horizon 2020 - Fostering industrial symbiosis for a sustainable resource intensive industry across the extended construction value chain (FISSAC). 1/09/2015 – 29/02/2020. The overall objective of the project is to create a new paradigm for industrial symbiosis towards a zero waste approach in the resource intensive industries of the construction extended value chain, tacking harmonized technological and non-technological requirements, leading to materials closed-loops processes and moving to a circular economy. FISSAC will demonstrate eco-innovative solutions in the re-use of industrial waste materials through industrial symbiosis synergies among industrial leaders (steel; non-ferrous metals, mineral: cement, ceramics, and glass; construction; and chemical sector), achieving closed-

materials loops driving innovation across product design, development of product-to-service approaches and new materials recovery methods.

[P44] Horizon 2020 – GA No. 730471: efficient mineral processing and Hydrometallurgical RecOvery of by-product Metals from low-grade metal containing secondary raw materials (CHROMIC) 1/11/2017-31/10/2020. Cr, Nb, Mo and V are of strategic importance for the competitiveness of the European economy. But Europe is highly dependent on import for these metals, leading to an inflexible and insecure supply. The CHROMIC project aims to unlock the potential of these resources. By smart combinations of existing methods and new technological innovations, CHROMIC will develop new processes to recover chromium, vanadium, molybdenum and niobium from industrial waste (such as EAF slag or FeCr slag). A range of chemical and physical methods will be developed, tested and validated to extract valuable and critical metals from the initial slags in the most sustainable way: economically, environmentally and socially.

[P45] Horizon 2020 GA No. 642067: Turning waste from steel industry into a valuable low cost feedstock for energy intensive industry (RESLAG) 2015/09/01 to 2019/07/31. The main objective of the project was to valorise the steel slag that is currently not being recycled and reuse it as a raw material for four innovative applications. The different applications have been extraction of valuable/critical metals, Thermal Energy Storage (TEM) system for heat recovery in industry as well as in solar thermal plants and production of refractory ceramics. The applications were demonstrated at pilot level and led by end-user industries. The aim of the project has been to develop an innovative organizational steel by-products management model, considering a cascade of upgrading processes and a life cycle perspective, in order to achieve high levels of resource and energy efficiency. Altogether the project opens enormously the range of possibilities of taking profit from slag not only for the steel sector but also for many other sectors.

3. Criteria for selection of the projects which are targeted by the dissemination target

In order to organise the previous and running projects, the projects will be evaluated based on selected criteria and aggregated in a limited number of classes. For including or excluding new or ongoing projects by using the selected criteria, some issues will be considered such as: an ongoing project, which did not yet provide results, might be included, because its scope and aim are promising. However, later on, the project outcome might not be of interest to the scope. On the other hand, very recent projects initially excluded, as they are not foreseen to provide relevant results during the project, could later on show to be of relevance for the project. In addition, some projects, for instance developed by other industrial sectors, may be unknown to us currently even though they could be of interest. For this reason, they could be included in the dissemination actions of the REUSteel project, according to the identified criteria.

The following criteria will be used as a start for evaluation in D.2.2:

- Relevance for the REUSteel-project, i.e. contributing to the reuse and recycling of by-products with relevance to the steel industry;

    - Slag internal recycling
    - Slag valorisation outside the steel production cycle
    - Extraction of valuable material from waste and wastewater
    - Internal and external recycling of Fe-bearing by-products different from slag
    - Internal and external recycling of by-product with other beneficial and valuable contents like metals, coal and lime (e.g. secondary raw materials generation for exchange in IS and CE possibilities)
    - Elimination of harmful elements
    - Minimisation of waste generation and landfill
    - Process integration solutions for by-products management
    - Modelling and simulation
- Time of completion, i.e. in relation to the actuality and development of regulations, sustainable issues etc.;
- Real implementation of the results;
- Directly discuss properties and possible reutilization route of by-products...

The following classification by type of by-products will be done in D.2.2 to facilitate dissemination:

- Slag
    - BF
    - EAF
    - BOF
    - LF
- Sludge
    - BF
    - BOF
    - EAF
- Dusts
    - BF
    - BOF
    - EAF
- Refractory
- Millscale
- Other by-products (inside of the steelwork)
- Secondary raw materials (outside of the steelwork)

4. List of symbols, indices, acronyms and abbreviations (besides International Standards (IS))

Acronym	Name
AOD	Argon Oxygen Decarburization vessel
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CE	Circular Economy
EAF	Electric Arc Furnace
ECSC	European Coal and Steel Community
ESTEP	European Steel Technology Platform
FP	Framework Programme
IS	Industrial Symbiosis
LF	Ladle Furnace
RFCS	Research Fund for Coal and Steel
SRA	Strategic Research Agenda