European Commission

Grant Agreement Number: 839227

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 4.2

Proceedings of webinars

Table of Content

1. Project Summary and purpose of the present document 3
2. Schedule of webinars 3
3. ESTAD symposium 5
4. List of figures 6
5. List of symbols, indices, acronyms, and abbreviations (besides International Standards) 6
6. Appendix: 7

- Program of the Webinars 8
- Overview of the REUSteel project 9
- Overview of the EU funded research on slag 25
- ActiSlag, New activation routes for early strength development, of granulated blast furnace slag 47
- Slag as a fertilizer with respect to current EU regulations 74
- Slag as a fertilizer with respect to the Italian situation 86
- Recovery of Valuables from Steel Slag and Other Residues – IPBM and Other Pilot Experiences 98
- Modelling, simulation and digital tools to improve slag reuse and recycling 116
- Introduction in the REUSteel project – Overview of the EU-research on Sludge and Dust .. 134
- Recovery of dust and sludge in the sinter plant 143
- Metal recovery from iron and steelmaking dust and sludge residues 160
- Briquettes from dust and sludge for shaft furnace charging 175
- Lowering local blast furnace hearth wear by TiO_2-materials injection 193
- Alternative carbon materials injection into the blast furnace 204
- Overview of the EU-funded research on Refractory, Millscale and other residual material from inside and outside of the steelwork 215
- Use of external sources of carbon (biomass and plastic) in EAF 228
- Residual material for slag foaming in EAF 261
- Processes and technologies for environmentally friendly recovery and treatment of scrap – PROTECT 282
- Program of the REUSteel Workshop at ESTAD 2021 294
- Overview of the REUSteel project 296
- Research of use of slag from the steel industry 312
- EU-Research on the use of sludge, dust, refractory, mill scale and other residual materials from the steel industry and external secondary raw material in the Blast furnace and Sinter plant 347
- Research of the use of sludge, dust, refractory, millscale, and other residual materials from the steel industry and external secondary raw material in the EAF 365
- Merging our ideas for improving and enhancing residual materials valorization in the steel sector: final discussion 390

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). A list of projects to be evaluated has been compiled (in deliverable 2.2) and the REUSteel-project aims at performing an integrated critical analysis to improve the dissemination of the achieved results in the previous projects, to establish a roadmap for future research in the topic as well as to promote synergies with other industrial sectors, according to the concepts of Circular Economy (CE) and Industrial Symbiosis (IS).

The aim of REUSteel is to review, analyse, organise, and disseminate the most important achieved results from studied EU-projects. The dissemination and valorisation actions of the most relevant results will provide a 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. 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 the new roadmap, future synergies with other sectors and industrial trends.

The present document provides proceedings of webinars organized by ESTEP that took place 14 to 16 June 2021 and a half day symposium that took place at the 5th ESTAD 31 August 2021. In the following sections, the webinars and symposium are briefly described. Proceedings from each event are found in appendix.

2. Schedule of webinars

In the original plan of dissemination, local workshops were planned in each country where the project consortium is represented. Due to COVID-19, these local workshops were transformed into a webinar series with three 2 h long webinars during 14 to 16 June 2021. Each date, presentations were given on a specific topic, starting off with findings from the REUSteel analyses followed by presentations from invited speakers of projects either included in the list of analysed projects in deliverable 2.2 or projects related to identified topics of interest in deliverable 2.2. The themes of the three webinars were: “Slag”, “Sludge & Dust” and “Refractory, Millscale, other residual material from inside and outside of the steelwork”. Each webinar consisted of 4-6 presentations followed by discussion with the speakers (see **Figure 1**). The webinars were organized and promoted by ESTEP with free registration.


Research Fund for Coal & Steel

ESTEP

REUSteel

Dissemination of results of the European projects dealing with reuse and recycling of by-products in the Steel sector – REUSteel (G.A. 839227)

Open Webinars

Free registration

Programme

Day 1 – 14.06.2021 9:00-11:00 – Webinar on Slag			
Time	**Speaker**	**Speaker Organization**	**Presentation**
09:00	Valentina Colla (*Chairman*)	Scuola Superiore Sant'Anna	*General description of the REUSteel project*
09:15	Agnieszka Morillon	FEHS	*Overview of the EU-funded research on slag*
09:30	Andreas Ehrenberg	FEHS	*ActiSlag - A broad approach to optimize granulated blast furnace slag*
09:45	Uwe Pihl Teresa Annunziata Branca	FEHS Scuola Superiore Sant'Anna	*Slag as a fertilizer with respect to current EU regulations and Italian situation*
10:00	Guozhu Ye	SWERIM	*Metal recovery from slag*
10:15	Ismael Matino	Scuola Superiore Sant'Anna	*Modelling, simulation and digital tools to improve slag reuse and recycling*
10:30	All		***Plenary Discussion with speakers***
11:00	Valentina Colla (*Session Chairman*)	Scuola Superiore Sant'Anna	***Closure of the Webinar***

Day 2 – 15.06.2021 10:00-12.00 – Webinar on Sludge and Dust			
Time	**Speaker**	**Speaker Organization**	**Presentation**
10:00	Roland Pietruck (*Chairman*)	BFI	*Overview of the EU-funded research on sludge and dust*
10:10	Roland Pietruck	BFI	*Recovery of dust and sludge in the sinter plant*
10:30	Gerald Stubbe	BFI	*Metal recovery from iron and steelmaking dust and sludge residues*
10:45	Simon Wölfelschneider Steffen Möhring	BFI	*Briquettes from dust and sludge for shaft furnace charging*
11:00	Jörg Adam	BFI	*Lowering local blast furnace hearth wear by TiO_2-materials injection*
11:15	Lena Sundqvist	SWERIM	*Flexible injection of alternative carbon material into the blast furnace*
11:30	All		***Plenary Discussion with speakers***
12:00	Roland Pietruck (*Chairman*)	BFI	***Closure of the Webinar***

Day 3 – 16.06.2021 8:00- 10:00 Webinar on Refractory, Millscale, other residual material from inside and outside of the steelwork			
Time	**Speaker**	**Speaker Organization**	**Presentation**
08:00	Umberto Martini (*Chairman*)	RINA-Centro Sviluppo Materiali	*Overview of the EU-funded research on Refractory, Millscale and other residual material from inside and outside of the steelwork*
08:10	Umberto Martini	RINA-Centro Sviluppo Materiali	*Use of external sources of carbon (biomass and plastic) in EAF*
08:40	Johan Björkvall	SWERIM	*Residual material for slag foaming in EAF*
09:00	Mikael Larsson	SWERIM	*Processes and technologies for environmentally friendly recovery and treatment of scrap*
09:30	All		***Plenary Discussion with speakers***
10:00	Umberto Martini (*Chairman*)	RINA-Centro Sviluppo Materiali	***Closure of the Webinar***

ESTEP • Av. de Cortenbergh, 172 • B-1000 Brussels • Tel. +32 2 738 79 43 • secretariat@steelresearch-estep.eu • Disclaimer

Figure 1 Flyer with program for the webinar series.

3. ESTAD symposium

In addition to the previously described webinar series, the REUSteel consortium held a half day symposium at 5th ESTAD on 31 August 2021, presenting results and analyses from the project (see **Figure 2**). The symposium also served as an opportunity to gather the opinions of the audience on the potential for reuse and recycling within the steel industry.

Program

8.30-10.00	Two presentations including time for questions. • General presentation of the REUSteel project and the symposium – Valentina Colla (SSSA) • Research of use of slag from the steel industry – Agnieszka Morillon (FEhS)
10.00-10.30	Coffee break
10.30-12.00	Two presentations including time for questions followed by an outlook, together with the audience, on future use of and research on residual materials. • Research of the use of sludge, dust, refractory, millscale, and other residual materials from the steel industry and external secondary raw material in the BF and Sinter – Roland Pietruck (BFI) • Research of the use of sludge, dust, refractory, millscale, and other residual materials from the steel industry and external secondary raw material in the EAF – Umberto Martini (CSM) • An outlook: How will the use of residual material change in the future? – Valentina Colla (SSSA)

Figure 2 Program of the 5th ESTAD REUSteel symposium.

4. List of figures

Figure No	Caption	Page
1	Flyer with program for the webinar series.	4
2	Program of the 5th ESTAD REUSteel symposium.	5

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

Acronym	Name
AIM	Associazione Italiana di Metallurgia
AIST	Association for Iron and Steel Technology
CE	Circular Economy
COVID-19	Coronavirus Disease 2019
ECSC	European Coal and Steel Community
ESTAD	European Steel Technology and Application Days
ESTEP	European Steel Technology Platform
FP	Framework Programme
ICSTI	International Council for Scientific and Technical Information
IS	Industrial Symbiosis
RFCS	Research Fund for Coal and Steel

6. Appendix:

In the following pages all the presentations held during the webinar series hosted by ESTEP and the ESTAD workshop are reported.

Research Fund for Coal & Steel

ESTEP

REUSteel

Dissemination of results of the European projects dealing with reuse and recycling of by-products in the Steel sector – REUSteel (G.A. 839227)

Open Webinars

Free registration

Programme

Day 1 – 14.06.2021 9:00-11:00 – Webinar on Slag			
Time	**Speaker**	**Speaker Organization**	**Presentation**
09:00	Valentina Colla (*Chairman*)	Scuola Superiore Sant'Anna	*General description of the REUSteel project*
09:15	Agnieszka Morillon	FEHS	*Overview of the EU-funded research on slag*
09:30	Andreas Ehrenberg	FEHS	*ActiSlag - A broad approach to optimize granulated blast furnace slag*
09:45	Uwe Pihl Teresa Annunziata Branca	FEHS Scuola Superiore Sant'Anna	*Slag as a fertilizer with respect to current EU regulations and Italian situation*
10:00	Guozhu Ye	SWERIM	*Metal recovery from slag*
10:15	Ismael Matino	Scuola Superiore Sant'Anna	*Modelling, simulation and digital tools to improve slag reuse and recycling*
10:30	All		***Plenary Discussion with speakers***
11:00	Valentina Colla (*Session Chairman*)	Scuola Superiore Sant'Anna	***Closure of the Webinar***

Day 2 – 15.06.2021 10:00-12.00 – Webinar on Sludge and Dust			
Time	**Speaker**	**Speaker Organization**	**Presentation**
10:00	Roland Pietruck (*Chairman*)	BFI	*Overview of the EU-funded research on sludge and dust*
10:10	Roland Pietruck	BFI	*Recovery of dust and sludge in the sinter plant*
10:30	Gerald Stubbe	BFI	*Metal recovery from iron and steelmaking dust and sludge residues*
10:45	Simon Wölfelschneider Steffen Möhring	BFI	*Briquettes from dust and sludge for shaft furnace charging*
11:00	Jörg Adam	BFI	*Lowering local blast furnace hearth wear by TiO_2-materials injection*
11:15	Lena Sundqvist	SWERIM	*Flexible injection of alternative carbon material into the blast furnace*
11:30	All		***Plenary Discussion with speakers***
12:00	Roland Pietruck (*Chairman*)	BFI	***Closure of the Webinar***

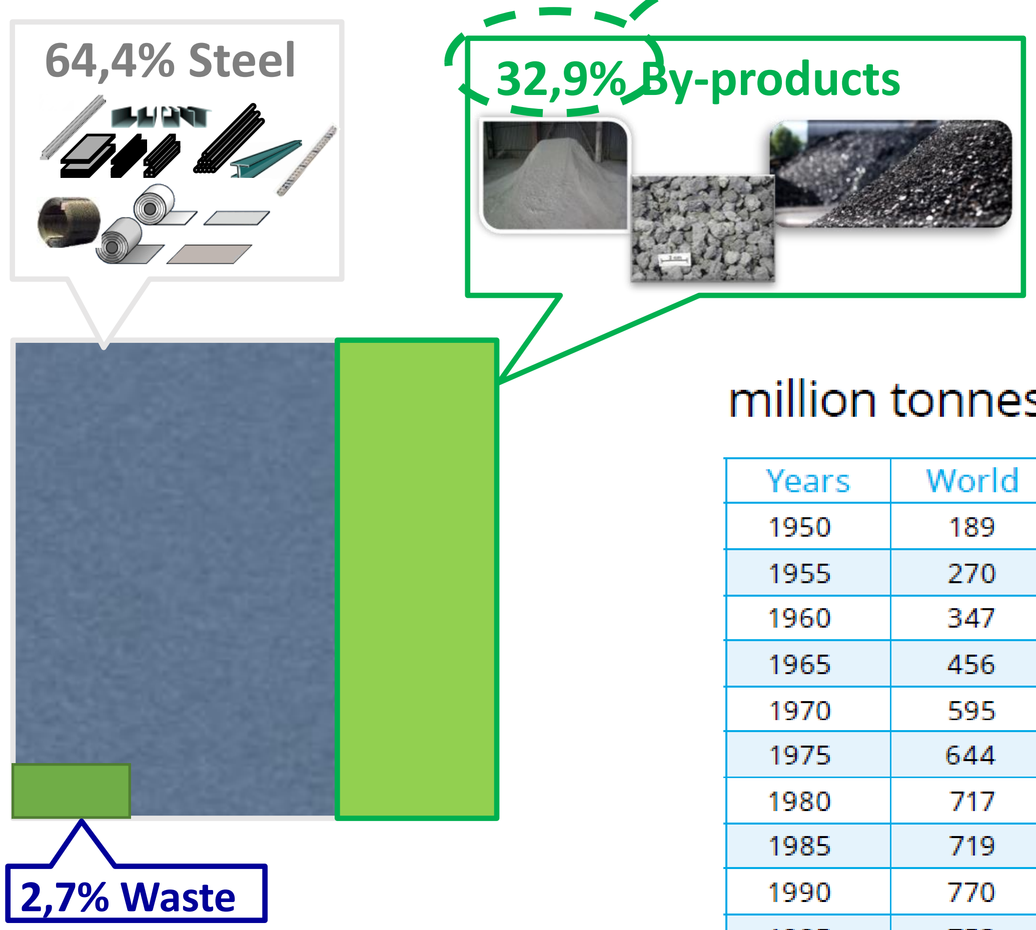
Day 3 – 16.06.2021 8:00- 10:00 *Webinar on Refractory, Millscale, other residual material from inside and outside of the steelwork*			
Time	**Speaker**	**Speaker Organization**	**Presentation**
08:00	Umberto Martini (*Chairman*)	RINA-Centro Sviluppo Materiali	*Overview of the EU-funded research on Refractory, Millscale and other residual material from inside and outside of the steelwork*
08:10	Umberto Martini	RINA-Centro Sviluppo Materiali	*Use of external sources of carbon (biomass and plastic) in EAF*
08:40	Johan Björkvall	SWERIM	*Residual material for slag foaming in EAF*
09:00	Mikael Larsson	SWERIM	*Processes and technologies for environmentally friendly recovery and treatment of scrap*
09:30	All		***Plenary Discussion with speakers***
10:00	Umberto Martini (*Chairman*)	RINA-Centro Sviluppo Materiali	***Closure of the Webinar***

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

Overview of the REUSteel project

Valentina Colla – Scuola Superiore Sant’Anna

Goal & Main Objectives



The order is of hundreds of million tonnes per year

million tonnes, crude steel production

Years	World
1950	189
1955	270
1960	347
1965	456
1970	595
1975	644
1980	717
1985	719
1990	770
1995	753

Years	World
2000	850
2001	852
2002	905
2003	971
2004	1 063
2005	1 148
2006	1 250
2007	1 348
2008	1 343
2009	1 239

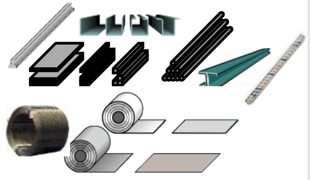
Years	World
2010	1 433
2011	1 538
2012	1 560
2013	1 650
2014	1 671
2015	1 621
2016	1 629
2017	1 732
2018	1 814
2019	1 869

Source woldsteel.org, 2020

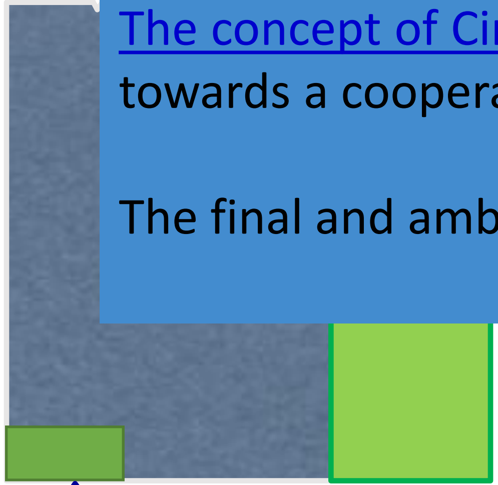
Goal & Main Objectives

Reuse of steel by-products concerns both their internal recycling in steelmaking route and their use for external applications.

64,4% Steel



32,9% By-products



The concept of Circular Economy drives several industrial sectors towards a cooperation in reuse and recycling of by products.

The final and ambitious goal is to reach the so called:

«zero waste»

2,7% Waste

Other by-products

- Pencil pitch
- Fertilisers
- Plastics
- Paints…

This "virtuous process" allows recovery of valuable elements and reuse of by products in different industrial sectors by limiting the need of landfill disposal.

Research Fund for Coal & St

Goal & Main Objectives

Promoting the dissemination of the knowledge gained and the technological solutions introduced in relevant European projects on the reuse and recycling of by-products in the steel sector

Identifying present merits and limitations of the various technological solutions, as well as the spread of their implementation in the European steel plants

Evaluating the principal reasons of success and failure in the past projects, taking into account scientific, technical, economic and legislative aspects

Evaluating the impact of the results on the sustainability and the competitiveness of the European steel industry

Identifying the most promising and useful emerging development lines and encouraging the use of best results and innovative solutions, taking into account possible technological barriers

Identifying non-technological barriers to these innovations, research outcomes and other actions which can support the elimination of such barriers

Encouraging synergies with other industrial sectors in projects promoting industrial symbiosis and circular economy

Identifying a **future roadmap** and a sequence of research topics for the next years

The development of the wider improvement of by-products reuse and recycling in the future years

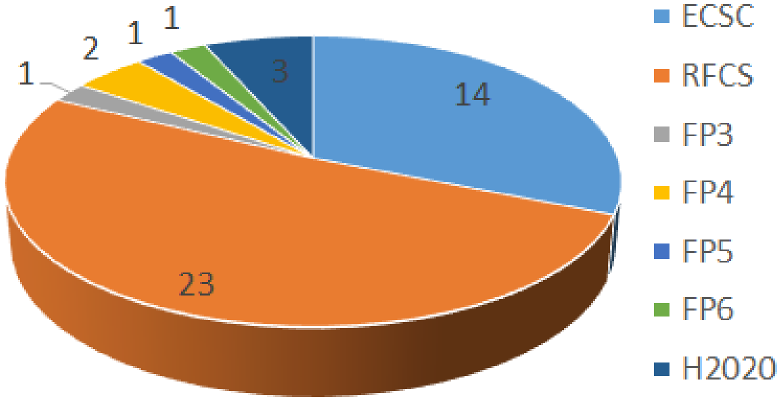
The basis of the pursued analysis

A list of relevant EU funded projects was compiled

Projects were subdivided based on the type of investigated by-product.

35 projects were kept for further dissemination

Exclusions due to inaccessible reports (report not available or confidential) or missing reports (for ongoing projects).



Slag
- BF
- EAF
- BOF
- LF

Sludge
- BF
- EAF
- BOF

Dusts
- BF
- EAF
- BOF

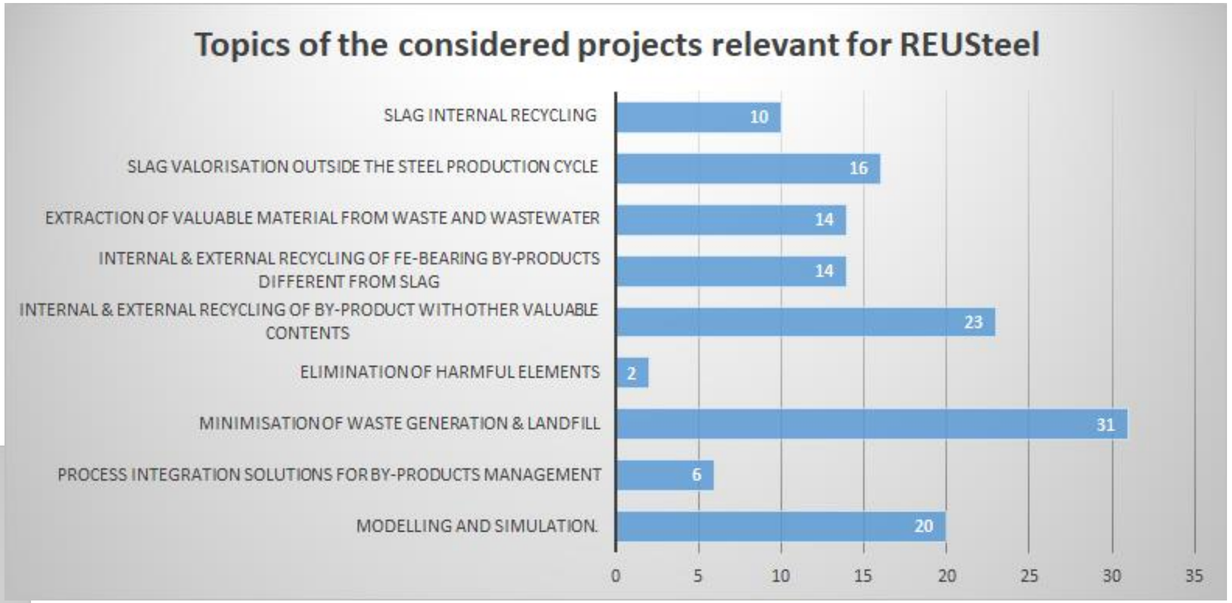
Refractory

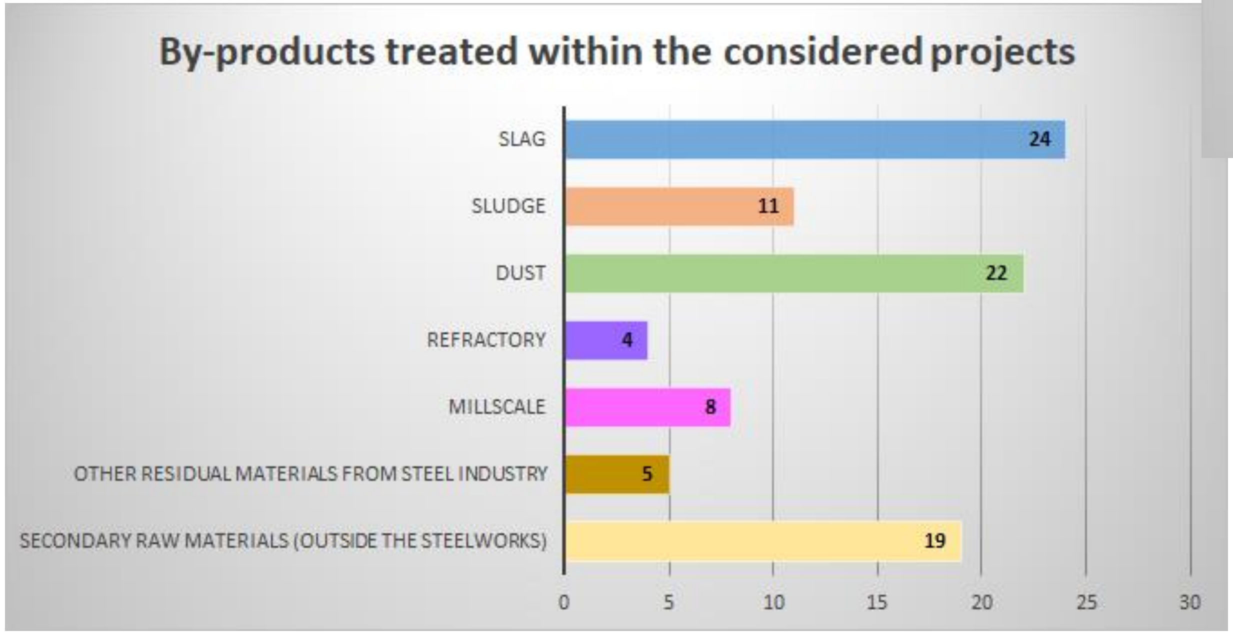
Other by-products

Mill scale

Secondary raw materials

The basis of the pursued analysis



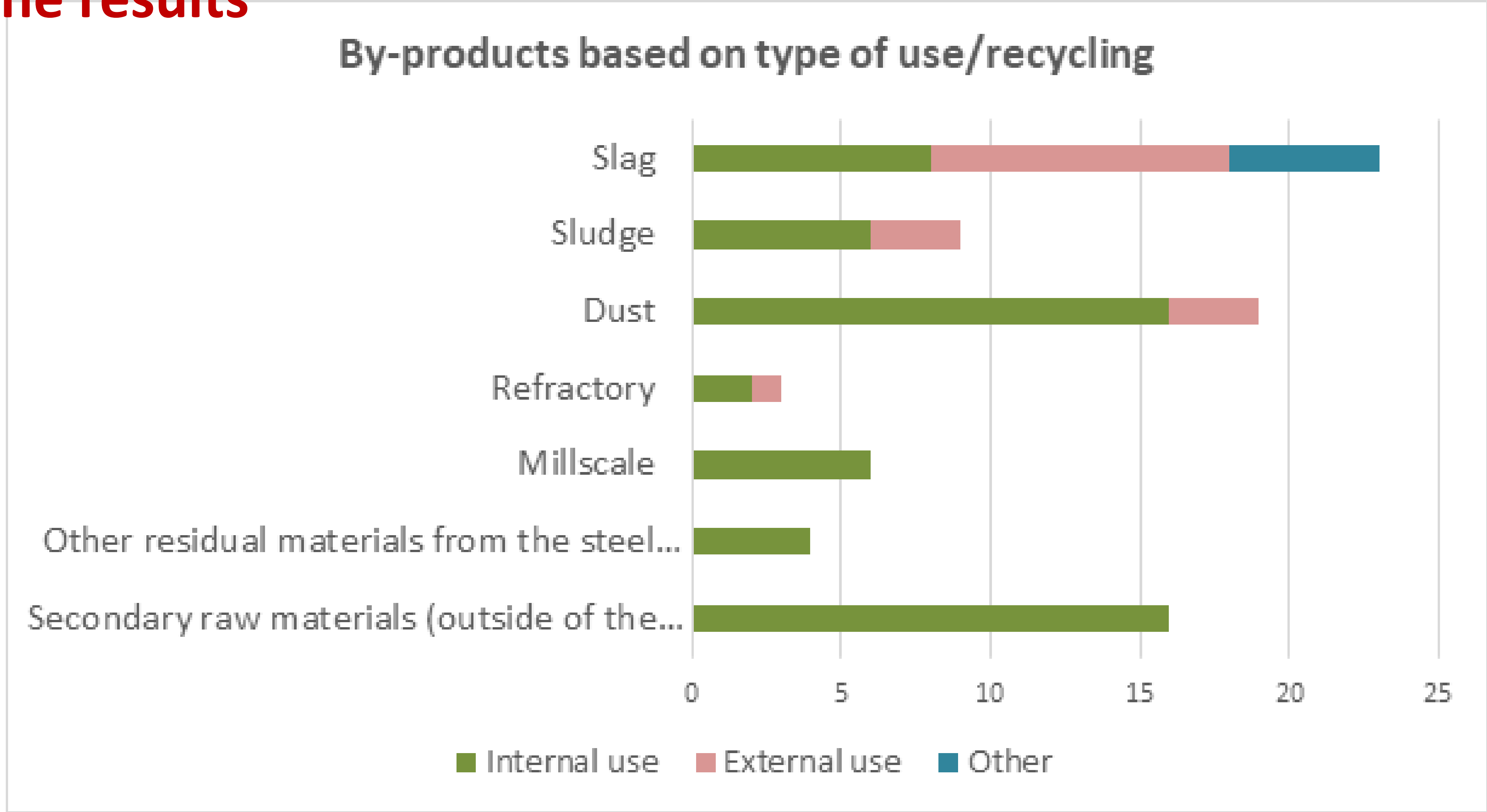


Criteria of the pursued analysis

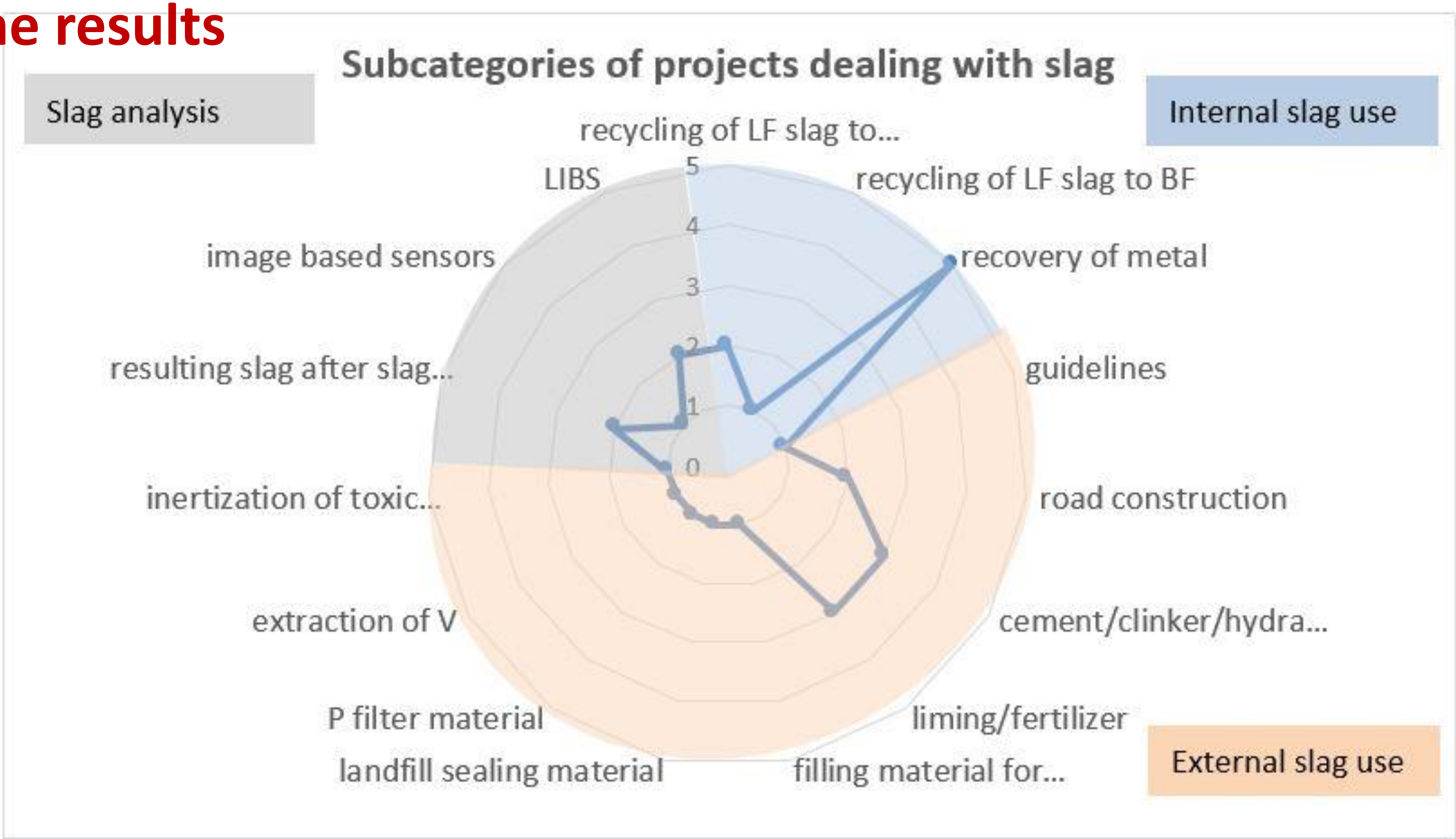
Projects were analysed and the relevant information was collected:

- Type of by-product (e.g. slag, dust, sludges)
- Project duration
- Use (concerning the reuse of materials internally or externally steel production. Cases of IS are also considered here).
- Objective of the project (e.g. slag used as filter or as fertilizer, high purity Zinc for reuse from steelmaking dusts, etc.)
- Ideas investigated (technologies, processes, new operating practices, etc.)
- Test conducted (developed experimental activity)
- Main results (this includes techniques, processes, etc.)
- Successes (most successful outcomes)
- Failures (e.g. expected results not completely achieved).
- Achieved TRL
- Eventual follow up
- Things that were not clear
- Interesting ideas that could be further investigated
- Economical evaluation
- Environmental evaluation

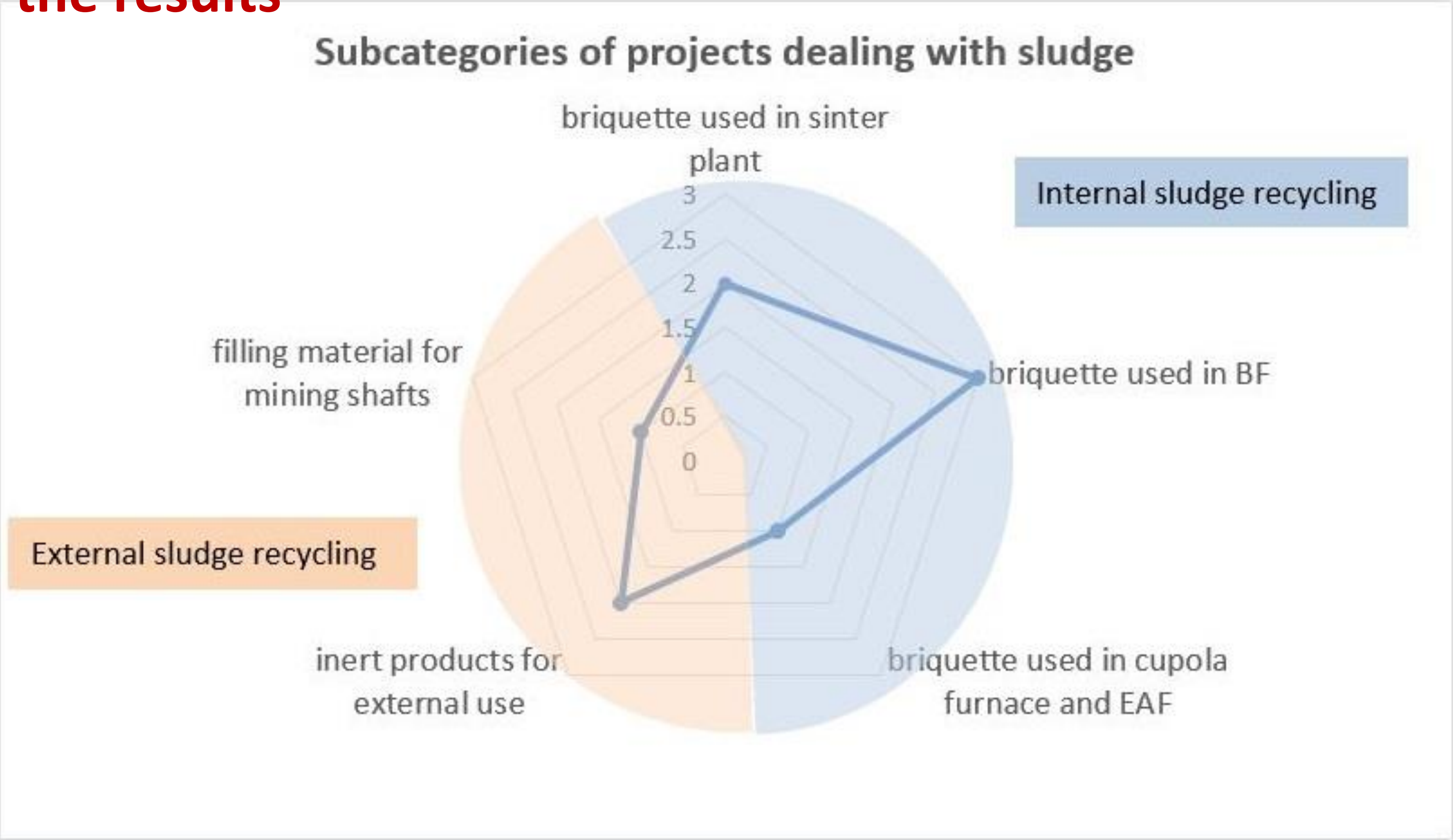
Overview of the results



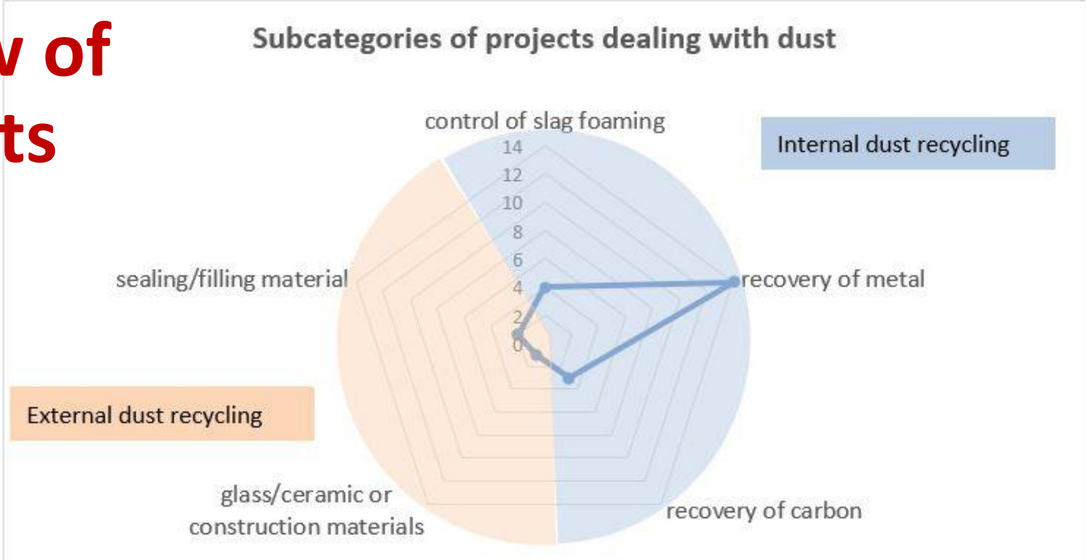
Overview of the results

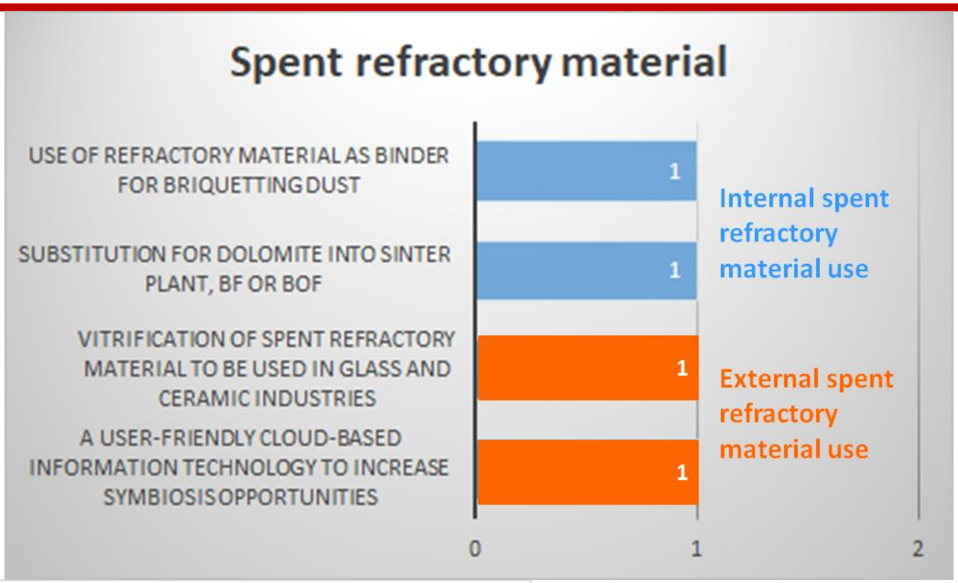


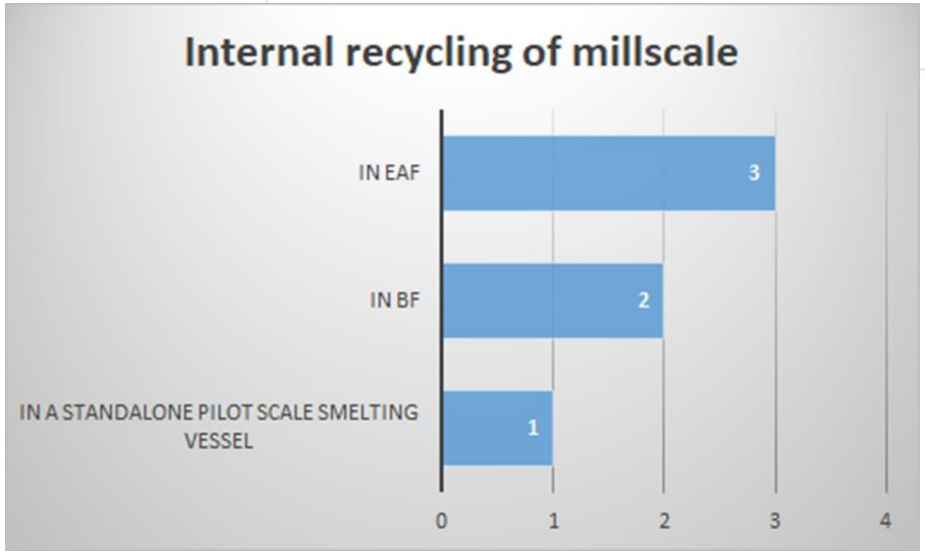
Overview of the results

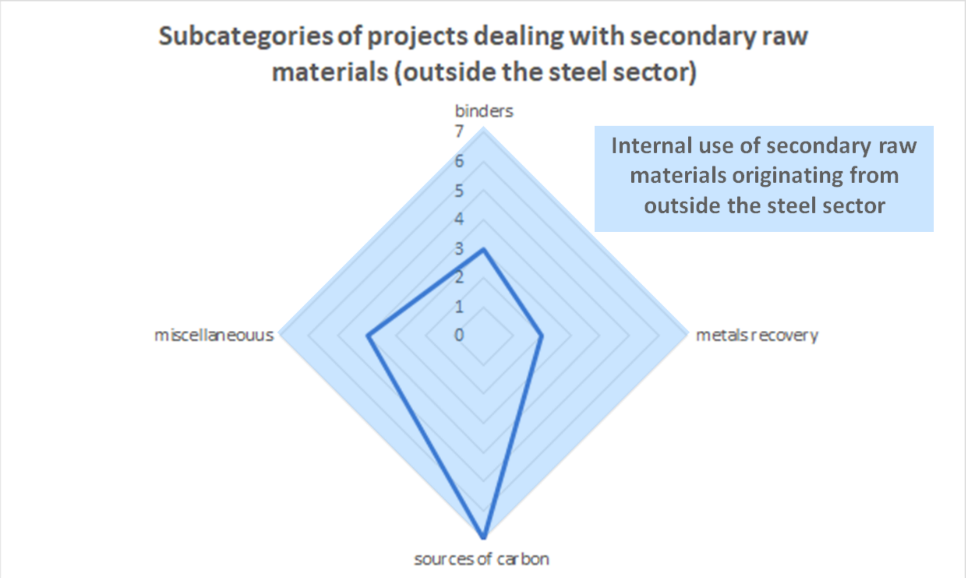


Overview of the results









Preparing a Roadmap for by-products reuse and recycling in the steel sector

- Participation to workshops and conferences with presentation on specific topics
- Organization of webinars and seminars
- Organization of workshop

Dissemination of results

- Identification of industrial needs and technological trends
- Identification of technological challenges
- Identification of research needs

Roadmap

Preparing a Roadmap for by-products reuse and recycling in the steel sector

Long term industrial needs in steel industry :

- Internal and external utilization of by products
- Zero Waste
- CO2 mitigation technologies

Technological trends:

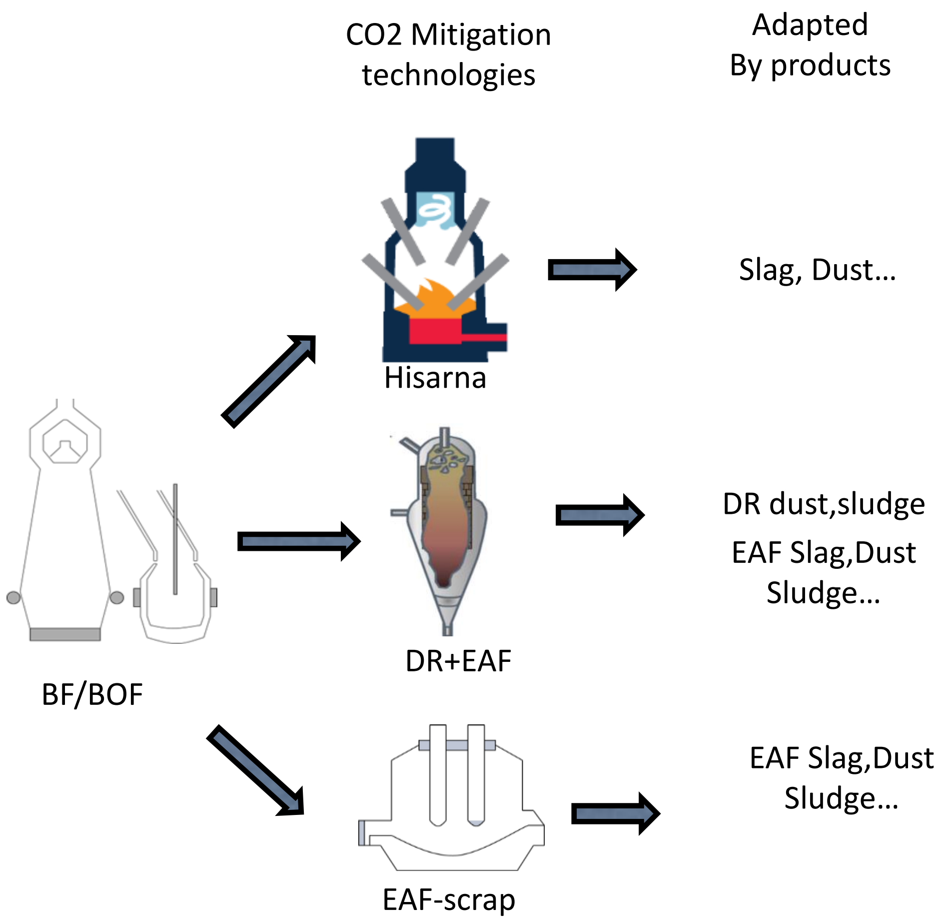
- Carbon Direct Avoidance (CDA)
- Smart Carbon Usage (SCU)

Challenges, Constraints:

- Structural barriers,
- EU and national regulatory framework

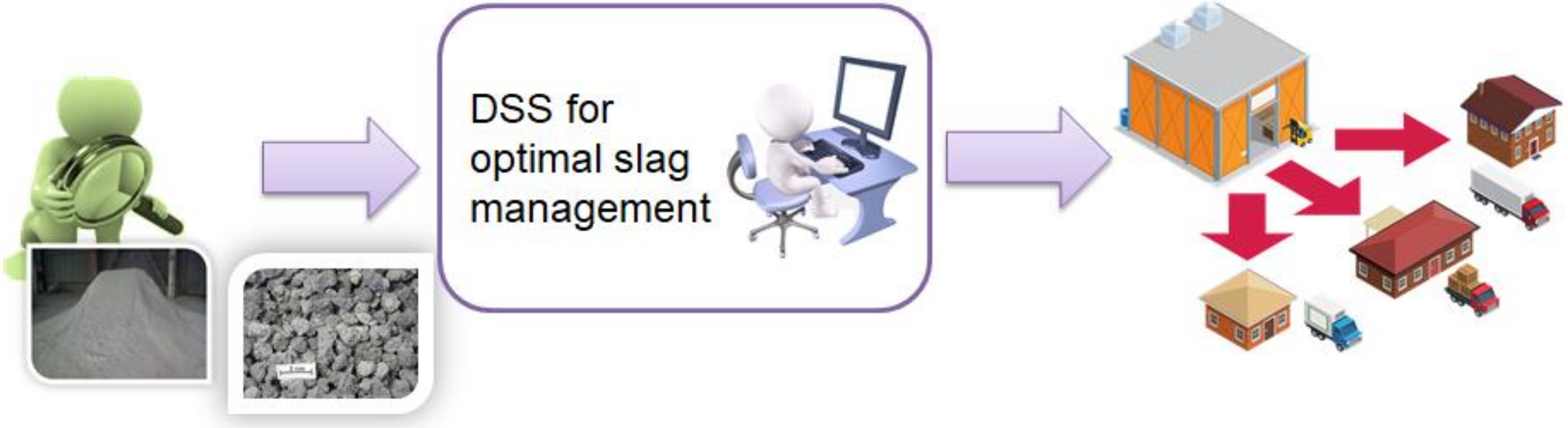
Research needs:

by-products reuse and recycling



What is the future? An example

- Intensify cross-sectoral cooperation for implementing IS
- Improve accurate and fast characterization of by-products on a smaller lot scale
- Provide operators with easy-to-use tools to support IS and CE practices



- New production cycles ➡ different by products features?

5th ESTAD (European Steel Technology and Application Days)
REUSteel Symposium: Stockholm, 31 Aug 2021, 8.30-12.00

- Presentation of concluded and ongoing research
- In-depth look at three topics
  - Slag use
  - Residual material use in BF and sinter plant
  - Residual material use in EAF
- Outlook about the future of residual materials within the steel industry

The symposium will include time for questions and comments from the audience. Opinions and feedback from the audience will be collected and used in the Roadmap preparation.


thank you
danke
謝謝
ngiyabonga
شكراً جزيلاً
teşekkür ederim
gracias
merci
obrigado
dziękuję
bedankt
спасибо
Баярлалаа
рахмат
go raibh maith agat
mochchakkeram
sukriya
kop khun krap
grazie
arigatô
dakujem
terima kasih
감사합니다
ありがとう
ευχαριστώ
мерси
хвала
tapadh leat
dank je
takk
hvala
tack
mersi
barka
spas
kiitos
dankie
dhanyavad
faafetai lava
vinaka
blagodaram
misaotra
matondo
paldies
grazzi
mahalo
asante
manana
obrigada
enkosi
sagolun
köszönöm
mauruuru
nandri
nanni
bayarlalaa
gràcie
chnorakaloutioun
gràcies
sulpay
taiku
dekuji
sobodi
mesi
najis tuke
kam sah hamnida
rahmat
tanemirt
rahmet
xiexie
diolch
dhanyavadagalu
shukriya
trugarez
mamnun
дякую
djiere dieuf
murakoze
tenki
dankon
akun

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

Overview of the EU funded research on slag

Agnieszka, Morillon - FEhS

Projects dealing with slag

- 24 finished projects were taken into consideration

Internal slag use

- 8 projects dealt with internal slag use/recycling

2 projects:
Recycling of LF slag to replace lime in EAF

1 project:
Recycling of BOF slag and LF slag to BF

5 projects:
Recovery of metal

Recycling of LF slag to replace lime in EAF

7210-PR/203

Liquid LF slag was recycled in an EAF (pilot scale)

- LF was able to replace lime, without increase in sulphur or negatively impacting the resulting composition of EAF slag
- At one steelwork, 80% of LF was recycled and the practice was transferred to daily operation
- Depending on the infrastructure of the steelwork this process can have limitations, e.g. not possible to transfer directly liquid slag or no time to calculate the amount needed

Optimal synthetic slag former was developed with LF slag and spent dolomite

- Development of optimal formula, including the binder, for palatalization
- The replacement of lime with optimized LF slag was successful and did not increase the energy
- This requires dry processing and handling

EIRES

Modeling of lime and dolime replacement with LF slag in EAF (simulation, no physical tests)

- Replacement of lime and dolime with LF slag is possible
- The energy increase is slow (2.5%)
- Different simulation environments (e.g. Aspen Plus and Matlab) needed to be used in order to comply with specific needs of all the partners, e.g. not possible to use a unique simulation system to take into account specific demands of the industrial partners

Recycling of BOF slag in sinter plant and LF slag in BF

REFFIPLANT

- Summery of by-products and waste management in the steel works
- Integrated process optimization in the steelworks: case studies using holistic models for material treatment units
    - Simulation of BOF slag use as pellets for sinter plant showed potential benefits related to reduction of waste amount
    - As the Italian law does not allow manufacturing industry to treat its own wastes without a special permission this solution was not tested
- On-site tests to use LF slag as slag former in BF to partially replace limestone
    - LF slag was able to replace partial amounts of limestone
    - The only effect seen was an increase in Al_2O_3 content in the BF slag

Recovery of metal

IPBM

DC furnace pilot plant to recycle BOF slag and EAF slag to recover metal (V) and to create valuable products from the remaining slag

- Stand-alone alternative gives possibilities to optimize slag and metal products
- High operating costs (electricity) creates uncertainty and is dependent on V costs.

EPOSS

Increase energy efficiency in EAF and productivity by development of innovative slag conditioning techniques for slag foaming which result in less Cr going to slag

- Injection of CaC_2, FeSi, carbon/oxygen or Al granules
- Electricity was reduced by 13 % and Cr decreased in the slag by 22 %.

PSP-BOF

Separation of BOF slag into Fe-rich and P-rich fraction

- Pretreatment of slag to facilitate separation of the slag fractions (grinding and magnetic separation)
- Treatment of liquid slag with P- and Fe-containing residues
- Different cooling rates were investigated in laboratory and industrial scale
- Fe-rich fraction was investigated in laboratory and pilot sinter plant

URIOM

Use of inductively heated coke bed reactor (ICBR) coupled with Flash reactor prototype to recover metal from EAF slag (Fe and Cr)

- The process almost completely removed metal from the slag

REFFIPLANT

Integrated process optimization in the steelworks: case studies using holistic models for material treatment units

- Simulation of use of BOF slag made into pellets for sinter plant

External slag use

- 15 projects dealt with external slag use/recycling

3 projects: Use of slag in cement/clinker/ hydraulic binders

4 projects: Use of slag as liming/fertilizer material

1 project: Guidelines how to increase EAF slag use by solving environmental issues

2 projects: Use of slag in road construction

1 project: Use of slag as P filter material

1 project: Inertization of toxic wastes

1 project: Use of slag as filling materials for mining shafts

1 project: Use of slag as landfill sealing material

1 project: Use of slag Fe-poor fraction as V source

Guidelines how to increase EAF slag use by solving environmental issues

SLACON

Solutions to specific environmental problems at different steelworks though laboratory and industrial trials

- Immobilization of leachable substances in EAF slag
  - As the quality of slag depends on different aspects, including which country it is produces (as different limiting values are implemented) in the project different ways to improve EAF slag were investigated.
  - Paramters investigated include Ba, V, Cr, Mo and free lime
- Elimination of leachable substances from slag washing/cooling water in a closed loop system
  - Design and tests of a filter that removes at the same time F, Mo and V from water

Use of slag in road construction

7210-PR/195

EAF slag, BOF slag, GBF slag and BF slag were investigated for their properties to be used in road construction

- Laboratory tests, in-situ investigations, modelling were used to assess the impact of slags or slag mixtures in road construction
- Percolation test in pilot lysimeter was used to evaluate leaching of slag and the data was used in modeling
- Both physical and environmental impact of the slag was investigated

FP4-BRPR970446

Production of BOF and EAF slag with stable volume and good environmental behavior (reduced Cr content) was investigated to be used in road construction

- Pilot scale reduction tests in DC-furnace of slag with anthracite coal additions
- Addition of quartz sand, glass cullet and BOF-converter dust to liquid slag aiming to improve volume stability

Use of slag in cement/clinker/hydraulic binders

IPBM

After extraction of metal from slag in a pilot smelting vessel (outside the main steel production), the remining slag was assessed towards use as clinker or hydraulic binders

PSP-BOF

After separation of Fe-poor from Fe-rich fractions the Fe-poor fraction was assessed for applications towards the cement industry

FISSAC

To establish a valorization scheme for EAF and LF slag similar to BF slag by incorporating it into cement industry

- Development of methodology and a software platform to implement the innovative industrial symbiosis model
- Case studies of using EAF slag or LF slag in different applications e.g. green concrete slag, pre-industrial production of CSA cement, industrial production of blended cement…

Use of slag as liming/fertilizer material

7210-PR/267

Investigation of slag as liming/fertilizing material

- Investigation of influence of different input materials into the metallurgical cycle of BF-BOF route on Cr and V content in slag
- Investigation of BF, BOF, LF and basic slag as liming/fertilizing and their effects on harvest yield of crops and hay.
- Cr and V content in soil after liming/fertilizing with slag

SLAGFERTILISER

Investigation of slag as liming/fertilizing material in long-term and short-term field trials

- Comparison of the effects of slag as liming/fertilizing material to products available on the market in short-term field trials in different climates (Finland, Germany, Austria and Italy)
- Evaluation of long-term slag utilization as liming/fertilizing material
- Evaluation of Cr and V in soil after liming/fertilizing with slag

PSP-BOF

After separation of Fe-poor from Fe-rich fractions the Fe-poor fraction was assessed for applications towards use as liming material

Remelting of sewage ash (high in P, but not bioavailable) with slag to create slag with high P content that is bioavailable

- Laboratory tests to assess use of slag after treatment as P fertilizer

SLASORB

Pot trials to assess slag as a P fertilizer after slag was used as a filter material to remove P from municipal wastewater treatment plant

Use of slag as filling materials for mining shafts

FP4-BRPR970446

Production of BOF and EAF slag with stable volume and good environmental behavior (reduced Cr content) was investigated to be used as aggregates in refilling mixtures for mining shafts

- Laboratory tests to chemical and physical properties

Use of slag as landfill sealing material

7215-PP/028

Investigation of slag (BOF, EAF and LF) with other by-products to create mixtures that preform as good or better than products used to seal landfills

- Laboratory tests to optimize sealing material
- Pilot scale tests with sealing materials on inhouse landfill that were tests for 15 months

Use of slag as P filter material

SLASORB

Investigation of BOF and EAF slag to be used as a filter material to remove P from wastewater treatment plant in small communities

- Laboratory tests to investigate slag properties as filter material to remove P
- Two demonstration scale slag filters were installed at municipal wastewater treatment plants and tested

Use of slag Fe-poor fraction as V source

PSP-BOF

After separation of Fe-poor from Fe-rich fractions the Fe-poor fraction was assessed for as a source of V

- Laboratory smelting tests with up to 1 kg of slag were conducted to recover V

Inertization of toxic wastes

IPBM

Development of a treatment process for vitrifying wastes such as spent refractory, zinc containing dust and sludge by using steel slags. By this process inertization of toxic-noxious metals was obtained.

- Laboratory tests where liquid slag was used to vitrify by-products

Slag analysis

- 5 projects dealt with slag analysis

2 projects:
Resulting slag after slag foaming optimization

1 project:
Image based sensors

2 projects:
LIBS

Resulting slag after slag foaming optimization

7215-PP/026

Analysis of slag after internal recycling of dust to reduce slag foaming in EAF

- EAF slag was investigated for chemical and mineral properties before and after dust injection to EAF to control its quality

EPOSS

Analysis of slag after CaC_2 mix injection to reduce slag foaming in EAF

- EAF slag was investigated for chemical properties before and after dust injection to EAF to control its quality

Image based sensors

OPTDESLAG

Test of monitoring systems combining camera installations, image analysis, new senor information (stirring gas flow rate and pressure at EAF plant) and process models

- Monitoring and control of deslagging operations
- Dynamic online process models to monitor and control the slag properties throughout the production route of steelmaking
- Calculate set-point for slag conditioning

LIBS - laser induced breakdown spectroscopy

7210-PR/271

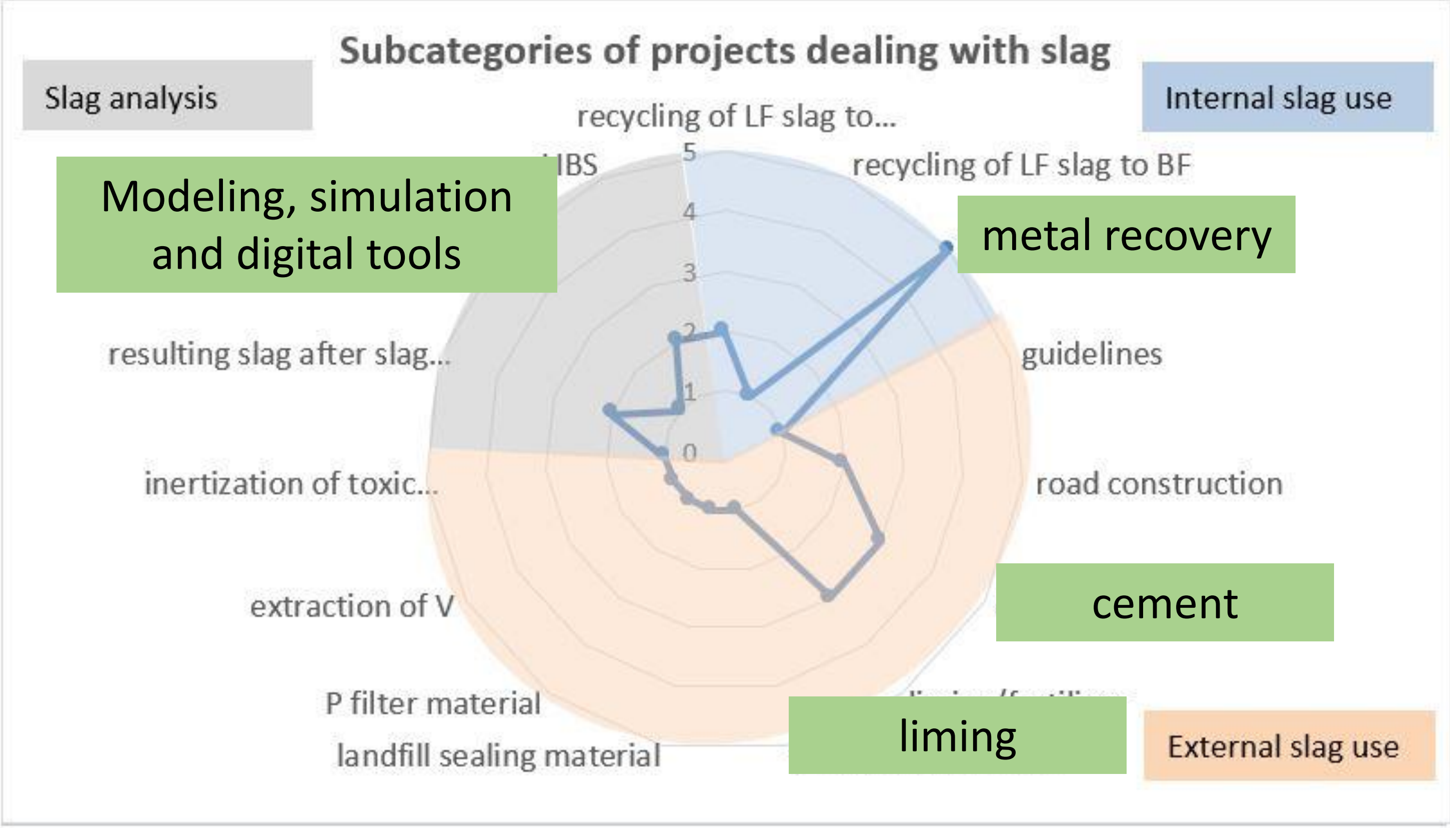
Investigation of adaptation of LIBS to EAF, converter and ladle units

- Detection of Fe, Ca, Si, Al, Mg, Cr and Mn by LIBS
- Quick determination of oxidation potential, of slag foaming and basicity of the slag
- Prove of the online feasibility of the quick detection system
- Application of INQUISSS to support slag recycling measures by online detection of its recycling capacity

SLAGFERTILISER

LIBS was used to measure the quality of BOF slag that was used in liming tests

Today’s presentations will highlight



Thank you for your attention

Agnieszka Morillon, PhD
Phone: +49 2065 9945-85
E-mail: a.morillon@fehs.de

web site: www.fehs.de

INSTITUT FÜR BAUSTOFF FORSCHUNG

FEhS

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Research Fund for Coal & Steel

Project 749809 (01/07/17-31/12/21)

Dr.-Ing. Andreas Ehrenberg

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Consortium partners:

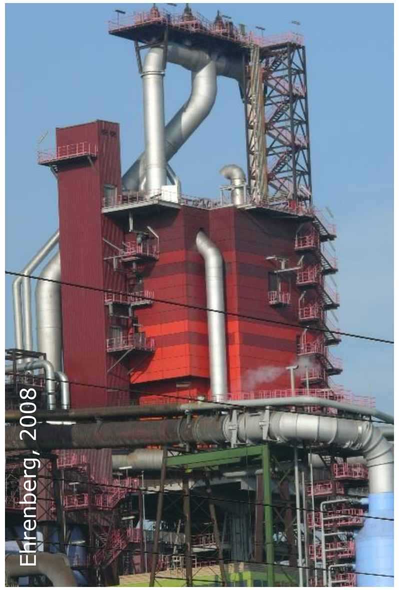
- **ArcelorMittal R&D:** project coordinator (Maizières, F); upstream activation
- **ECOCEM**: GGBS producer (Moerdijk, NL); product development
- **FEhS**: slag research institute (Duisburg, D); characterization & modification of GBS
- **LMDC**: research group in civil engineering at University Paul Sabatier (Toulouse, F); downstream activation
- **CEMHTI**: CNRS laboratory(Orléans, F); characterization with high precision tools, in particular NMR analyses
- **TUC:** Technical University of Clausthal (D), glass analyses

Project management: Ms Judit Kacnics (AM Maizières, F)

ActiSlag

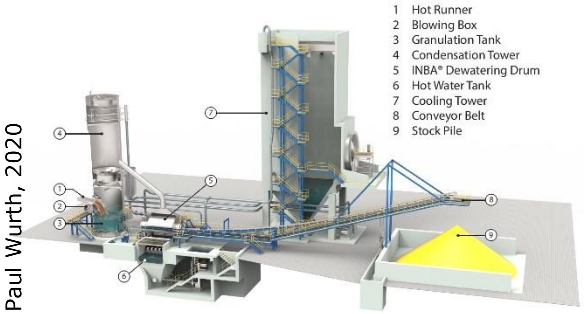
New activation routes for early strength development of granulated blast furnace slag

Project background:



Blast furnace
≈ 280 kg slag per ton_{HM}

EU-28: 19 mio. t/yr (2018)



Water quenching
("granulation")

Granulated blast
furnace slag (GBS)

95-100 vol.-% glassy

Grinding: Ground
granulated blast
furnace slag (GGBS)

-Slag cement
-Concrete addition

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Project background:

- ☺ Latent hydraulic property ➔ Portland cement clinker substitute
- ☺ Established use in cement since the late 19th century
- ☺ Positive technical properties of the concrete (workability, density, durability, chemical resistance, colour …)
- ☺ Positive environmental properties regarding CO_2 emission and ressource demand for cement/concrete production
- ☹ Lower early strength development
- ☹ Higher grinding energy demand
- ☹ Energy demand for drying

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

General project targets:

1. **Preserve and increase the use of GGBS in cement ➔** (Early) strength optimization

Table 2: Cement mortar compressive strength developments according to EN 196-1 and performanced aimed for ActiSlag GGBS

	2 Days compr. strength	28 Days compr. strength
CEM II (20% GGBS + 80% clinker)	*18 to 24 MPa*	*48 to 56 MPa*
CEM III (50% GGBS + 50% clinker)	*9 to 15 MPa*	*48 to 56 MPa*
CEM III (70% GGBS + 30% clinker)	*6 to 10 MPa*	*45 to 52 MPa*
ActiSlag GGBS (>80% GGBS+ <20% clinker)	***Objective: 18 to 24 MPa***	***Objective: 48 to 56 MPa***

GBS demand is already very high due to CO_2 advantages. However, a better technical performance would justify higher prices

2. **Open new markets for GGBS** in order to reduce the steel industry dependency on cement industry
   ➔ Application in precast concrete, dry mix mortars…
3. **Keep economical value ➔** reasonable modification costs ➔ reasonable product costs

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Main project objectives:

1. **Understand how the slag works in the mortar/what influences the quality and performance**

   - Chemical and mineralogical composition, micro and nanostructure of the glassy phase

   - Minor elements beside the major oxides

   - Describe the mechanism of hydration at early age

2. **Improve short term performance and the performance of high GGBS content mortars**

   - upstream activation (liquid state): Chemical & physical modification of the glassy structure

   - downstream activation (solid state): Combination with chemical activators

3. **Product development of a "second generation GGBS"**

   Develop a binding system composed of more than 80 wt.% GGBS having the same performances as CEM II with 50 wt.-% GGBS

ActiSlag

Project structure and timeline:

- 2017 July
- 2018 Jan
- 2019 Jan
- 2020 Jan
- 2021 Jan
- **2021 June**
- + 6 months extension

WP1: Fundamental understanding *(**CEMHTI**, TUC, FEhS, LMDC, ArcelorMittal)*

- Systematic characterization of 16 industrial GBS with very different reactivities
- GBS Nano-structural organisation
- GBS State of disorder
- Reactions involved in strength development & kinetics
- Key parameters limiting strength development

WP2: Upstream activation

*(**TUC**, ArcelorMittal, LMDC, FEhS, CEMHTI)*

- Optimisation of chemistry & microstructure
- Optimisation of cooling conditions
- Industrial evaluation

WP3: Downstream activation

*(**LMDC**, ECOCEM, CEMHTI, FEhS, ArcelorMittal)*

- Enhancement of slag reactivity via chemical and physical activators
- Finding best combination of upstream and downstream modifications

WP4: Product development

*(**ECOCEM**, LMDC)*

- Concrete formulations of GGBS/activator combination
- C2 tile adhesive recipe with 50-80% & >80% GGBS

WP5: Economic evaluation & LCA & Next Step

*(**ArcelorMittal**, ECOCEM, FEhS)*

- Evaluation of the market potential
- Life cycle assessment
- Technical exchanges to prepare a demonstrator project

WP6: Project management *(**ArcelorMittal**, ECOCEM, FEhS, LMDC, CEMHTI, TUC)*

ActiSlag

WP 1: Structure and performance of industrial GBS

- Based on FEhS database, **16 industrial GBS samples** were selected from Austria, France, Germany, The Netherlands, India and USA to cover a wide range of production parameters (e.g. granulation) and chemical/physical/cementitious properties
- FEhS analysed all samples with **classical methods:** physical and chemical parameters and cementitious properties ➔ wide range confirmed, as expected
- The consortium selected the **most interesting 7 GBS**
- Project partners performed a **multiscale analysis** of selected samples:
  - CEMHTI: structure of glass **before and after hydration**
  - TUC: effect of **thermal history** on fictive temperature (= freezing temp. under real conditions)
  - LMDC: **dissolution** tests, **synchrotron** beam line before and after hydration
- Some hypotheses were tested on **model glasses** made in lab-scale at ArcelorMittal (= possibility to control composition, eliminate effect of minor elements, different industrial cooling rates)

ActiSlag

WP 1: Structure and performance of industrial GBS

➔ Big differences in chemistry; nearly no differences in glass content du to effective granulation processes

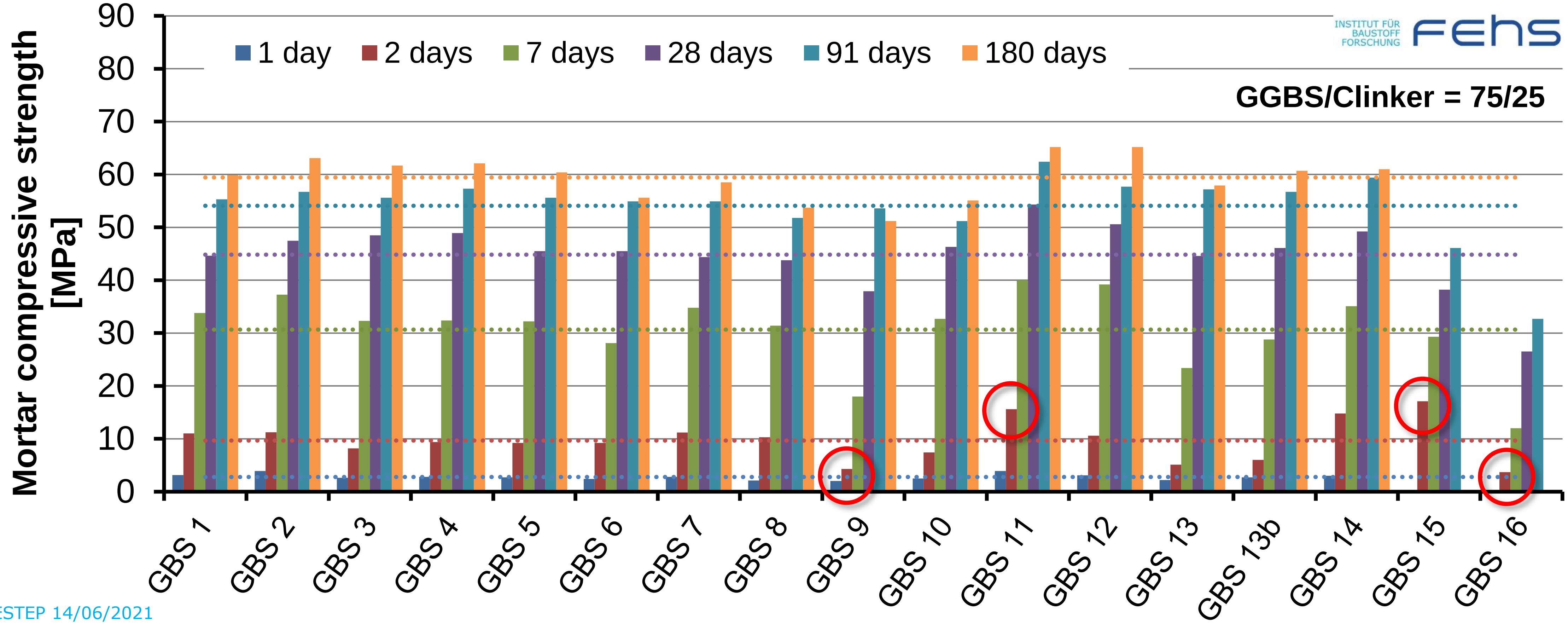
GBS	C/S	(C+M)/S	F value *	MgO	Al_2O_3	TiO_2	S^{2-}	Na_2O equiv.	$H_2O + CO_2$	Glass
1	1.14	1.33	1.61	6.83	13.6	0.75	0.69	0.74	0.42	99.9
2	1.15	1.34	1.57	6.94	12.0	0.74	0.63	0.77	0.47	99.7
3	1.09	1.26	1.43	6.40	9.6	0.61	0.58	0.62	0.28	99.9
4	1.14	1.30	1.48	6.12	9.4	0.66	0.44	0.61	0.34	96.6
5	1.04	1.23	1.49	7.32	12.9	0.77	0.71	0.92	0.32	99.8
6	1.16	1.35	1.57	6.84	11.0	1.79	1.04	0.63	0.28	99.9
7	1.14	1.31	1.54	6.35	11.5	0.70	0.93	0.65	0.22	99.9
8	1.12	1.30	1.52	6.84	11.2	1.12	1.08	0.71	0.22	100.0
9	1.06	1.23	1.44	6.64	11.0	3.02	1.37	0.70	0.18	100.0
10	1.10	1.27	1.46	6.46	10.1	0.40	1.35	0.79	0.33	99.8
11	1.19	1.36	1.61	6.30	11.8	0.43	0.97	0.57	0.36	99.8
12	1.14	1.32	1.55	6.60	11.7	0.70	0.80	0.99	0.40	99.8
13	0.86	1.13	1.25	10.4	11.2	0.57	0.66	1.44	0.17	99.9
14	1.13	1.44	1.74	8.36	13.7	1.16	0.79	0.68	0.34	98.2
15	0.84	1.17	1.56	11.6	20.1	0.78	0.58	0.56	0.21	100.0
16	1.02	1.32	1.35	11.1	6.8	0.27	0.89	0.48	1.13	94.5
	-	-	-	wt.-%	wt.-%	wt.-%	wt.-%	wt.-%	wt.-%	vol.-%

* F = $(CaO + 0.5 \times MgO + 0.5 \times S^{2-} + Al_2O_3) / (SiO_2 + MnO)$

ActiSlag

WP 1: Structure and performance of industrial GBS

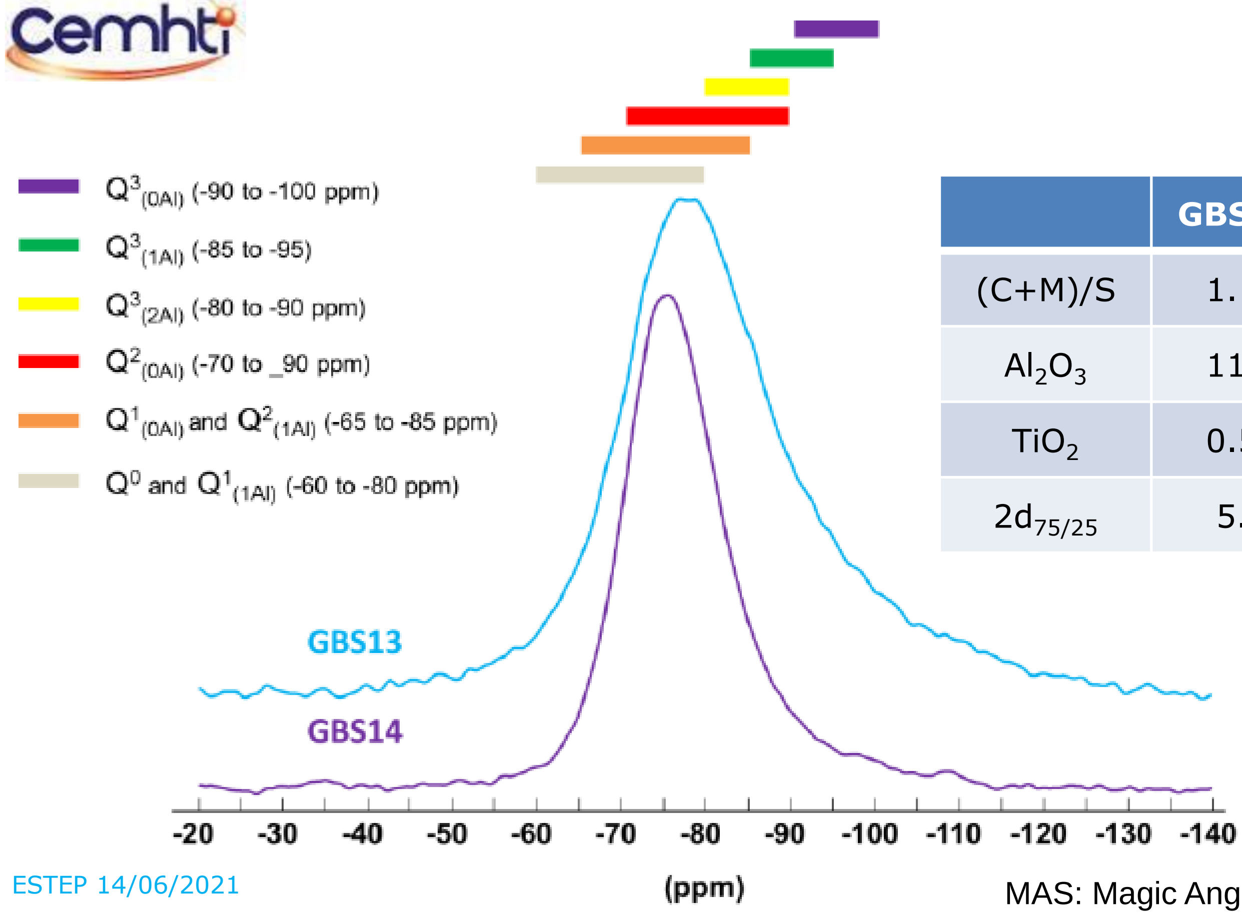
➔ Very different reactivities
(cement mortar tests acc. to EN 196-1, heat of hydration acc. to EN 196-11 and RILEM R3 protocol)



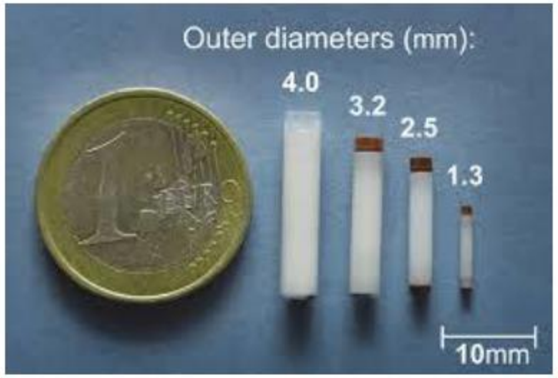
ActiSlag

WP 1: Structure and performance of industrial GBS

^{29}Si / ^{27}Al MAS NMR analyses ➔ no fully polymerized glass network; higher basicity = more Q^0; mainly Al_{IV}
➔ no simple transfer of classical glass theories based mainly on Q^3 structure



	GBS 13	GBS 14	
(C+M)/S	1.13	1.44	-
Al_2O_3	11.2	13.7	wt.-%
TiO_2	0.57	1.16	wt.-%
$2d_{75/25}$	5.1	14.8	MPa



MAS: Magic Angle Spinning, 54,74° against static magnetic field

ActiSlag

WP 1: Structure and performance of industrial GBS

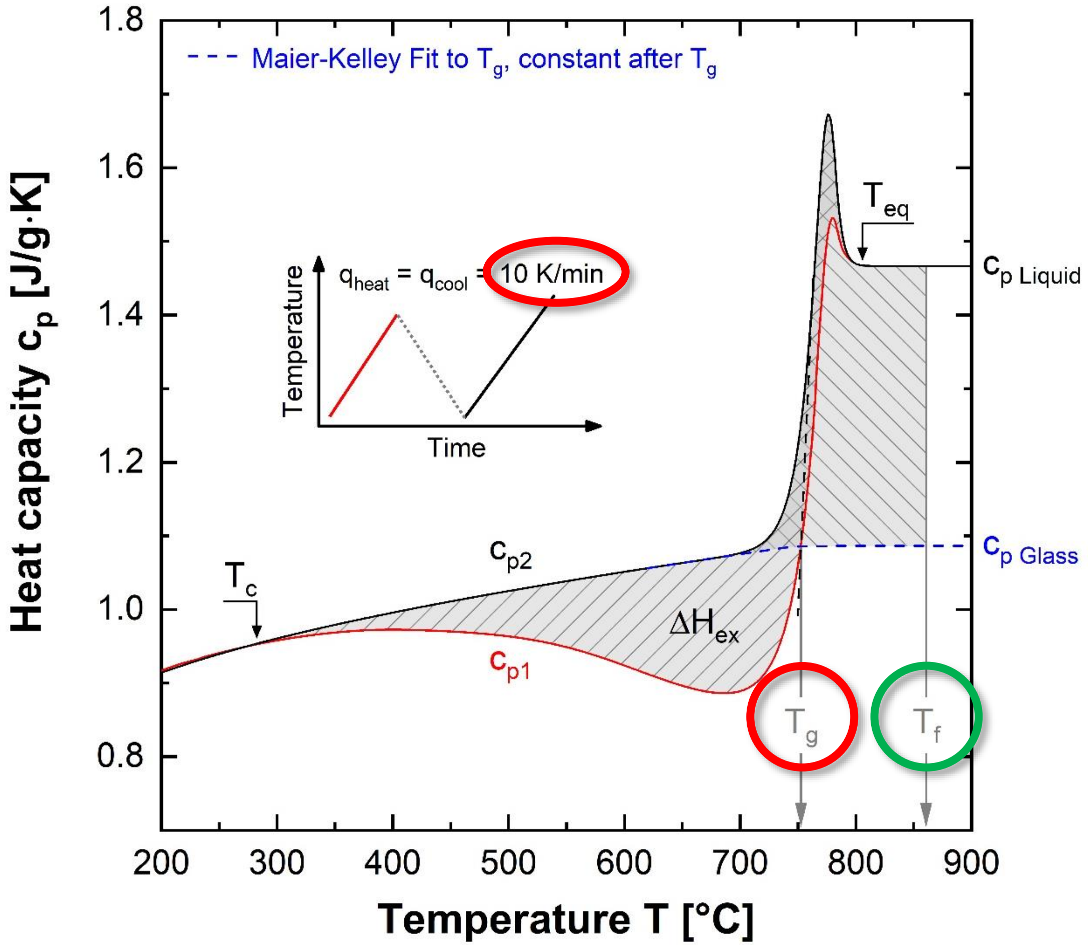
Hyperquenching annealing calorimetry

TU Clausthal

- ➔ For the 1st time used for GBS glass
- ➔ Developing of a test procedure (e.g. ground/unground, test fraction)
- ➔ T_g and T_f different due to different thermal history in lab and practice
- ➔ Smaller particles with higher T_f (= higher enthalpy)
- ➔ Annealing tests confirm relevant influence of glass enthalpy (separate national project with FEhS)

ActiSlag

WP 1: Structure and performance of industrial GBS



TU Clausthal

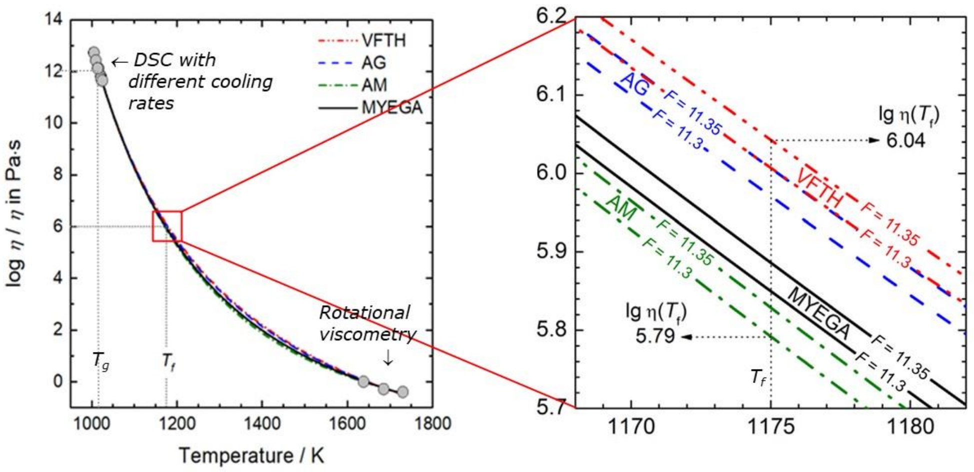
Hyperquenching annealing calorimetry

$$\int_{T_c}^{T_{eq}} (C_{p2} - C_{p1})\,dT = \int_{T_g}^{T_f} (C_{pl} - C_{pg})\,dT$$

$$C_{pg} = a + bT + c/T^2 + d/T^{0.5}$$

→ *$T_{fictive}$ (real freezing temperature)*

$$\log q_c = 11.35 - \log \eta(T_f)$$



Hart, D. (TU Clausthal, 2021)

→ *q_c (industrial cooling rate) ≈ 10^5 K/s*

Yue, Y. Z., Christiansen, J., Jensen, S. L.: Determination of the fictive temperature for a hyperquenched glass. Chemical Physics Letters 357 (2002) 1/2, 20-24

ActiSlag

WP 1: Structure and performance of industrial GBS

TU Clausthal

HAC ➔ T_g very similar; depending on chemistry (thermal history eliminated)

	T_f				ΔT (T_f - T_g)		T_g	ΔT_s - ΔT_l	Strength ranking	< 0.5 mm	Ø Cooling rate	
Fraction	**s**	**s (Ø)**	**l**	**l (Ø)**	**s**	**l**					**s**	**l**
	°C								-	wt.-%	K/s	
GBS 1	829-811	820	807-792	800	85	65	735	21	6	24	4386	540
GBS 2	858-820	839	822-821	822	102	85	737	18	4	28	45905	9276
GBS 3	847-826	837	830-822	826	95	84	742	11	7	35	31140	12120
GBS 4	845-830	838	812	812	96	70	742	26	5	19	30705	1983
GBS 5	833-820	827	809-808	809	95	77	732	18	9	25	20607	3258
GBS 6	829-826	828	816-799	808	91	71	737	20	13	30	14167	1773
GBS 7	823-817	820	821	821	79	80	741	-1	8	23	5890	6555
GBS 8	822-821	822	808-802	805	84	67	738	17	15	32	12681	1902
GBS 9	825-821	823	798-782	790	92	59	731	33	16	28	26626	684
GBS 10	832-827	830	821	821	94	85	736	9	11	24	18554	7606
GBS 11	824-817	821	795	795	78	52	**743**	26	1	26	5142	235
GBS 12	831-821	826	787	787	89	50	737	39	2	33	12635	144
GBS 13	831-787	809	787-780	784	87	62	**722**	26	14	13	15163	1188
GBS 14	841-835	838	793-782	788	105	55	733	51	3	21	100000	407
GBS 15	833-822	828	774-773	774	99	45	729	54	12	12	15814	44
GBS 16	774	774	768	768	52	46	**722**	6	17	19	298	133

s: 0.355 - 0.500 mm, l: 2-4 mm

ActiSlag

WP 1: Structure and performance of industrial GBS

TU Clausthal

HAC ➔ T_f very different; depending on chemistry <u>and</u> thermal history

	T_f				ΔT (T_f - T_g)		T_g	ΔT_s - ΔT_l	Strength ranking	< 0.5 mm	Ø Cooling rate	
Fraction	s	s (Ø)	l	l (Ø)	s	l					s	l
	°C								-	wt.-%	K/s	
GBS 1	829-811	820	807-792	800	85	65	735	21	6	24	4386	540
GBS 2	858-820	839	822-821	822	102	85	737	18	4	28	45905	9276
GBS 3	847-826	837	830-822	826	95	84	742	11	7	35	31140	12120
GBS 4	845-830	838	812	812	96	70	742	26	5	19	30705	1983
GBS 5	833-820	827	809-808	809	95	77	732	18	9	25	20607	3258
GBS 6	829-826	828	816-799	808	91	71	737	20	13	30	14167	1773
GBS 7	823-817	820	821	821	79	80	741	-1	8	23	5890	6555
GBS 8	822-821	822	808-802	805	84	67	738	17	15	32	12681	1902
GBS 9	825-821	823	798-782	790	92	59	731	33	16	28	26626	684
GBS 10	832-827	830	821	821	94	85	736	9	11	24	18554	7606
GBS 11	824-817	821	795	795	78	52	743	26	1	26	5142	235
GBS 12	831-821	826	787	787	89	50	737	39	2	33	12635	144
GBS 13	831-787	809	787-780	784	87	62	722	26	14	13	15163	1188
GBS 14	841-835	838	793-782	788	105	55	733	51	3	21	100000	407
GBS 15	833-822	828	774-773	774	99	45	729	54	12	12	15814	44
GBS 16	774	774	768	768	52	46	722	6	17	19	298	133

s: 0.355 - 0.500 mm, l: 2-4 mm

ActiSlag

WP 1: Structure and performance of industrial GBS

TU Clausthal

HAC ➔ For same GBS: T_f higher for smaller particles

	T_f				ΔT (T_f - T_g)		T_g	ΔT_s - ΔT_l	Strength ranking	< 0.5 mm	Ø Cooling rate	
Fraction	**s**	**s (Ø)**	**l**	**l (Ø)**	**s**	**l**					**s**	**l**
				°C					-	wt.-%	K/s	
GBS 1	829-811	820	807-792	800	85	65	735	21	6	24	4386	540
GBS 2	858-820	839	822-821	822	102	85	737	18	4	28	45905	9276
GBS 3	847-826	837	830-822	826	95	84	742	11	7	35	31140	12120
GBS 4	845-830	838	812	812	96	70	742	26	5	19	30705	1983
GBS 5	833-820	827	809-808	809	95	77	732	18	9	25	20607	3258
GBS 6	829-826	828	816-799	808	91	71	737	20	13	30	14167	1773
GBS 7	823-817	820	821	821	79	80	741	-1	8	23	5890	6555
GBS 8	822-821	822	808-802	805	84	67	738	17	15	32	12681	1902
GBS 9	825-821	823	798-782	790	92	59	731	33	16	28	26626	684
GBS 10	832-827	830	821	821	94	85	736	9	11	24	18554	7606
GBS 11	824-817	821	795	795	78	52	743	26	1	26	5142	235
GBS 12	831-821	826	787	787	89	50	737	39	2	33	12635	144
GBS 13	831-787	809	787-780	784	87	62	722	26	14	13	15163	1188
GBS 14	841-835	838	793-782	788	105	55	733	51	3	21	100000	407
GBS 15	833-822	828	774-773	774	99	45	729	54	12	12	15814	44
GBS 16	774	774	768	768	52	46	722	6	17	19	298	133

s: 0.355 - 0.500 mm, l: 2-4 mm

ActiSlag

WP 1: Structure and performance of industrial GBS

TU Clausthal

HAC ➔ Cooling rates: very high and very different; higher for smaller particles (= higher enthalpy)

s: 0.355 - 0.500 mm, l: 2-4 mm

	T_f				ΔT (T_f - T_g)		T_g	ΔT_s - ΔT_l	Strength ranking	< 0.5 mm	Ø Cooling rate	
Fraction	**s**	**s (Ø)**	**l**	**l (Ø)**	**s**	**l**					**s**	**l**
	°C								-	wt.-%	K/s	
GBS 1	829-811	820	807-792	800	85	65	735	21	6	24	4386	540
GBS 2	858-820	839	822-821	822	102	85	737	18	4	28	45905	9276
GBS 3	847-826	837	830-822	826	95	84	742	11	7	35	31140	**12120**
GBS 4	845-830	838	812	812	96	70	742	26	5	19	30705	1983
GBS 5	833-820	827	809-808	809	95	77	732	18	9	25	20607	3258
GBS 6	829-826	828	816-799	808	91	71	737	20	12	30	14167	1773
GBS 7	823-817	820	821	821	79	80	741	-1	8	23	5890	6555
GBS 8	822-821	822	808-802	805	84	67	738	17	14	32	12681	1902
GBS 9	825-821	823	798-782	790	92	59	731	33	15	28	26626	684
GBS 10	832-827	830	821	821	94	85	736	9	10	24	18554	7606
GBS 11	824-817	821	795	795	78	52	743	26	1	26	5142	235
GBS 12	831-821	826	787	787	89	50	737	39	2	33	12635	144
GBS 13	831-787	809	787-780	784	87	62	722	26	13	13	15163	1188
GBS 14	841-835	838	793-782	788	105	55	733	51	3	21	**100000**	407
GBS 15	833-822	828	774-773	774	99	45	729	54	11	12	15814	**44**
GBS 16	774	774	768	768	52	46	722	6	16	19	**298**	133

ActiSlag

WP 1: Structure and performance of industrial GBS

TU Clausthal

HAC ➔ Cooling rates: no simple correlation with reactivity (overlapping influence of different parameters)

s: 0.355 - 0.500 mm, l: 2-4 mm

	T_f				ΔT (T_f - T_g)		T_g	ΔT_s - ΔT_l	Strength ranking	< 0.5 mm	Ø Cooling rate	
Fraction	**s**	**s (Ø)**	**l**	**l (Ø)**	**s**	**l**					**s**	**l**
	°C								-	wt.-%	K/s	
GBS 1	829-811	820	807-792	800	85	65	735	21	6	24	4386	540
GBS 2	858-820	839	822-821	822	102	85	737	18	4	28	45905	9276
GBS 3	847-826	837	830-822	826	95	84	742	11	7	35	31140	**12120**
GBS 4	845-830	838	812	812	96	70	742	26	5	19	30705	1983
GBS 5	833-820	827	809-808	809	95	77	732	18	9	25	20607	3258
GBS 6	829-826	828	816-799	808	91	71	737	20	12	30	14167	1773
GBS 7	823-817	820	821	821	79	80	741	-1	8	23	5890	6555
GBS 8	822-821	822	808-802	805	84	67	738	17	14	32	12681	1902
GBS 9	825-821	823	798-782	790	92	59	731	33	15	28	26626	684
GBS 10	832-827	830	821	821	94	85	736	9	10	24	18554	7606
GBS 11	824-817	821	795	795	78	52	743	26	1	26	5142	235
GBS 12	831-821	826	787	787	89	50	737	39	2	33	12635	144
GBS 13	831-787	809	787-780	784	87	62	722	26	13	13	15163	1188
GBS 14	841-835	838	793-782	788	105	55	733	51	3	21	**100000**	407
GBS 15	833-822	828	774-773	774	99	45	729	54	11	12	15814	**44**
GBS 16	774	774	768	768	52	46	722	6	16	19	**298**	133

ActiSlag

WP 2: Upstream activation

- Chemical modifications:
  - Main constituents (CaO, SiO_2, Al_2O_3, MgO) → "chemical" reactivity + glass content + structure
  - Minor constituents (Na_2O, K_2O) → glass structure
  - Glass modifiers (Li_2O …) → glass structure
- Cooling modifications:
  - Water volume and pressure; atmosphere → glass content + structure + enthalpy

Several granulator modifications (water volume, geometry)

→ glass content

→ grading curve

→ glass enthalpy (fictive temperature)

ArcelorMittal

ActiSlag

WP 2: Upstream activation

- Chemical modifications: - Main constituents (CaO, SiO_2, Al_2O_3, MgO) ➔ "chemical" reactivity + glass content + structure
  - Minor constituents (Na_2O, K_2O) ➔ glass structure
  - Glass modifiers (Li_2O …) ➔ glass structure
- Cooling modifications: - Water volume and pressure; atmosphere ➔ glass content + structure + enthalpy

ID	Experimental Heat.24h Heat.24h (1) J/g	Heat.24h (2) J/g	Δ %
DOE1	441.3	462.63	-4.8
DOE2	435.23	434.46	0.2
DOE3	496.63	406.58	18.1
DOE4	448.83	383.03	14.7
DOE5	412.88	410.31	0.6
DOE6	403.34	395.32	2.0
DOE7	138.49	135.96	1.8
DOE8	157.16	159.31	-1.4
DOE9	358.16	355.73	0.7
DOE10	207.68	206.47	0.6
DOE11	172.31	170.87	0.8
DOE12	117.54	138.39	-17.7
DOE13	158.07	171.67	-8.6
DOE14	115.22	141.54	-22.8
DOE15	153.32	165.98	-8.3
DOE16	116.09	133.3	-14.8
GBS	212		

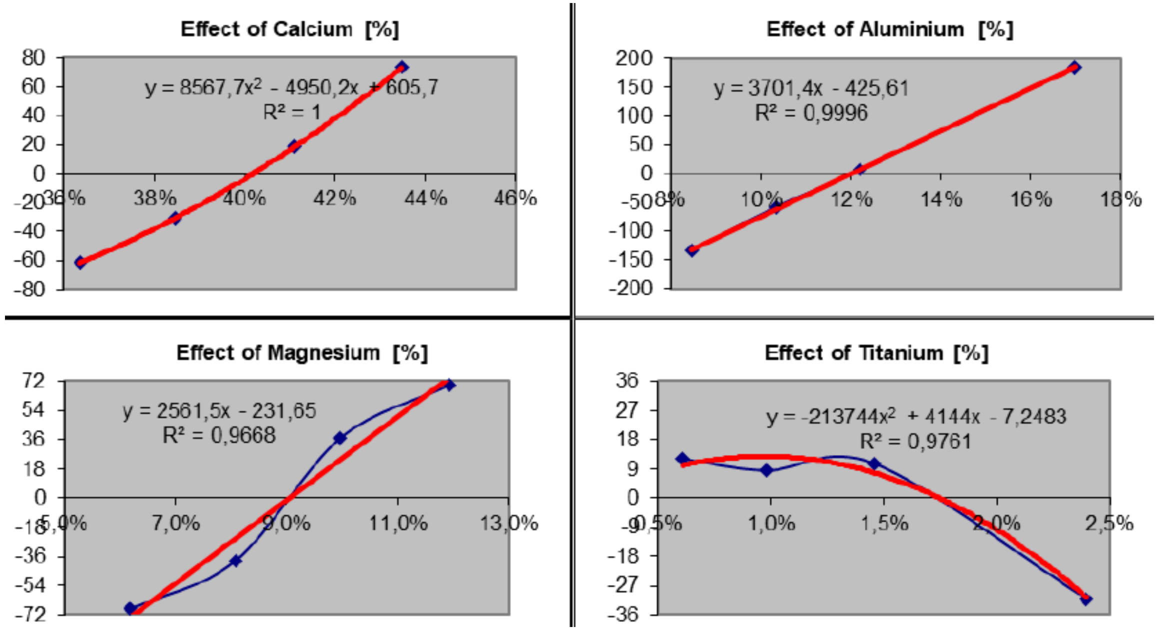
Highest heat (>2x baseline)

Baseline: GBS 3 (average of multiple re-melts)

Statistical DoE:

- Major elements:
- Silicon
- Calcium
- Aluminium
- Magnesium
- +Titanium

Lmdc toulouse



➔ confirms well-known experiences
➔ in practice overlapping influence of different constituents

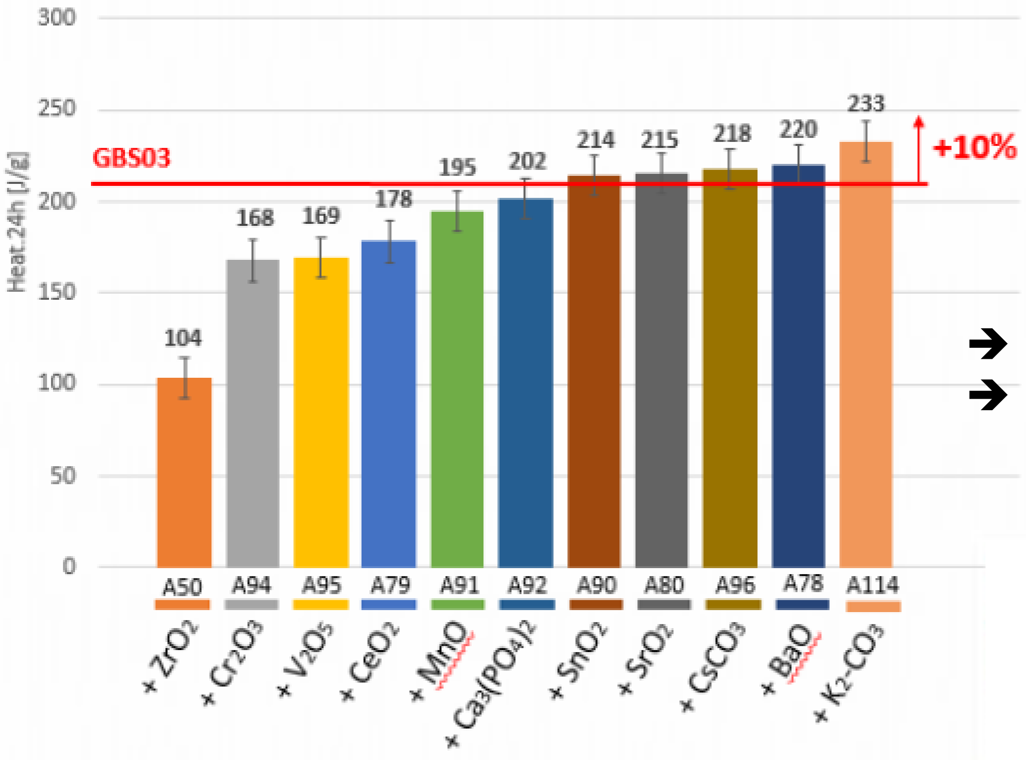
ActiSlag

WP 2: Upstream activation

- Chemical modifications:
  - Main constituents (CaO, SiO_2, Al_2O_3, MgO) ➔ "chemical" reactivity + glass content + structure
  - Minor constituents (Na_2O, K_2O) ➔ glass structure
  - Glass modifiers (Li_2O …) ➔ glass structure
- Cooling modifications:
  - Water volume and pressure; atmosphere ➔ glass content + structure + enthalpy

Sample	Addition	Concentration in slag	Heat.24h [J/g]	↑ reactivity (%)
A50	ZrO_2	5.1 %wt ZrO_2	104	-51
A94	Cr_2O_3	1.28 %wt Cr_2O_3	168	-21
A95	V_2O_5	TBA	169	-20
A79	CeO_2	1.91 %wt CeO_2	178	-16
A91	MnO	2.92 %wt MnO	195	-8
A92	$Ca_3(PO_4)_2$	1.12 %wt P_2O_5 (+1% wt CaO)	202	-5
A90	SnO_2	1.17 %wt SnO_2	214	1
A80	SrO	1.75 %wt SrO	215	1
A96	$CsCO_3$	0.173 %wt Cs_2O	218	3
A78	BaO	2.01 %wt BaO	220	4
A114	K_2CO_3	1.17 %wt K_2O	233	10

Baseline GBS03 remelted:
212 ± 11 J/g



➔ no positive effects
➔ only K_2O might be an option

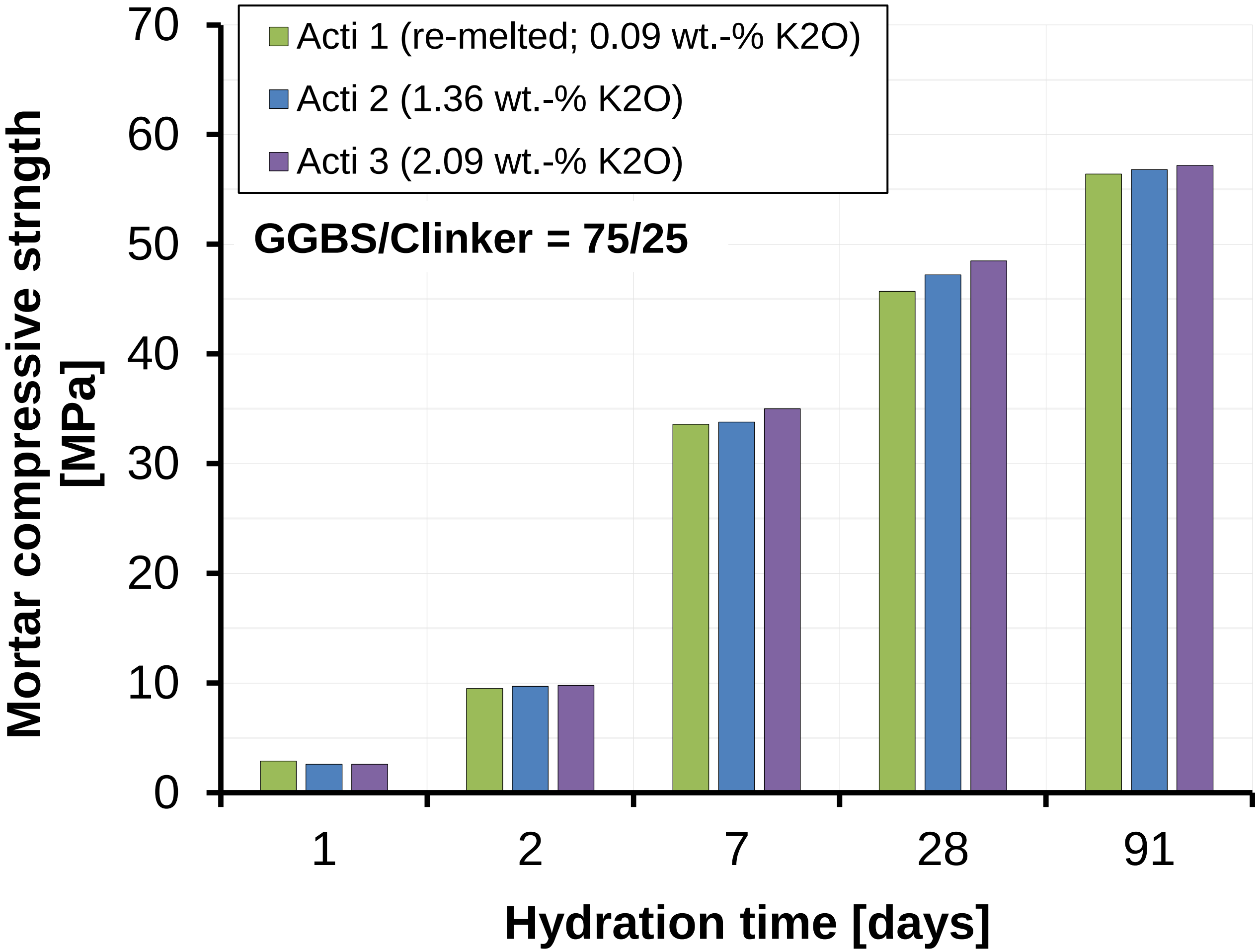
Lmdc toulouse

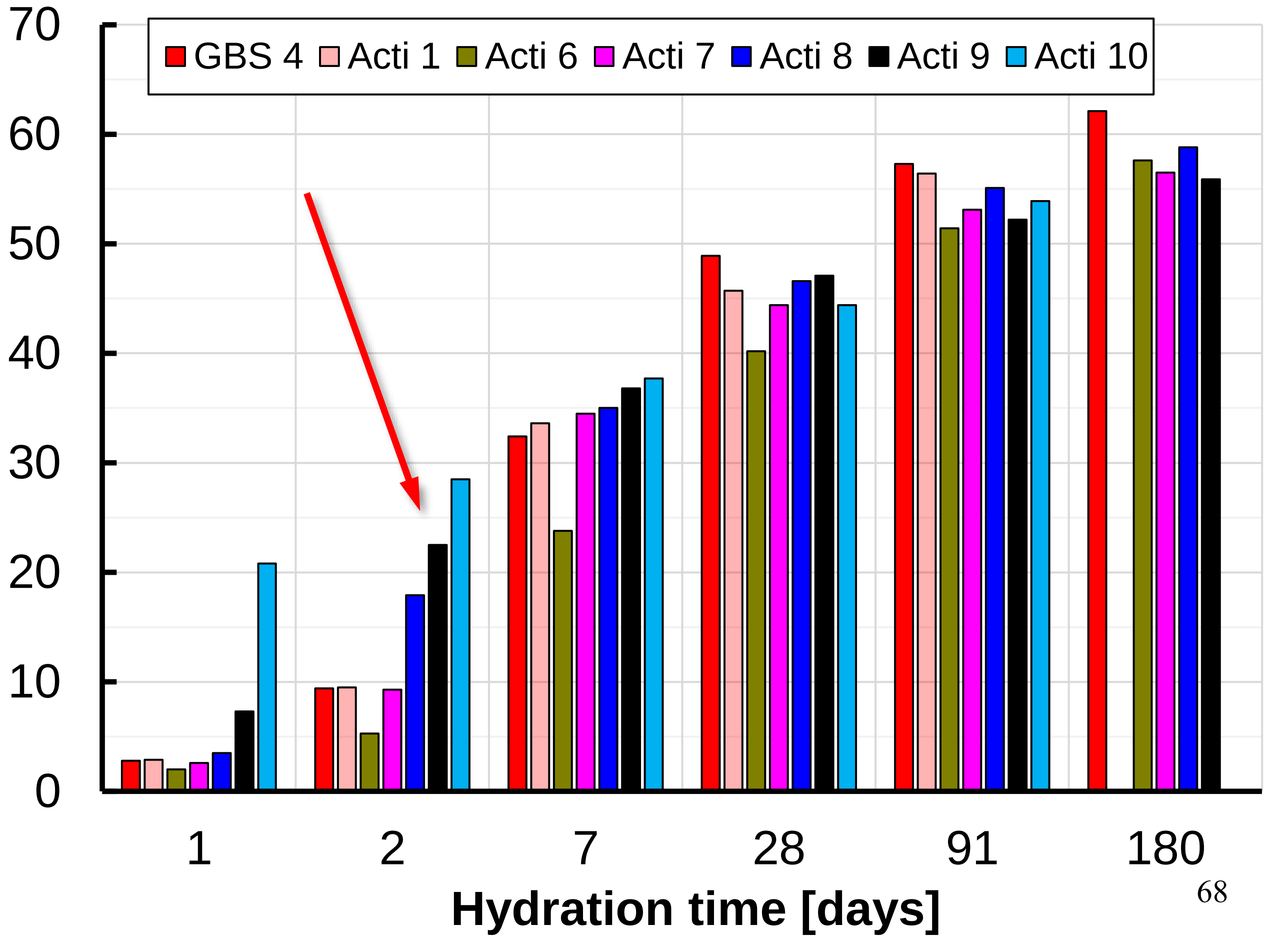
ActiSlag

WP 2: Upstream activation

INSTITUT FÜR BAUSTOFF FORSCHUNG fehs

Lab-scale granulation "Acti 1-3": Adjusting K_2O contents between ➔ Limited positive effects; high vaporisation
Lab-scale granulation "Acti 6-10": Adjusting TiO_2, MgO, Al_2O_3, combination ➔ Significant positive/negative effects

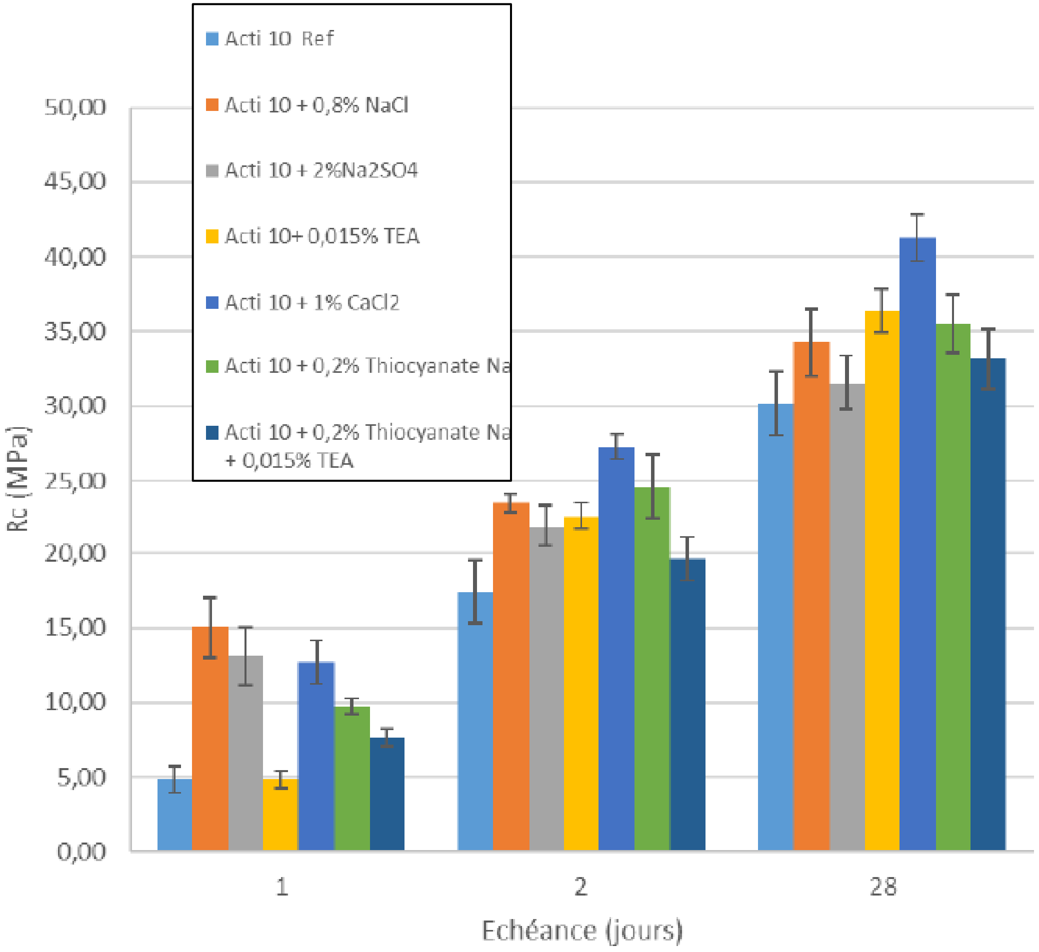




ActiSlag

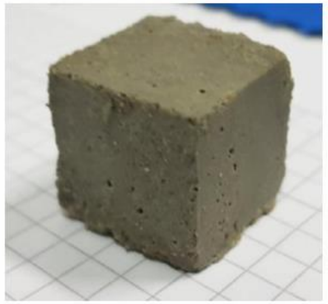
WP 3: Downstream activation

Optimized GBS + several additives ➔ Further early strength improvement



Method : 2cm*2cm*2cm mortar cubes

- 2cm * 2cm * 2 cm cubes
- Average of 6 cubes for 1 value of compressive strength
- Compressive strength at 1d, 2d, 28d
- w/b = 0.5
- GGBS/clinker = 75/25
- Clinker from LMDC (4.1 wt.-% SO_3 by adding Gypsum)



	Mass 18 cubes (g)
Cement	25.54
GGBS	76.63
Sand	306.52

Modified test protocol due to limited sample availability

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Preliminary outcome:

- Development or adoption of new test methods for GBS (HAC, Raman spectroscopy, R3 protocol)
- Well-known influence of chemical parameters confirmed, based on statistical DoE
- New informations on glass structure of GBS (NMR, Raman spectroscopy)
- New informations on thermal history of GBS (T_f vs. T_g) and its influence on reactivity
- New informations on hydrations products based on GGBS
- Potential and limits for chemical optimisation of liquid slag within or after the blast furnace (upstream)
- Recommendations for granulation process: fast cooling, small particles (upstream)
- Some recommendations for activators (downstream)

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Current activities:

- Analysis of "Acti 12", a lab-scale optimized GBS 4 (increased basicity and Alumina content, but not K_2O)
- Technical feasability and economical evaluation of upstream modifications
- LCA study of combined products (modified GBS + activators)
- Describe the negative role of TiO_2 – finalization (synchrotron analyses)
- Trials on combining modified GBS with activators (upstream & downstream modifications) → investigation of the mechanism (synchrotron analyses)
- Develop recipes for 2 products with improved early strength (concrete and tile adhesives)
- Workshop at LMDC in Toulouse (pending on pandemic situation)

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Project dissemination:

International conferences (oral & poster)	14
National conferences	2
Peer reviewed publications	4
Other publications	1

EUROSLAG 2019
10th European Slag Conference
Slag based products – best practices for Circular Economy
8th-11th October 2019
Thessaloniki, Greece
KEDEA Building, Aristotle University of Thessaloniki
Conference Proceedings

HVG-DGG
Service and Research in the Field of Glass

Cooling rate and reactivity of granulated blast furnace slag

Daniel Hart[1], Natalja Romero Sarcos[1], Hansjörg Bornhöft[1], Joachim Deubener[1], Andreas Ehrenberg[2]

[1] Institute of Non-Metallic Materials, Clausthal University of Technology, Clausthal-Z...
[2] FEhS – Institut für Baustoff-Forschung e.V., Duisburg

STUDY OF THE KINETICS OF HYDRATION OF INDUSTRIAL GRANULATED BLAST FURNACE SLAGS: A STRUCTURAL INVESTIGATION

Abel DANEZAN[1], Franck FAYON[2], Cécile GENEVOIS[1], Emmanuel VERON[1], Mathieu ALLIX[1], Catherine BESSADA[1], Simon BLOTEVOGEL[2], Laurent STEGER[2,3], Cédric PATAPY[2], Martin CYR[2], Judit KAKNICS[4], Valérie MONTOUILLOUT[1]

[1] CNRS, CEMHTI, 1D avenue de la Recherche Scientifique, 45071 Orléans Cedex 2, France
[2] LMDC, Université de Toulouse, INSA, UPS, Génie Civil, 135 Avenue de Rangueil, 31077 Toulouse Cedex 04, France
[3] ECOCEM Materials Ltd., 4 place Louis Armand, 75012 Paris, France
[4] ArcelorMittal Global Research and Development (Maizières Process), ArcelorMittal Maizières Research, Voie Romaine, BP 30320 – 57283 Maizières-lès-Metz Cedex, France
abel.danezan@cnrs-orleans.fr, valerie.montouillout@cnrs-orleans.fr

Cement and Concrete Research 130 (2020) 105998
Contents lists available at ScienceDirect
Cement and Concrete Research
journal homepage: www.elsevier.com/locate/cemconres
ELSEVIER

Ability of the R3 test to evaluate differences in early age reactivity of 16 industrial ground granulated blast furnace slags (GGBS)

Simon Blotevogel[a,*], Andreas Ehrenberg[b], Laurent Steger[a,c], Lola Doussang[c], Judit Kaknics[d], Cedric Patapy[a], Martin Cyr[a]

ActiSlag

New activation routes for early strength development of granulated blast furnace slag

Thank you for your interest!

ArcelorMittal

INSTITUT FÜR BAUSTOFF FORSCHUNG fehs

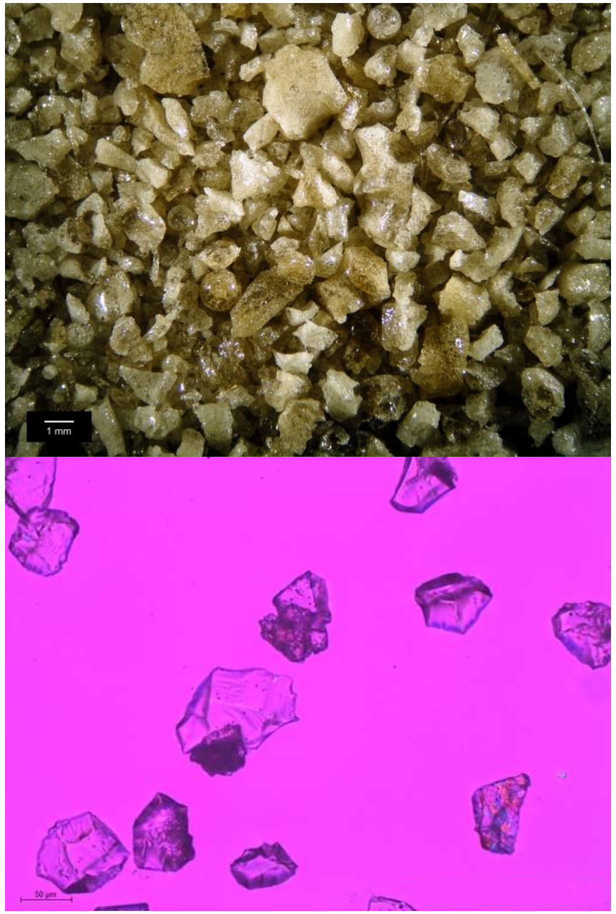
Lmdc toulouse

ecocem

TU Clausthal

Cemhti

GBS 14



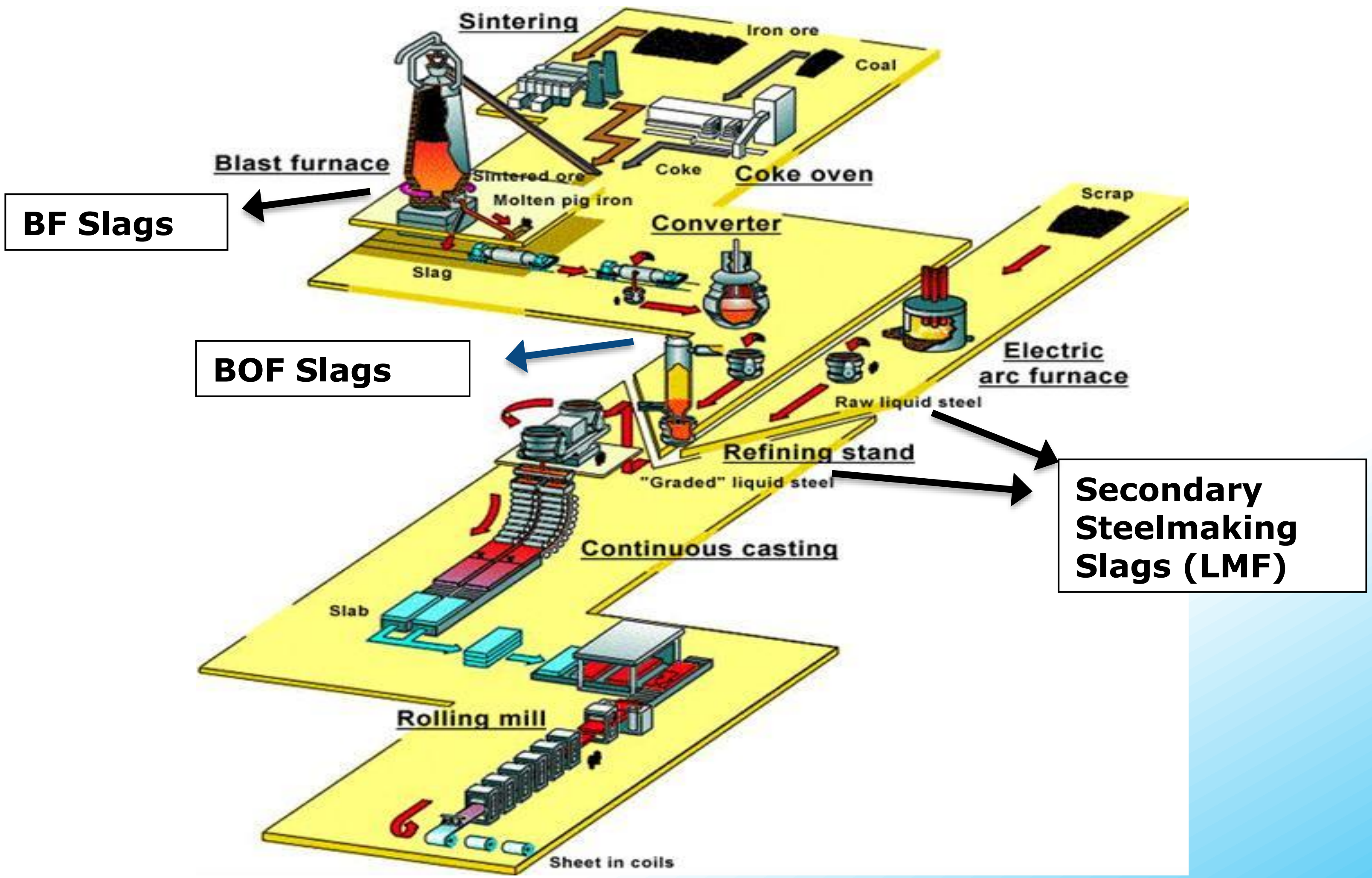


ESTEP Workshop
REUSSTEEL
Slag as a fertilizer with respect to current EU regulations

16. June 2021

Uwe Pihl – FEhS-Building material Institute, Germany

Suitable slags for fertilizers in the steelmaking production process

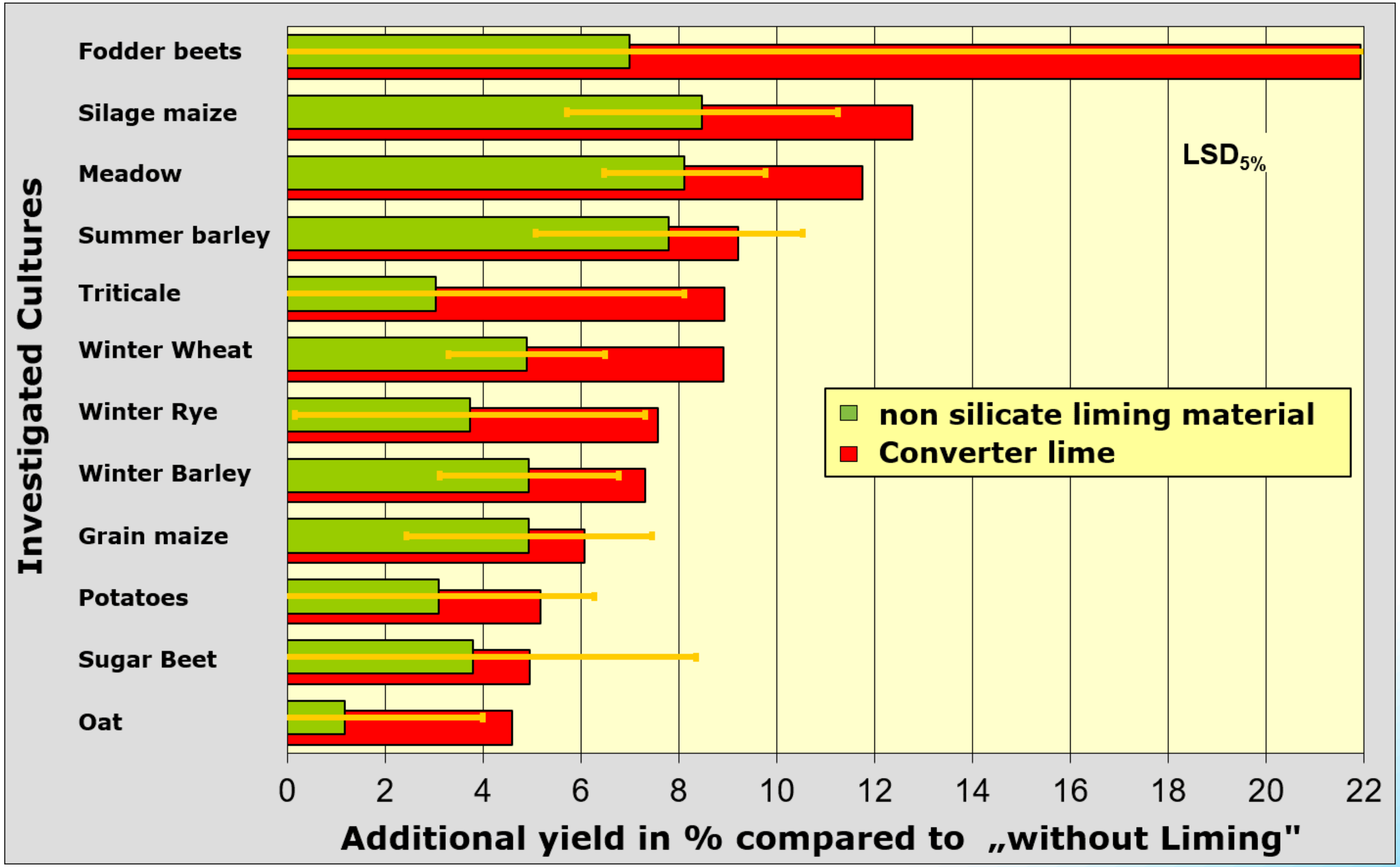


Ingredients and benefits of slag-based fertilizer as liming materials

- **Usually the fine fraction (0 - 3 mm) of self disintegrated slags are used.**
- **The slags is used in humid regions as a lime fertilizer to stabilize the pH value in soils and to maintain soil fertility.**

Essential Components	Content in %	Benefit and characteristics
Basic constituent (CaO)	35 – 50	Correcting soil acidity and essentially plant nutrient. Mainly in a silicate based lime form.
Magnesium (MgO)	up to 8	Basic constituent for correcting soil acidity and essentially plant nutrient.
Phosphate (P_2O_5)	up to 1,5	Essentially plant nutrient
reactive silicic acid	9 – 20	Supports yield, quality and health, soil structure, higher efficiency of other fertilizers
Trace elements: manganese, boron, copper, zinc, cobalt, selenium, molybdenum	2 – 3	Additional supply with essential micro nutrients for plants

Effect of different forms lime fertilizer on the yields of various arable crops



Short Summary

Efficient valorization of the fine fraction (0 - 3 mm) of certain steelmaking slags as (lime)fertilizer

Effects on soil acidity

- The use of BF, converter and ladle slags as agricultural liming materials resulted in significant increases of soil pH value, comparable with the effects of carbonate limestone and burnt lime or other liming materials of natural origin.

Effects on crop yields

- The long-term use of BF, converter and ladle slags always resulted in highest yields of crops with partly remarkable profits compared to treatments with liming materials of natural origin.

History and current regulatory status in using slag-based fertilizer

- Thomas phosphate as a by-product from the steel making process up to end of the 90´s last century was the most common phosphorus fertilizer.
- Is up to now still listed in the EU fertilizer regulation EU 2003/2003 and EU 2018/848 (for biological farming).
- The currently occurring slag material flows actual are not listed in any EU regulations. Efforts were made in 2013 to be included in the EU in 2003/2003 together with the other lime fertilizers. This was blocked by some member states at the time, referring to the lack of regulations for contaminants in the ordinance.
- Currently it is possible to bring slag-based fertilizer into the market:
  - ➢ On national level under the national fertilizer regulations (if allowed)
  - ➢ Mutual recognition EU 2019/515

New Fertilizer Products regulation - Mind switch:

The regulation EU 2019/1009 will replace the currently valid regulation EU 2003/2003 in mid-2022.

The national fertilizer regulations should remain in parallel.

Efforts are currently being made by FEhS/EUROSLAG/EUROFER to incorporate suitable substances (with reference to the EN standard 14069) into the new EU fertilizer regulation EU 2019/1009.

In the future on EU level the fertilizer products can come into the market only as CE marked products.

All used materials and products have to belong to a:

- Component Material Category (CMC)
- Product Function Category (PFC)
- Conformity assessment necessary

Component material Categories for by-products (CMC 11) in the new fertilizing products regulation (FPR) EU 2019/1009

- The EU Commission has commissioned the Joint Research Center (JRC) to develop proposals for suitable materials for the Component Material Category CMC 11 "by-products".
- In the next 2 years, suitable substances are to be defined and the necessary requirements with regard to effectiveness and safety are to be developed in cooperation with the "Commission Expert Group on Fertilizing Products".
- The basis for consideration are:
  - ✓ The materials must be registered for use as fertilizers in accordance with Section 5 of the European Waste Framework Directive 2008/98/EG and in accordance with Regulation (EC) No 1907/2006 (REACH).
  - ✓ The substances must meet the criteria for efficacy and safety that the JRC is currently working on: Concerns are expressed here about accompanying substances in slags such as Chromium/Vanadium in the slag (accumulation in soils).
- For defined fertilizer steelmaking slags, the CMC 11 offers the potential opportunity to get into the legal framework of the regulation.

Previous research projects and necessary research needs in the context of slag-based fertilizer

Previous research projects linked to fertilizer application

- RFCS Contract 7210-PR/267: Sustainable agriculture using blast furnace and steel slags as liming agents, 2004
- RFSR-CT-2011-00037 SLAGFERTILISER: Impact of long-term application of blast furnace and steel slags as liming materials on soil fertility, crop yields and plant health, 2015
- RFSP-CT-2009-00028, SLASORB, Using Slag as Sorbent to remove Phosphorus from Wastewater, June 2014
- RFSR-CT-201300032 PSP-BOF: Removal of phosphorus from BOF-slag, December 2016

Diverse research work on national level in Germany (Thomas-Dünger AG, AG Hüttenkalk, FEhS-Institute)

Research needs in the segment “fertilizer”

- What are the current barriers to use steel slag as fertilizer?
  - ➢ Production process; separation, preparation of suitable slags
  - ➢ Legal aspects (national, EU-Level)
- Research into evidence of the benefits, the unique selling points (silicic acid)
- Research into evidence of ecotoxicological harmlessness of these products in long-term use
  - ➢ for example, long-time behavior of unwanted substances like Chromium/Vanadium-compound in the environment.

RFCS project planned: “AGRISlag”: Advancement in agriculture of steel slag use through examination of current barriers and effects of these products.

Thank you for your kind attention!

Uwe Pihl: u.pihl@fehs.de

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

Slag as a fertilizer with respect to the Italian situation

Teresa Annunziata, Branca – Scuola Superiore Sant'Anna

Research Fund for Coal & Steel

Webinar on Slag (14.06.2021, Day 1)

Content

- Current Italian regulations
- Background
- Case study #1
- Case study #2
- Conclusions

Current Italian regulations

- Italian legislation: slag is a waste (not dangerous), which must be managed according to the *Italian Ministerial Decree 186/2006 (updating the Annex 3 of the Italian Ministerial Decree 05/02/98)*. For instance, BOF slag as a non-dangerous waste can be recycled in the quarries, but it could be a by-product for other uses.

- The identification of the material as a by-product must meet characteristics defined in the *Legislative Decree No 205/10, art.12*, transposed in *Legislative Decree No 152/06 at art. 184-bis, para 1*:
  "It is a by-product and not a waste in compliance with article 183, para 1, letter a), any substance or object that fulfils the following requirements:
  1. *the substance or object is produced as an integral part of a production process, the primary purpose of which is not the production of that item;*
  2. *it is certain that the substance or object will be used, during the same or a subsequent production process, by the manufacturer or a third party;*
  3. *the substance or object may be used directly without any further treatment other than normal industrial practice;*
  4. *further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts".*

- In order to define a residue as by-product, a recent Italian law (*Law n.128 of 02 November 2019, published in the Official Gazette No. 257 of 2/11/19, modification of art. 184-ter D. Lgs 152/2006*) provides criteria to be satisfied for using it as raw material.

Background

❖ **Northern Europe**:

Slag as liming agent or fertilizer is allowed for increasing soil pH, phosphate availability and as a silicon source or to provide calcium, magnesium, copper, zinc, boron and cobalt.

❖ **Italy**:

Soils are mainly alkaline, and in coastal areas there is excess of salt and exchangeable sodium (Na^+):

- saline intrusion in coastal aquifers;
- irrigation with saline water.

→ dispersion of soil

→ reduction of the bioavailability of other plant nutrients (e.g. Calcium, Magnesium).

Case study #1
Soil Column Tests [1]

❖ Assessing the application of BOF slag as fertilizer, in 2 typical Mediterranean soils (loamy and sandy): low organic matter content and alkaline reaction.

❖ Two slag fractions: before magnetic separation (S) and after magnetic separation (SFe), both of size of < 1mm.

[1] Removal of Phosphorus from BOF-slag (PSP-BOF) Final report. Grant Agreement RFSR-CT-2013-00032 (01/07/2013 – 31/12/2016). Available on: https://op.europa.eu/en/publication-detail/-/publication/cd7e0571-22af-11e9-8d04-01aa75ed71a1/language-en/format-PDF/source-165557998#

Case study #1

Soil Column Tests - Conclusions [1]

- BOF slag contributed to enhance the available P content in the top soil.
- No significant difference observed between the 2 fractions of slag.
- Sandy soil: BOF slag application increased the soil Electrical Conductivity, but below critical thresholds.
- Loamy soil (richer in soil organic matter): BOF slag allowed to increase the Cation Exchange Capacity, enhancing the nutrients retention capacity of the soil

→ positive effect on soil fertility and groundwater protection from cation overloading.

[1] Removal of Phosphorus from BOF-slag (PSP-BOF) Final report. Grant Agreement RFSR-CT-2013-00032 (01/07/2013 – 31/12/2016). Available on: https://op.europa.eu/en/publication-detail/-/publication/cd7e0571-22af-11e9-8d04-01aa75ed71a1/language-en/format-PDF/source-165557998#

Case study #2
Application of Basic Oxygen Furnace slag to saline sodic soils

Three-year Lysimeter tests performed in Italy using BOF slag [2]

Assessing the potential ability of BOF slag in reducing the soil sodicity to investigate:

- the potential of two different BOF slag doses in decreasing the exchangeable sodium content of saline sodic soil irrigate with saline water;
- the potential effect on tomato growth and productivity in comparison with untreated controls;

[2] Impact of long-term application of blast furnace and steel slags as liming materials on soil fertility, crop yields and plant health (SLAGFERTILISER), Final Report, Grant Agreement RFSR-CT-2011-00037 (1 July 2011 to 30 June 2015). Available on: https://op.europa.eu/en/publication-detail/-/publication/af62312a-024b-11e7-8a35-01aa75ed71a1/language-en/format-PDF/source-174834003

Case study #2

Application of Basic Oxygen Furnace slag to saline sodic soils - Conclusions

After 28 months of treatment with BOF slag application → Exchangeable Sodium Percentage (ESP) reduction, due to the increased leaching of Na^{+} :

- D1: ESP was reduced by 87%
- D2: ESP was reduced by 90%
- compared to a reduction of 62% in D0 (leaching effect of rainfall)

Effect of slag: the competition of Ca^{++} supplied with the slag for the sorption sites in the soil

Result: higher tomato yield

Conclusions

- The encouraging results can be a first step for the future use of BOF slag in agriculture and to find alternative uses of BOF slag.

- The achieved results can provide guidelines for legislators. This would also help not only for a future Italian legislation but also for more uniform regulations in Europe about slag use.

References

- Branca, T. A., Fornai, B., Colla, V., Pistocchi, C., & Ragaglini, G. (2019). APPLICATION OF BASIC OXYGEN FURNACE (BOFS) IN AGRICULTURE: A STUDY ON THE ECONOMIC VIABILITY AND EFFECTS ON THE SOIL. Environmental Engineering & Management Journal (EEMJ), 18(6).
- Pistocchi, C., Ragaglini, G., Colla, V., Branca, T. A., Tozzini, C., & Romaniello, L. (2017). Exchangeable Sodium Percentage decrease in saline sodic soil after Basic Oxygen Furnace Slag application in a lysimeter trial. Journal of environmental management, 203, 896-906.
- T.A. Branca, C. Pistocchi, V. Colla, G. Ragaglini, C. Tozzini, D. Mudersbach, A. Morillon, M. Rex, L. Romaniello, "Investigation of (BOF) converter slag use for agriculture in Europe", Metallurgical Research Technology, Vol. 111, 2014, pp. 155-167.
- C. Pistocchi, G. Ragaglini, T. A. Branca, E. Bonari, and V. Colla, “Use of BOF steel slag in agriculture: column test evaluation of effects on alkaline soils and drainage water”. In Proc. of the 7th Conference on Sustainable Development of Energy, Water and Environment Systems, July 1-7, 2012, Ohirid, Republic of Macedonia.

thank you!

e-mail:
teresa.branca@santannapisa.it

www.ict-coisp.it

Short instruction of Dr. Guozhu Ye

- Chief Metallurgist
- Specialist in Thermochemist/pyrometallurgy and Pilot palnt R&D
- >30 years experiences in applying pyrometallurgy for development of new recycling processes;
- Senior expert on slag metallurgy, slag processing and battery recycling
- Executive project manager of the IPBM project

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

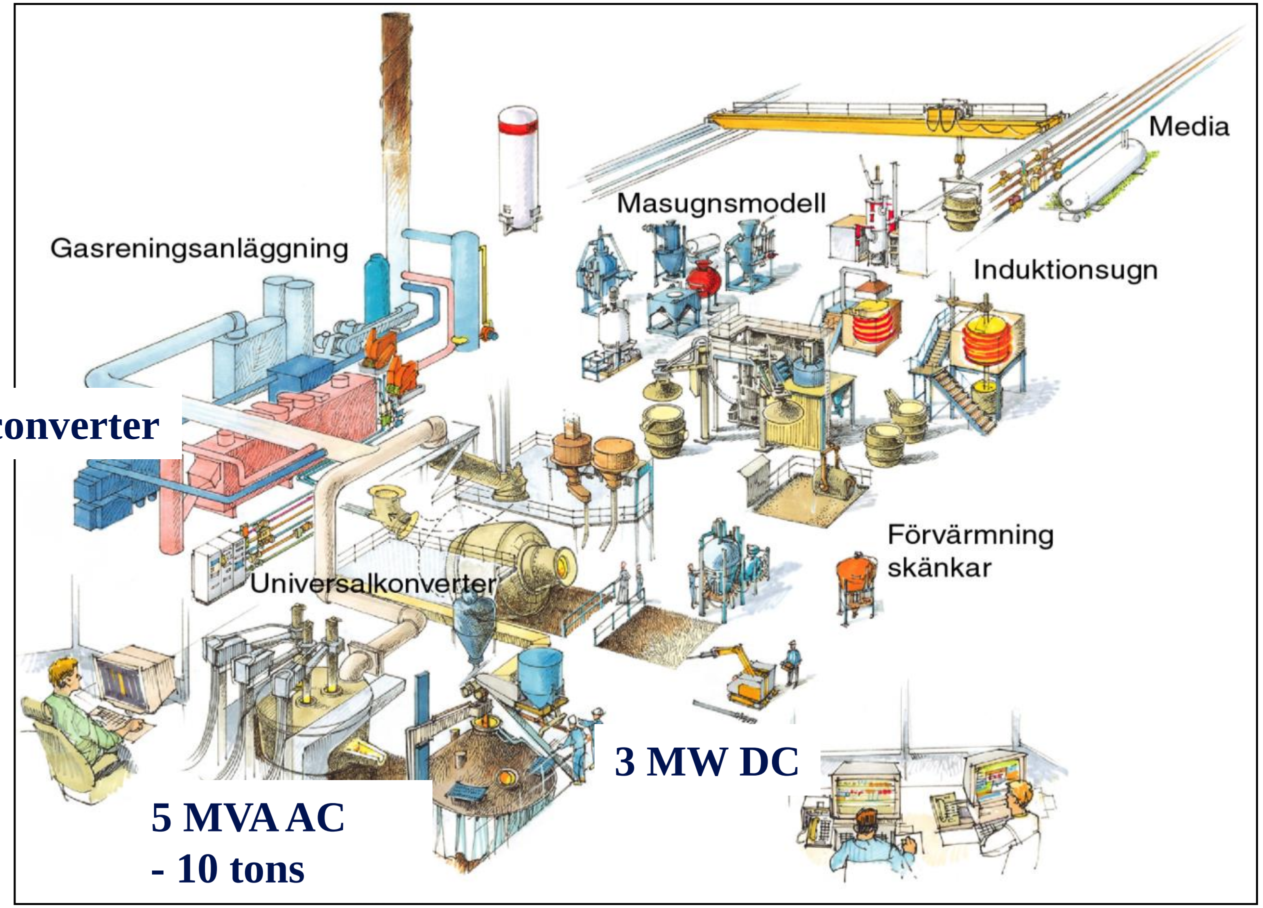
Recovery of Valuables from Steel Slag and Other Residues – IPBM and Other Pilot Experiences

Guozhu, YE – Swerim; guozhu.ye@swerim.se

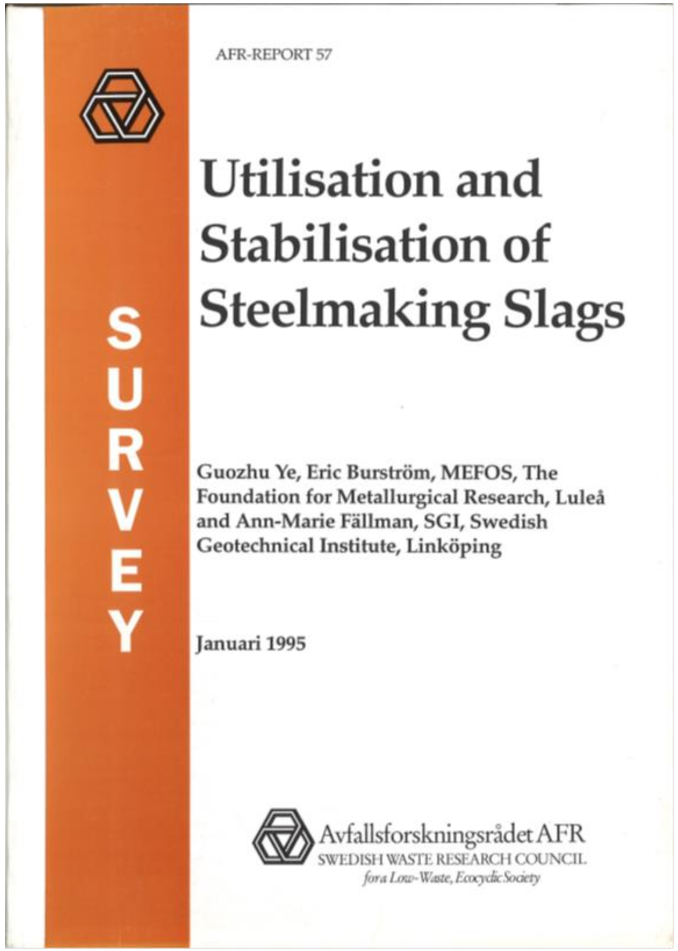
Content

- The IPBM Project
- VILD – Recovery of vanadium from Swedish BOF-slag
- IPBM II -REWA
- IPX – NSC
- Other recent international slag projects
- Waste as slag formers

Swerim Pilot Plant



Steel slag research in Sweden


AFR-REPORT 57

Utilisation and Stabilisation of Steelmaking Slags

SURVEY

Guozhu Ye, Eric Burström, MEFOS, The Foundation for Metallurgical Research, Luleå and Ann-Marie Fällman, SGI, Swedish Geotechnical Institute, Linköping

Januari 1995

Avfallsforskningsrådet AFR
SWEDISH WASTE RESEARCH COUNCIL
for a Low-Waste, Ecocyclic Society

>25 years ago

- Trip to Japan: Prof. Suito, Prof. Iwasa and steelplants Japan
- Tarco AS Denmark
- FEhS (Prof Geiselser &Dr. Kuhn)
- Slag seminar Sweden

State of the art 1993

- **Free lime – volume stability**
- **Leaching of heavy metal Cr etc**
- **Phase transformation of the C2S, B-stabilization, ladle and AOD-slag**
- C2S/C3P2 separation from LD-slag
- Air granulation for heat recovery

Why slag reduction?

Slag might cost voestalpine millions of Euros

March 6, 2013 - By Charlotte Stubben

If slag no longer rated as building material but as waste, voestalpine will need to pay EUR 30 million for its disposal.

Metal Supply

The company is also facing back payments to the rehabilitation of inherited waste fund of up to EUR 150 million.

The planned innovation is based on a study of the Environmental Umbrella Association. The study shows that LD-slag is dangerous to health. According to previous information, the material had, however, been examined several times and was rated harmless.

The environmental compatibility was also tested by the EU commission within the framework of the Chemicals Act, which allows the use of slag as a by-product.

Södermanlands NYHETER

Nr 179 97:e årg. Måndagen den 6 augusti 1990 Pris 4:50

Giftig kalk dödade 24 kor

I Oxelösund säljs 20 000 ton om året

Den kalk, innehållande det giftiga grundämnet vanadin, som påstås ha dödat 24 kor i Norrland säljs också av SSAB i Oxelösund.

Det är Odal som handlar in ungefär 20 000 ton kalk årligen och säljer till jordbrukarna i bl a Sörmland.

– Men jag begriper inte hur den här förgiftningen har gått till. Korna måste ha fått i sig enorma mängder kalk för att bli vanadinförgiftade, säger Bo Svahn – chef för SSAB:s dotterbolag Merox i

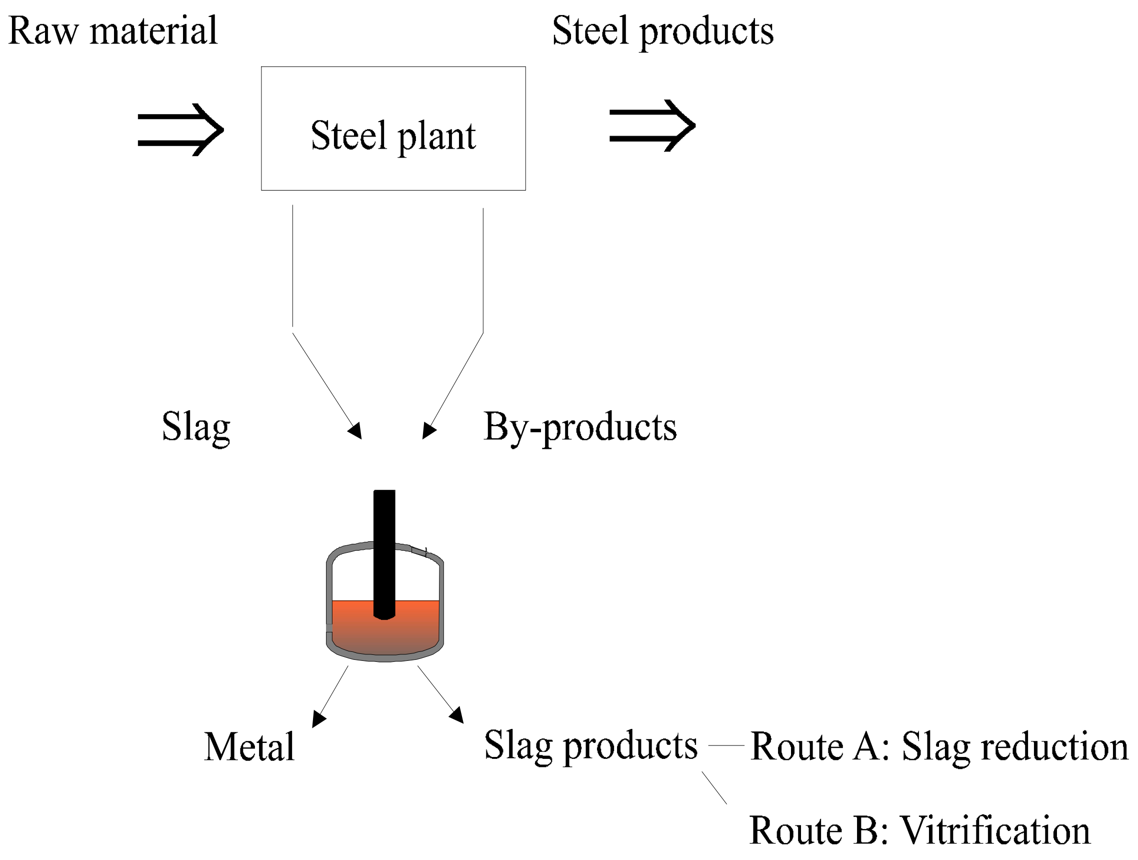
24 kor i Norrland dog sedan de genom kalk fått i sig det giftiga grundämnet vanadin. Kalken har använts som jordförbättringsmedel, och även i Sörmland används samma typ av kalk.

Kalken är heller inte avsedd som djurfoder utan som jordförbättringsmedel.

– Och kalk innehållande vanadin har använts 100 år, utan några förgiftningar, säger Bo Svahn.

- Clean Slag/New market, value-added, flexible
- Regulations, lower limits, accidents and acceptance

The IPBM Project (1995-98): In-Plant Byproduct Melting

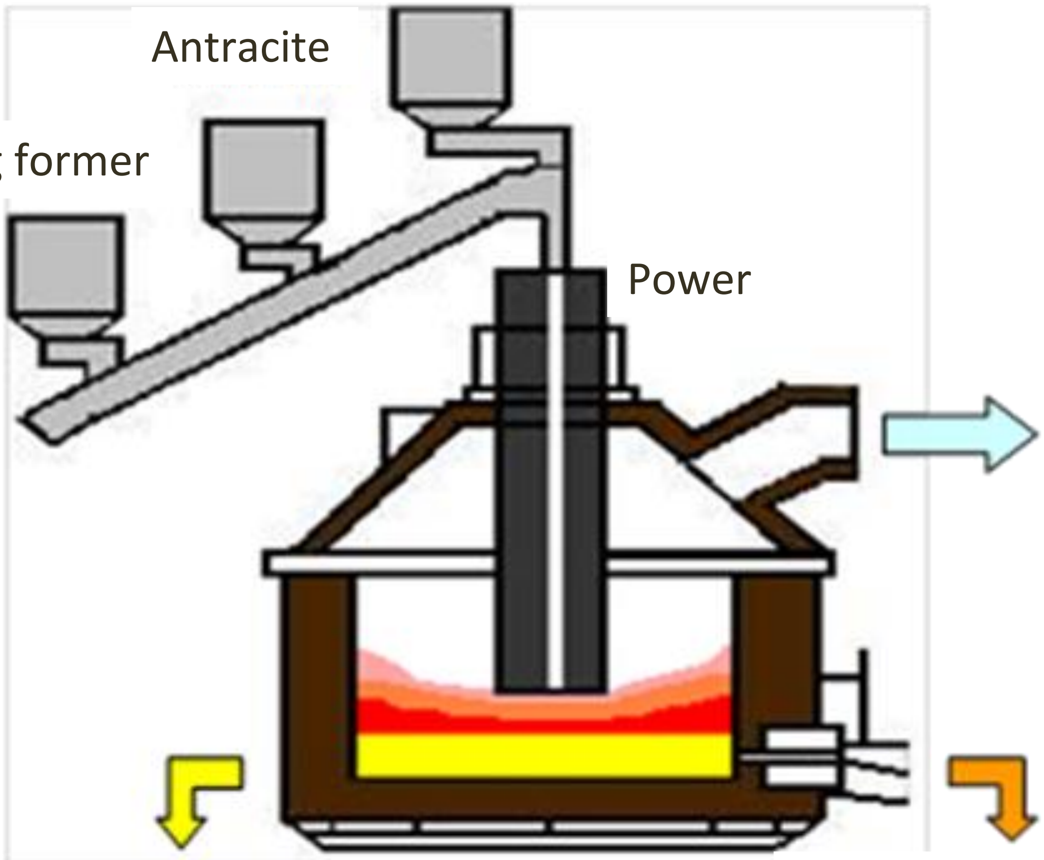


- Stand-alone
- All in one
- Metal recovery
- Clean slag products
- Zero waste

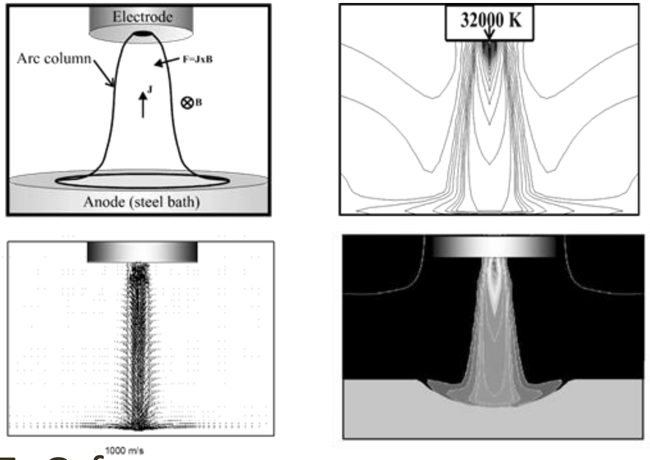
MEFOS(Swerim)-FEhS-CRM-CSM

Concept flowsheet - IPBM

Slag, millscale, dust etc



ZnO-fume



Metal (Fe, Mn, Ni, Cr, V)
About 250 kg/LD-slag

Slag products
Ca 1 ton/ton LD-slag

1. **Clinker material**
2.
3.

Water granulated glassy slag | Calcium aluminate powder

Materials treated in the IPBM project and later the ETEUSCE project (*Brite-EURAM; 1998-2000*)

Steel work resdiues

- ***BOF-slag with high VOx***
- ***Normal BOF-slag***
- ***EAF- and AOD-slag***
- BOF-dust/sludge
- BF-dust/sludge
- EAF-dust from carbon steel making
- EAF-dust from SS
- Millscale
- Pickling sludge

Other residues

- V- and C- rich ashes from power plant
- Fayalite slag from copper smelter (FeO/SiO2)
- Bauxite (low quality, iron rich)
- Scrap residue from scrap transportation and handling

Major Results: Easy to control

Test no	Product	Slag modifier		Fe	CaO	SiO_2	MnO	P_2O_5	Al_2O_3	MgO	Cr_2O_3
1	Clinker material	Sand, Bauxite	Target From test	3.7 4-3	62-66 54.7	20-21 20.8	 3.5	 2.2	4.7 6.9	<5 2.2	 0.24
2	Metallurgical powder	Bauxite	Target From test	<2 0.35	50-55 56.6	16 19.6	 1.18	 0.2	22 21.9	2-10 2.85	 0.03
3	Metallurgical powder	Bauxite	Target From test	<2 0.3	50-55 54.2	 13.6	 1.75	 0.47	25-30 27.3	2-10 1.81	 0.03
4	Hydraulic binder	Scrap residue Bauxite	Target From test	<2 1.81	45 41.8	33 31.5	 51.7	 0.06	14 17.3	2.5 4.41	 0.08
5	Hydraulic binder	Scrap residue Bauxite	Target From test	<2 0.45	45 44.5	33 34.4	 0.93	 0.04	14 14.0	2.5 4.41	 0.04
-	BOF-slag analysis	-	-	18.4	51.0	11.3	3.67	2.56	1.60	1.20	-

BOF-slag from AM, Gent, Belgium

Major Results

Specific figures

- DC-power: 1.3 MWh/ton slag
- Anthracite: 130 kg anthracite/ton
- Graphite electrode: 2-3 kg

Metal recovery

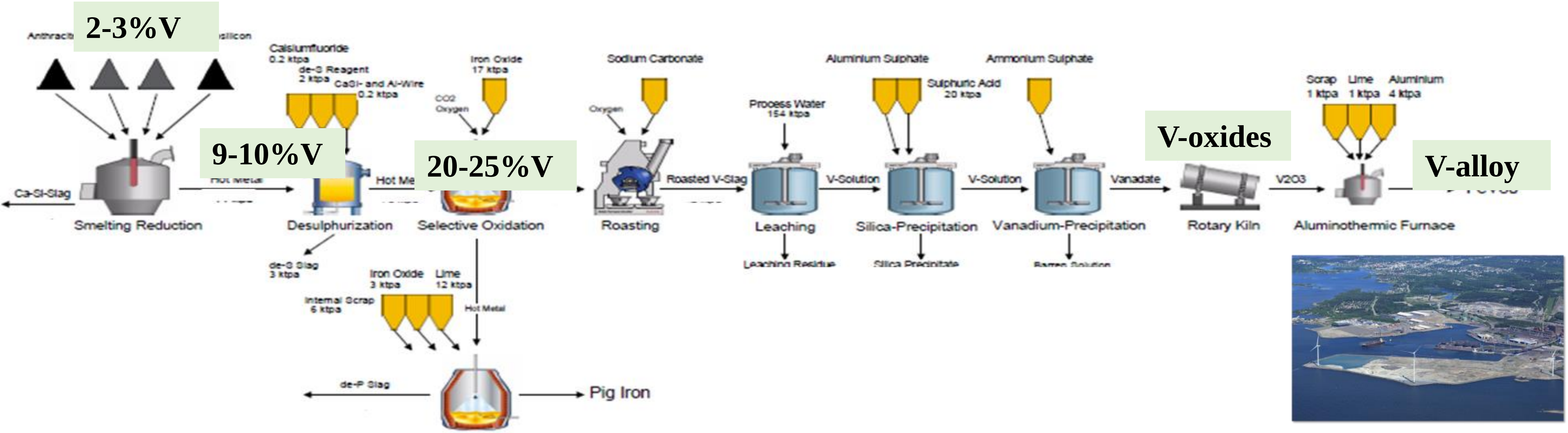
V: 85%

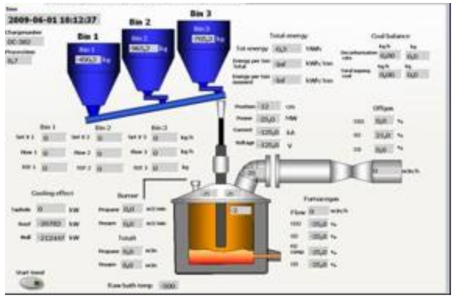
Cr: 99% (0.02%Cr in the slag)

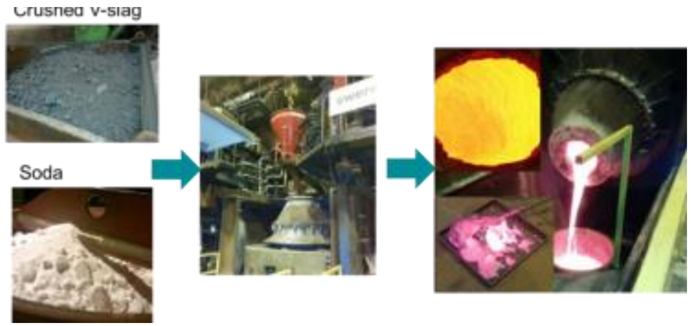
Ni and Mo: close to 100%

***Scandinavia Journal of Metallurgy: probably the most referred slag reduction project**

Recovery of V from Nordic Steel Slag: IPBM-VILD-Clean Slag/ Ferrovan

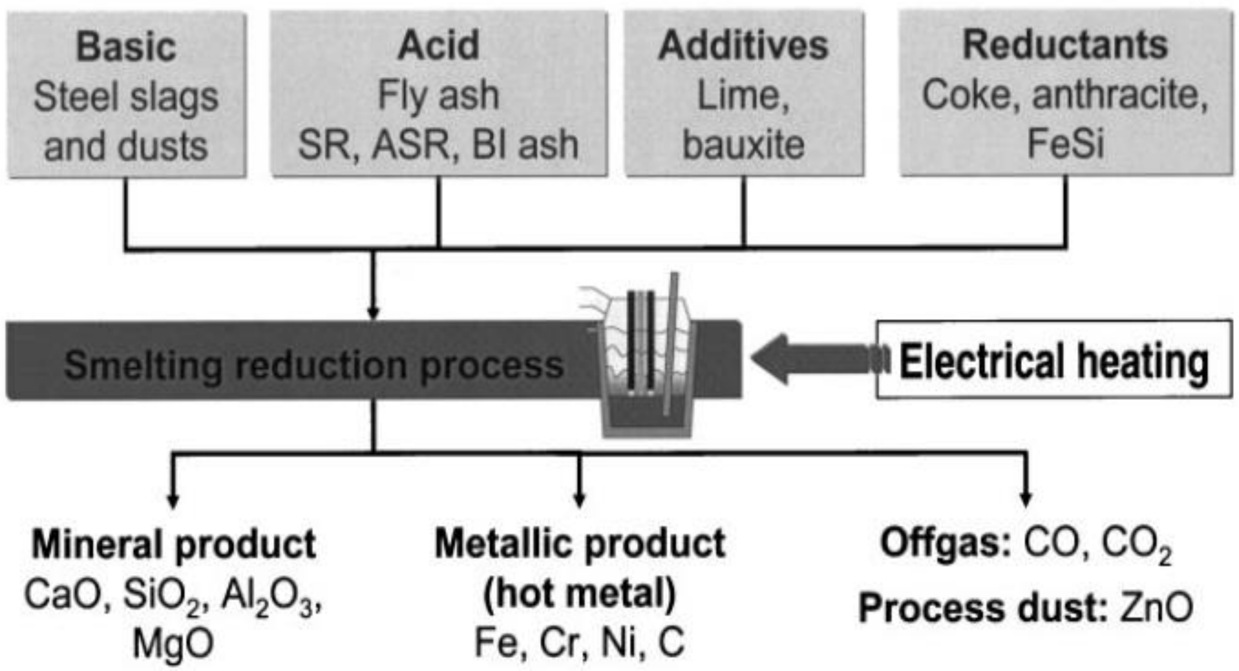


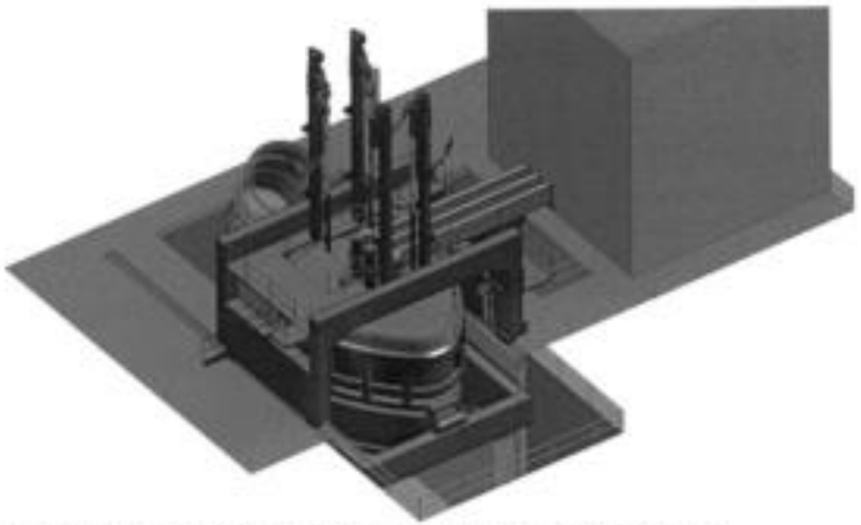




IPBM II –ZEWA (00-2004; CRM-VAI etc)

Smelting reduction of suitable blends of by-products

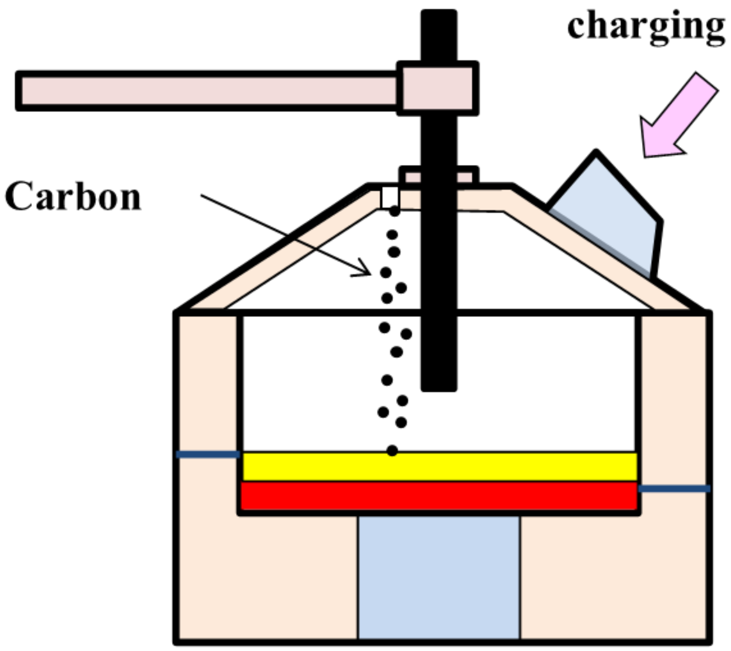




8 Three-dimensional representation of industrial-scale ZEWA rector

Total 160 000 ton LD-slag + 90 000 ton dusts, 45 M€

IPX-process (2009, Japan)



1

MEFOS直流還元電気炉を用いた製鋼スラグの還元試験

Reduction experiments of the steelmaking slag using DC smelting arc furnace at MEFOS

新日鐵住金㈱ プロセス研究所 原田俊哉、平田浩
設備・保全技術センター 新井貴士
先端技術研究所 藤健彦
SWEREA MEFOS Guozhu.Ye、 M.Lindvall

日本鉄鋼協会第168回 秋季大会 2014年9月24日

新日鐵住金 NIPPON STEEL & SUMITOMO METAL

What have been learnt?

Electric Arc furnaces (DC/AC)

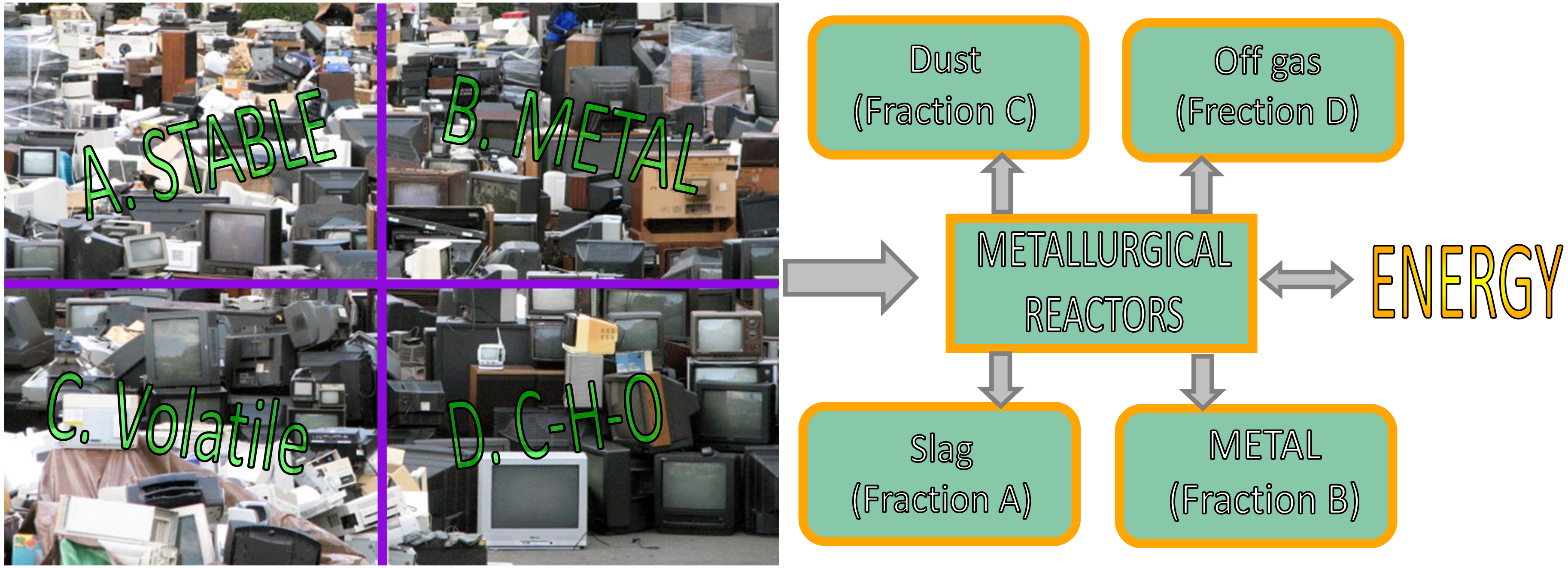
- High selectivity in reduction degree and in the "to be treated" materials
- High accuracy in control of the final slag composition
- Rapid response time of important process parameters such as energy consumption rate and reduction efficiency
- High energy efficiency

Other important issues/drivers

- Metal price including Fe-ore price
- CaO-potential (CO2)
- Circular economy

- **IPBM has inspired many SR porjects**
- **Scandinavia Journal of Metallurgy: probably the most referred slag reduction project**

Metallurgical processes for recycling?



A: CaO, SiO2, Al2O3, MgO

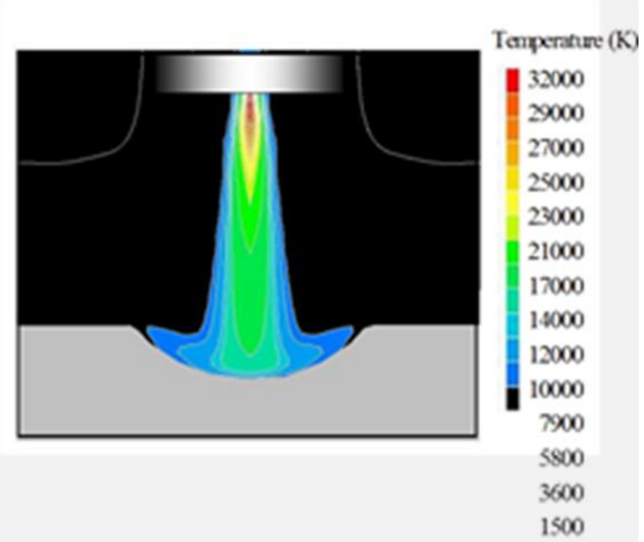
B: NiO, FeO, MnO, V2O3, Cr2O3, P2O5,Cu, Co, Mo

C: ZnO, PbO, Na, K, Cl, Cd, Hg

D: C-H-O, plastics/textile/fluff

Pilot trials with DC furnace technology

- **Dust/Sludge** → Fe, Ni, Cr; Zn, Pb, Cd; Slag cement
- **Steel slags** → Fe, Mn, V, Ni, Cr; Slag cement
- **Catalyst** → Fe, Ni, Cu, Co; V-slag for FeV production
- **Ashes** → Na, K rich fume; Slag product → Road construction
- **Sludge** → Syngas; Slag product
- **Mn-Sludge** → Zn, Na, K rich dust; Mn-slag for FeMn/SiMn production
- **Alkaline batteries** → Zn for zinc production; Mn for FeMn production
- **Nonferrous slags/dusts** → Ni recovery; Slag cement

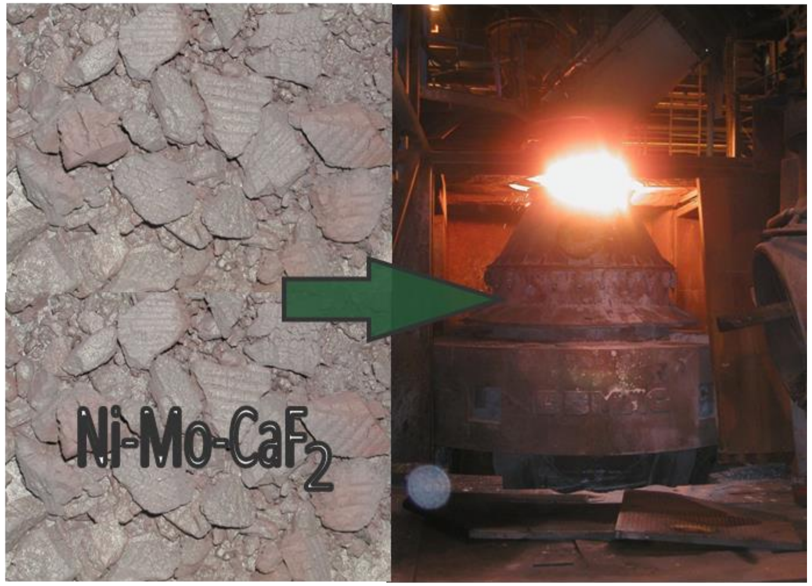


Pickling sludge to substitue fluorspar




2004-2008

- Lab-pilot-tests
- World patent
- 50%CaF2-Cr2O3-NiO-CaO-S
- No more disposal
- Saving of millions €




Thank you for listening

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

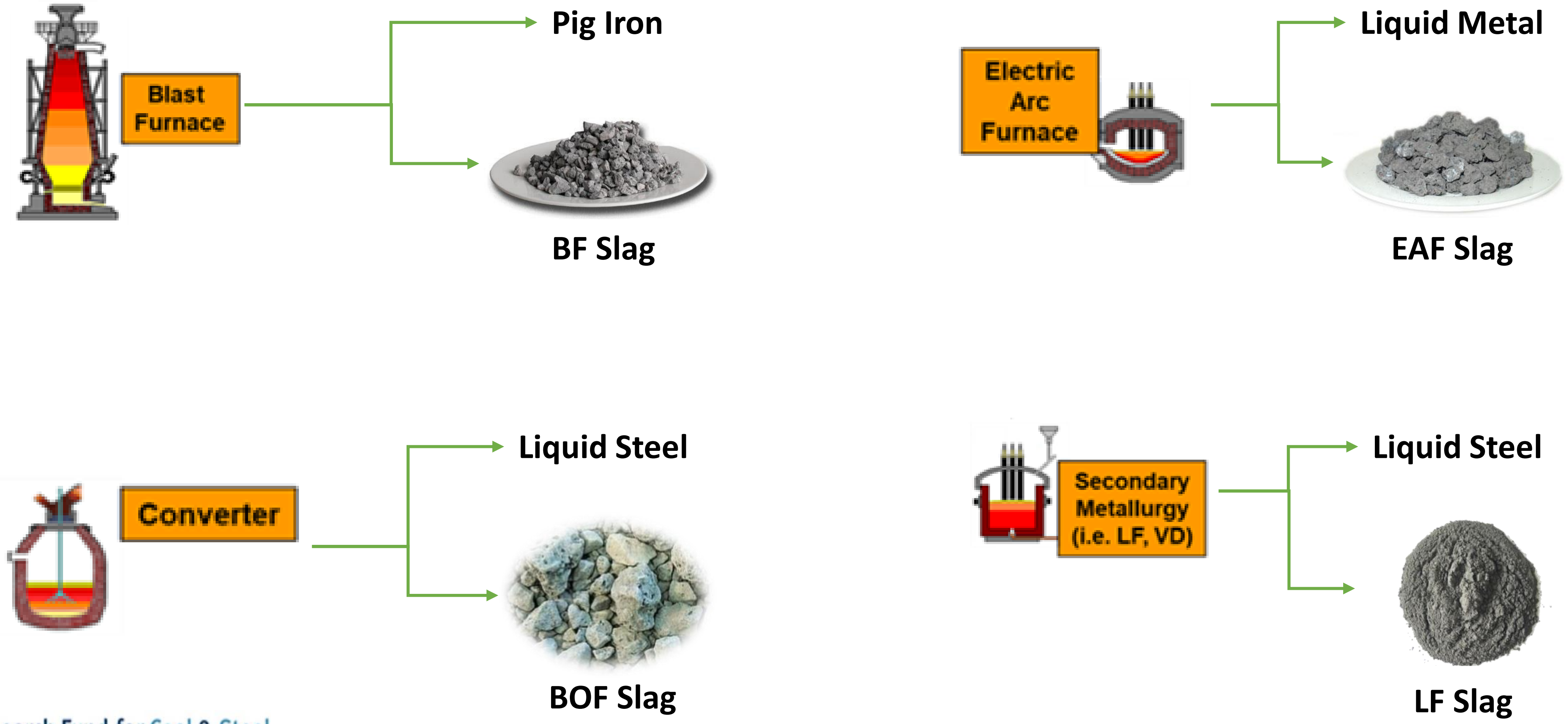
Modelling, simulation and digital tools to improve slag reuse and recycling

Ismael Matino, Valentina Colla, Teresa Annunziata Branca – TeCIP Institute, Scuola Superiore Sant'Anna

Content

- Introduction
- The role of modelling, simulation and digital tools
- Application of a digital tool for evaluating slag reuse in EAF steelmaking
- Combination of simulation and optimization tools for maximizing the recovery of valuable fractions of BOF slag
- Conclusions

Introduction



Introduction


BF Slag


EAF Slag


BOF Slag


LF Slag

Depending on the slag features, they can be

- **Internally Reused**
  - Substitution of fresh raw materials
- **Externally Recycled**
  - Substitution of clinker in cement-making
  - Road construction
  - Solid improvements
  - Fertilizer
  - Etc.

The objective is to decrease as much as possible slag disposal

Introduction

The objective is to decrease as much as possible slag disposal

Optimization of slag internal or external reuse and recycling

Pretreaments could be required

Economic and environmental impacts need to be considered

Consequences have to be investigated

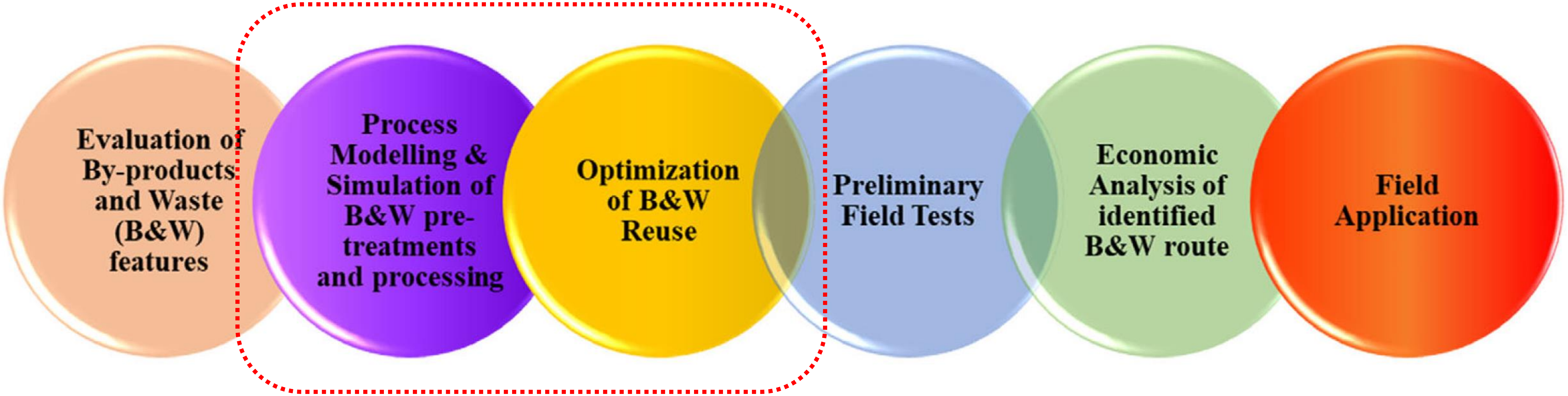
The role of modelling, simulation and digital tools

Conventional Industrial Process Investigation Techniques + Industrial Process Simulation through standard and advanced tools = Detailed Industrial Process Analyses

- Theoretical studies
- Experimental Campaign

- Assessment of non-conventional scenarios difficult to evaluate or test
- Consideration of multiple aspects jointly

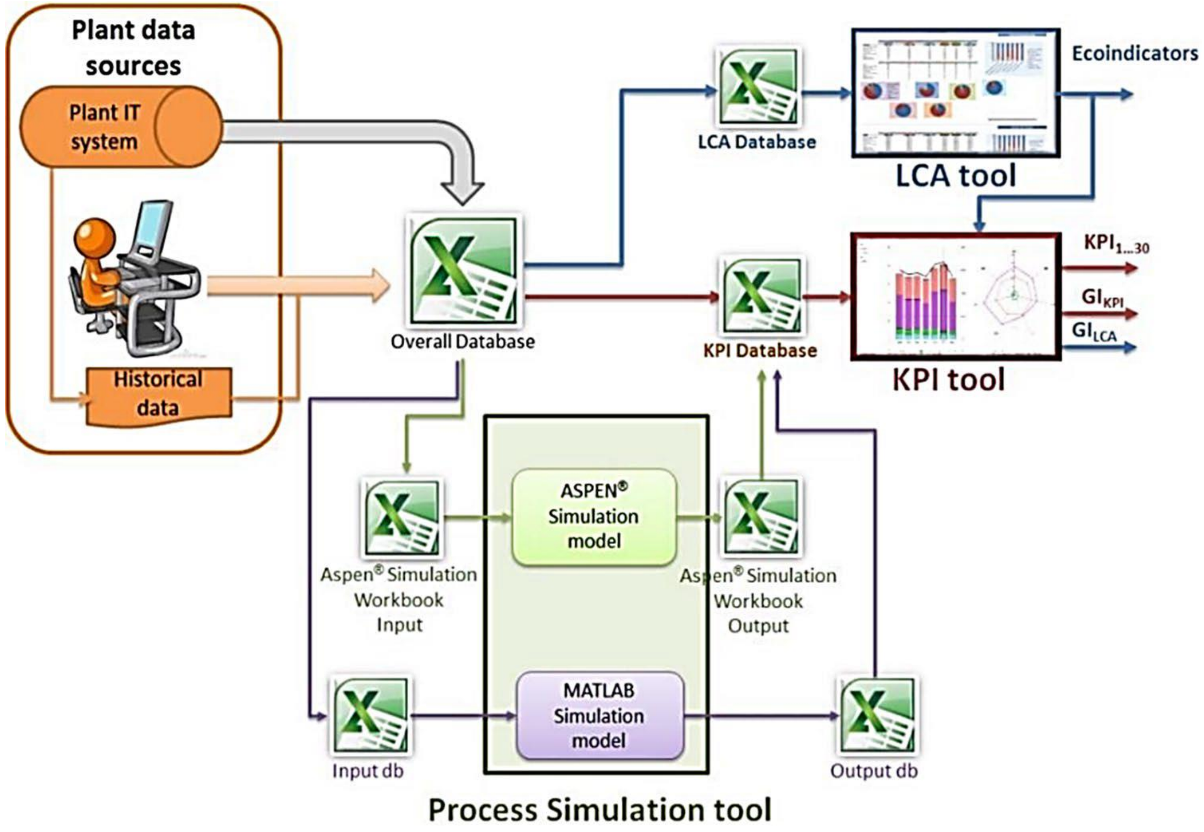
The role of modelling, simulation and digital tools



Approach scheme to optimize the reuse of by-products and coproducts in process industries

Matino, I., Branca, T. A., Fornai, B., Colla, V., & Romaniello, L. (2019). Scenario Analyses for By-Products Reuse in Integrated Steelmaking Plants by Combining Process Modeling, Simulation, and Optimization Techniques. steel research international, 90(10), 1900150.

Application of a digital tool for evaluating slag reuse in EAF stelmaking



- The digital tool developed during EIRES RFCS project and continuously improved includes a **digital twin of EAF steelmaking production process**
- It has several functionalities and among others, it allows:
  - **monitoring the composition of slags**
  - **Evaluating the process behavior and product effects in case of process modifications** → e.g. in the case of reuse of slags

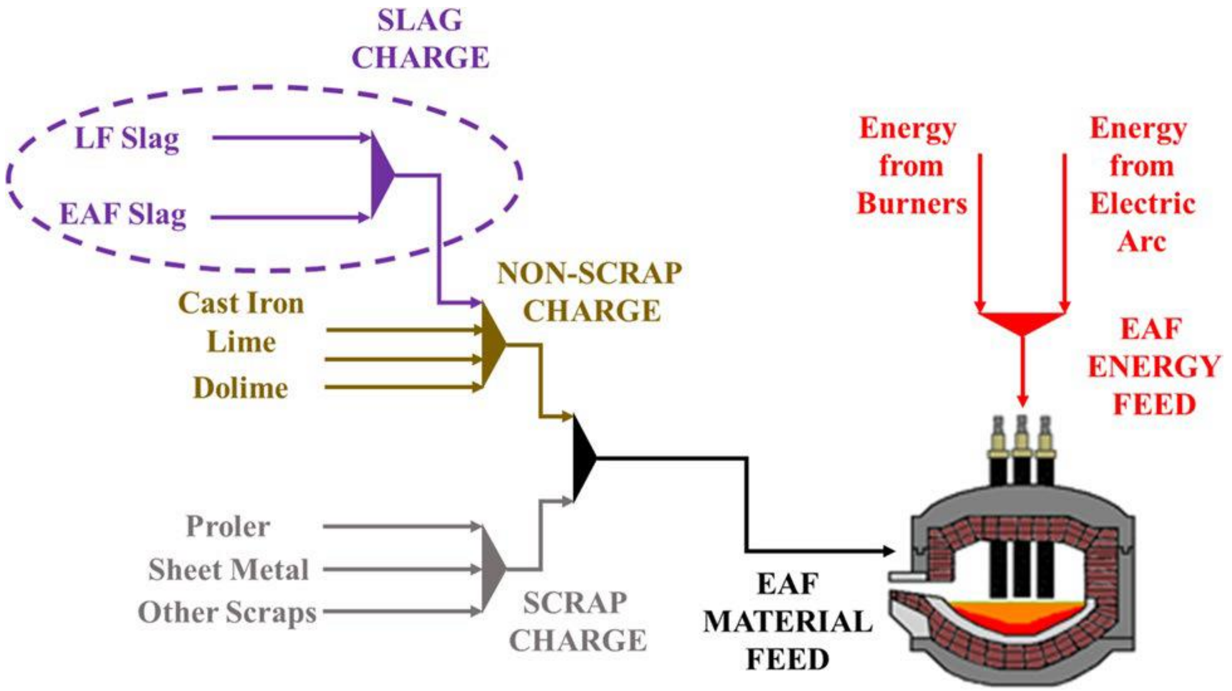
Matino, I., Colla, V., & Baragiola, S. (2018). Internal slags reuse in an electric steelmaking route and process sustainability: Simulation of different scenarios through the EIRES monitoring tool. Waste and Biomass Valorization, 9(12), 2481-2491.

Application of a digital tool for evaluating slag reuse in EAF stelmaking

The effect of the exploitation of different ratio of LF and EAF slags have been evaluated.

Analysed scenarios:

- Standard process
- Complete reuse of LF slag
- Complete reuse of LF slag + partial reuse of EAF slag



Matino, I., Colla, V., & Baragiola, S. (2018). Internal slags reuse in an electric steelmaking route and process sustainability: Simulation of different scenarios through the EIRES monitoring tool. Waste and Biomass Valorization, 9(12), 2481-2491.

Application of a digital tool for evaluating slag reuse in EAF stelmaking

Standard process → CS_standard

Complete reuse of LF slag → CS1

Complete reuse of LF slag + partial reuse of EAF slag → CS2_a, CS2_b, CS2_c

Case Study	Steel Family	Recovered EAF slag	Recovered LF Slag	Recovered EAF slag/ Recovered LF slag	Recovered LF slag/lime	Recovered LF slag/dolime
CS_standard	A, B	0%	0%	-	0	0
CS1	A	0%	100%	0	1.38	2.18
	B	0%	100%	0	1.03	1.44
CS2_a	A	35%	100%	1.07	2.53	3.4
	B	35%	100%	1.37	1.81	2.24
CS2_b	A	70%	100%	2.14	14.08	7.99
	B	70%	100%	2.74	7.31	5.03
CS2_c	A	78%	100%	2.39	No fresh lime	11.6
	B	82%	100%	3.21	No fresh lime	8.8

Matino, I., Colla, V., & Baragiola, S. (2018). Internal slags reuse in an electric steelmaking route and process sustainability: Simulation of different scenarios through the EIRES monitoring tool. Waste and Biomass Valorization, 9(12), 2481-2491.

Application of a digital tool for evaluating slag reuse in EAF stelmaking

Effects on steel composition:
Negligible for all the scenarios

Effects on EAF slag:
the increase of slags reuse resulted in an increase of iron oxides and silica and in a decrease of calcium oxides and alumina

Effects on LF slag:
not so significant

Best results in terms of sustainability are obtained without the reuse of EAF slag (CS_1)

Application of a digital tool for evaluating slag reuse in EAF stelmaking

CS_1 – Steel Family A

KPI_2: required electric energy

KPI_{12}: specific non-metallic charge material

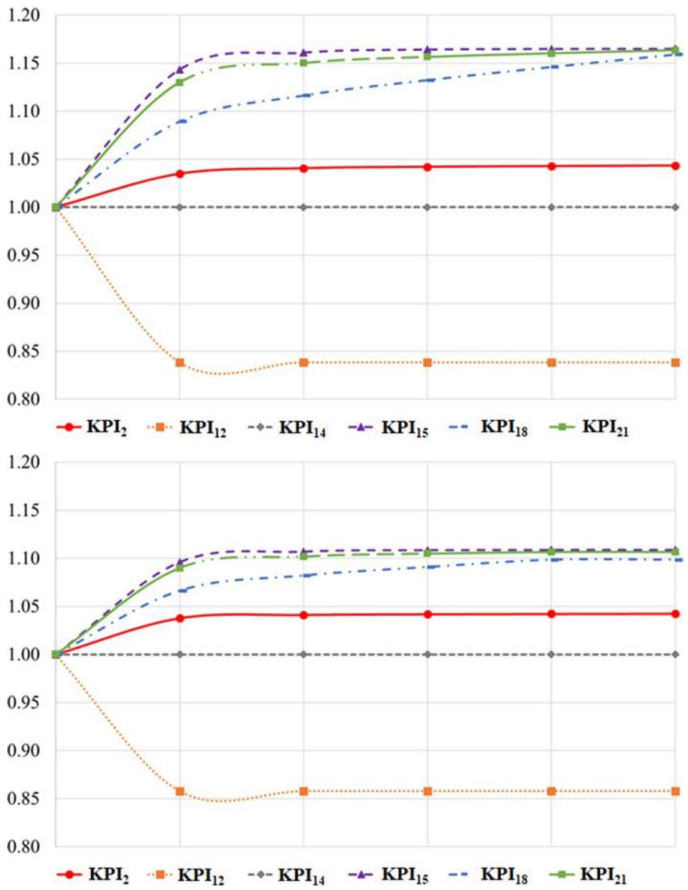
KPI_{14}: metallic yield

KPI_{15}: specific EAF slag

KPI_{18}: specific LF slag

KPI_{21}: total amount of slag

CS_1 – Steel Family B



- **The continuous reuse of LF slag leads to a first significant change of considered KPIs during the first LF slag reuse but then they tend to stabilize toward asymptotical values without oscillations**

- **no significant changes in:**
  - **metallic yield**
  - **steel composition**

- **The tool allows virtually monitoring the composition of slags on a cast-by-cast basis → slags reuse can be evaluated case-by-case**

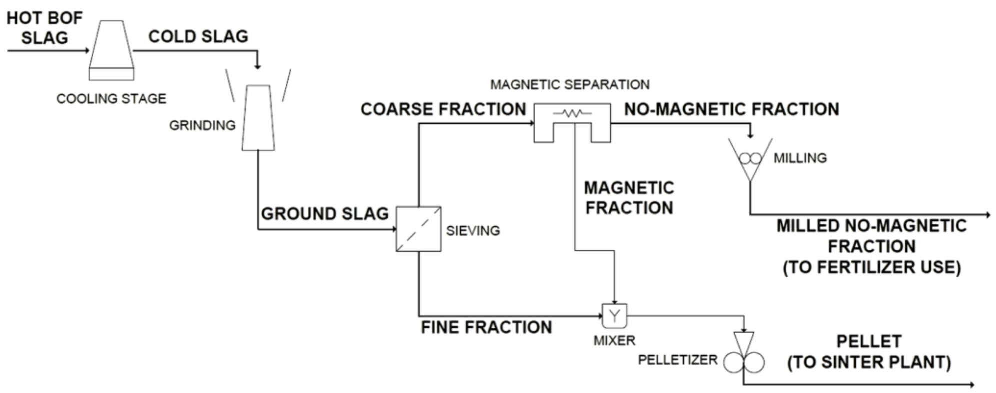
Matino, I., Colla, V., & Baragiola, S. (2018). Internal slags reuse in an electric steelmaking route and process sustainability: Simulation of different scenarios through the EIRES monitoring tool. Waste and Biomass Valorization, 9(12), 2481-2491.

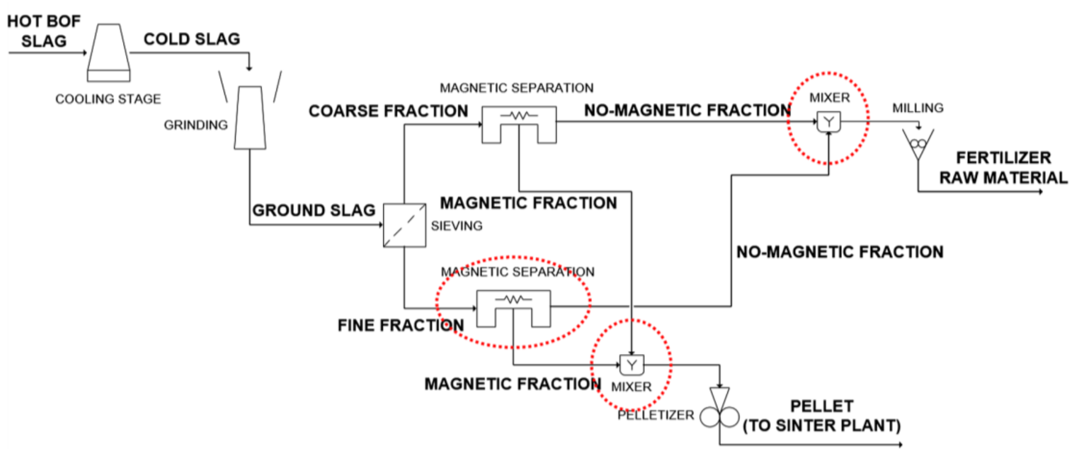
Combination of simulation and optimization tools for maximizing the recovery of valuable fractions of BOF slag

During REFFIPLANT and PSP-BOF project the following tools have been developed:

- A **flowsheet model for analysing the separation of the two main fractions of BOF slags** (i.e. magnetic and no-magnetic ones)
- An **optimization tool for maximizing the internal or external recovery of obtained fractions of BOF slags** (alone or combined with further by-products)
- A **simplified model for computing the chemical composition of pellets having the magnetic fraction of BOF slag as main component**

Combination of simulation and optimization tools for maximizing the recovery of valuable fractions of BOF slag





Two main BOF slag pre-treatment configurations were simulated → **the second one appears to be better**

Different Magnetic Separations were investigated (e.g. wet high and low intensity, dry) → **wet high intensity gives better separation results**

Matino, I., Colla, V., Branca, T. A., & Romaniello, L. (2017). Optimization of by-products reuse in the steel industry: valorization of secondary resources with a particular attention on their pelletization. Waste and Biomass Valorization, 8(8), 2569-2581.

Combination of simulation and optimization tools for maximizing the recovery of valuable fractions of BOF slag

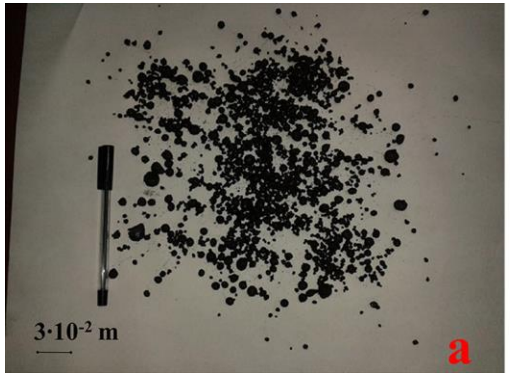
- The optimization tool allows **multi-objective optimizations for maximizing the internal (e.g. pelletization) or external reuse (e.g. for fertilizer production) of separated fractions of BOF slags** alone or combined with further by-products (i.e. BOF sludge, mill scale)

- **Different combination of economic, environmental and quality factors were considered** in the optimization analyses

- **The jointly simulation and optimization tests with real experimentations allowed producing high quality pellets and founding the best solutions for improving the benefits**

Combination of simulation and optimization tools for maximizing the recovery of valuable fractions of BOF slag

Pilot pellet production



Low quality pellets

Optimized high quality pellets
(BOF slag: 56÷65%;
BOF sludge: 27÷36%;
Lime: 1%; Cement: 7%)

The optimal combination of internal (i.e. pellet production) **and external recovery** (e.g., fertilizer raw material) **of BOF slag can produce significant revenues**, although the management costs for the separation of slag fractions increase.

Matino, I., Colla, V., Branca, T. A., & Romaniello, L. (2017). Optimization of by-products reuse in the steel industry: valorization of secondary resources with a particular attention on their pelletization. Waste and Biomass Valorization, 8(8), 2569-2581.
Matino, I., Branca, T. A., Fornai, B., Colla, V., & Romaniello, L. (2019). Scenario Analyses for By-Products Reuse in Integrated Steelmaking Plants by Combining Process Modeling, Simulation, and Optimization Techniques. steel research international, 90(10), 1900150.

Conclusions

Slags are valuable by-products

Optimization of internal and external slag reuse and recycling requires the evaluations of necessary pretreatments or the impacts and effects of their reuse

Digital tools can help on these evaluation, especially if combined with real experimentations

Zero slag disposal

ismael.matino@santannapisa.it

valentina.colla@santannapisa.it

teresa.branca@santannapisa.it

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

REUSteel – 2. Webinar

Introduction in the REUSteel project – Overview of the EU-research on Sludge and Dust

Roland Pietruck - BFI

Day 2 – 15.06.2021 10:00-12.00 – Webinar on Sludge and Dust

Compliance Statement: "Competition law compliance is of utmost importance for ESTEP and its member companies. Therefore, ESTEP member companies must ensure that their representatives and other delegates that may participate in any ESTEP activity dispose of profound knowledge of the competition laws and have undergone sound competition law compliance training.
Persons who do not fulfil these requirements or who otherwise by their behaviour present a competition law compliance risk can be excluded from any ESTEP activity. The ESTEP Secretariat and Compliance Working Group can provide You with additional guidance and information."

Workshop guidelines: **Attendees**

- Please ensure that Your microphone is muted
- Please deactivate Your camera
- Please do not put Your questions at this stage, keep them for the final Plenary discussion

Workshop guidelines: **For presenters** (co-host of the session)

- Please ensure that Your microphone is NOT muted
- Please deactivate Your camera
- Please share Your presentation and in case of video with audio, after sharing the presentation, please "Share computer sound"
- Presentation itself will be recorded (no Plenary discussion). If presenter disagree, presentation will not be recorded.

THE USE OF HIDDEN RECORDING SOFTWARE AND THE USE OF WORKSHOP MATERIAL WITHOUT ESTEP APPROVAL IS PROHIBITED

Promoting the **dissemination of the knowledge/technological** solutions of **European projects** on the **reuse and recycling of by-products** in the steel sector

Identifying **merits** and **limitations** of technological solutions and their implementation

Taking into account **scientific**, **technical**, **economic** and **legislative aspects**

Impact of the results on the **sustainability** and the **competitiveness** of the European steel industry

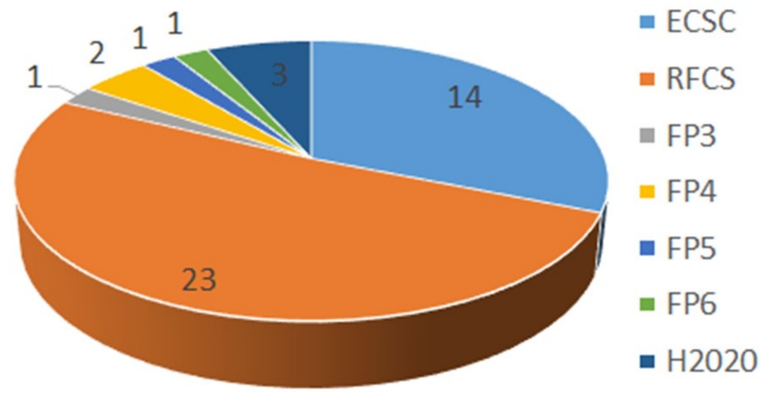
Identifying promising **development lines** taking into account possible **technological barriers**

Identifying **non-technological barriers** to these innovations

Find **synergies with other industrial sectors** to reach industrial symbiosis for circular economy

Identifying a **future roadmap** and **research topics** for the future years based on current and **future requirements**

35 projects of relevant EU funded projects;
2000 – 2020



Projects were subdivided based on the type of investigated by-product.

Slag: BF, BOF, LF, EAF

Sludge: BF, EAF, BOF

Dusts: Sinter, BF, EAF, BOF

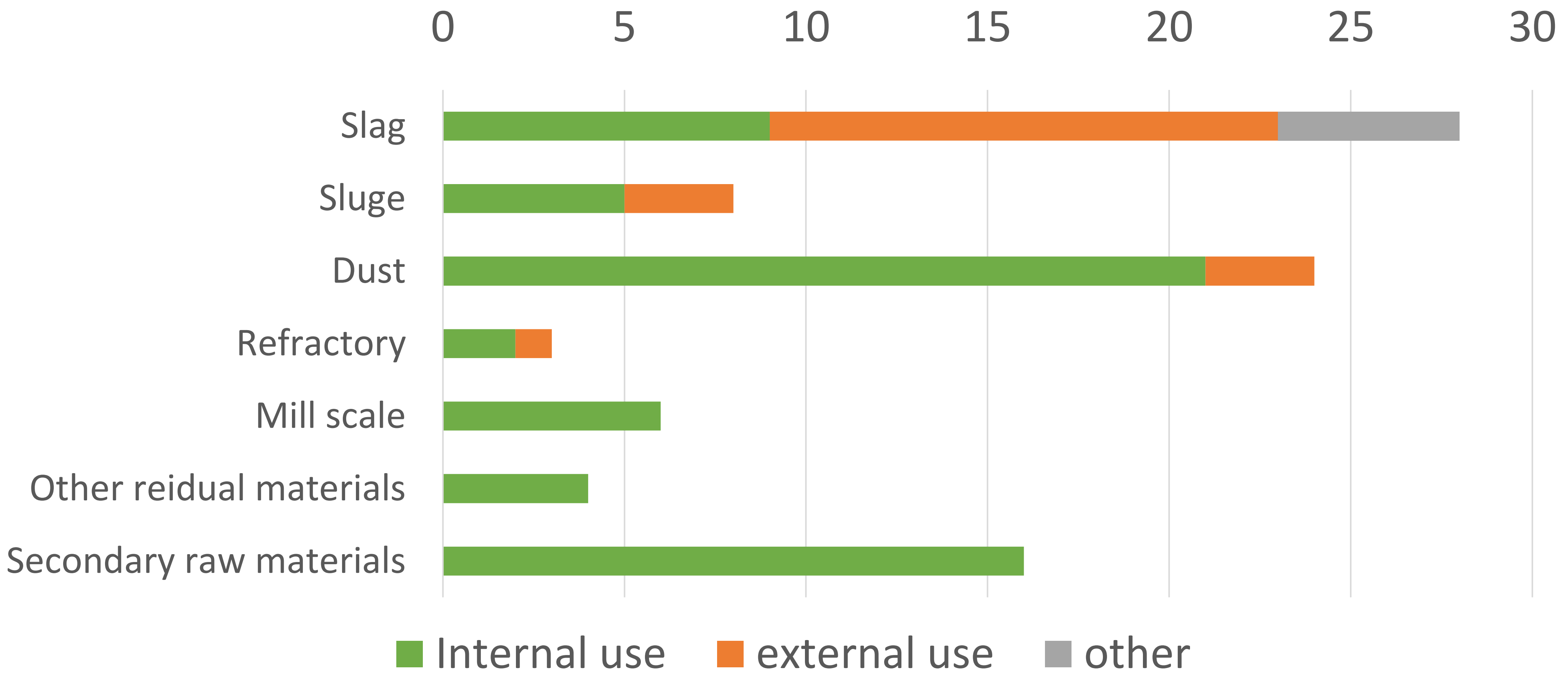
Refractory

Other by-products

Mill scale

Secondary raw materials

Sub-Topics within the Projects



Projects: Reuse and recycling of DUST

INTERNAL USE:

- **14 projects:** **Recovery of valuable metals**
- **3 projects:** Utilization with **carbon containing dust materials**
- **4 projects :** Different aspects of control of **slag conditioning**.

EXTERNAL USE

- **1 project:** **Injection in metal bath**
- **2 projects:** Dust for **sealing and filling**

Projects: Reuse and recycling of SLUDGE

INTERNAL USE

- **4 projects:** Aspects of **briquette/pellet production** for recycling
- **1 project:** Substitute for coke-breeze and ore fines in sinter plant

EXTERNAL USE

- **1 project:** Use for civil **engineering an construction**
- **2 projects:** **Sealing and filling**

Day 2 – 15.06.2021 10:00-12.00 – Webinar on Sludge and Dust			
Time	**Speaker**	**Speaker Organization**	**Presentation**
10:00	Roland Pietruck (*Chairman*)	BFI	*Overview of the EU-funded research on sludge and dust*
10:10	Roland Pietruck	BFI	*Recovery of dust and sludge in the **sinter plant***
10:30	Gerald Stubbe	BFI	***Metal recovery** from iron and steelmaking dust and sludge residues*
10:45	Simon Wölfelschneider	BFI	***Briquettes** from dust and sludge for **shaft furnace charging***
11:00	Jörg Adam	BFI	*Lowering local **blast furnace** hearth wear by TiO2-materials **injection***
11:15	Lena Sundqvist	SWERIM	*Flexible injection of **alternative carbon material** into the* blast furnace
11:30	All		***Plenary Discussion with speakers***
12:00	Roland Pietruck	BFI	***Closure of the Webinar***

Roadmap: Your input to future topics – online survey - 29 questions

https://it.surveymonkey.com/r/NFKJJY2 by SSSA

Question24 Type of By-product/residual	Slag Internal recycling	Slag valorisation outside	Extraction of valuable material	Fe-bearing by-products non slag	other beneficial and valuable contents like metals, coal and lime	Elimination of harmful elements	Minimisation of waste generation and landfill	Process integration solutions for by-products	Modelling and management simulation
BF-Slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
BOF-Slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
EAF-Slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
LF-Slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
BF-Dust	☐	☐	X	☐	☐	☐	☐	☐	☐
BOF-Dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
EAF-Dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
LF-Dust	☐	☐	☐	☐	☐	X	☐	☐	☐
Sinter plant	☐	X	☐	☐	☐	☐	☐	☐	☐
Coke-dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
BF-Sludge	☐	☐	☐	☐	☐	☐	☒	☐	☐
BOF-Sludge	☐	☐	☐	☐	☐	☐	☐	☐	☐
EAF-Sludge	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mill-Sludge	☐	☐	☐	☐	☐	☐	☐	☐	☐
Refractory	☐	☐	☐	☐	☐	☐	☐	☐	☐

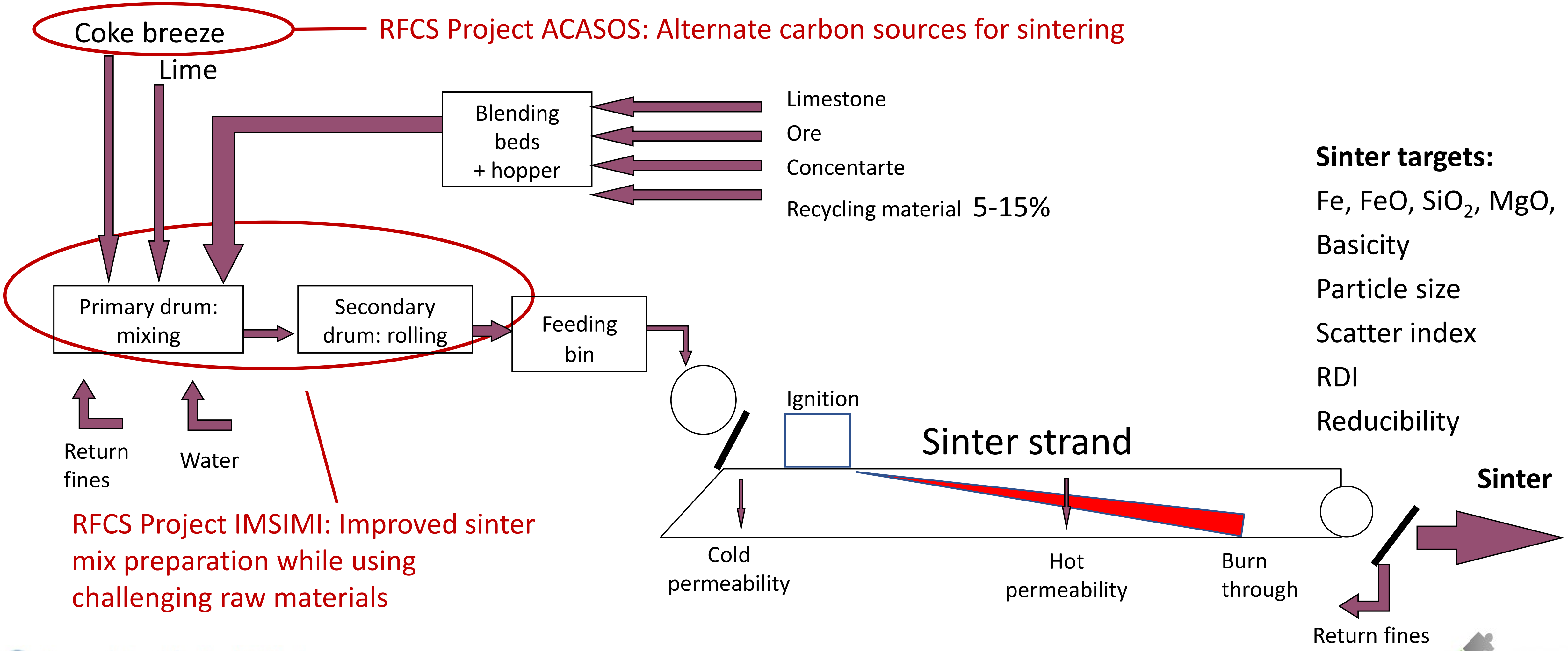
Thank you for filling in !

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

Recovery of dust and sludge in the sinter plant

Roland Pietruck, BFI

Recovery of dust and sludge in the sinter plant



RFCS: **Im**proved **si**nter **mi**x preparation while using challenging raw materials (IMSIMI) 20011-2014

Iron ores show a **downward trend of their quality** (**finer particles**, **broader size distribution**, **lower grades** and **higher fluctuation** of properties).
To ensure its competitiveness sinter pants must use such ores together **with recycled materials**

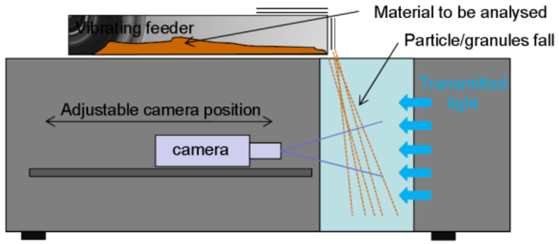
Improvement of the sinter quality and performance when using high content of fine ores and recycling materials by (mixing, granulation, etc.) by :

- use of selective preparation incl. standard and intensive mixer
- use of organic binder/water

IMSIMI Work program

1.) Characterisation of recycling materials

- Chemical Analysis
- Particle size analysis (wet/dry)
- Wettability
- Particle form
- Bulk properties



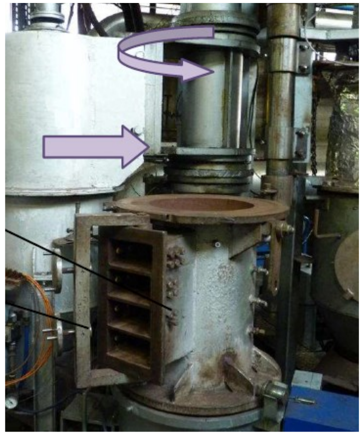
2.) Granulation behavior of residues and fines

Selective pre-treatment

- Standard mixer
- Intensive mixer

3.) Sinter pot tests: Evaluation of

- Productivity
- Quality

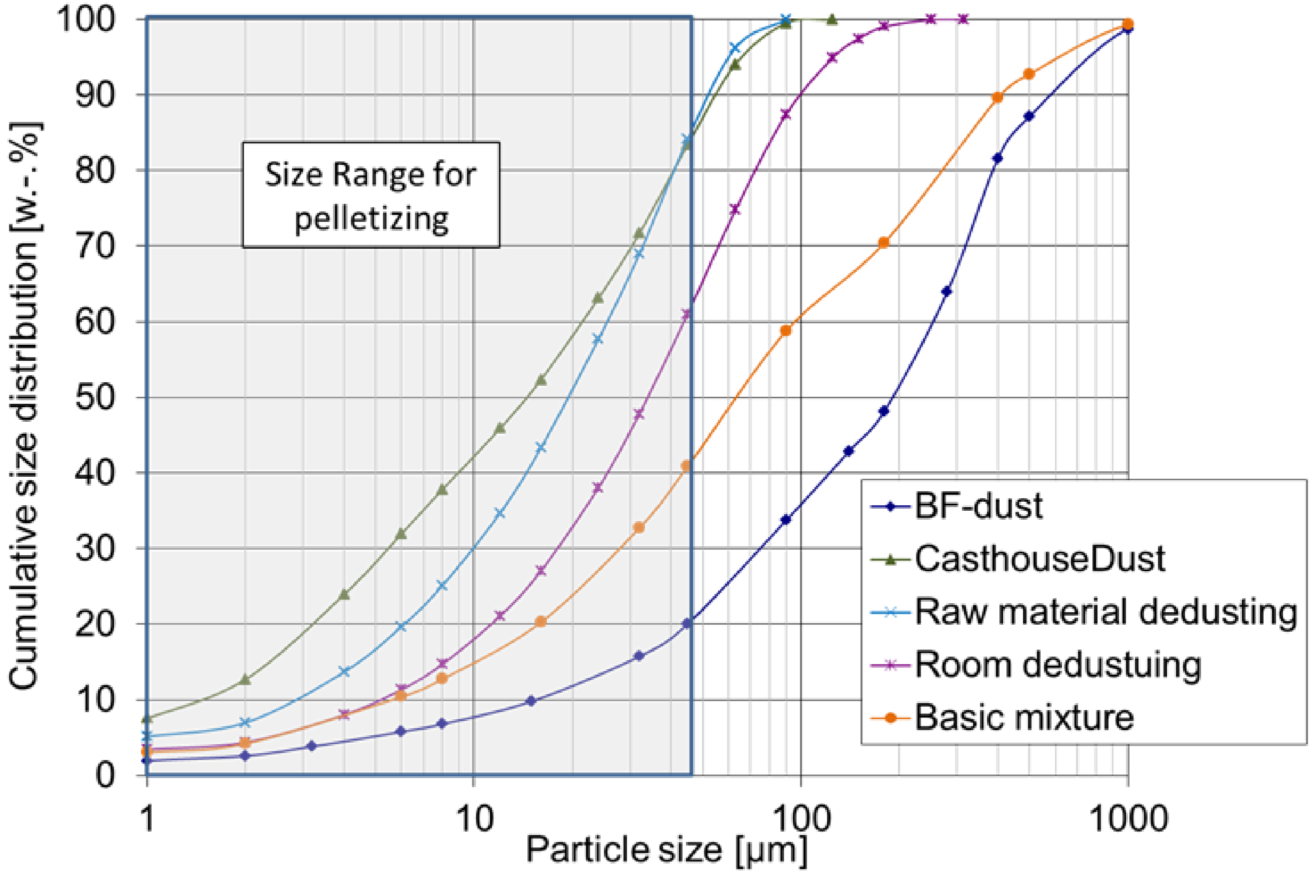


4.) Industrial tests

- Productivity
- Quality

IMSIMI - Characterisation of Recycling materials

		Room dedusting	BF dust	Casthouse dust
Fe	%	42	37	54
SiO2	%	7,6	5,1	5,1
CaO	%	20	3,0	9,4
C	%	4,8	36	4,3
X90*	µm	100	622	55
Bulk density	t/m3	1,2	1,3	1,4



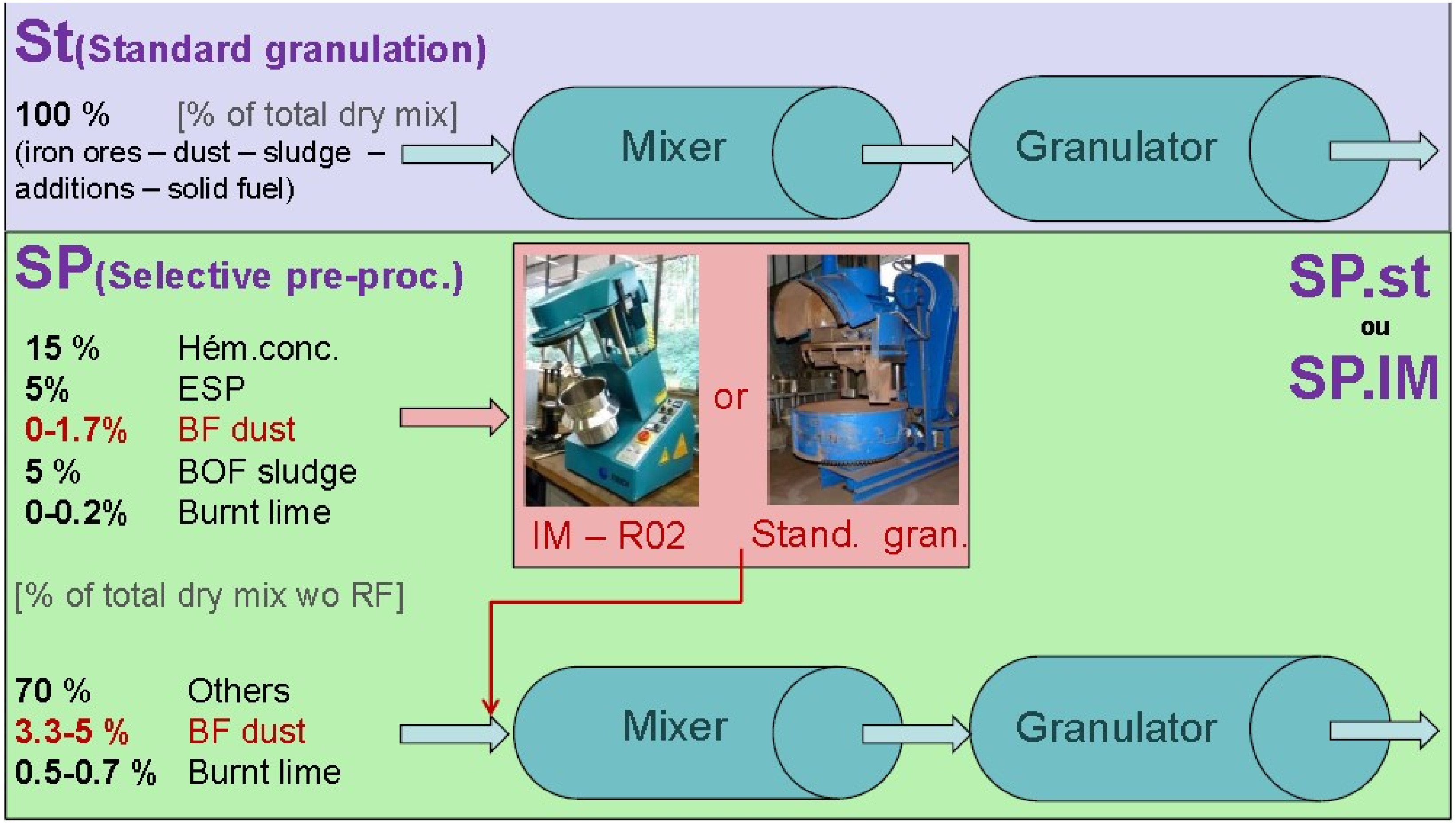
IMSIMI Granulation trials

Standard granulation :
100% in mixer and granulator

Selective granulation :
25-30% fines and recycling material in
- standard granulator
- intensiv mixer (IM)

70-75% in mixer and granulator
At variation of BF dust feeding

Organic binder at selective granulator



IMSIMI – Granulation results

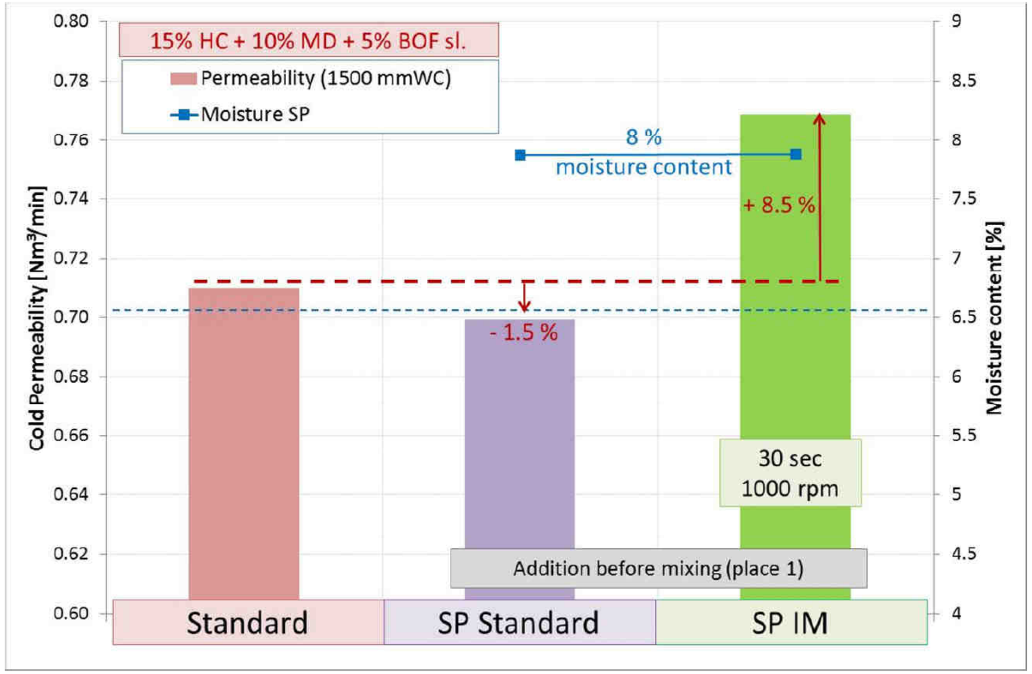
Influences on Granulation at SP with intensive mixer: Filling ratio; Rotor speed, Water addition, Binder

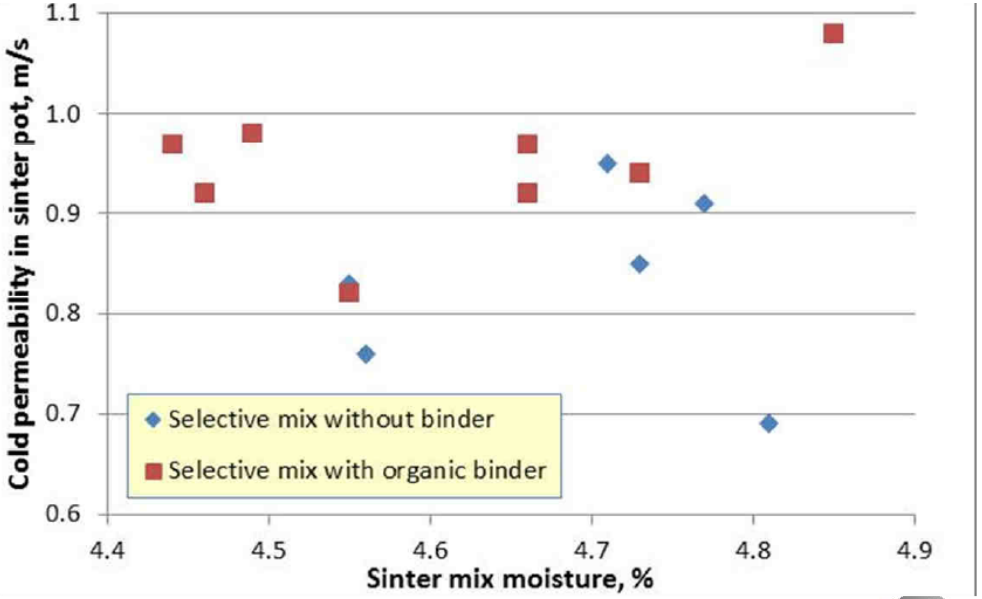
Cold permeability (CP) at 30% concentrate + reverts

- SP with a standard granulator presented a slight negative effect on CP at 6.5% moisture content
- SP with intensive mixer could improve CP it of 8.5% and 8 % moisture content

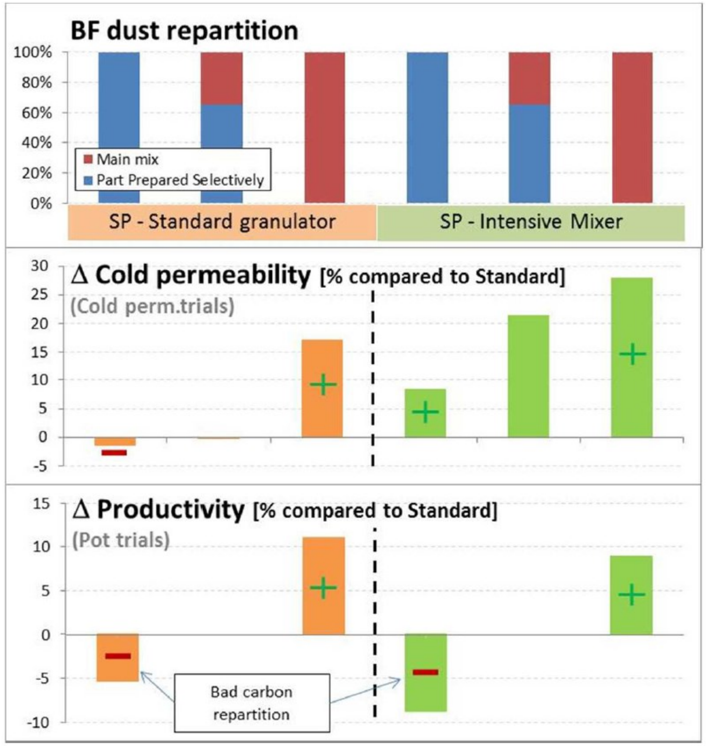
Cold permeability – organic binder + reverts:

- CP at SP with intensive mixer and organic binder higher than without

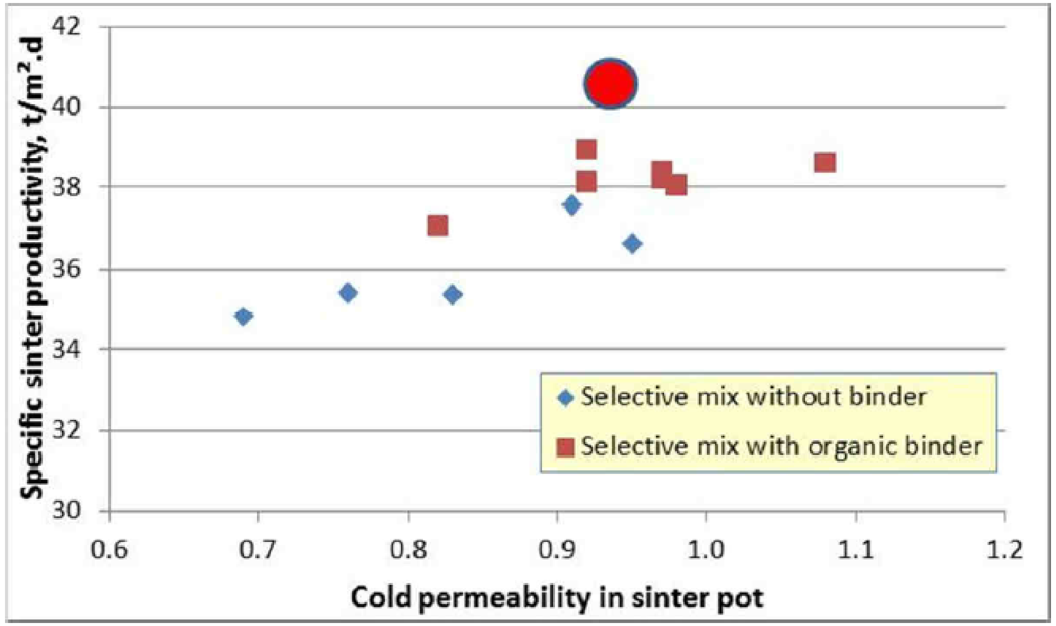




IMSIMI – Productivity



Selective granulation with intensive mixer lead not necessarily to an improved productivity



Selective granulation of dust mix with organic binder lead to increased cold permeability in sinter pot and higher sinter productivity, preferred at high dust content

IMSIMI – Results from industrial scale

Conclusion from selective preparation of dust for sintering at lab scale

- Impact of Selective Preprocessing on sintering depends strongly on dust properties as size distribution, wettability and moisture content;
- Intensive Mixer for Selective Preprocessing increases cold permeability and moisture content at optimized mixture nature
- Addition of organic binder at selective preprocessing leads to increase of cold permeability and spec. sinter productivity – economic barriers

Industrial scale:

In industrial scale intensive mixers improve productivity and flexibility when increasing fine iron ores in the sinter feed. Adjustment of water and binders' amount and position has to be carefully determined regarding raw material characteristic - **Industrially applicable**

RFCS: **Al**ternate **Ca**rbon **So**urces for Sintering of iron ore (ACASOS) 2007-2010

ACASOS as replacement for coke breeze.

ACASOS: biomass, BF sludge, BF-dust, petroleum coke and anthracite

Investigation of **pre-treatment process**: grinding, separation, agglomeration, drying to adapt and optimize the properties of ACASOS.

Influences on **sinter process and results** determined with **sinter-pot tests**.

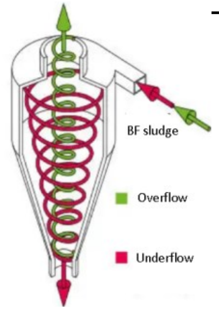
Industrial scale trials to determine **replacement factors** and influences on the sintering process and emissions.

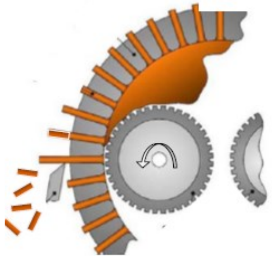
Characterisation of ACASOS

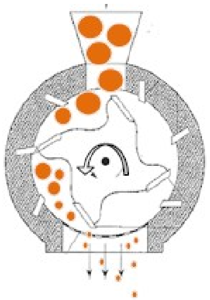
Chem. Composition		Coke breeze	Biological Acasos	BF dust	BF sludge	Pet coke	Anthracite
Total C	%	85	42 - 55	25 - 41	27 – 34	95	89
Volatile content	%	1.5	60 – 83	1.4	/	1.9	10
Ash	%	8-12	<2	< 74	< 73	1	10-15
Particle size	mm	1 - 3	/	0.2	0.05	1.0	1.8
Bulk density	kg/m³	880	350	830	920	730	740
Calorific value	MJ/kg	28	7 – 20	6 – 9	11 - 13	36	34

Pre-treatment of ACASOS

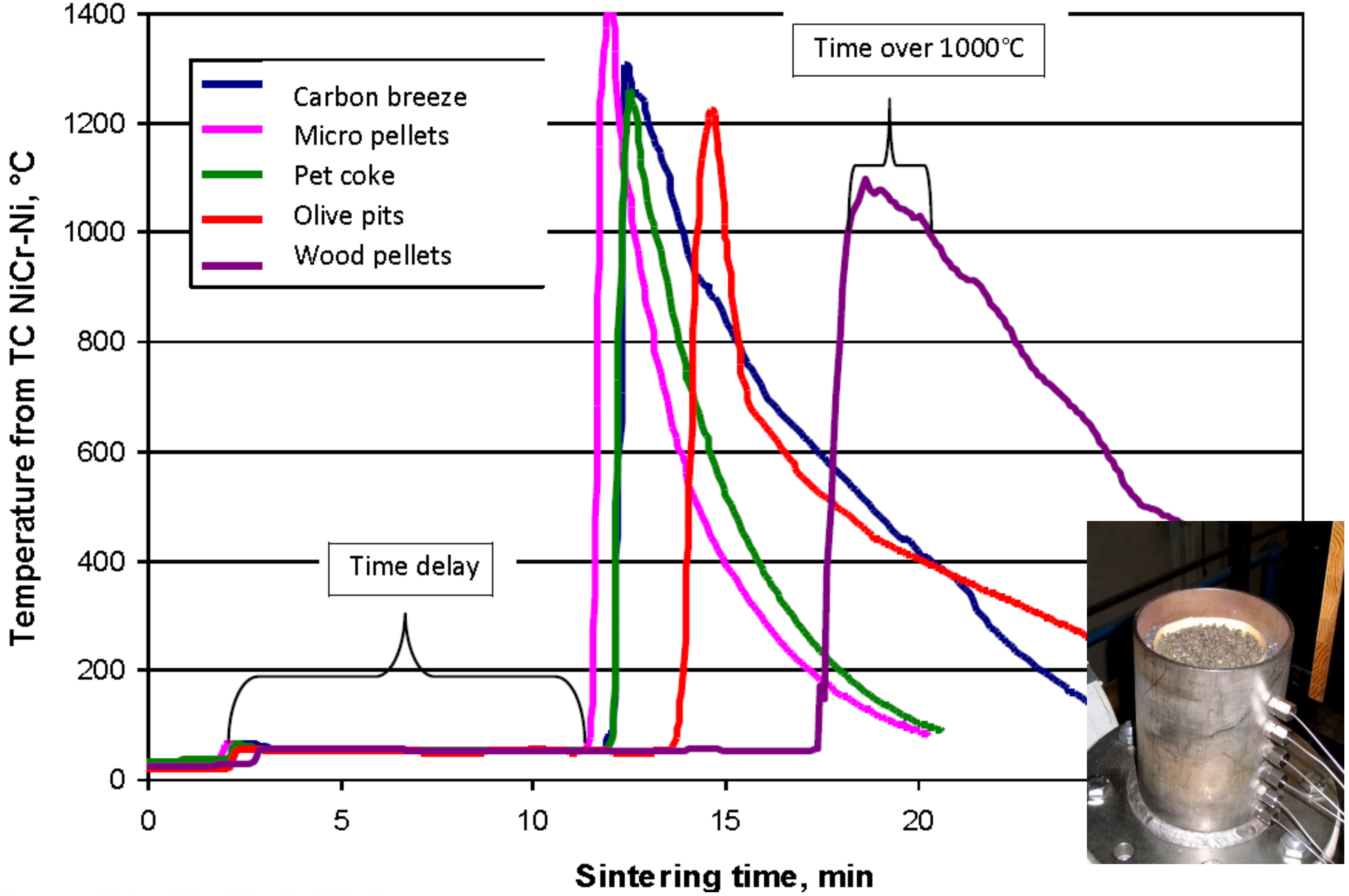
Raw mixture	BF sludge	BF dust	Olive pits, Wood
Challenge	Slurry, Heavy metal	Particle size	Volatiles, High Moisture, Bulk density
Pre-treatment	Carbon enrichment + Dewatering	Mikro pelletizing	Crushing, Milling + Drying
Devices	Hydro-Cyclon and Filter-Press	Intensive mixer or Die press	Cutter mill, Thermal drying







Sinter pot tests with ACASOS – Process Results



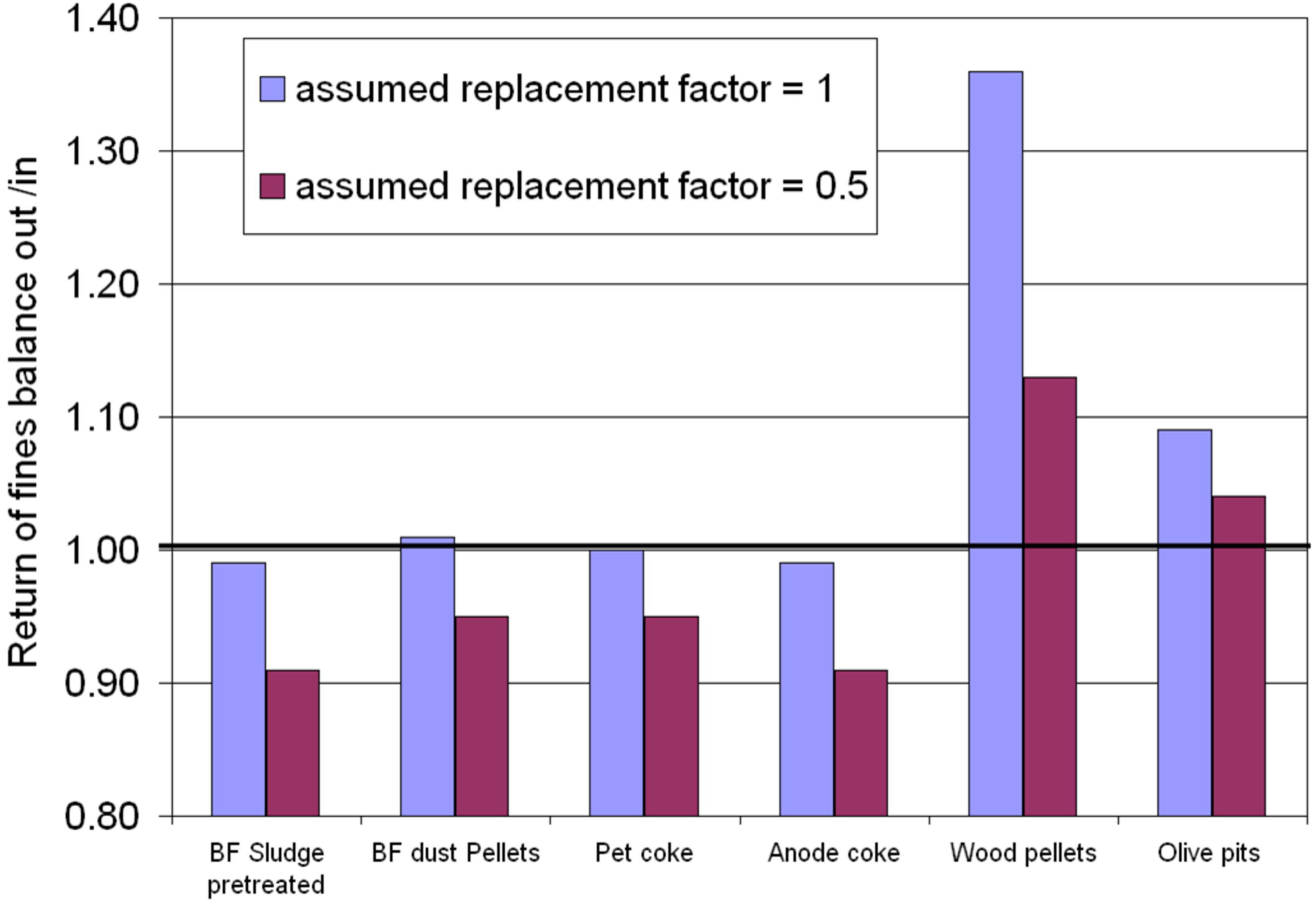
Temperature evolution in sinter mix:

Carbon breeze: standard process

BF dust pellets, Pet coke in range of standard process

Olive pits, Wood pellets diver from standard process

Evaluation of ACASOS with sinter pot – Replacement factor



Replacement factor = C coke breeze/C ACASOS

Return of fines balance = Fines out/ Fines in

Return of fines balance:
Carbon breeze: standard process

BF dust pellets, Pet coke in range of standard process

Olive pits, Wood pellets diver from standard process

ACASOS – Results, Application and Barriers

Carbon enriched BF sludge: 10 – 20% of the carbon breeze in sinter mixture was replaced by the carbon of the BF sludge; carbon replacement factor was increased to 1; No enrichment of heavy metal content - **Industrially applicable**

Micro-pelletized BF dust: ca 30% of carbon content of the sinter mixture was replaced by carbon in BF dust - carbon replacement factor was increased from 0.6 to 1 – no changes in sinter quality

Anthracite: 60% replacement of carbon breeze in sinter mixture– sinter yield slightly decrease while sinter quality remain unchanged - slight increase in SOx, decreasing of NOx in off gas - **Industrially applicable**

Biological ACAOS: Redcution of CO2 emissions, but chemical and physical properties of the ACASOS differ considerably from that of fossil-based reductants; also economic barriers due to logistic and pre-preatment,
Product development must be carried out (torrefied material)

Recent research shows the relevance of the issues

IMISMI:
"**THE EFFECT OF HIGH GRADE PELLET FEED ON SINTERING PERFORMANCE**." Pereira, Helio Cardoso et al. Tecnologia em Metalurgia, Materiais e Mineração 13, **2016**, Page 340-345.

ACASOS
Extensive review of the opportunities to use biomass-based fuels in iron and steelmaking processes, Fabritius,T.; Journal of Cleaner Production, Volume 148, **2017**, Pages 709-734,

Thank you

Roland Pietruck

Researcher
Dept. Resource Technology Feedstock

roland.pietruck@bfi.de
VDEh-Betriebsforschungsinstitut GmbH
Sohnstraße 69, 40237 Düsseldorf, Germany
Tel: +49 211 98492-891

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

Metal recovery from iron and steelmaking dust and sludge residues

Stubbe, Gerald – VDEh Betriebsforschungsinstitut GmbH

Content

- Introduction / Dust and sludge residues
- Overview on processes for metal recovery
  - Pyrometallurgy
  - Hydrometallurgy
  - Combined Pyro- and Hydrometallurgical processes
- Evaluation of relevant EU projects in REUSteel – Preliminary conclusion on dust and sludge processing

Introduction / Valuable dusts and sludges from the steel industry

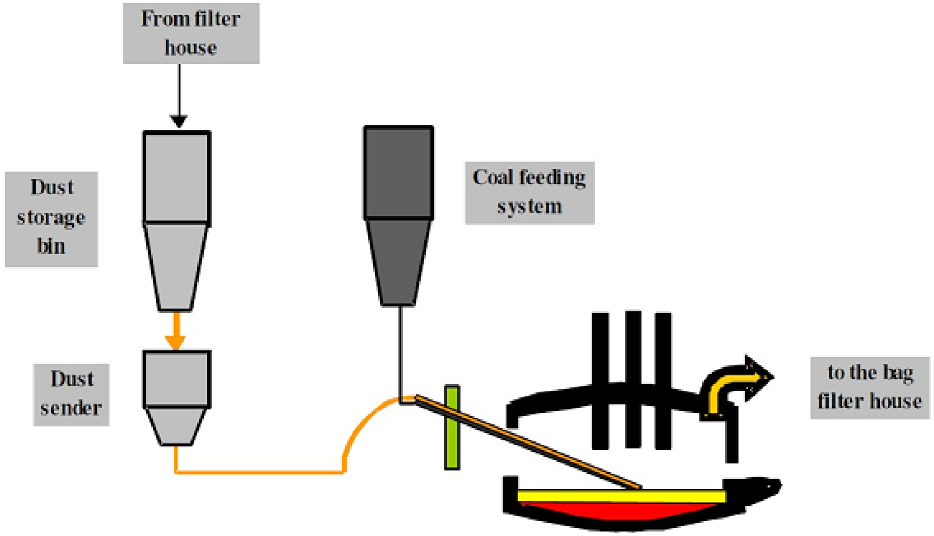
- **Valuable metals**
  - Iron -> High content, low specific value -> for internal recovery within primary metallurgy
  - Zinc -> low to medium content; high specific value -> external recovery in zinc primary metallurgy
  - Alloying elements (especially Cr, Ni) -> relatively low content; very high specific value -> for recovery within stainless steelmaking

Typical composition of Zn bearing iron- and steelmaking dusts and sludges

	C	*Fe*	*Zn*	*Pb*	*Further*
Blast furnace sludge	< 47	< 35	1 - 10	< 2	
BOF fine dust /-sludge	1	< 70	< 5	< 1	
EAF dust (carbon steel)	< 3	< 45	21 - 43	2	
EAF dust (high alloyed steel)	< 1	< 65	2 - 25	0,5	Cr: 6 - 14; Ni: 1 - 8
					[values in mass-%]

Pyrometallurgy - Re-circulation into existing process steps

- **Electric arc furnace (EAF)**
  - Return of zinc-rich filter dust to the EAF by molten bath injection
  - Production of a zinc-enriched product dust -> sale to zinc smelter



Similar EU projects (Rep.-No.)	Title	Results/Success/Failures	TRL	Follow-up/ideas
EUR 20926 [P8]	Foaming of slag and recycling of steel dust by injection into the electric arc furnace	Successful recycling of Cr, Mn, Ni and Fe from the dust; Zn was increased to 30-40% in the product dust; slag foaming successful; - 9 % operating costs	8	Not mentioned
BRE20116 [P38]	Recycling of zinc and lead containing dusts from the electric arc furnace	Successful Zn enrichment in dust (max. 34 wt.-%); -30% total amount of dust; economic efficiency depends on average Zn concentration (and Zn price)	6	Influence on: Energy consumption, refractory lining, steel quality to be clarified

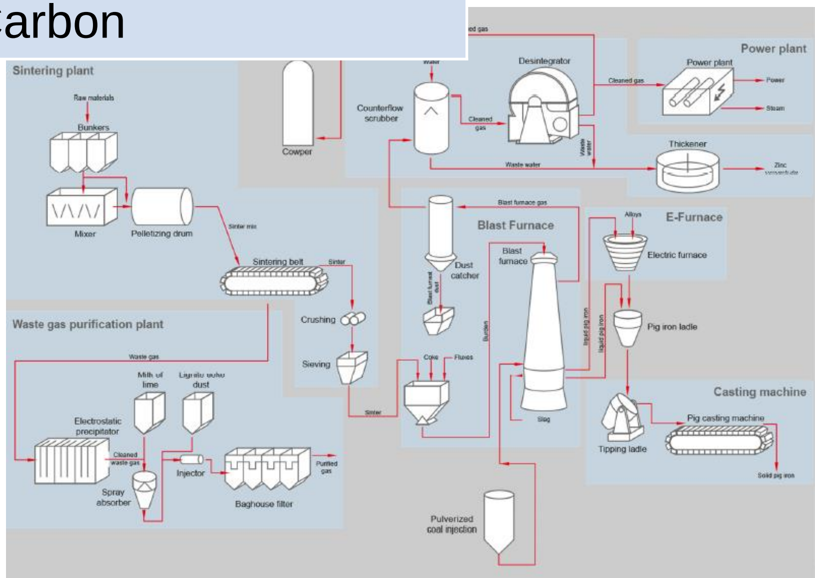
Pyrometallurgy

- Shaft furnaces: Blast Furnace (DK-Process); Cupola Furnace (OxyCup ®)

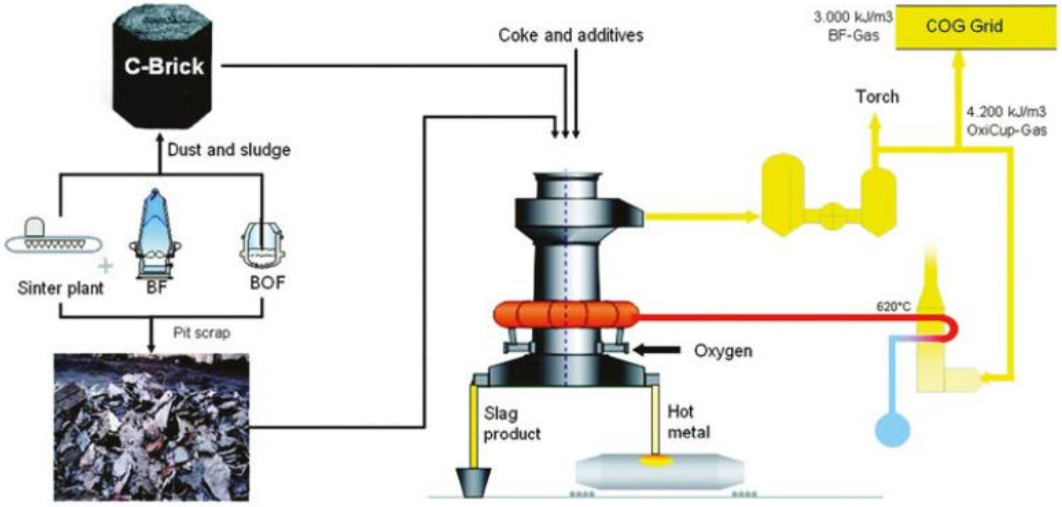
Energy carrier
Coke; Injection coal

Reductant
Carbon

Processed residues	Main products
Low-zinc; e.g. converter sludge	• Hot metal (foundry quality) • Zinc concentrate / Zinc enriched filter dust (Zinc oxide)



Process scheme of DK-Process



Process scheme – OXYCUP ® cupola furnace process

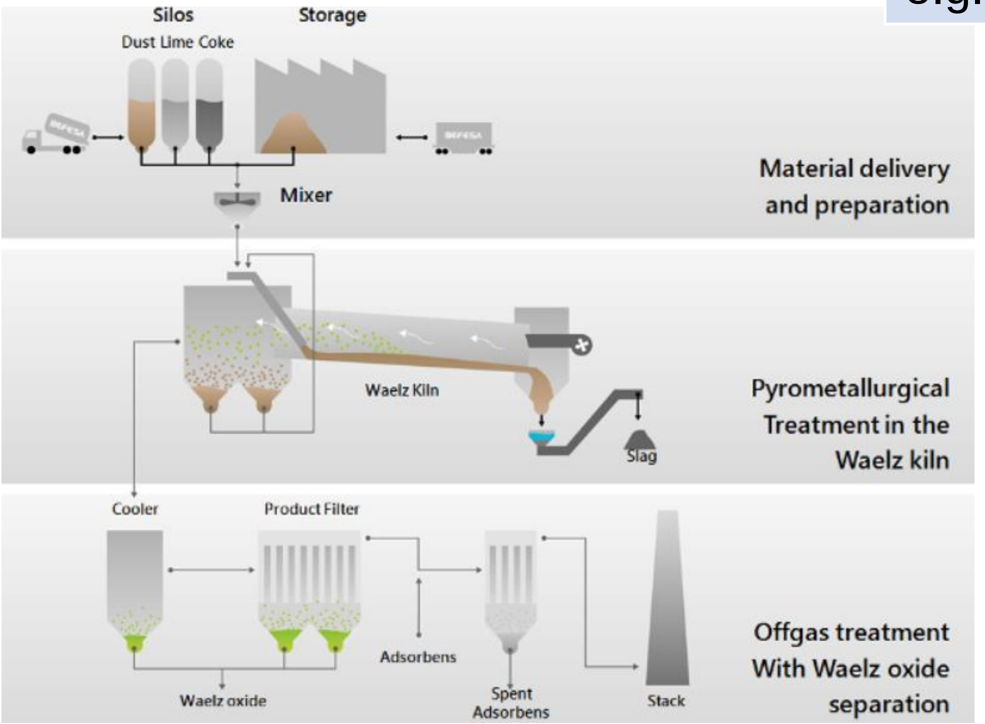
Pyrometallurgy

- Rotary Kiln (Waelz process)

Processed residues	Main products
Higher-zinc residues; e.g. Electric arc furnace dust	• Waelz oxide (Zn, Pb) • By-product: Iron bearing slag

Energy carrier
Coke breeze; evtl. oil

Reductant
Carbon



Process scheme – Waelz process [Befesa]

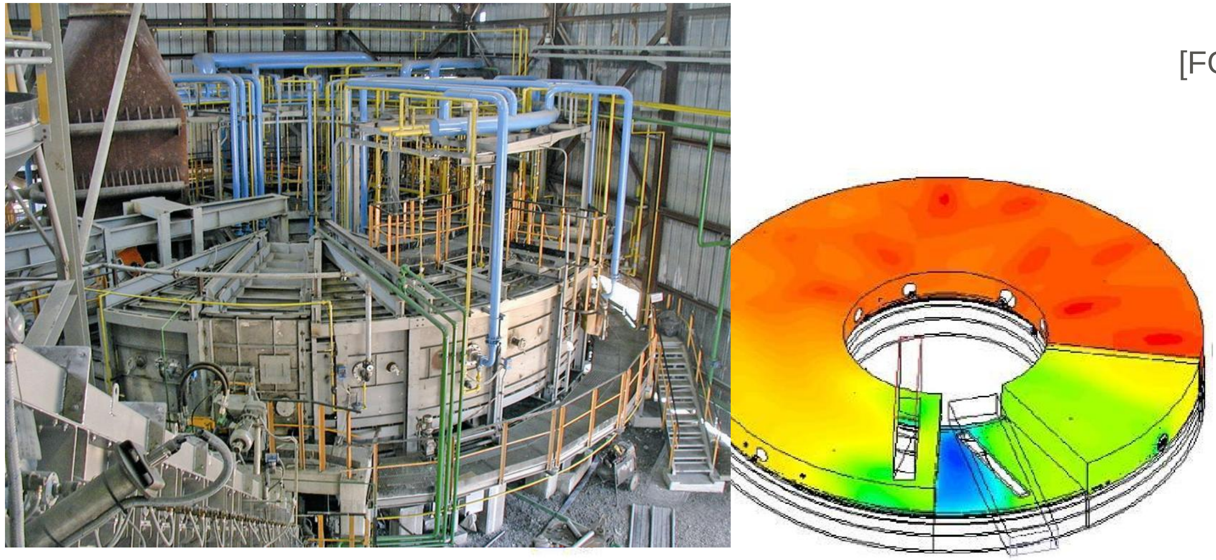
Pyrometallurgy

- Rotary Hearth Furnace (RHF; e.g. INMETCO®, RedIron®)
- Multiple Hearth Furnace (MHF; e.g. PRIMUS®)

Processed residues	Main products
Higher-zinc residues; e.g. Electric arc furnace dust	• Zinc enriched product dust; Direct reduced iron (DRI)

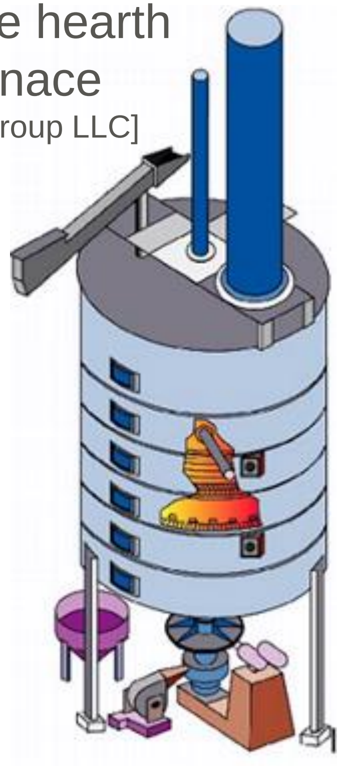
Energy carrier
Coal; Natural gas

Reductant
Carbon



Rotary Hearth Furnace - RedIron®, [Paul Wurth]

Multiple hearth Furnace
[FGC Group LLC]



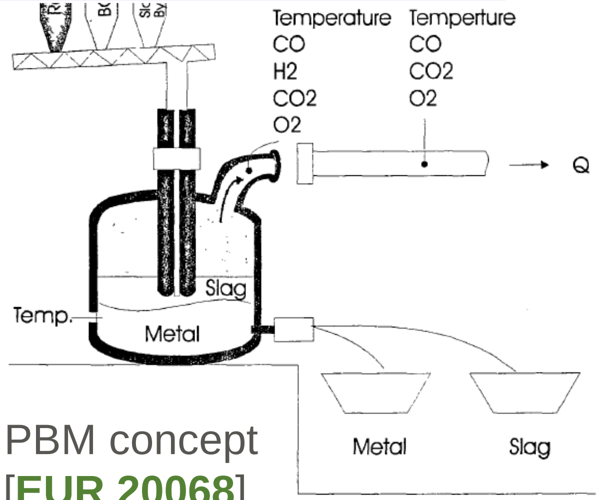
Pyrometallurgy

- Melt Bath Processes

Energy carrier
Electric energy; evtl. Natural gas

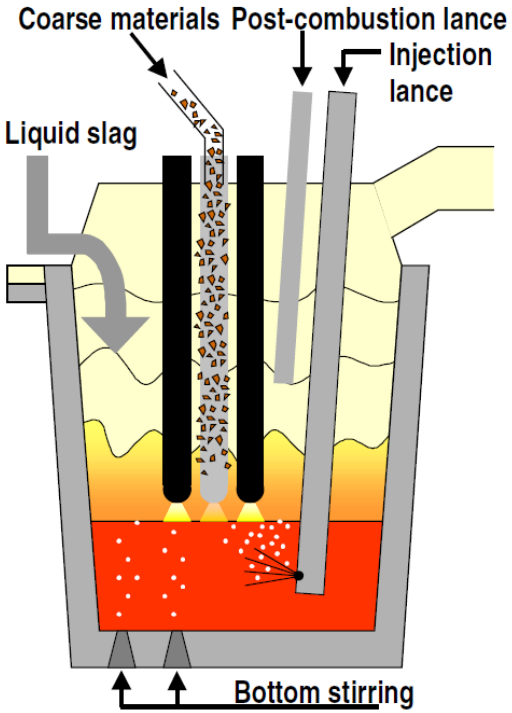
Reductant
Carbon

Processed residues	Main products
Medium to high-zinc residues; e.g. Electric arc furnace dust	• Zinc enriched product dust • Hot metal • Slag product



IPBM concept
[EUR 20068]

Melt bath injection into an induction furnace



Scheme ZEWA ® Process

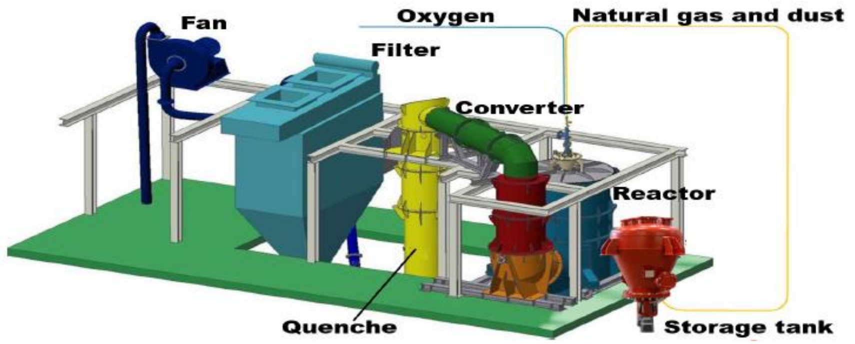
Pyrometallurgy

- Processes with Flash reactor/ Melting Cyclone

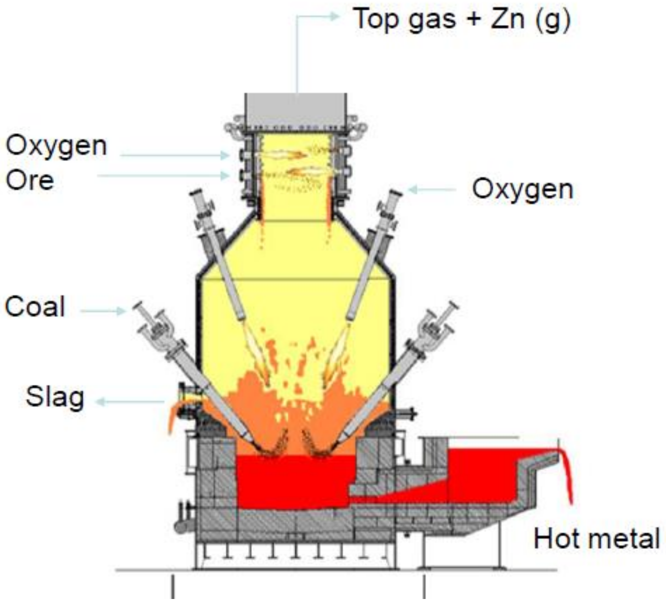
Energy carrier
Coal; Natural gas

Reductant
Carbon; Natural gas

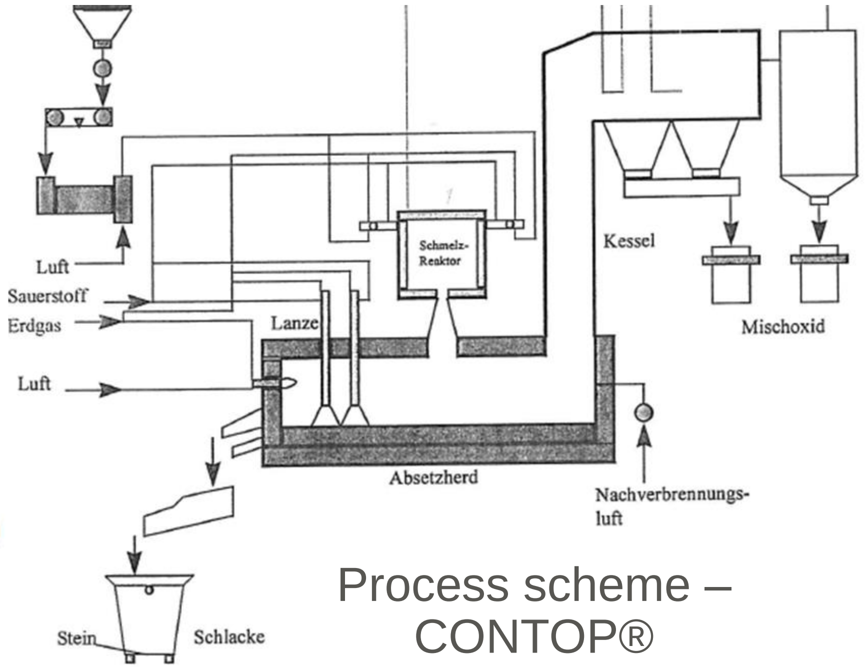
Processed residues	Main products
Low- to high-zinc residues; e.g. Electric arc furnace dust; BOF dust	• Zinc enriched product dust • Iron bearing slag phase • Hot metal



RecoDust® process [K1MET, Uni Leoben]



HIsarna®; Reclamet project [**EIT RawMaterials Project No:17209**]



Process scheme – CONTOP® Melting cyclone

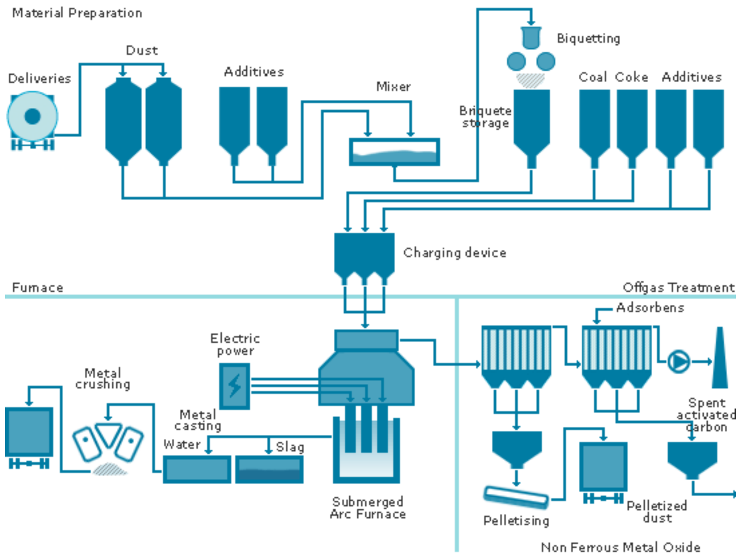
Pyrometallurgy

- Submerged Arc Furnace (SAF)
- Plasma Furnace (e.g. SCANDUST ®)

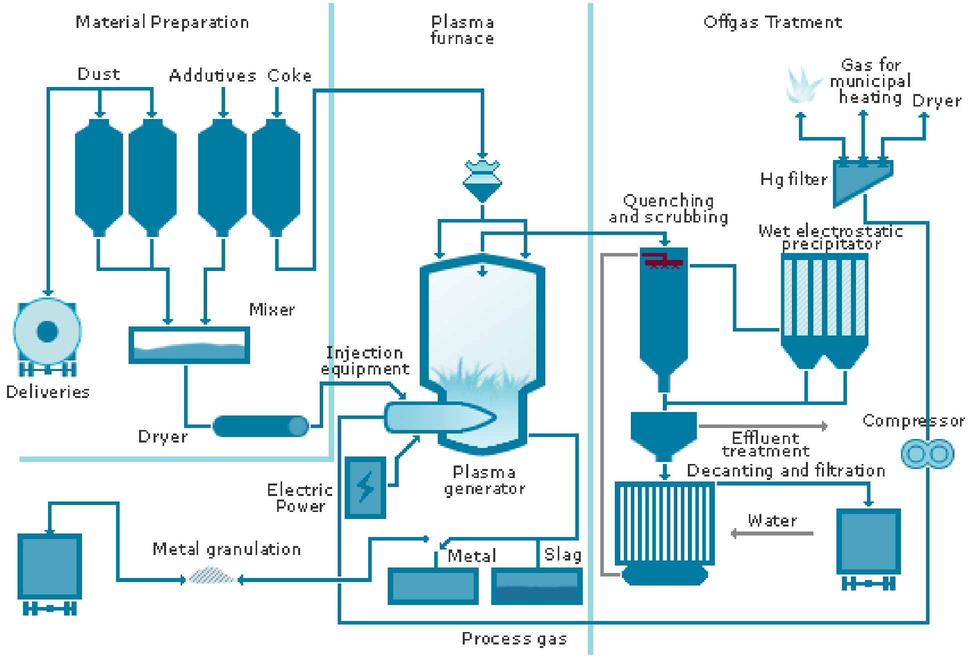
Processed residues	Main products
Cr- and Ni-bearing residues from stainless steelmaking; e.g. Electric arc furnace dust	• Ferrroalloy (Cr, Ni)

Energy carrier
Electric energy; Coke

Reductant
Carbon

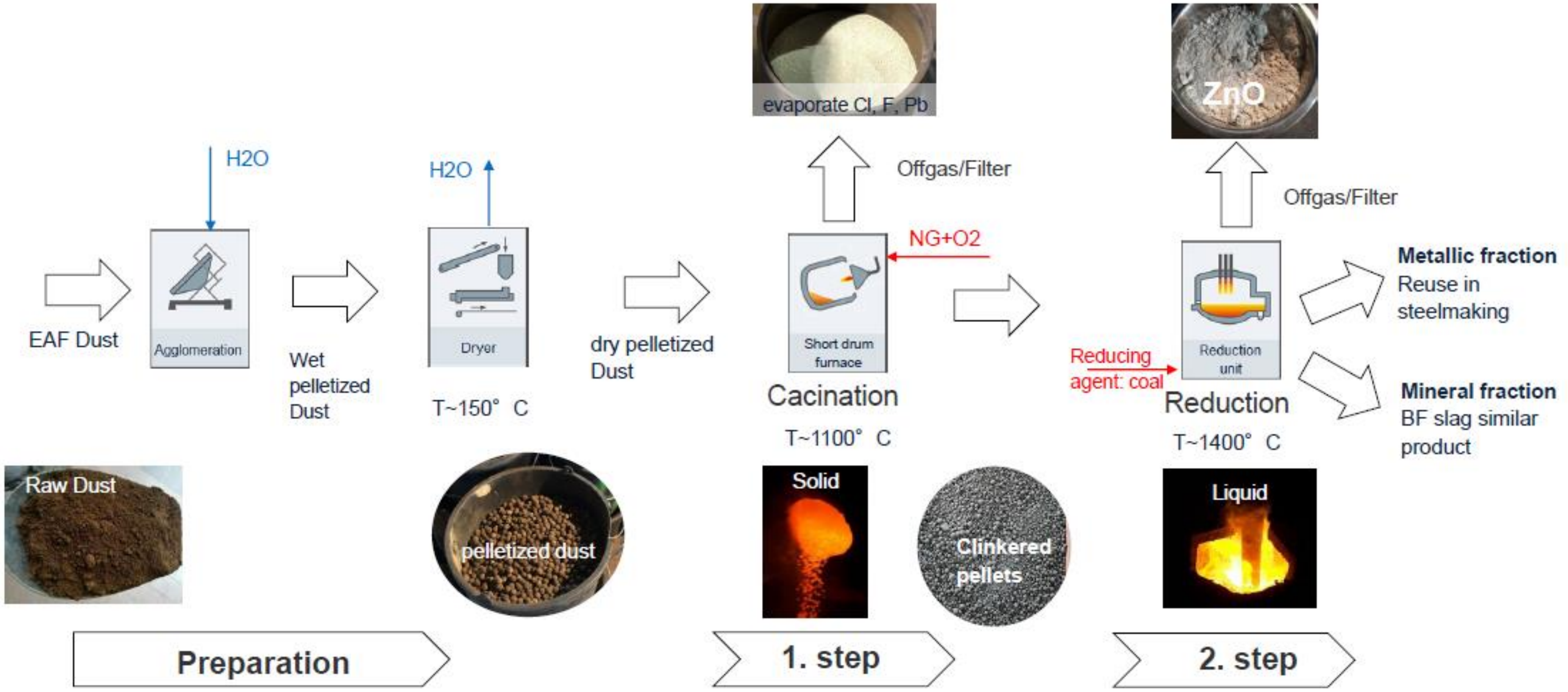


Process scheme – Submerged arc furnace



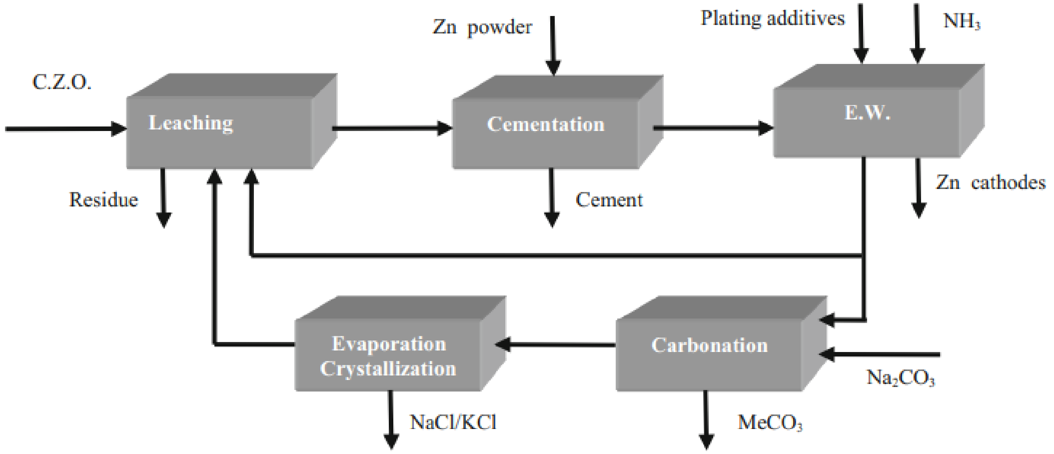
Process scheme – SCANDUST® Plasma furnace

Pyrometallurgy – two step processes

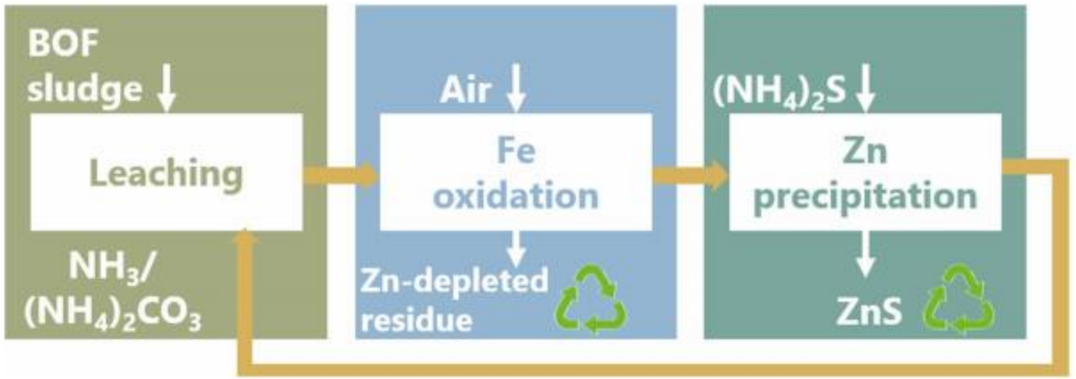


2sDR® process scheme [PRIMETALS; **EIT RawMaterials project: 2sDR**]

Hydrometallurgy



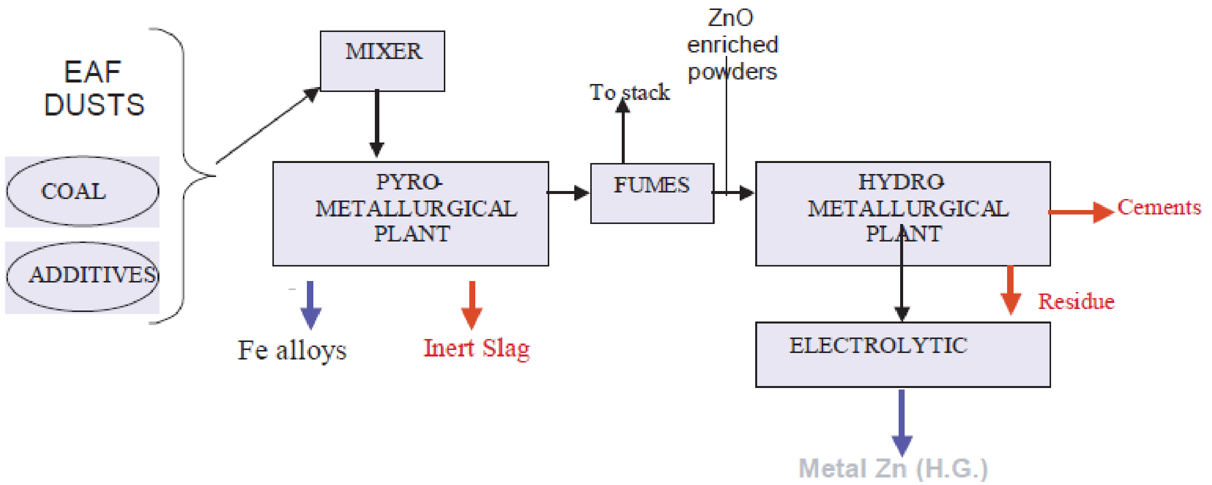
Ammonical leaching, leachate purification and electrowinning [1]; EZINEX® process [**EUR 19393**]



Ammonical leaching process [2]; e.g. SAMEX® project [**EIT RawMaterials project No. 19205**]

Similar EU projects (Rep.-No.)	Title	Results/Success/Failures	TRL	Follow-up/ideas
EUR 19393 [P1]	Economic advantages of integrated processing of steelworks EAF wastes, mainly containing Zn, Pb, Cd, FeOx, Zn ferrite and others, with total recovery	Effective for recycling of EAF dusts and obtaining metallic Zn at high purity level; Economy depends on Zn content and raw material and energy prices	6	Integrated system for treatment of larger quantities of dusts with higher zinc content in order to increase the overall yield
GA ID 508714; REDILP [P42]	Recycling of EAF dust by an integrated leach-grinding process	The resulting REDILP-Process works in the technological way but not in the economic way	7	Marketing and exploiting the developed system at EU level

Combined Pyro- and Hydrometallurgy



Full-Rec technology; [EUR 20505, EUR 22989]

Similar EU projects (Rep.-No.)	Title	Results/Success/Failures	TRL	Follow-up/ideas
EUR 20505; FULL-REC [P6]	High purity zinc and ferroalloys recovery from EAF dusts through a combined pyro-hydrometallurgical treatment	Complete recovery of Zn and Pb is achieved ($ZnO+PbO>84\%$); Very high purity (99.96%) metallic zinc product	5	Implementation of the hydro-metallurgical plant in continuous mode
EUR 22989; FULL-REC 2 [P13]	Hydrometallurgical continuous treatment of ZnO enriched powders for metal zinc production	The feasibility has been successfully demonstrated, but lower purity of metallic Zn product (99.98%) than targeted due to solution impurities; Economic operation is expected	5	Ti Anodes instead of Pb ones; Double purifying treatment for better Ni removal

Evaluation of relevant EU projects in REUSteel – Preliminary conclusion on dust and sludge processing

- All of the evaluated projects basically were successful from technical point of view – only minor technical challenges still have to be tackled
- Economic efficiency is diverse - depends on many aspects
  - Zn concentration in residue; Zn price
  - Product quality and value: Often impurities in Zn product of one-step metallurgical processes (two steps are better); however good product quality in hydrometallurgy
  - Energy and raw material costs
- Follow-up activities mainly devoted to detailed technical improvements, scale-up and marketing

Gerald Stubbe
VDEh-Betriebsforschungsinstitut GmbH
Stahl-Zentrum · Sohnstraße 69 · 40237 Düsseldorf
Tel. +49 211 98492-969
E-Mail gerald.stubbe@bfi.de · www.bfi.de

[1] M. G. Maccagni: INDUTEC®/EZINEX® Integrate Process on Secondary Zinc-Bearing Materials. J. Sustain. Metall. (2016) 2:133–140

[2] N. Rodriguez Rodriguez et. al.: Selective Removal of Zinc from BOF Sludge by Leaching with Mixtures of Ammonia and Ammonium Carbonate. Journal of Sustainable Metallurgy (2020) 6:680–690

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

Briquettes from dust and sludge for shaft furnace charging

Simon Wölfelschneider, Steffen Möhring
– VDEh Betriebsforschungsinstitut GmbH

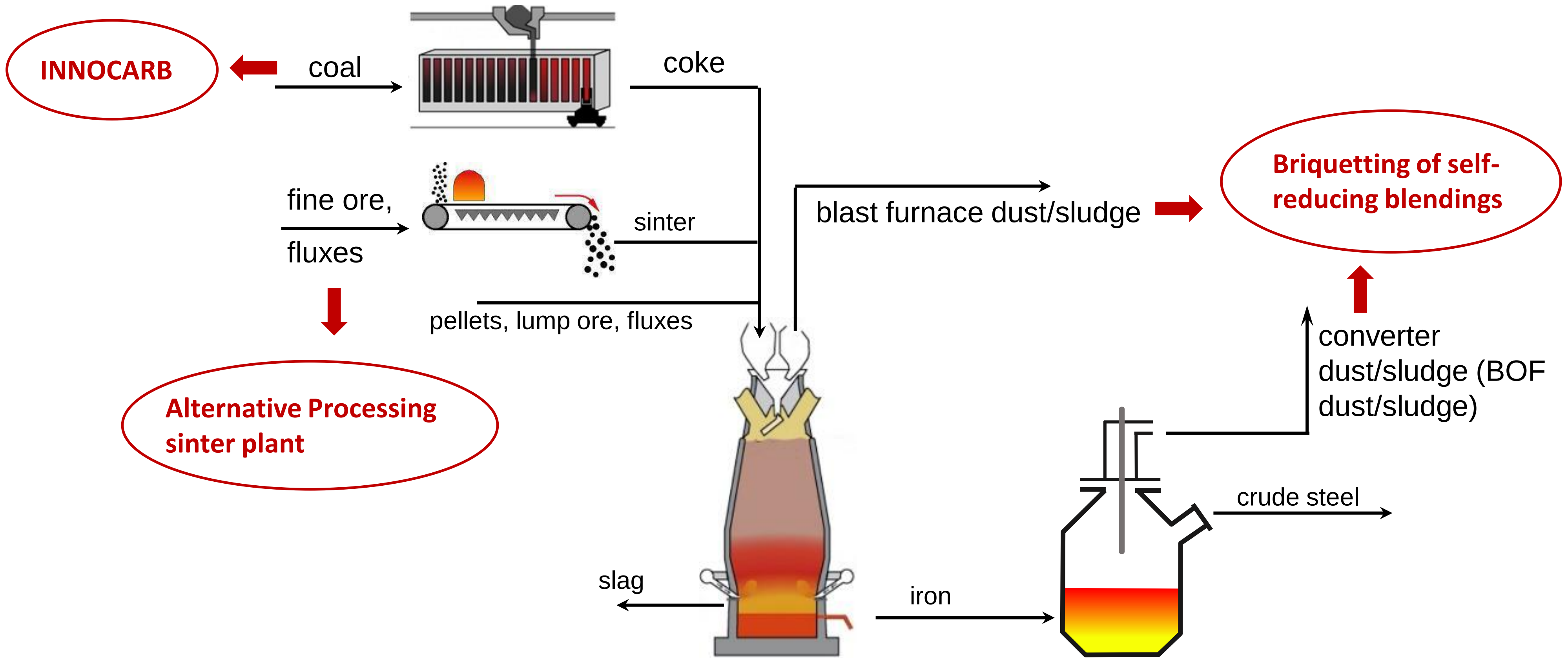
Webinar on Sludge and Dust (15.06.2021)

Content

- Introduction / Projects
- Materials for Briquetting
- Approach/ Recipe development
- Influencing variables
- Briquetting tests
- Results

Exemplary EU projects:

- ECSC 7210-PR/005: Briquetting of self-reducing blendings of waste iron oxide mixtures; 1997 – 2000
- ECSC 7210-PR/326: Alternative Processing of Sinter Plant Recycling Materials; 2002-2005
- INNOCARB: Innovative carbon products for substituting coke on BF operation; 2010-2013



Mean composition of the test materials

	Fe	C	CaO	SiO_2	Al_2O_3	Zn	H_2O	x50 [mm]
BF Sludge	26	35	5,2	7,3	3,4	4,6	40	<0,05
Mill Scale	56	0,8	5,0	7,0	2,2	0,04	12	0,60
BF Dust	28	32	5,5	6,8	2,5	0,15	3,5	0,25
BOF Dust	58	0,9	5,9	0,6	0,02	3,3	2,5	0,30
Iron Ore (fines)	66	0,02	0,4	0,4	0,1	0,1	10	0,50
Coke Breeze	0,5	88	0,3	5,0	3,7	0,0	14	1,50
Lignite coke	0,2	86	3,5	0,8	0,5	0,0	5	0,40

Requirements for the residue briquettes (e. g. coke substitute):

Size	mm	65…85
C - content	%	> 70,0
Ash	%	< 20,0
Volatiles	%	< 1,5
Cold Strength	MPa	≥ 2,5

- No interfering components(max. binder content < 20 %)
- Low production costs

General procedure for projects involving the briquetting of residues and/or raw materials

1.) Material characterisation
- Chemical Analysis
- Determination of humidity
- Particle size analysis

2.) Recipe development (recipe matrix)
- Material preparation (grinding, sieving, drying)
- Selection of binders, additives and auxiliary substances
- Composition of agglomerat
- Adjustment to optimal particle size distribution

3.) Production and investigation of :
laboratory test samples (tablets)

4.) technical samples (briquettes)

Recipe development

binder	limiting properties	Laboratory tests	Industrial trials
tar; pitch	carbon black / hydrocarbon emissions	X	
sulfite liquor	SO_2-emissions; corrosive; water soluble	X	
molasses	water soluble; limited availability	X	
starch	water soluble; expensive	X	
resins; wax	expensive; thermoplastic	X	
plastics	limited availability; expensive; hydrocarbon emissions	X	
lime, cement	increase slag content; high water content	X	X

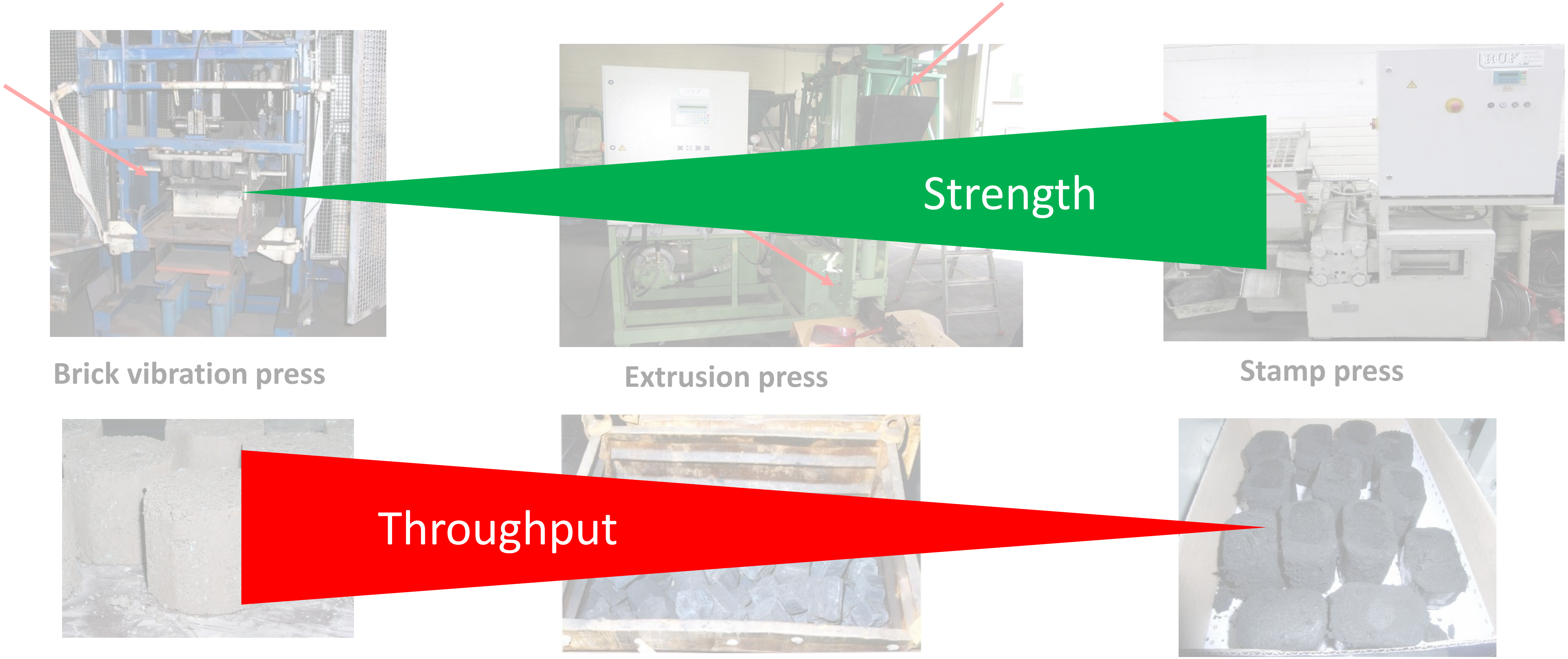
Particle size distribution

Homogenity + high packing density
→
Increasing strength

Example for a recipe matrix (INNOCARB)

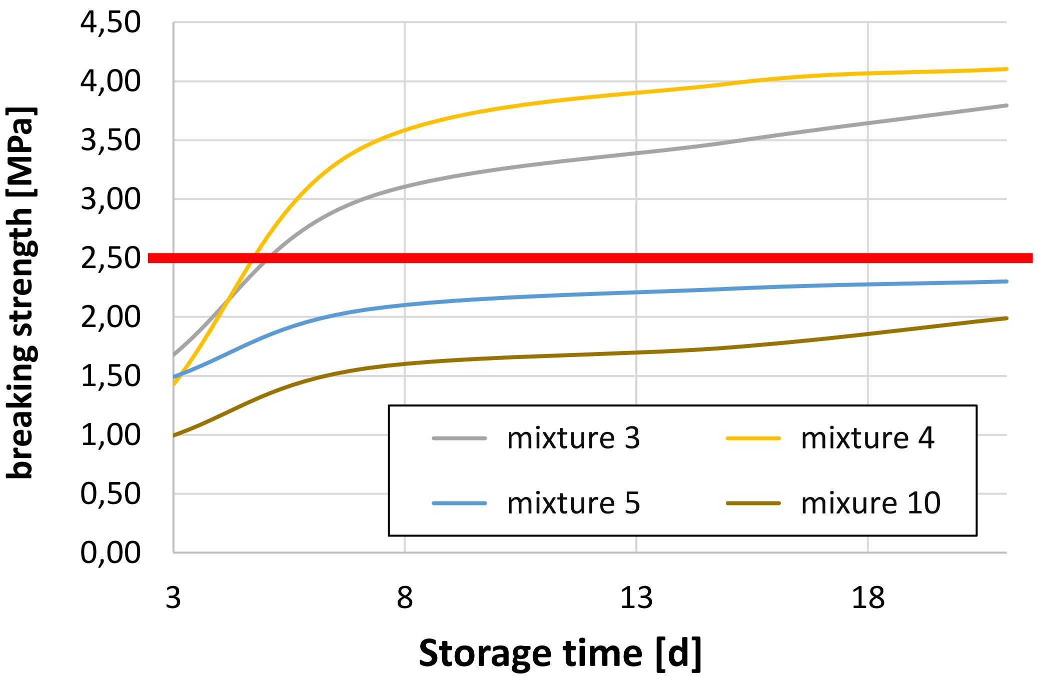
Mix.	Coke breeze	Lignite coke	Portland cement	Molasses
T-1	90	0	0	10
T-2	0	90	0	10
T-3	85	0	0	15
T-4	0	85	0	15
T-5	82	0	18	0
T-6	0	82	18	0
T-7	88	0	12	0
T-8	0	88	12	0

Briquetting technology for pilot plant trials and industrial tests



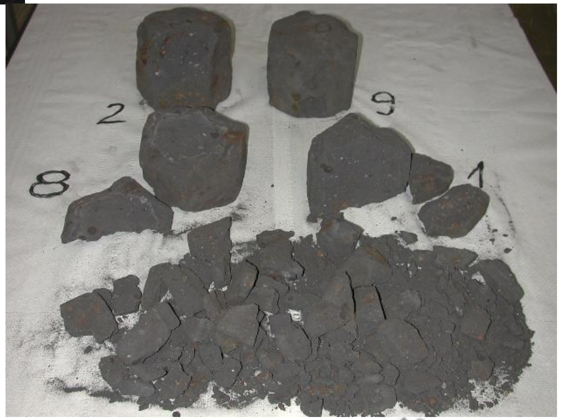
Briquetting tests

breaking strength



Reduction (Under Load) tests

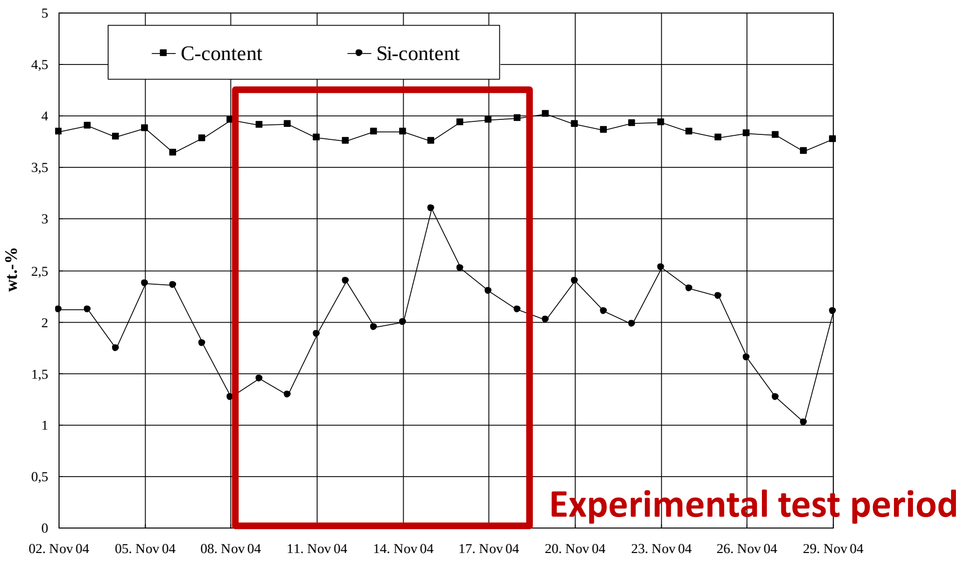
Bricks after shatter tests



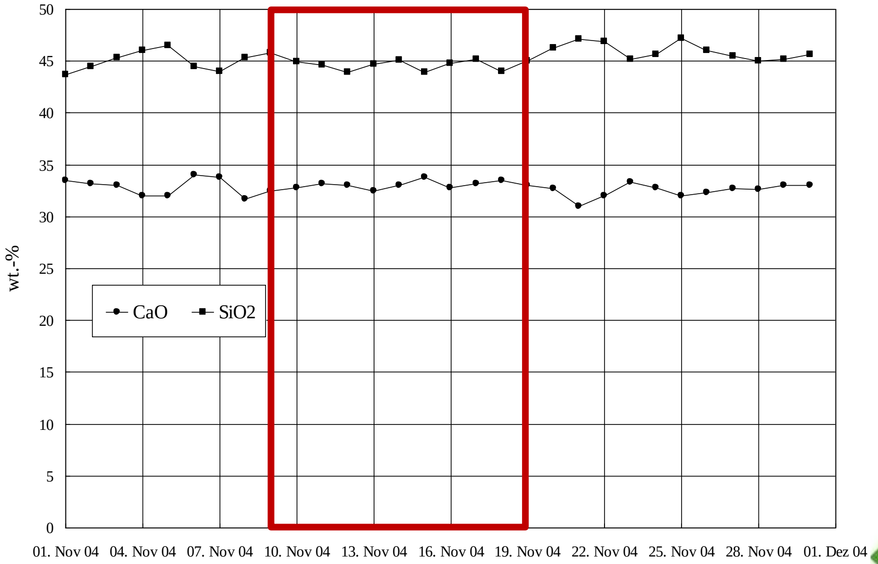
Blast furnace (Alternative Processing...):

- 300 t batch of residual-material bricks
- 40 kg/tHM
- mill scale and blast-furnace dust
- produced with vibrating press

C- and Si- content in hot metal



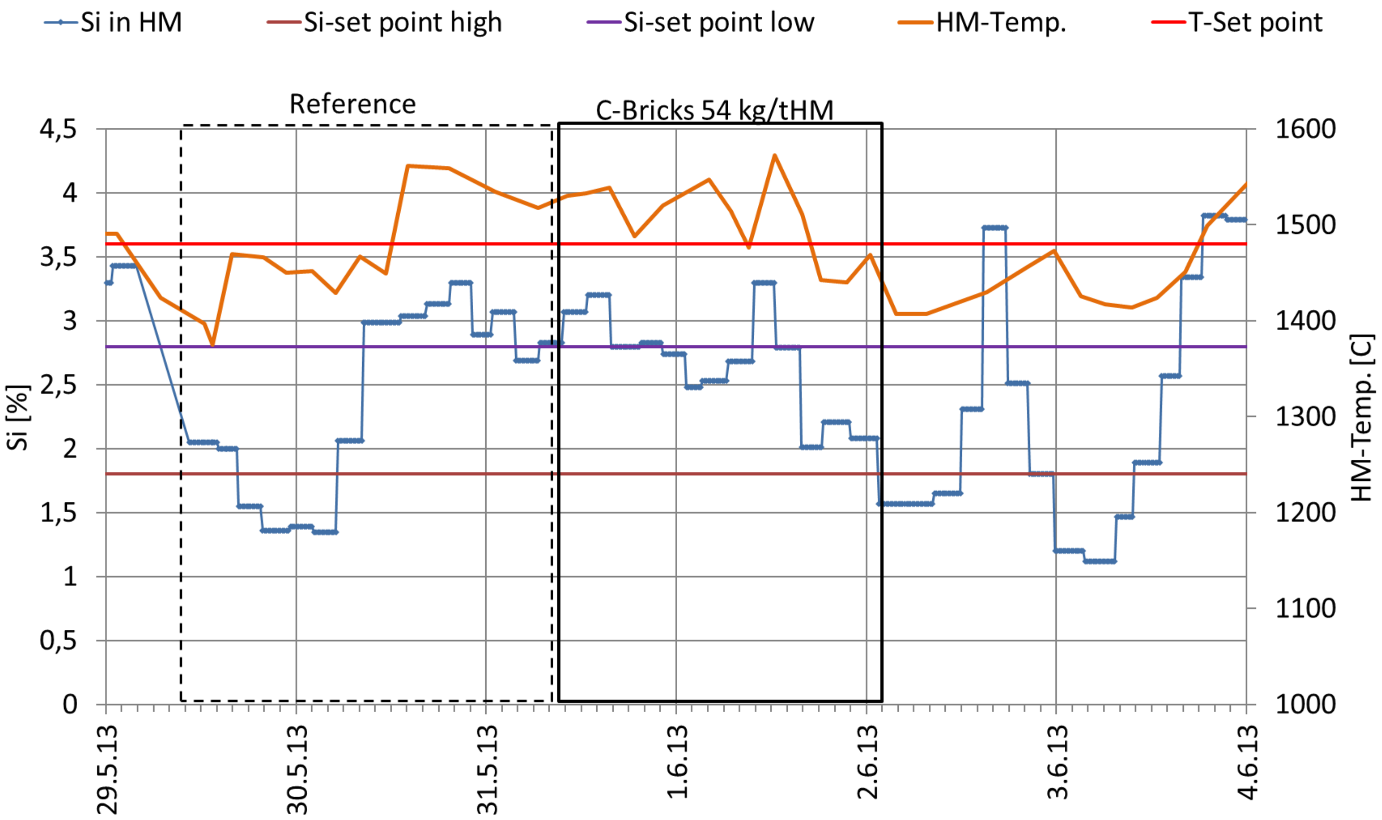
CaO- and SiO_2-content in slag



Blast furnace (INNOCARB):

- 2000 t of carbon briquettes were produced
- Charging to DK BF

Si- content in hot metal



RFCS project main results

Briquetting of self-reducing blendings of waste iron oxide mixtures

- BF sludge → self-reducing briquettes
- Charging to small shaft furnace (5 of load %) → only mineral binders feasible
- self-reducing briquettes with an optimised iron oxide/carbon ratio

Alternative Processing of Sinter Plant Recycling Materials

- Residual briquettes → max. breaking strength 1800 N (with 20 % cement as binder)
- charging of 40 kg/t hot metal → no direct negative influences on BF operation
- Iron, slag and dust composition analyses → no significant changes in comparison with normal operation

INNOCARB: Innovative carbon products for substituting coke on BF operation

- Substitution of metallurgical coke with residual carbon briquettes possible
- Coke substitution rate of about 10% in BF
- Utilisation of carbon materials with low reactivity

Is briquetting still relevant ? → **Yes!**

Focus: biomass

- Production, Analysis and Optimization of Low-Cost Briquettes from Biomass Residues, 2017 — *Kaur et al. ; Adv. Res., vol. 12, no. 4, pp. 1–10, Jan. 2017*
- Characterization and Production of Fuel Briquettes Made from Biomass and Plastic Wastes, 2017 — *Garrido et al. ; Energies, vol. 10, no. 7, p. 850, Jun. 2017*

Focus: raw materials and residuals

- Iron Ore Agglomeration Technologies, 2018 — *Fernández-González et al. ; Ed. InTech, 2018. doi: 10.5772/intechopen.72546.*
- Iron Ore-Coal Composite Pellets/Briquettes as New Feed Material for Iron and Steelmaking, 2017 — *Dutta et al. ; Mater. Sci. Eng. Int. J., vol. 1, no. 1, Jul. 2017*

Focus: New Technologies

- Hot Briquetting of Fine-Grained Residual Materials from Iron and Steel Production, 2020 — *Lohmeier et al. ; Steel Res. Int., vol. 91, no. 12*
- Cold briquetting of iron ore fines for DRI production: challenges, possibilities and solutions, 2019 — *Bhattacharyya et al. ; Iron Ore, p. 7, 2019*

Contact:

Simon Wölfelschneider/ Steffen Möhring

VDEh-Betriebsforschungsinstitut GmbH

Stahl-Zentrum · Sohnstraße 69 · 40237 Düsseldorf

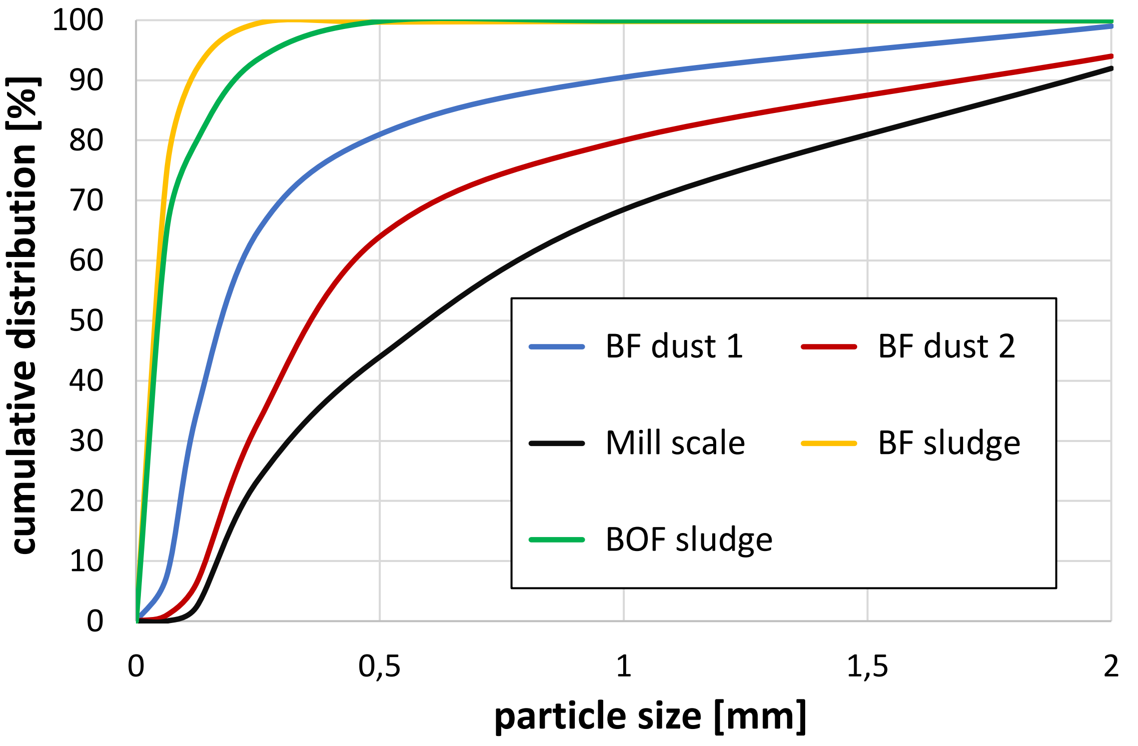
Tel. +49 211 98492-221

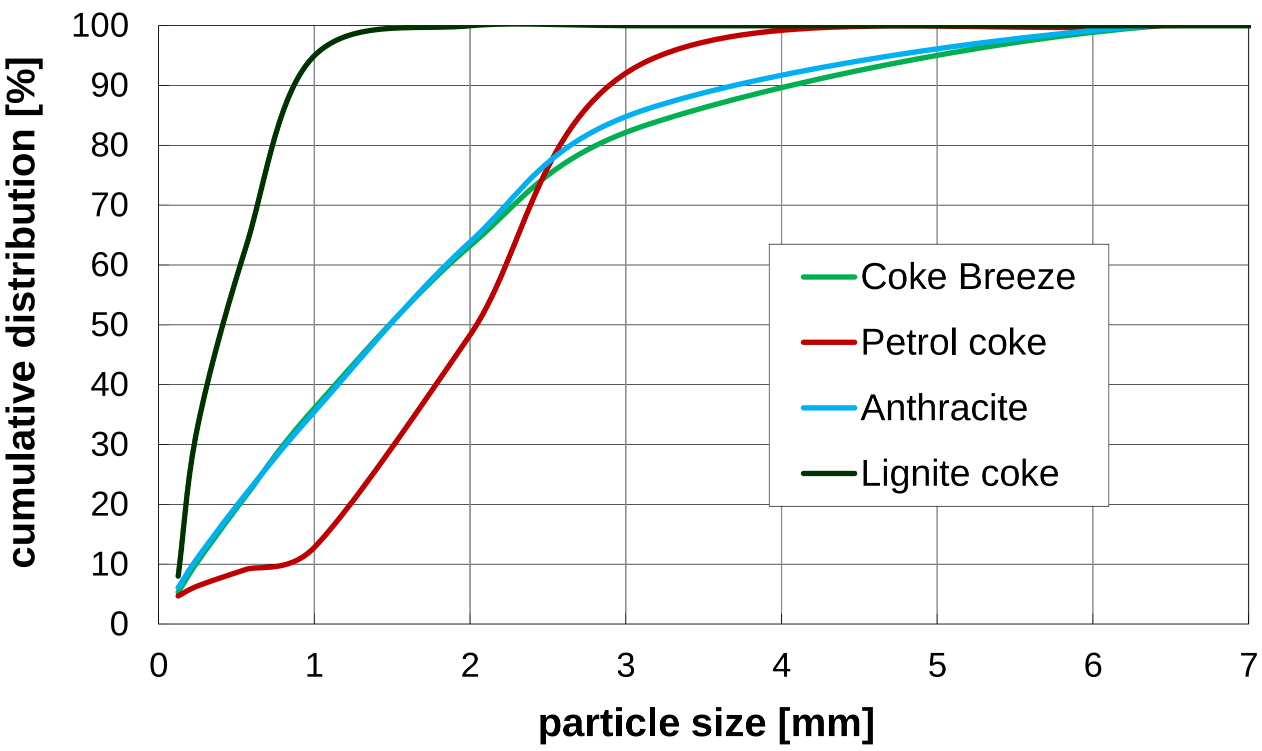
www.bfi.de

E-Mail simon.woelfelschneider@bfi.de

steffen.moehring@bfi.de

Materials analysis





Suitable material preparation

Homogenization of material +
Optimal high packing density
(FULLER curve) =
Increasing the strength

$$A = 100 \cdot \left(\frac{d}{D}\right)^n$$

A Cumulative percentage sieve passage
d aggregate size being considered
D maximum aggregate size
N Parameter which adjusts curve for fineness or coarseness (for maximum particle dencity **n ≈ 0,5**)

Binders in BFI investigations (recipe development)

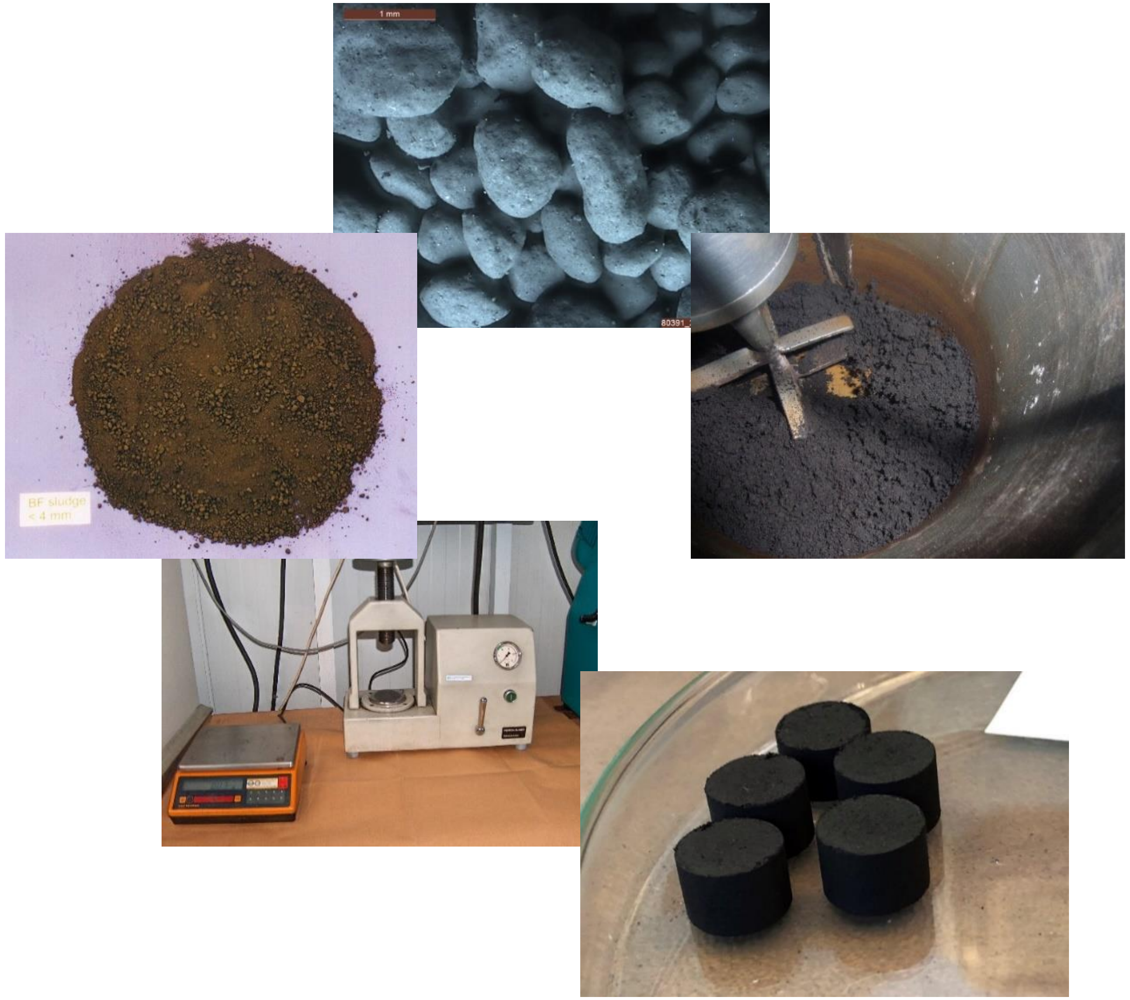
binder	limiting properties	Laboratory tests	Industrial trials
tar; pitch; coal tar pitch	thermoplastic; carbon black / hydrocarbons emissions during combustion	X	
sulfite liquor	SO_2-emissions; corrosive; water soluble	X	
molasses	water soluble; limited availability	X	
starch	water soluble; expensive	X	
resins; wax	expensive; thermoplastic	X	
plastics	limited availability; expensive; thermoplastic; partially high emissions during combustion	X	
lime, cement	increase slag content; high water content	X	X

Selection criteria:

- Chemical composition
- Necessary after-treatment steps
- Behaviour in application
- Available quantity
- Technical suitability in the manufacturing process
- Price

Example for a recipe matrix (INNOCARB)

mixture	Coke breeze	Lignite coke	Portland cement	Molasses
T-1	90	0	0	10
T-2	0	90	0	10
T-3	85	0	0	15
T-4	0	85	0	15
T-5	82	0	18	0
T-6	0	82	18	0
T-7	88	0	12	0
T-8	0	88	12	0



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

Lowering local blast furnace hearth wear by TiO_2-materials injection

Adam, Jörg – VDEh-Betriebsforschungsinstitut GmbH

Commission of European Communities

RFCS Sponsored Research Project

TECHNICAL GROUP TGS 1: Ore agglomeration and Ironmaking

Contract N°: 7210-PA/PB/PC/PD/PE/PF/PG/327

Duration: 01.07.2002 – 31.12.2005

Partners:	ThyssenKrupp Stahl AG	Duisburg (Germany)
	EKO Stahl GmbH	Eisenhüttenstadt (Germany)
	BFI	Düsseldorf (Germany)
	voestalpine Stahl GmbH	Linz (Austria)
	Ruukki	Raahe (Finland)
	MEFOS	Lulea (Sweden)
	CSM	Roma (Italy)

Introduction

Initial situation

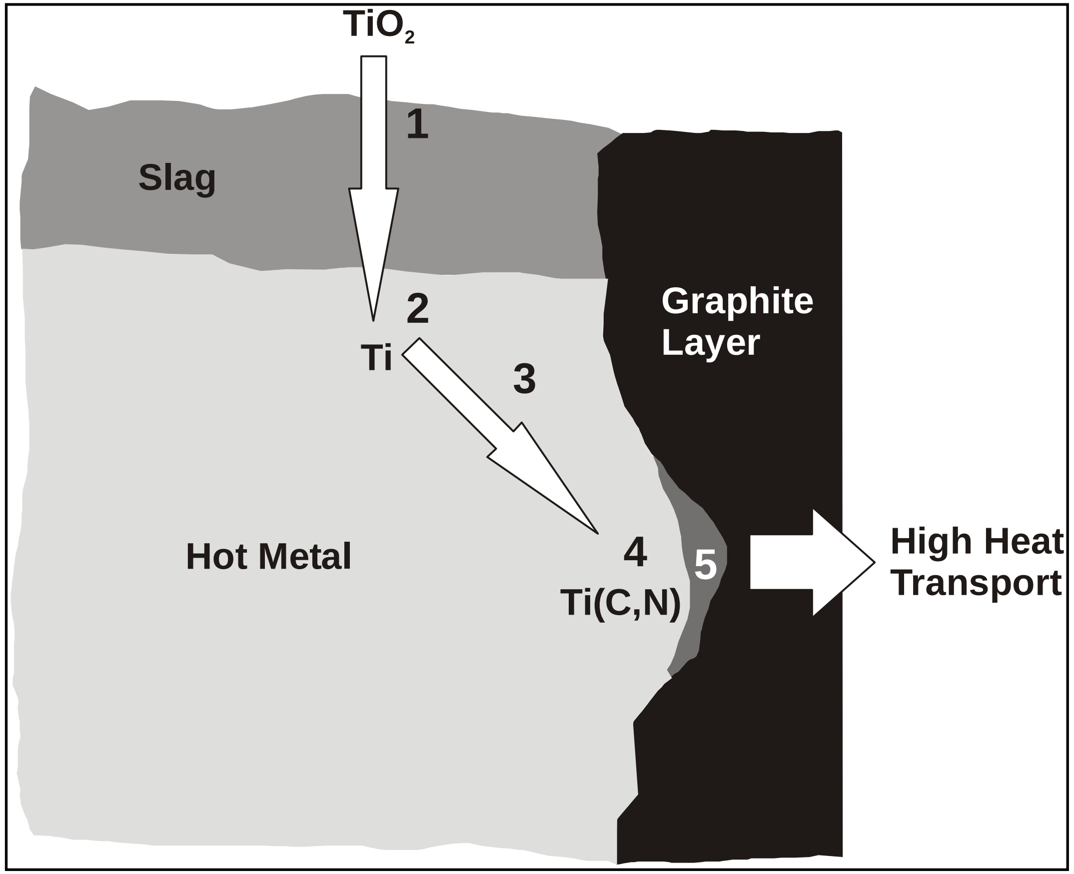
- Common practice: charging titanium containing ilmenite with the burden to shield the refractory in the BF hearth
- Charging ilmenite effects an increase of Ti-content in whole hearth, although wear occurs only locally
- Disadvantage of ilmenite charging: high Ti-content in slag (quality loss)

Objectives

- Wear protection / hot repair of worn areas **with low Ti-input** into the BF
- **Local injection** of Ti-rich material / external by-products through tuyeres **directly into hearth zones with high wear**
- **Local increase of Ti-content** at hearth areas with high wear

→ formation of high smelting Ti(C,N)-layers for hearth protection

Scaffolding process



1. Dissolving of TiO_2 in slag phase
2. Reduction of TiO_2 to Ti and dissolving of Ti in HM
3. Transport of dissolved Ti with HM flow to hearth wall
4. Building of solid TiCN formations at carbon surface of worn areas with high heat transport
5. TiCN scaffolds

Injection campaigns

(Ti-rich materials / by-products)

Catalyst material (unused)

Component	Content in wt.-%
TiO_2	75
MoO_3	< 13
SiO_2	< 10
WO_3	< 8
V_2O_5	< 3

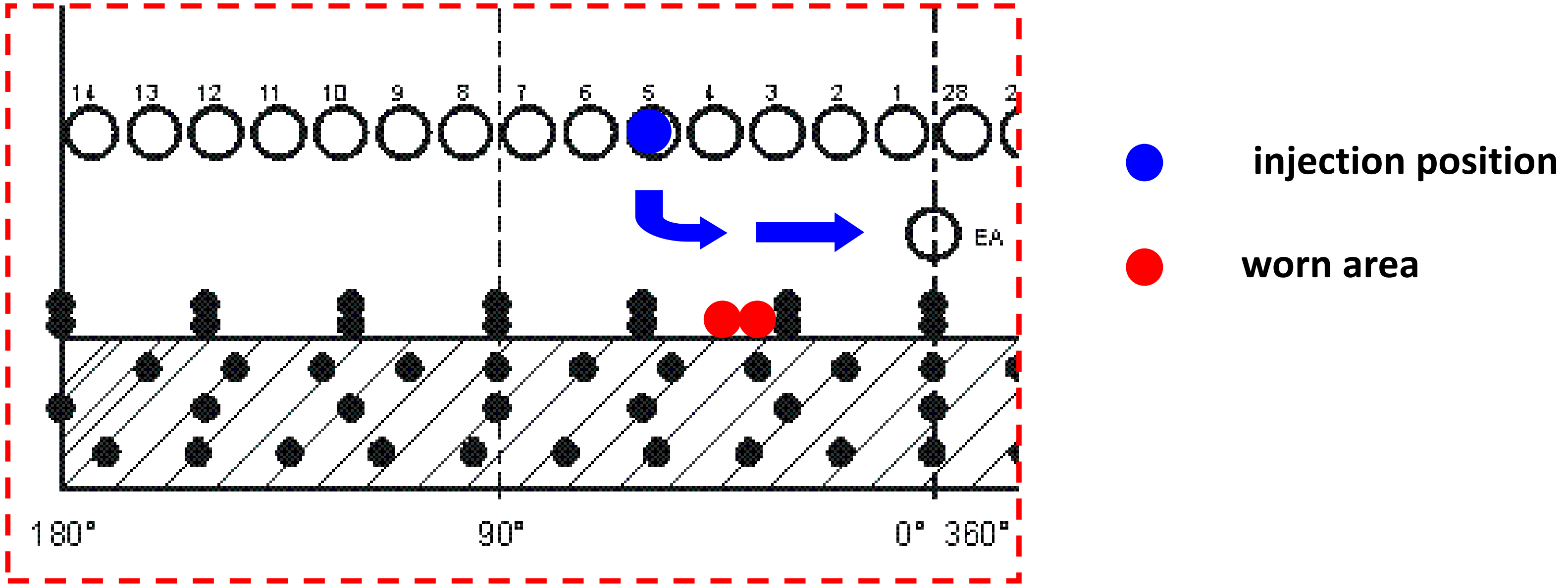
- catalysts damaged during production
- unused catalyst
- fin grinded powder

Rutilite F85

Component	Content in wt.-%
TiO_2	80 - 85
Fe_2O_3	< 15
SiO_2	< 15
CaO	< 3
Al_2O_3	< 3
MgO	< 3

- by-product of pigment production
- sold by Sachtleben

Injection campaign
(Rutilite)

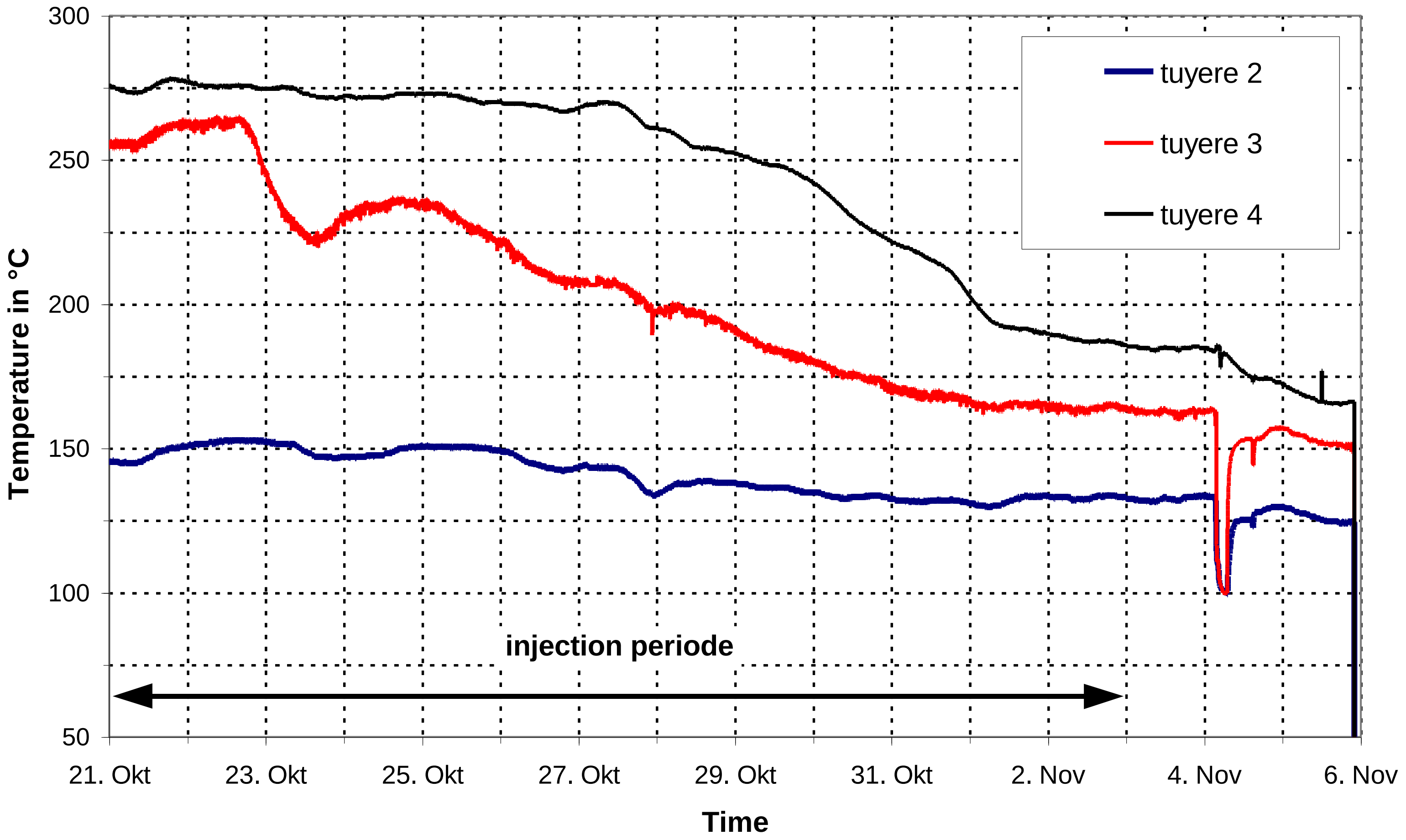


- Worn area in the transition zone between ring- and bottom layer below tuyeres 3 and 4
- Local injection of Ti-rich material through tuyere 5
- Transport of titanium along the worn area to the tap hole
- Ti-rich HM passes the worn area

Injection campaigns

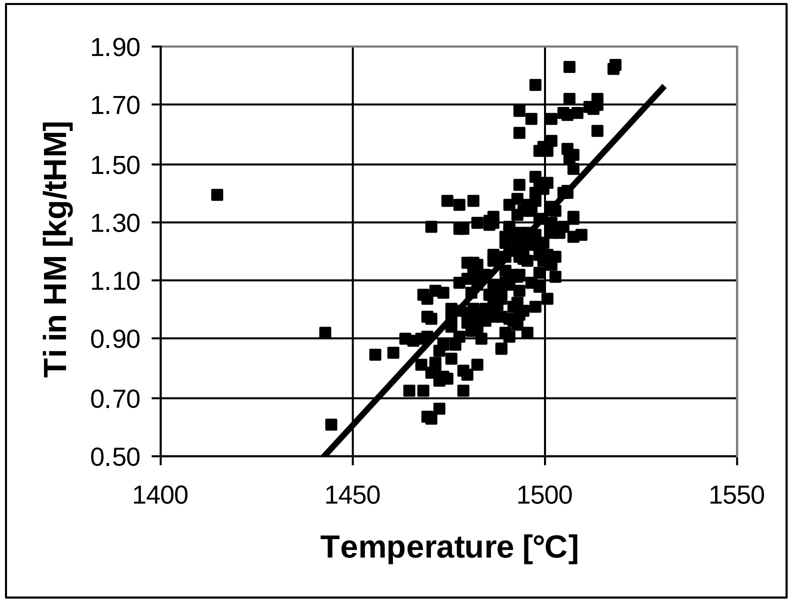
(Rutilite)

Hearth temperature at worn area

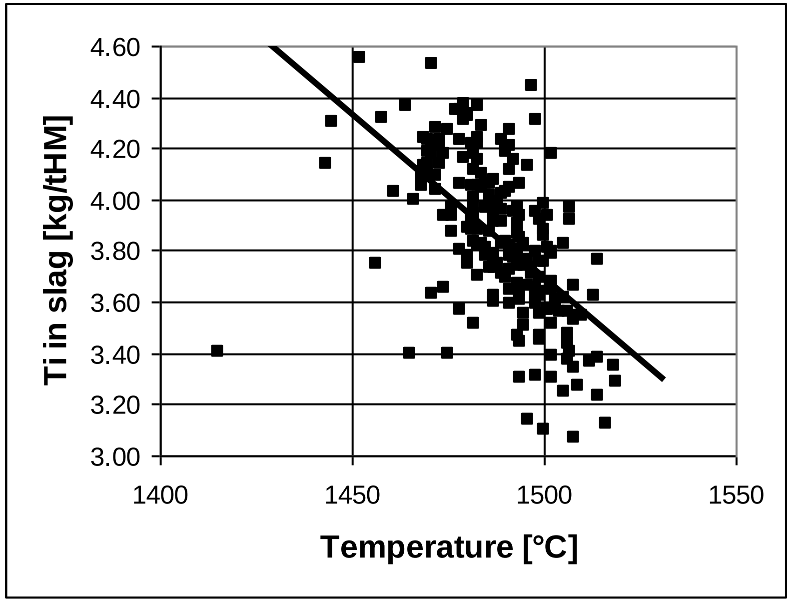


Titanium content in HM and slag

Titanium content in HM



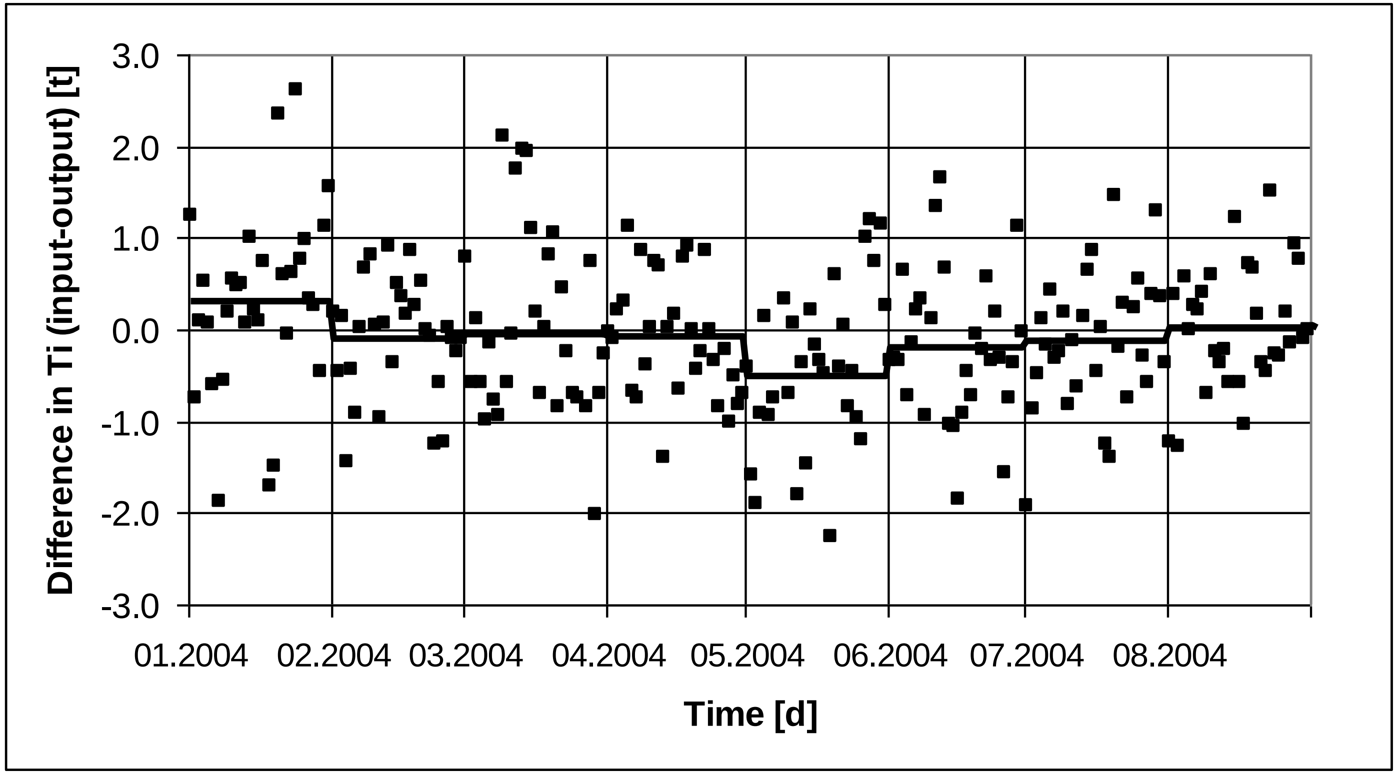
Titanium content in slag



- Temperature has a strong effect on titanium content in HM and slag
- Titanium content in HM raises with increasing temperature; contrary effect with slag

→ **Titanium injection at high HM temperature**

Titanium balance



- Partly big differences in daily average of titanium input and output
- Titanium balance is closed over a longer period (half a year, year)

Recommendations

1. Local titanium injection is a **suitable measure for BF hearth protection**

2. **Titanium injection at high temperatures** in the BF hearth
   → high titanium content in HM; low titanium content in slag

2. **Discontinuous injection** with **high injection rate** more efficient than continuous injection with low injection rate

3. Injection through tuyere **close to or directly above the worn area**

4. **Injection period of minimum one week** for a durable temperature decrease at worn areas

5. **Injection with high injection rates** in order to realise locally a high Ti content in the HM

Conclusion

1. Successful RFCS project with highly motivated partners

2. Technology Readiness Level (TRL) of 8 to 9
   → system complete and qualified / system proven in operational environment

Dr.-Ing.
Jörg Adam
Research Manager
Resource technology Feedstock

joerg.adam@bfi.de

Sohnstraße 69, 40237 Düsseldorf, Germany
Tel: +49 211 98492-276

www.bfi.de

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

Alternative carbon materials injection into the blast furnace:

Lena Sundqvist Öqvist, Swerim AB

Research Fund for Coal & Steel

Content

- Background to the Flexinject project
- Properties of BF flue dust and BF sludge
- Trials with injection of BF flue dust and BF sludge into the BF
    - Pilot scale tests
    - Industrial tests
- Implementation
- Further research conducted
- Conclusions

Background to the application for the RFCS project Flexinject

- SSAB operates on 100% pellets, there is no sinter plant and recycling of in-plant fines are conducted via cold bonded briquettes charged into the BF
- BF flue dust is a valuable raw material for the briquettes as the carbon contributes to reduction of iron oxide in the agglomerate, but to maintain the cold strength of briquettes at high additions, more cement must be added.
- The briquettes function as Coal Composite Agglomerates (CCA) in the BF, which improve the carbon efficiency by lowering of the temperature in the shaft.
- BF flue dust is pulverized and dry, and suitable for injection, which could release capacity in the briquette plant and reduce the cost for recycling. Additionally, it may be possible to add also some BF dust from intermediate storage to the briquette blend.
- Several BF dust injection tests had been conducted
  - Pilot tests in the experimental BF, collaboration between LKAB and SSAB, but also LTU and Swerim.
  - Addition of BF flue dust to injection coal before grinding (Luleå)
  - Addition of 10% BF flue dust to the fine coal silo using the old PCI plant for flow control (Luleå)
  - Injection of BF dust on one tuyere
  - A separate injection plant for BF dust injection was built and test with injection conducted (Oxelösund)

Material characteristics

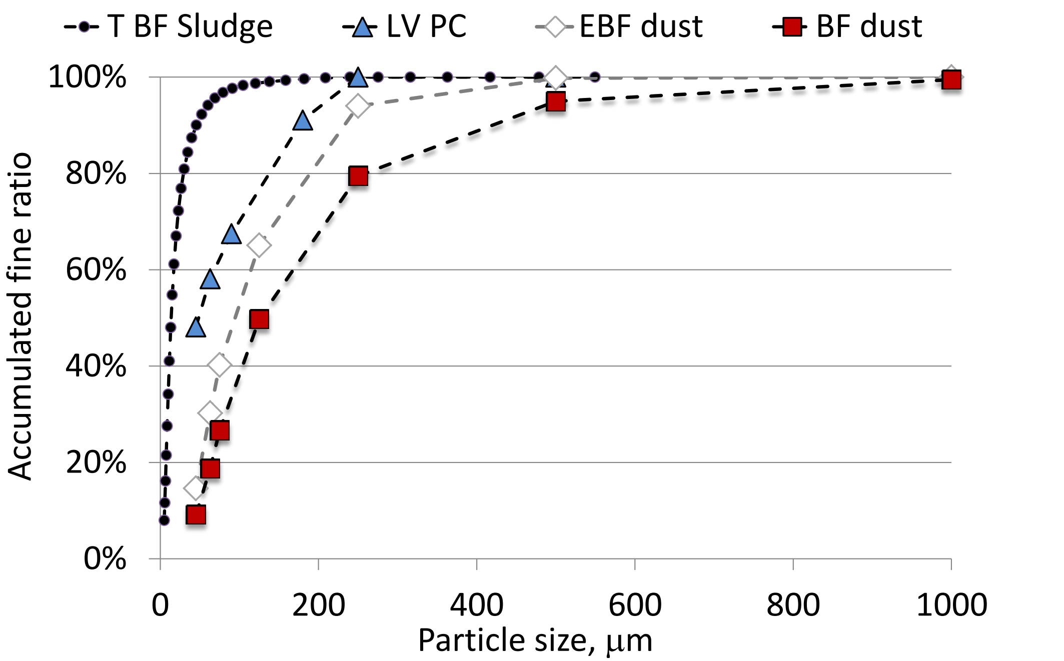
Contains valuable components with origin from charged materials but also impurities not desired in the process

BF flue dust – coarse fraction separated in dry cyclone

- consisting mainly of mechanically formed dust
- fines of ferrous material, coke, limestone, BOF slag, briquette fines
- **Abrasive** due to content of coke fines

BF sludge – fine fraction collected in the scrubber

- Formed mechanically and from gaseous compounds being oxidised and condensed.
- Contains iron oxide, carbon, quartzite and alkali oxides
- Very fine and wet with **contents of zinc**, alkalis



Chemical composition vary over time

BF flue dust contains ~ 35-55% Fe_2O_3 and ~ 35-50% C mainly as coke fines

BF sludge contains ~ 50-65% Fe_2O_3 and ~ 15-25% C

Pilot scale trials

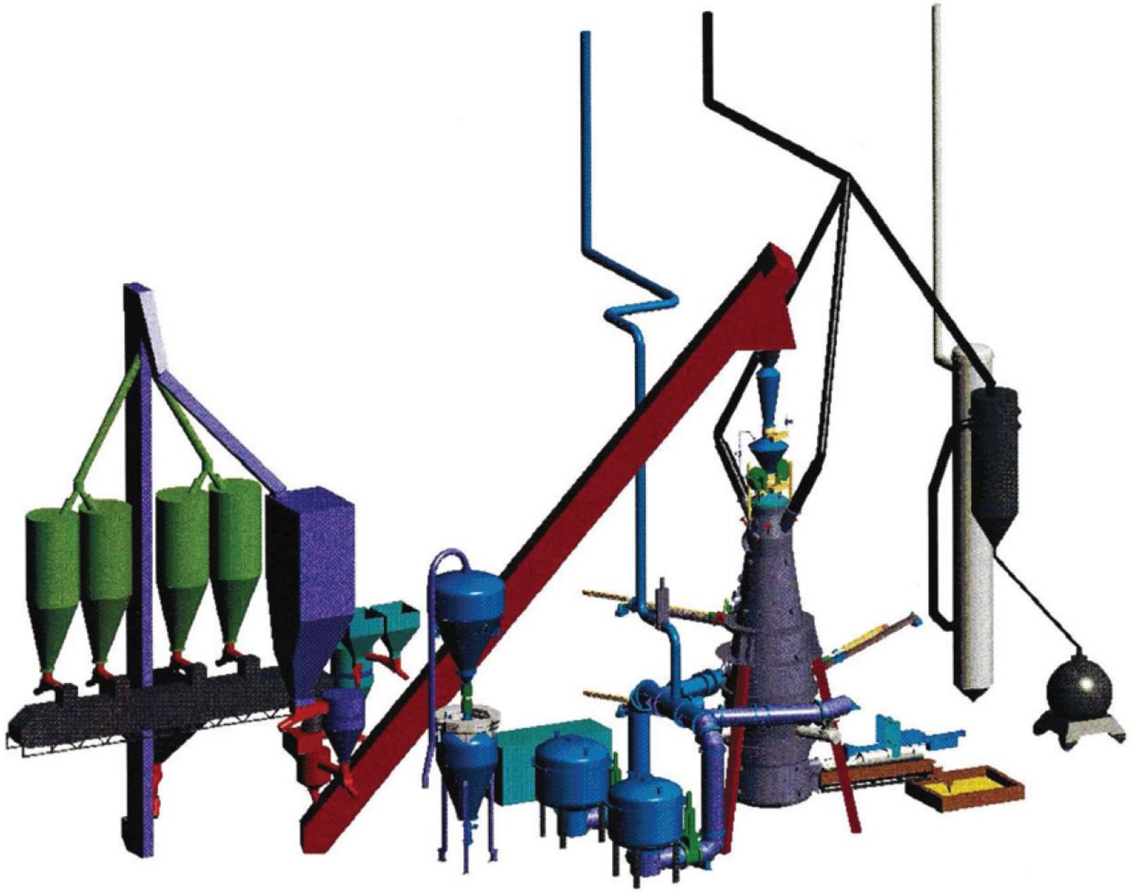
Injection trials involved tests with

- 20 kg/tHM of BF sludge pre-treated for drying and lowering of zinc content
- 20, 40, 50, and 60 kg/tHM of BF flue dust

Stable operation achieved up to the injection rate of 40 kg/tHM of BF flue dust.

Variation in pressure drop and other process variations especially at 60 kg/tHM indicated accumulation of injected BF dust at tuyere level.

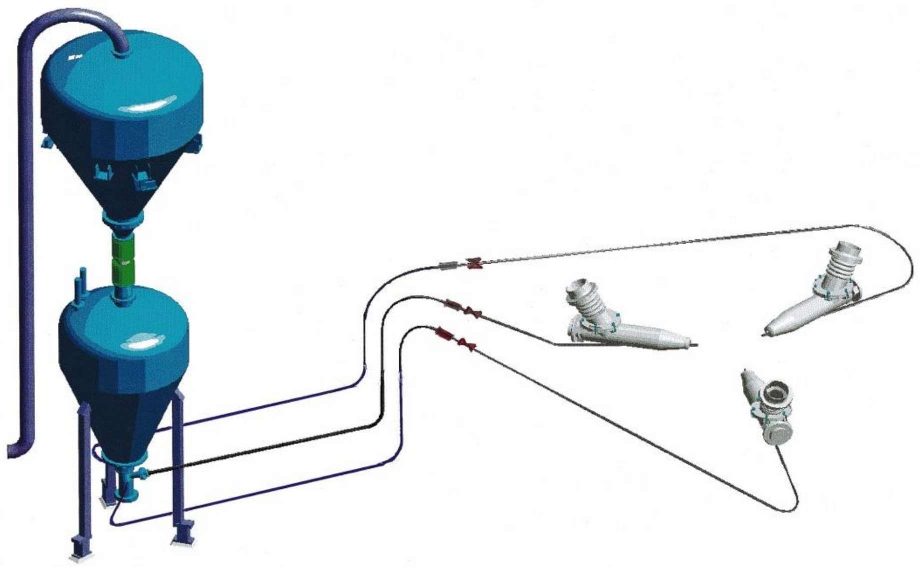
Some difficulties with injection of BF sludge after was indicated by low heat level. This was due to segregation.

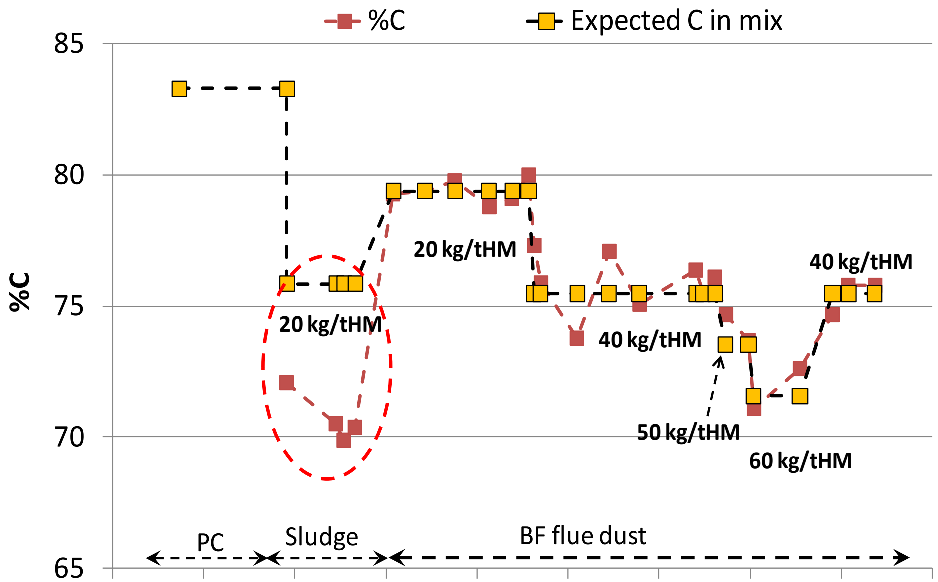


Article available at http://www.revue-metallurgie.org or http://dx.doi.org/10.1051/metal/2009067

Operational trials in the EBF

Bends and transport lines in the existing PC system at the EBF was redesigned and rebuilt to prevent wear.

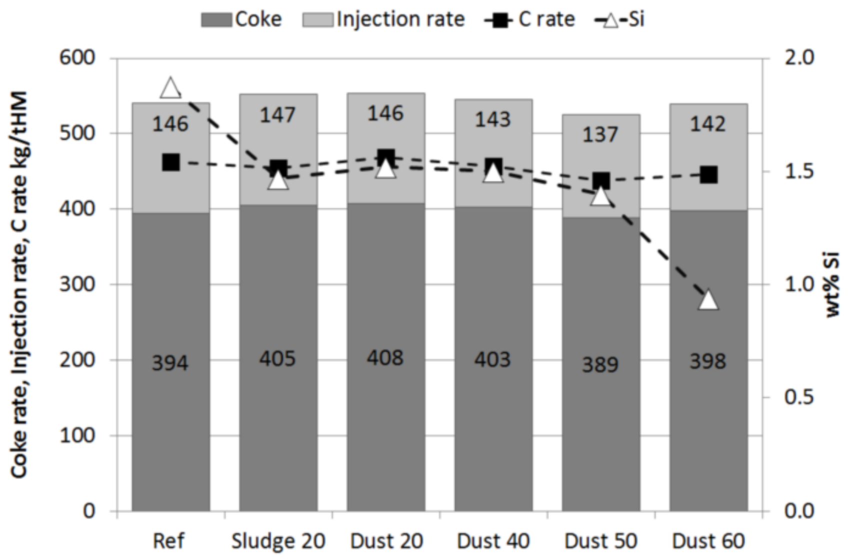


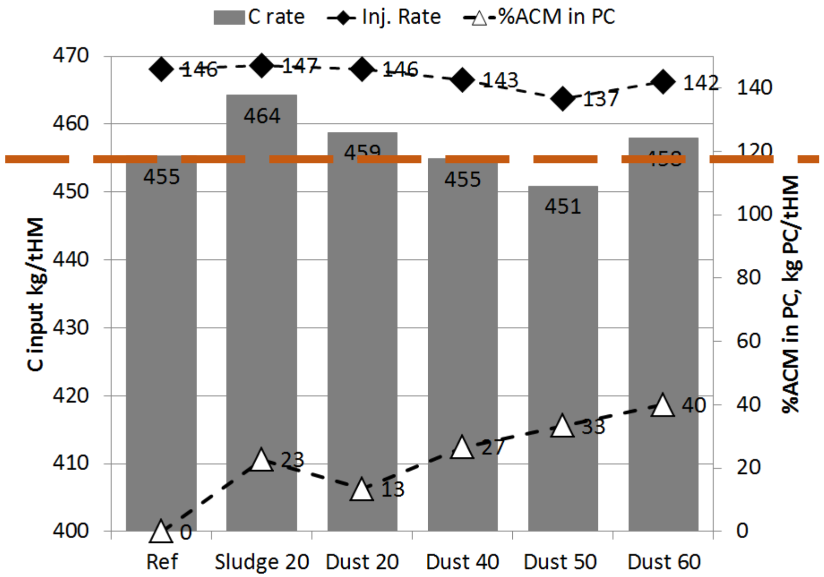


Operational trials in the EBF

Energy efficiency for C in injected dust

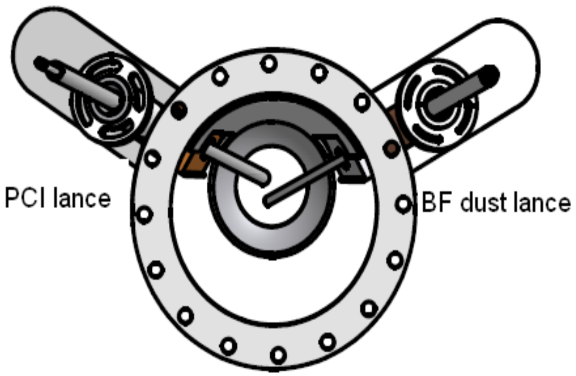
- Heat and mass balance calculations for each trial period
- Coke and PC consumption during trial are influenced by
    - Thermal state of operation
    - Historical data for periods prior the evaluation period
- Normalized HM data for C rate determination

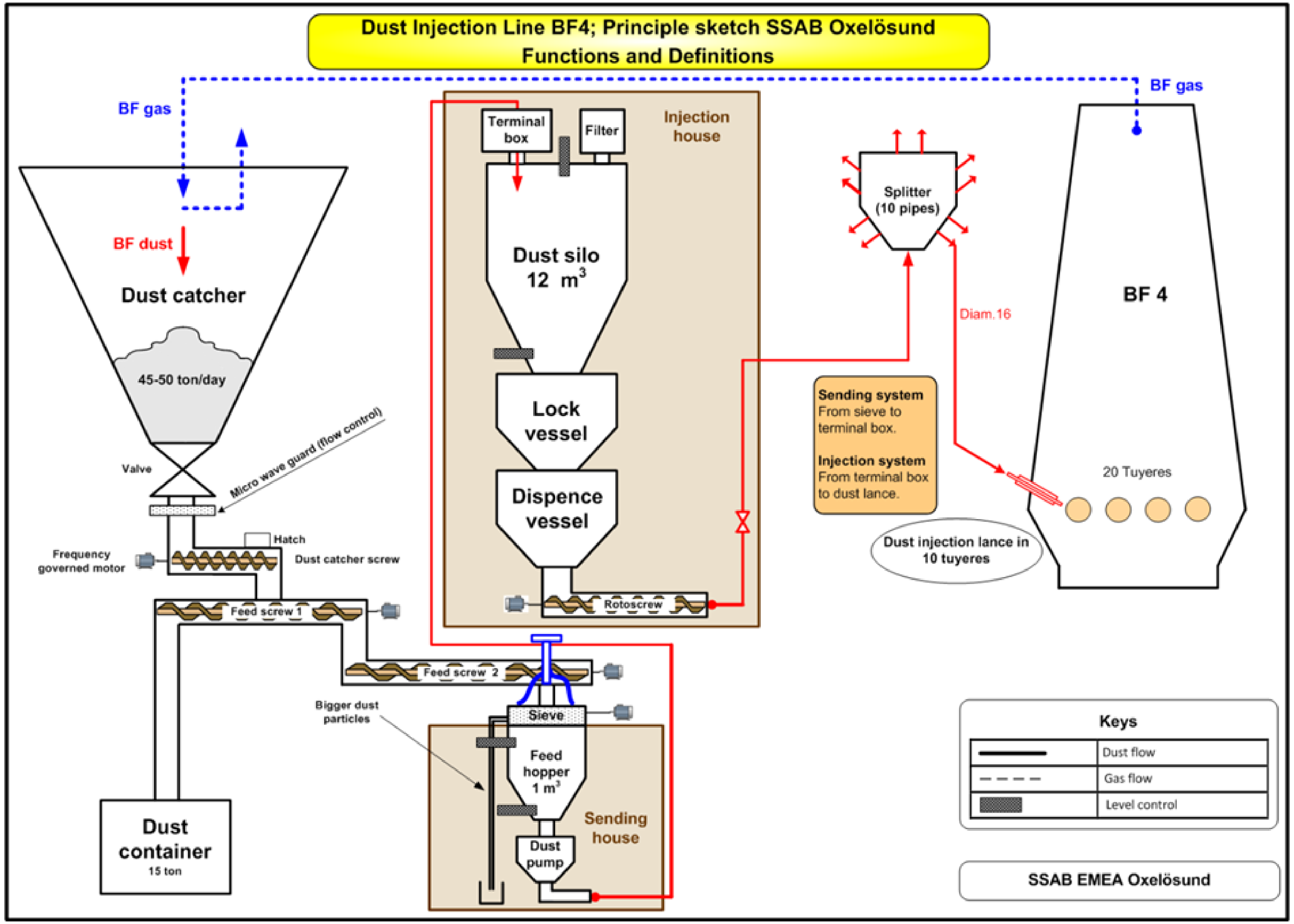




Industrial scale trials

- Several trial periods carried out
- During the project modification of the equipment allowed longer continuous injection tests





Industrial scale trials

	Test period	Reference period	
Production rate	111.5	105.5	ton/h
Coke	390.2	400.2	kg/tHM
PCI	75.6	80.0	kg/tHM
BF flue dust injection	14.8	0	kg/tHM
Net C input	**400.7**	**405.7**	kg/tHM
HM C	4.38	4.38	Wt%
HM Si	0.71	0.68	Wt%
HM S	0.050	0.065	Wt%
HMT	1485	1474	°C
Period length	85	264	hours

Implementation

BF dust injection is implemented

- At SSAB in Oxelösund, major part of BF flue dust is injected via the BF dust injection system on 10 out of 20 tuyeres
- At SSAB in Luleå all dust is recycled via briquettes and injection. The ratio varies somewhat over time but roughly half of the BF dust is injected on four out of 32 tuyeres.

Follow-up research have been conducted for BF sludge treatment and recycling

- Separation of zinc rich fraction by hydrocyclone or Tornado treatment, or removal of zinc via and sulphuric acid leaching can enable its use
- Studies on the use of BF sludge in cold bonded briquettes

Conclusion

BF dust injection is a feasible method for recycling of produced amount of BF dust

From process point co-injection and separate injection is possible.

- Abrasive coke particles makes wear resistant installation necessary, especially bends of the piping.
- Separate injection can be favorable due to the importance to minimize the stand still time for the PC plant

Zinc output must be managed via BF sludge, HM and slag. If recycling also the BF sludge too high zinc input may be reached

Due to very fine particles and a dominating content iron oxide in the BF sludge there is a risk for segregation if co-injection with PC is conducted. Separate injection of BF sludge requires efficient fluidization in the sender. Briquetting may be favorable alternative for BF sludge.

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

Overview of the EU-funded research on Refractory, Millscale and other residual material from inside and outside of the steelwork

Umberto Martini – RINA-Consulting Centro Sviluppo Materiali SpA

Guidelines – during presentations (1 of 2)

For attendees:

- Please ensure that your microphone is muted
- Please deactivate your camera
- Please do not put your questions at this stage, keep them for the final Plenary discussion

For presenters (co-host of the session):

- Please ensure that Your microphone is NOT muted
- Please deactivate Your camera
- Please share your presentation
  and in case of video with audio, after sharing the presentation, please "Share computer sound"
- Presentation itself will be recorded (no Plenary discussion). If presenter provides his disagreement, his presentation will not be recorded.

THE USE OF HIDDEN RECORDING SOFTWARE AND THE USE OF WORKSHOP MATERIAL WITHOUT ESTEP APPROVAL IS PROHIBITED

Guidelines – during presentations (2 of 2)

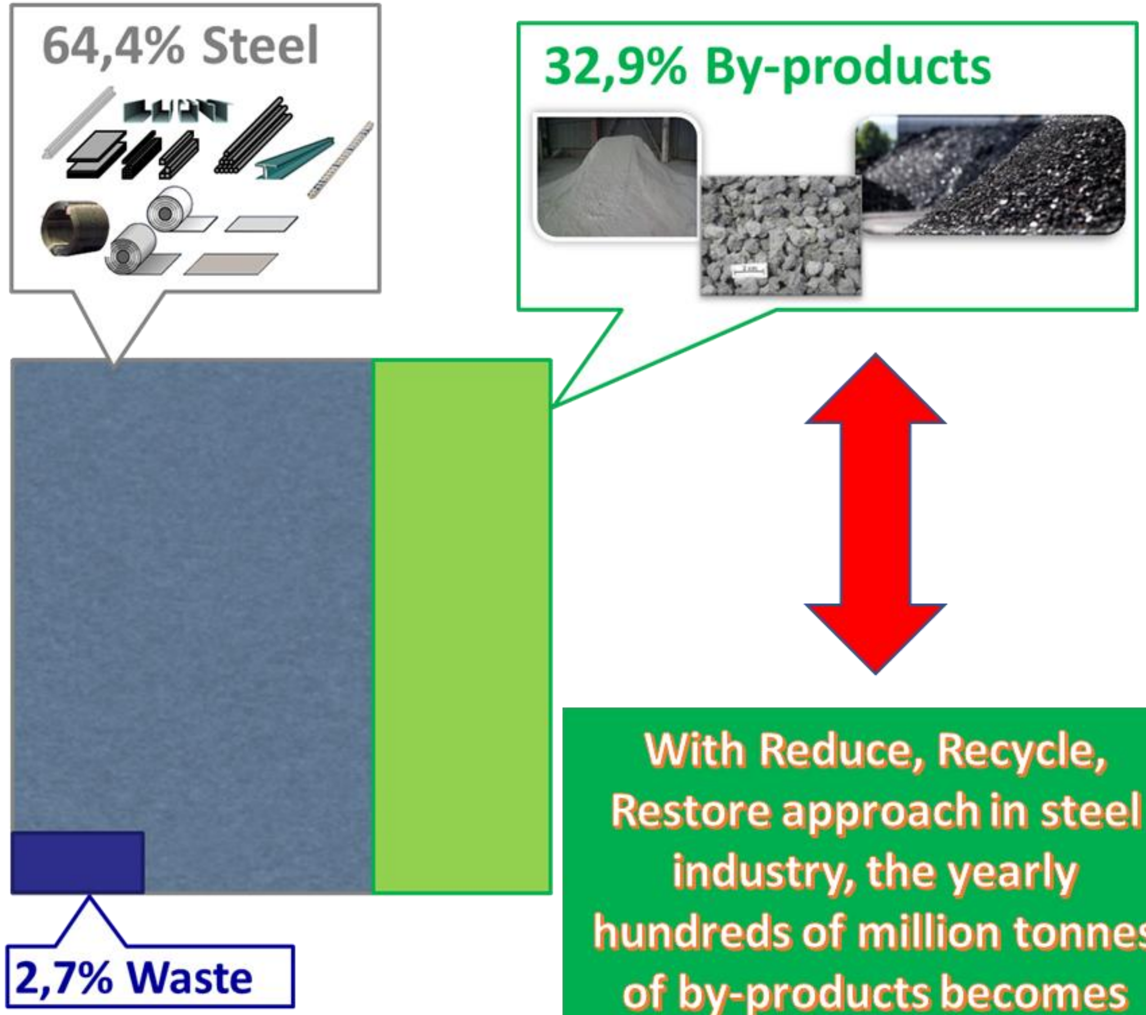
For attendees

- In order to make question, please raise your hand in Zoom and then wait until the moderator gives you the floor.
- When this happens, please unmute your microphone, present yourself and specify to whom your question is directed (might be more than one speaker).
- If You wish, please also activate Your camera

For presenter

- Please activate your microphone only when you answer to a question
- Please always keep your camera ACTIVE for the whole duration of the discussion
- In case you want to make question, as you are co-host and have the camera ACTIVE, please raise your own hand in the video because co-host has no possibility to raise the "Zoom hand"

Why REUSTEEL



With Reduce, Recycle, Restore approach in steel industry, the yearly hundreds of million tonnes of by-products becomes resource

million tonnes, crude steel production

Years	World	Years	World	Years	World
1950	189	2000	850	2010	1 433
1955	270	2001	852	2011	1 538
1960	347	2002	905	2012	1 560
1965	456	2003	971	2013	1 650
1970	595	2004	1 063	2014	1 671
1975	644	2005	1 148	2015	1 621
1980	717	2006	1 250	2016	1 629
1985	719	2007	1 348	2017	1 732
1990	770	2008	1 343	2018	1 814
1995	753	2009	1 239	2019	1 869

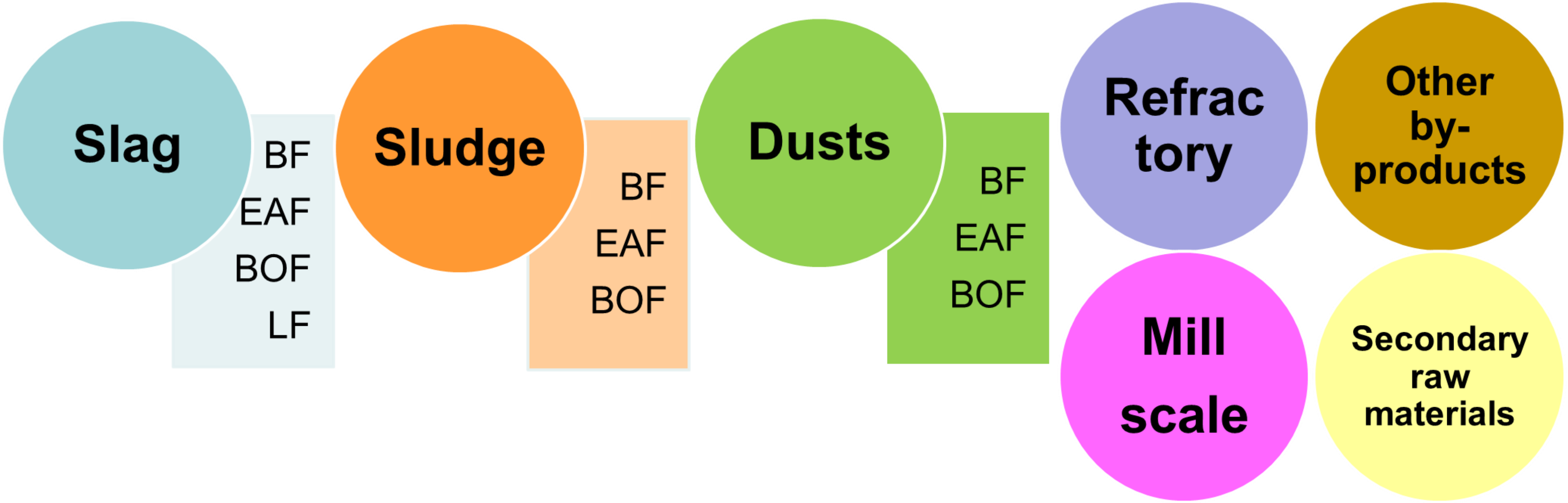
Source woldsteel.org

Reuse of steel by-products concerns both their internal recycling in steelmaking route and their use/reuse for external applications.

This "virtuous process" has the advantage to allow the recover of valuable elements (e.g. Fe, Zn) as well as the reuse of by products in different industrial sectors limiting at the same time the need of landfill disposal.

REUSTEEL - *Organization*

45 EU funded projects considered as relevant for dissemination

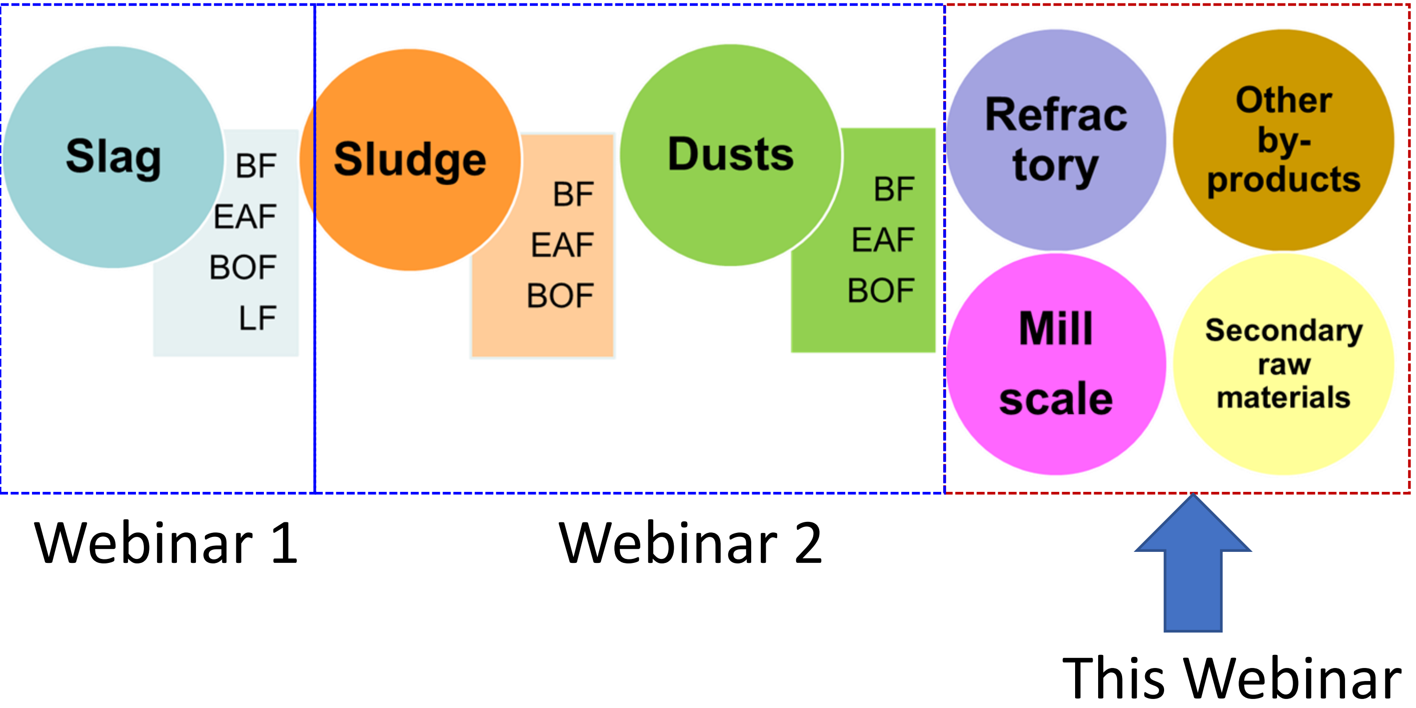


The projects are divided on the basis of the *type of steel by-products*.
Secondary raw materials from outside steelworks but used in steelmaking cycle are included as material of interest, too

Hence, REUSTEEL is aimed at:

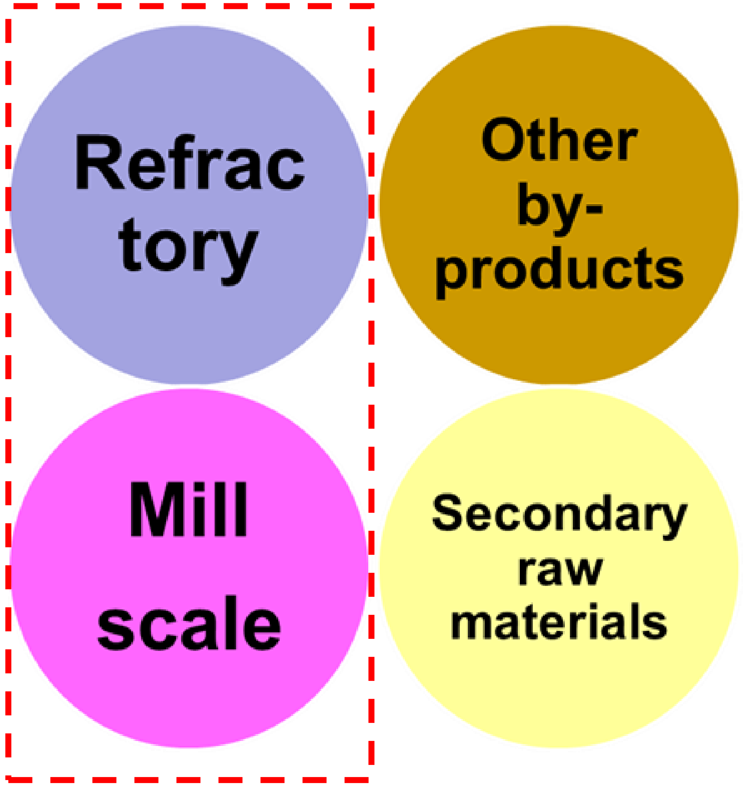
- Improving impact of the results achieved in EU-funded projects on the industrial practices compared to the potential achievements
- Finding connections among various researches following different processes but targeting similar objectives
- Providing indication on needed future developments and research activities;
- Promoting project results after project completion;
- Summarizing overtime results and achievements for new generations of steelmakers and potentially interested parties

REUSTEEL – *Topics of the present webinar*



This webinar is included is the 3rd of 3 webinars focused on the different types of steel by-products.

REUSTEEL – *Seminar topics*



Refractory: 3 projects involved

Internal use/recycling

- Use of spent refractory in replacement of olivine and dolomite (sinter plant, BF and BOF).

External use/recycling

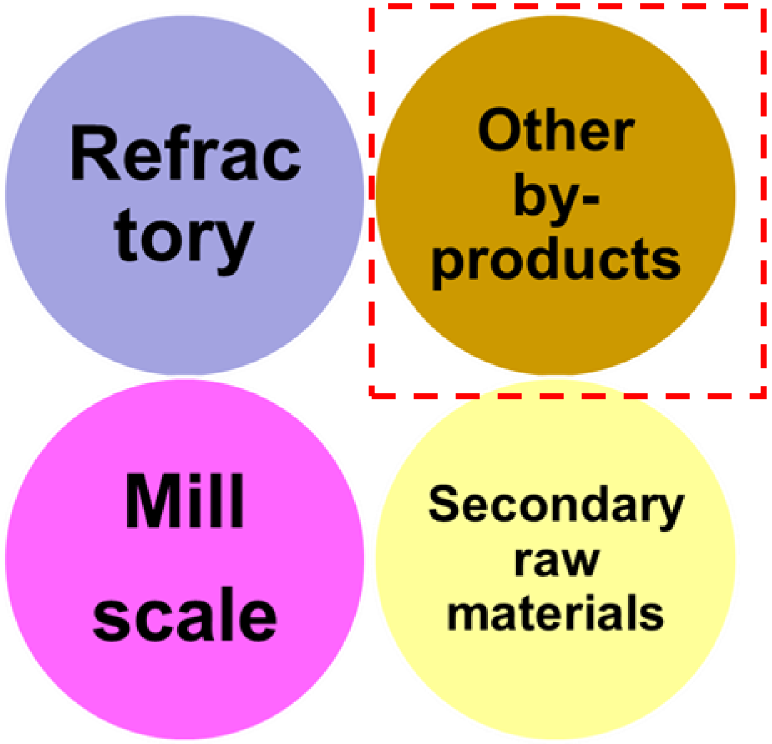
- Products for glass and ceramic industries: vitrification of high-silica and silica-alumina refractories by using slags.

Millscale: 6 projects involved

Internal use/recycling

- Use in mixture with dust (BF and BOF) an slag (BOF) in a standalone vessel (DC vessel) for metal recovery (up to 95%).
- Use as compound in high iron briquettes for direct BF charging.
- Use to manufacture self-reducing briquettes for direct use in EAF or with alternative binder materials.
- Use of rolling mill scale as scrap replacement in EAF.

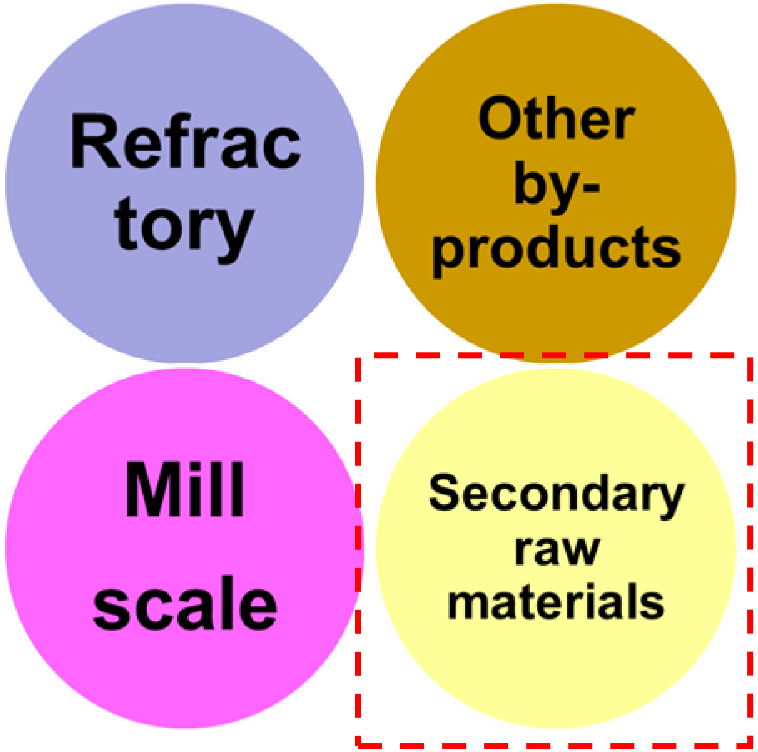
REUSTEEL – *Seminar topics*



Other by-products: 4 projects involved

Internal use/recycling

- Recovery of iron - use of iron containing fine ores with dusts (BF, BOF), sludge (BF), mill scale and cinders to manufacture briquettes for direct charging in BF.
- Recovery of chromium from spray roasting residues is evaluated modelling a system involving a process of inductive coke bed reactor and cupola furnace.
- Recovery of carbon – use of coke dust and coke breeze as components for briquettes to be used in BF.
- Destruction of hazardous waste – scrap residues treated together with BOF slag in the in-plant-by-product-melting process (IPBM). The resulting slag has potential use as hydraulic binder.



Outside the steelworks

Secondary raw materials (1 of 2): 16 projects involved

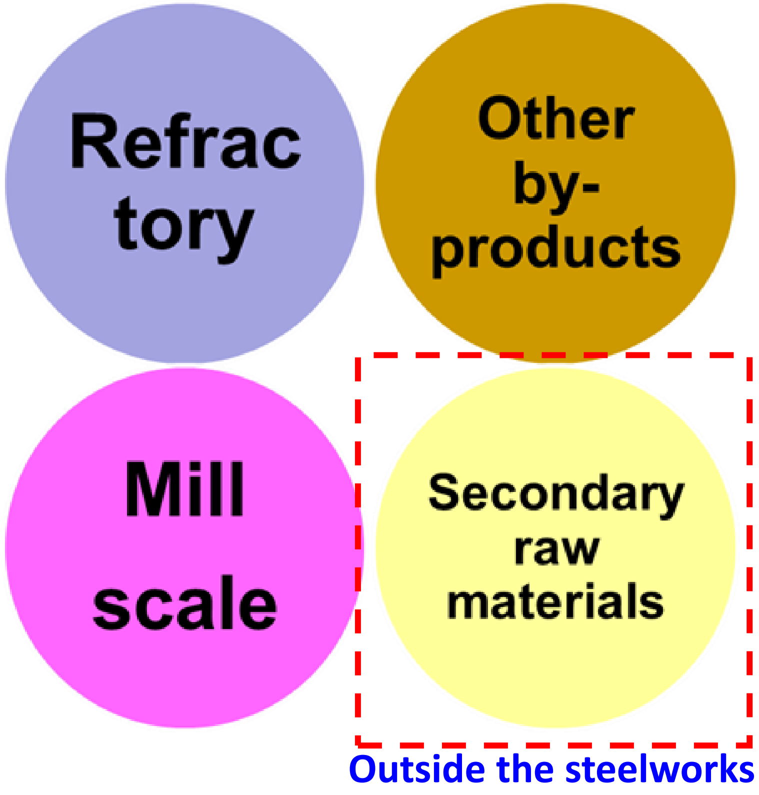
Used as binders

- Fayalite slag from copper smelter used together with sand and scrap residues as SiO_2 bearing material in the IPBM process.
- Use of molasses to produce self-reducing briquettes for EAF.
- Use of wastes from forest, agriculture and waste plastics as binders in briquette making.

Used for metal recovery

- Use of mixes of cinder with dusts (BF, BOF), sludge (BF) and mill scale to manufacture briquettes for direct charging in BF.
- Use of waste plastics as energy source for scrap pre-heating and for the production of syngas useful for zinc recovery

REUSTEEL – *Seminar topics*



Secondary raw materials (2 of 2): 16 projects involved

Used as carbon source

- Use of biomasses as source of charcoal and syngas in substitution of fossil coals and natural gas in EAF.
- Pet coke, charcoal, lignite coke are briquetted and then used as coke substitute in BF
- ASR plastics and other waste plastics such as for packaging submitted to a pre-treatment with the tornado process to make them suitable for BF injection
- Use of waste plastics or other carbon based waste materials (e.g. wood, agriculture, coke making) as binders for briquettes.
- Biological carbon sources (e.g. nut shells, olive pits), anthracite and pet coke are agglomerated and then tested

Miscellaneous use

- Use of secondary Al granules as foaming agent to achieve a good chromium reduction of liquid steel
- Use of sewage sludge ash to enrich BOF slag to favour the separation of P-rich and Fe-rich fractions.

REUSTEEL – *The plan for the next future*

Roadmap: please give us your input to future topics by filling our online survey (29 questions)

you can also promote your ideas in following discussion at ca. 9:30

REUSTEEL symposium
Next step → ESTAD21 30.08.2021

24. In which areas do You see a need for research? You may select multiple issues.

	Internal recycling	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 with other beneficial and valuable contents (e.g. metal, coal, lime)	limination of harmful elements	Minimisation of waste generation and landfill	Process integration solutions for by-products management	Modelling and simulation
BF slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
BOF slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
EAF slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
LF slag	☐	☐	☐	☐	☐	☐	☐	☐	☐
BF-Dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
BOF-Dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
EAF-Dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
LF-Dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sinter plant	☐	☐	☐	☐	☐	☐	☐	☐	☐
Coke-dust	☐	☐	☐	☐	☐	☐	☐	☐	☐
BF-Sludge	☐	☐	☐	☐	☐	☐	☐	☐	☐
BOF-Sludge	☐	☐	☐	☐	☐	☐	☐	☐	☐
EAF-Sludge	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mill-Sludge	☐	☐	☐	☐	☐	☐	☐	☐	☐
Refractory	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mill-scale	☐	☐	☐	☐	☐	☐	☐	☐	☐
Oily Mill scale	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other residues Inside Steel Industry	☐	☐	☐	☐	☐	☐	☐	☐	☐
Secondary raw materials from outside the steel industry	☐	☐	☐	☐	☐	☐	☐	☐	☐

REUSTEEL – *The plan for today*

Day 3 – 16.06.2021 8:00- 10:00 Webinar on Refractory, Millscale, other residual material from inside and outside of the steelwork			
Time	**Speaker**	**Speaker Organization**	**Presentation**
08:00	Umberto Martini (*Chairman*)	RINA-Centro Sviluppo Materiali	*Overview of the EU-funded research on Refractory, Millscale and other residual material from inside and outside of the steelwork*
08:10	Umberto Martini	RINA-Centro Sviluppo Materiali	*Use of external sources of carbon (biomass and plastic) in EAF*
08:40	Johan Björkvall	SWERIM	*Residual material for slag foaming in EAF*
09:00	Mikael Larsson	SWERIM	*Processes and technologies for environmentally friendly recovery and treatment of scrap*
09:30	All		*Plenary Discussion with speakers*
10:00	Umberto Martini (*Chairman*)	RINA-Centro Sviluppo Materiali	*Closure of the Webinar*

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

Use of external sources of carbon (biomass and plastic) in EAF

By: Filippo Cirilli, Umberto Martini (RINA-Consulting Centro Sviluppo Materiali SpA)
Presented by: Umberto Martini RINA-Consulting Centro Sviluppo Materiali SpA

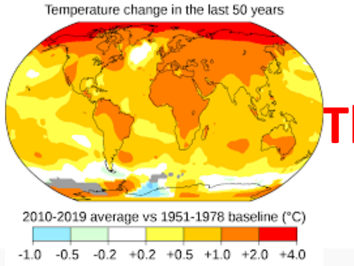
The presentation intends to shows the contribution of EAF to the decarbonization of the steel industry.

After a short recall to the main strategic pathways toward decarbonization,

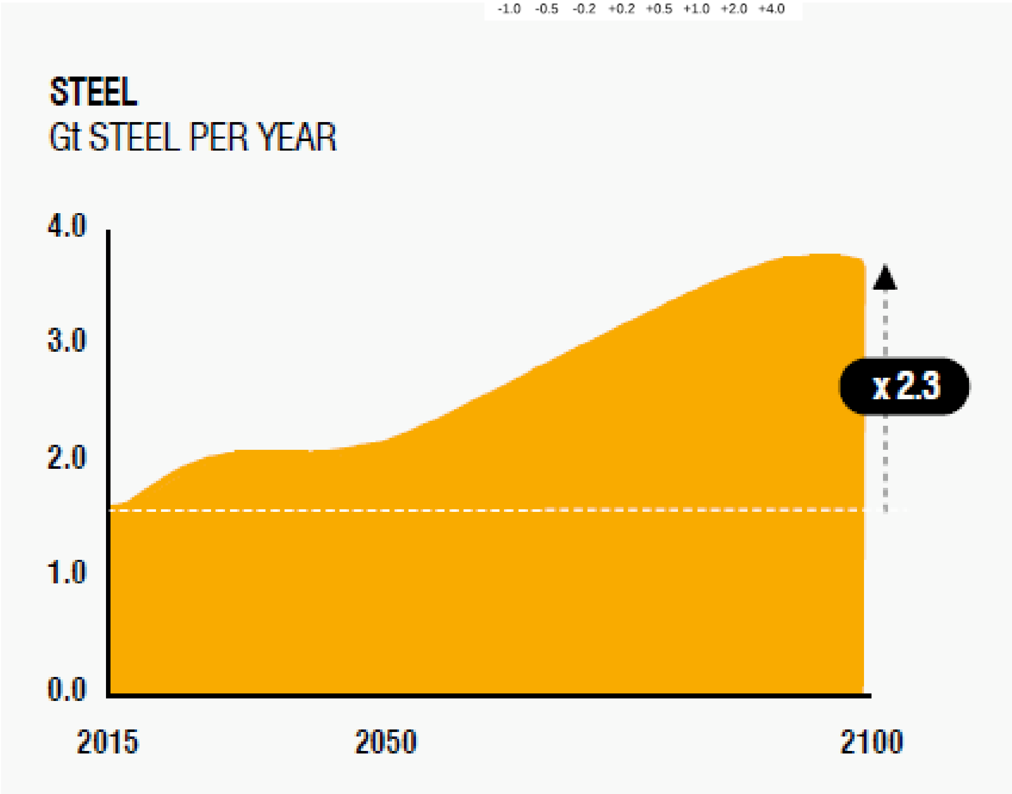
technological trends of the EAF technology are presented,

using examples of projects,

which underline the contribution of the European research to this evolution.



The global warming scenario and the challenge



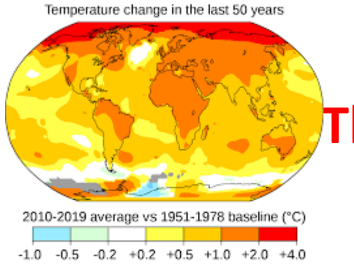
Steel: construction and infrastructure, transportation, industrial machinery, and consumer products.

Global steel production now stands around 1,6 billion tonnes per year.
The growth in the decade to 2015 has been by 40% with China alone accounting for nearly 95%.

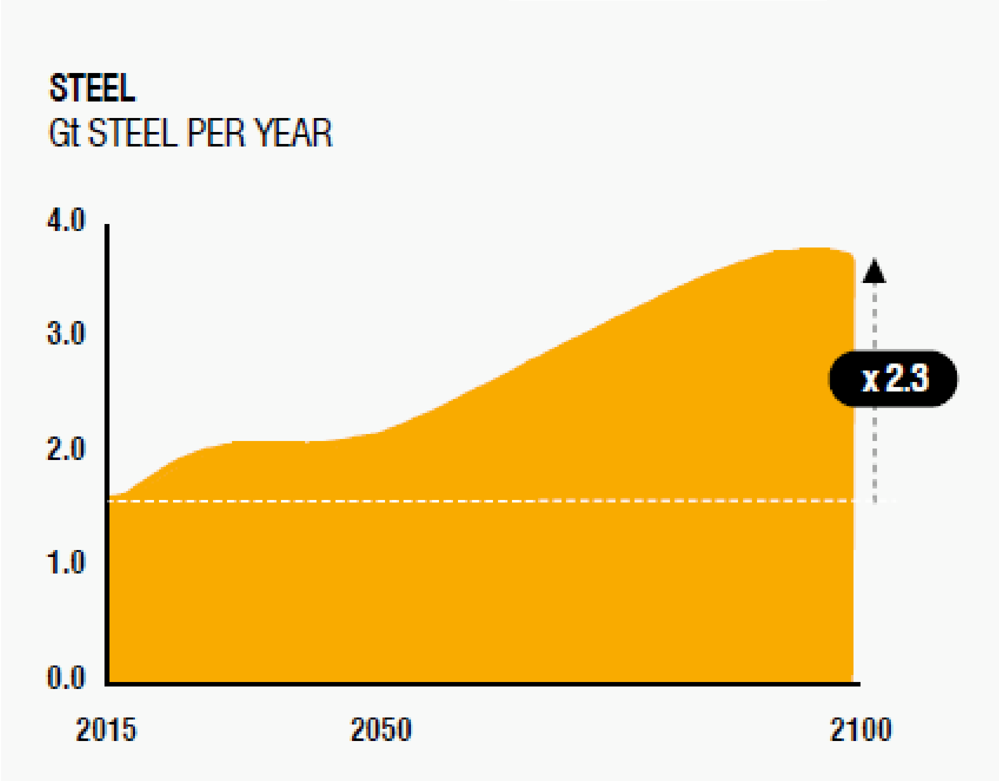
That growth is set to continue as large parts of the world are still at the initial stages of urbanization and industrialization.

The existing gap between industrialized and not industrialized countries is typically 10-14 tonnes for capita vs. 2 tonnes for capita.

From Material Economics Sverige AB Grev Turegatan 30, 114 38 Stockholm, Sweden materialeconomics.com



The global warming scenario and the challenge



Increasing steel demand and production in the future

Need to strongly reduces CO_2 emission

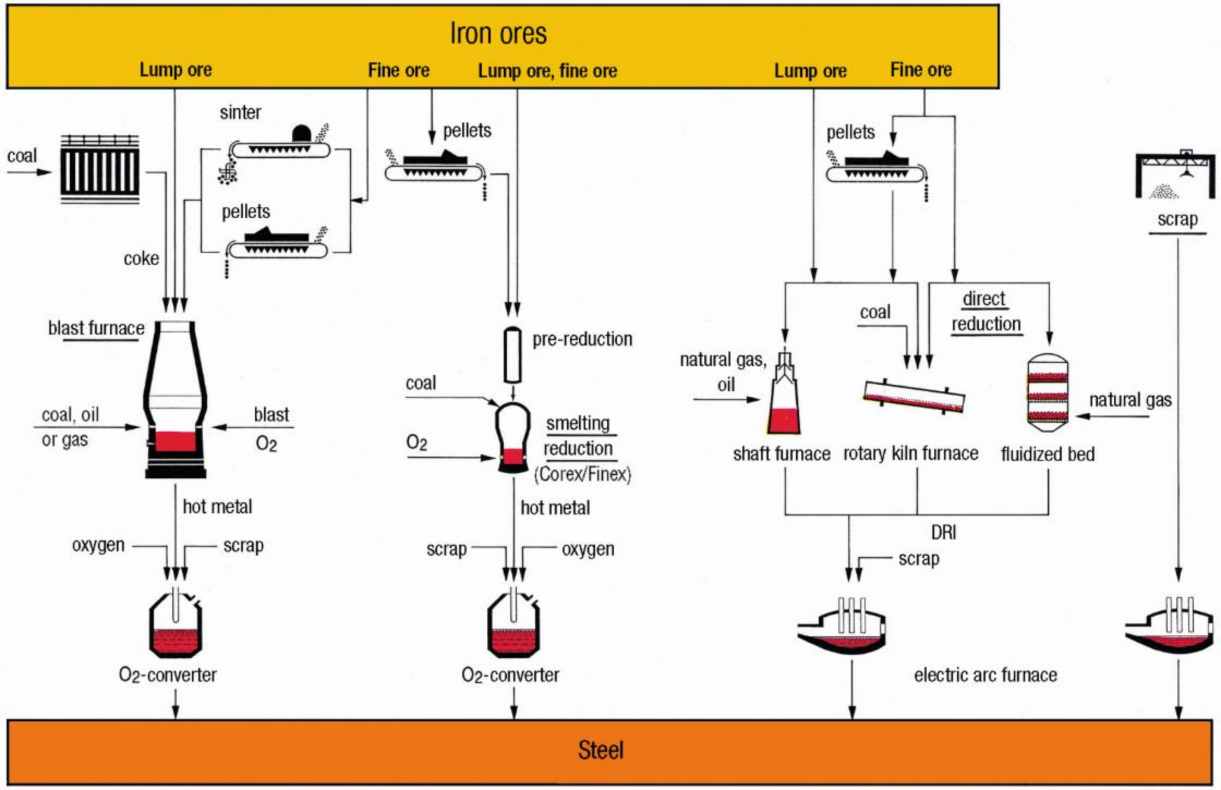
From Material Economics Sverige AB Grev Turegatan 30, 114 38 Stockholm, Sweden materialeconomics.com

Decarbonization pathways

Current technology routes for Steel production

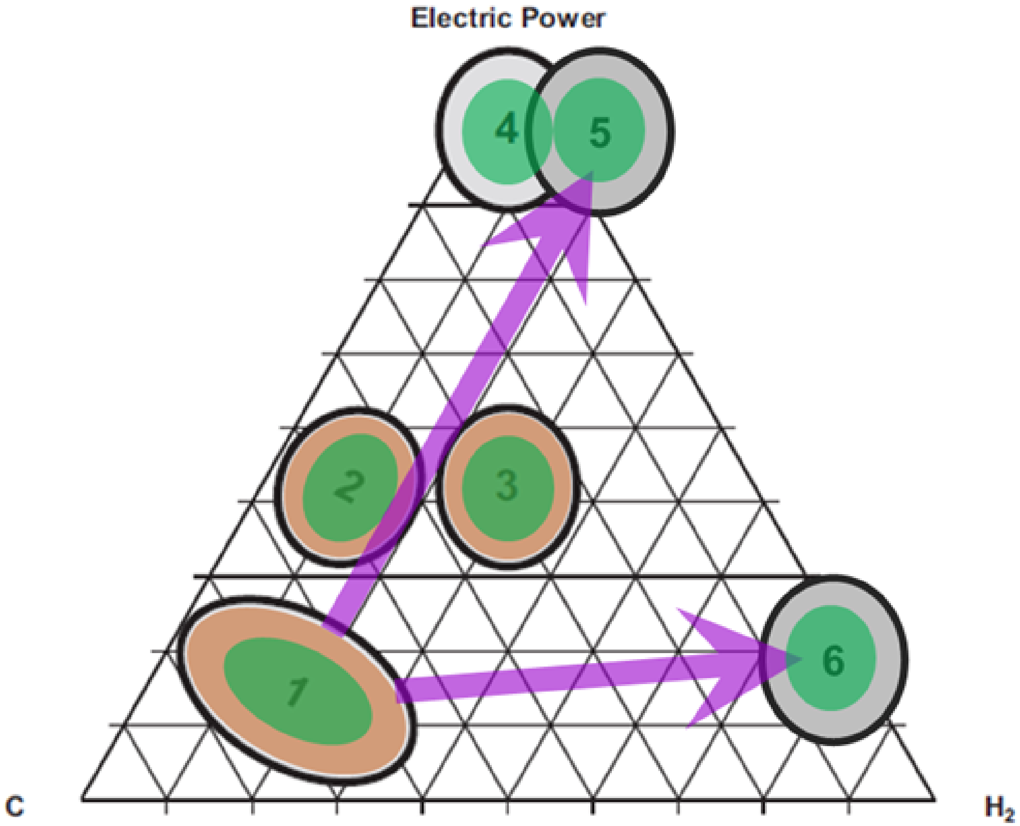
- **BF / BOF** (60 %*)
- **Scrap / EAF** (40 %*)
- Direct reduction (gas based) / EAF
- Smelting reduction (coal based) / BOF

** EU 28*



Decarbonization pathways

Mid/ long term-options



Future processes

1. C-based integrated metallurgy
2. C-based direct reduction + EAF
3. NG-based direct reduction + EAF

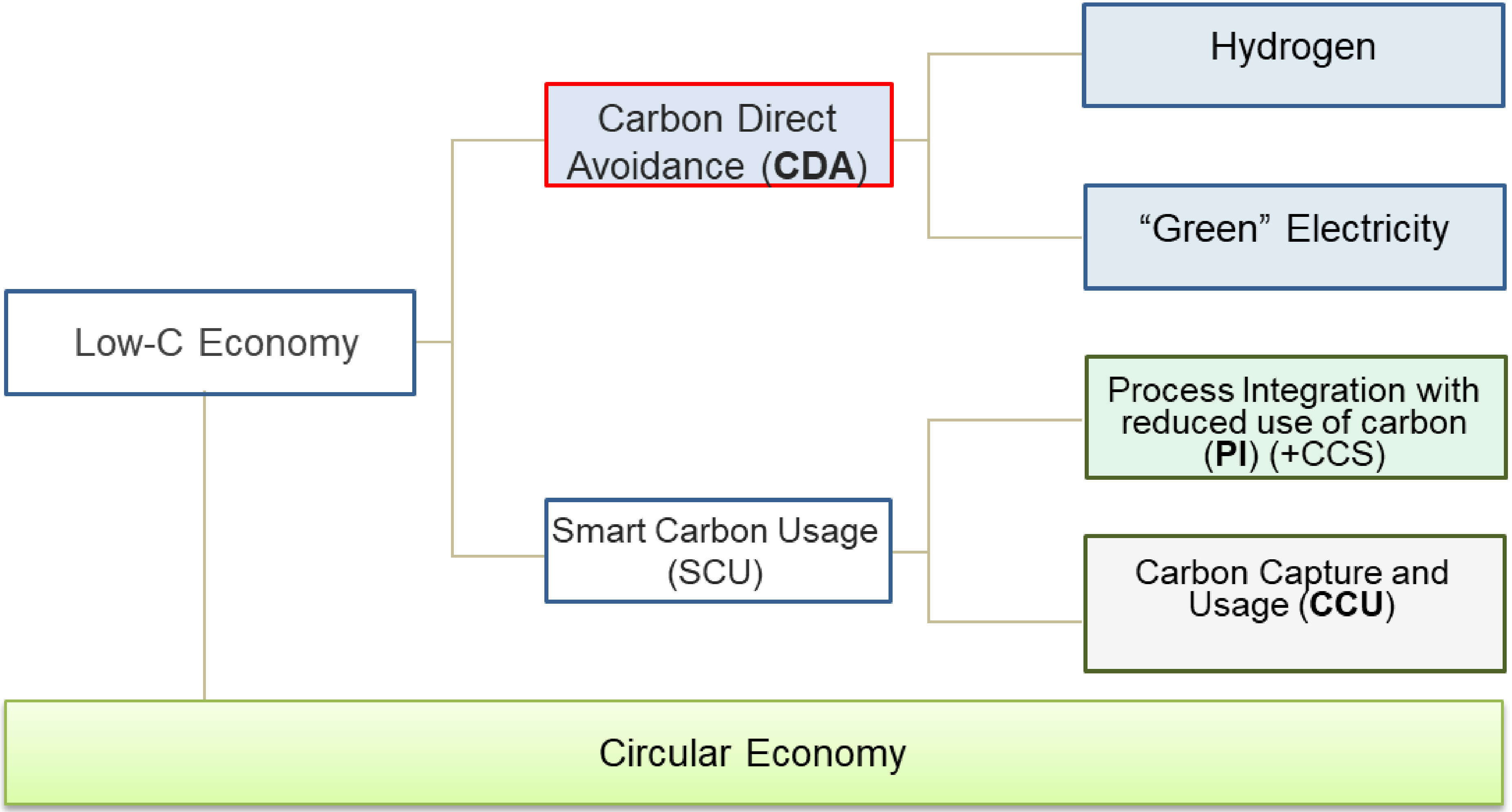
With renewable fuels/energy /reductants and/or CCUS

4. Scrap EAF route
5. Electrolysis of iron ores
6. H_2-based metallurgy (e.g. direct reduction + EAF)

New transition paths

CCUS (CO_2 capture and utilisation or storage)

Decarbonization pathways



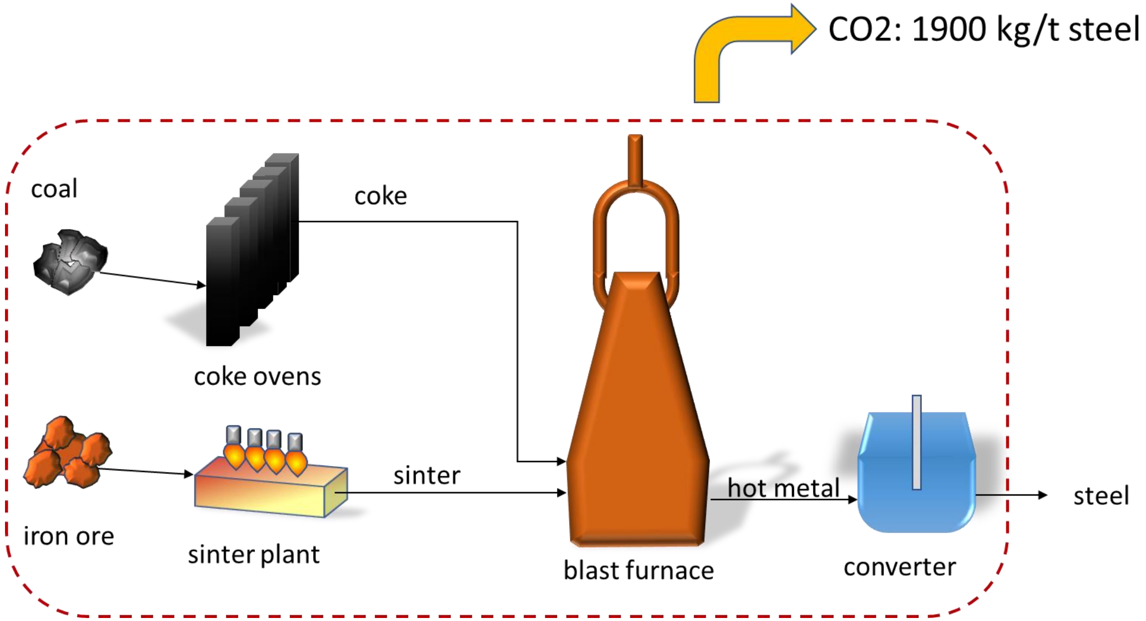
Decarbonization pathways – *The role of EAF*

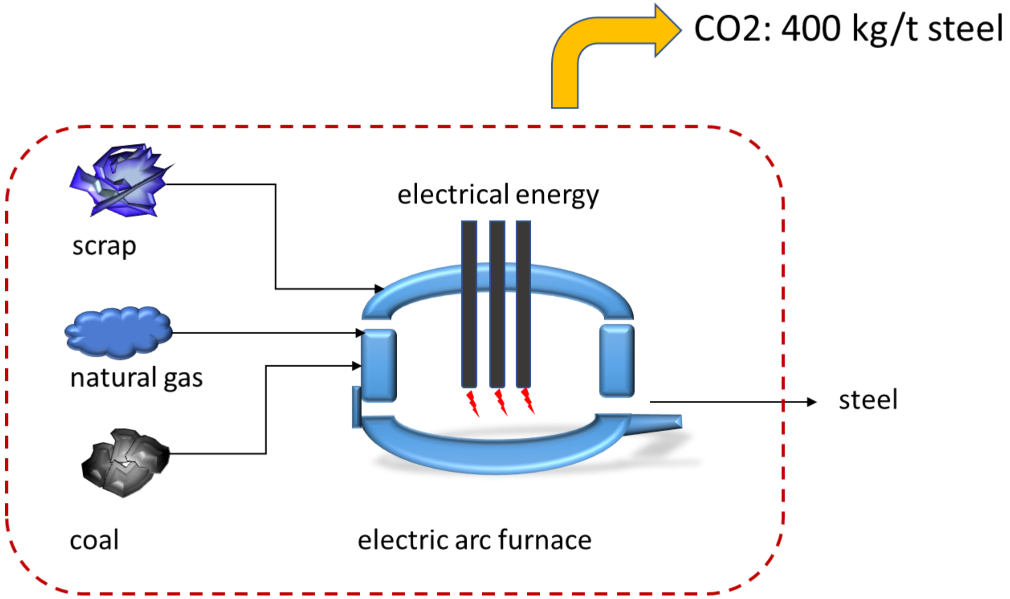
In this general pathways toward decarbonization a big role will be played by the EAF.

In what follows examples of present and future contribution of the EAF are presented.

Decarbonization pathways – *The role of EAF*

Producing steel from iron ore consumes much more energy and fossil fuels than the production from recycled scrap.





The increase of the steel production from scrap recycling means to reduce the CO_2 footprint of the steel industry.

Decarbonization pathways – *The role of EAF*

The improved utilization of steel scrap is an important factor in the decarbonization of the EAF steel production.

Although the modern EAF is an efficient plant at high performance,
to reach an almost carbon neutrality in the EAF process, a more complex set of actions is necessary, *implementing new technologies and adopting a circular economy and industrial symbiosis approach*.

EAF process, operating practices and plant redesign is necessary.

R&D activities and cooperation among EU and Industries (also of different sectors) is fundamental in a perspective view for the EAF to make a significant contribution to future green steel production.

Decarbonization pathways – *The role of EAF*

Decarbonization of EAF steel production is based on the following development lines:

Focus of this presentation

1. Increasing use of electrical energy and efficiency through energy recovery systems
2. Utilization of alternative carbon bearing materials
3. Utilization of DRI produced from iron ore and H_2 (carbon free material)
4. Substitution of natural gas with H2 in all burners (EAF and refractory preheating)
5. Development and implementation of CO2 capture and Utilization (CCU) techniques
6. Fostering circular economy (EAF as the earth of a industrial symbiotic system)
   (next presentation focus on this)

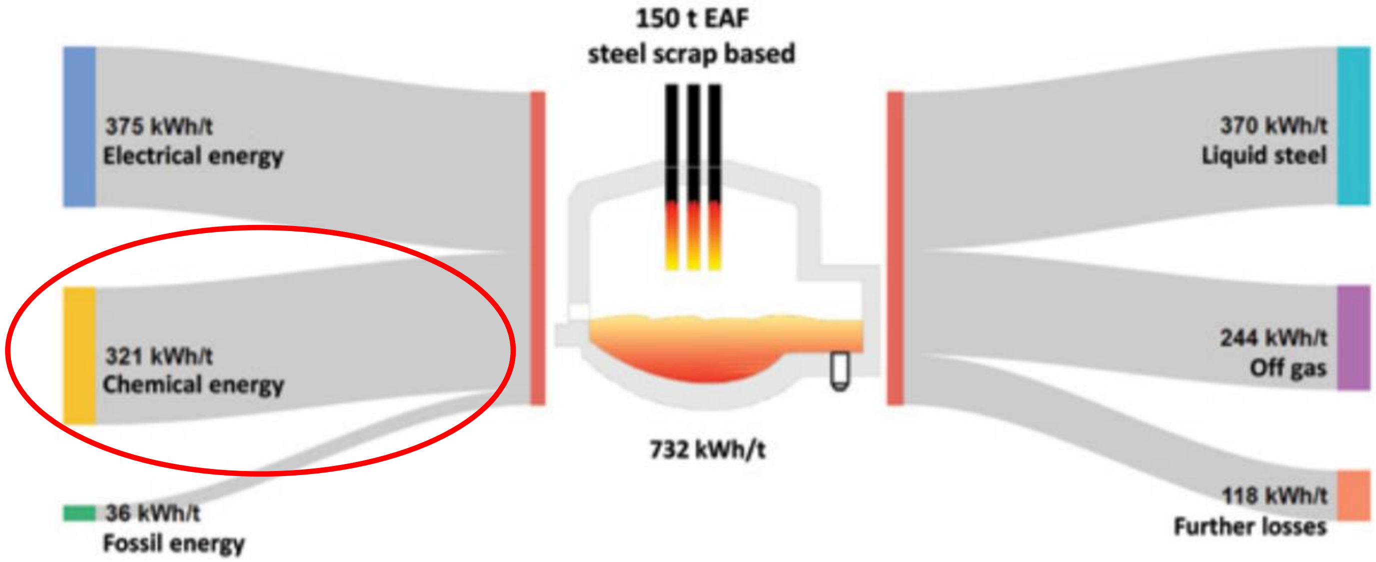
EAF technological developments

Decarbonization pathways – *The role of EAF*

Today a significant amount of energy in EAF derives from natural gas and coal.
A higher use of electrical energy would reduce CO2 emissions (especially in view of availability of electrical energy from renewable resources)

Higher electrification requires research

- Furnace thermal homogeneity and plant productivity (new furnace shape, improved electrodes, improvement of furnace electrical components)
- Impact on refractory materials and cooling systems
- Definition of plant power supply needs



Utilization of alternative carbon bearing materials for EAF process

This issue has already been studied in European projects.

The following aspects needs to be considered:

- Definition of list of alternative materials depending on local availability
- Materials characterization
- EAF operating practices adaptation
- EAF plant improvement (e.g. injection system)

Decarbonization pathways – *The role of EAF*

Utilization of alternative carbon bearing materials for EAF process

Ideas investigated

BIOMASS
(e.g. forest residue, agriculture residue)

Pyrolsys

Charcoal, tar, syngas

Use in EAF in substitution of

- Coal (charging and injection)
- Natural gas

GreenEAF, GreenEAF2 projects

Decarbonization pathways – *The role of EAF*

Definition of list of alternative materials depending on local availability

In Friuli large amount and variety of biomass is present:

- forest residues
- ligneous species
- agricultural residues
- biomass from cultivation

GreenEAF2 - Biochar for a sustainable EAF steel production, Final report

Decarbonization pathways – *The role of EAF*

Biomass availability

biomass type	ton	energy (tep*/year)	CO_2 avoided (t/year)
forest residues	218100	40100	93000
ligneous species	66200	12200	28000
agricultural residues	355100	100200	233000
biomass from cultivation	300000	95000	220000
tot	**939400**	**247500**	**574000**

Equivalent Tons of Petrol: 1 tep=10,000,000 kcal=11,600 kWh

Data available from online database (ENEA)

EAF produces about 400.000 t CO_2 per year (for an EAF having 1,000,000 t/year production, source: Fruehan, R., et al., 2000, "Theoretical minimum energies to produce steel for selected conditions", Prepared under contract to Energetics, Inc. Columbia, MD for the U.S. Department of Energy Office of Industrial Technologies Washington, DC.)

Decarbonization pathways – *The role of EAF*

Results from market survey

Different technological options available on the market for char production: pyrolysis, torrefaction, HTC (hydrothermal conversion)

A real market devoted for steel production is not present

What steel production requires respect current production?

- large amount
- Low grade biomass (or no need of biomass selection)
- Low costs

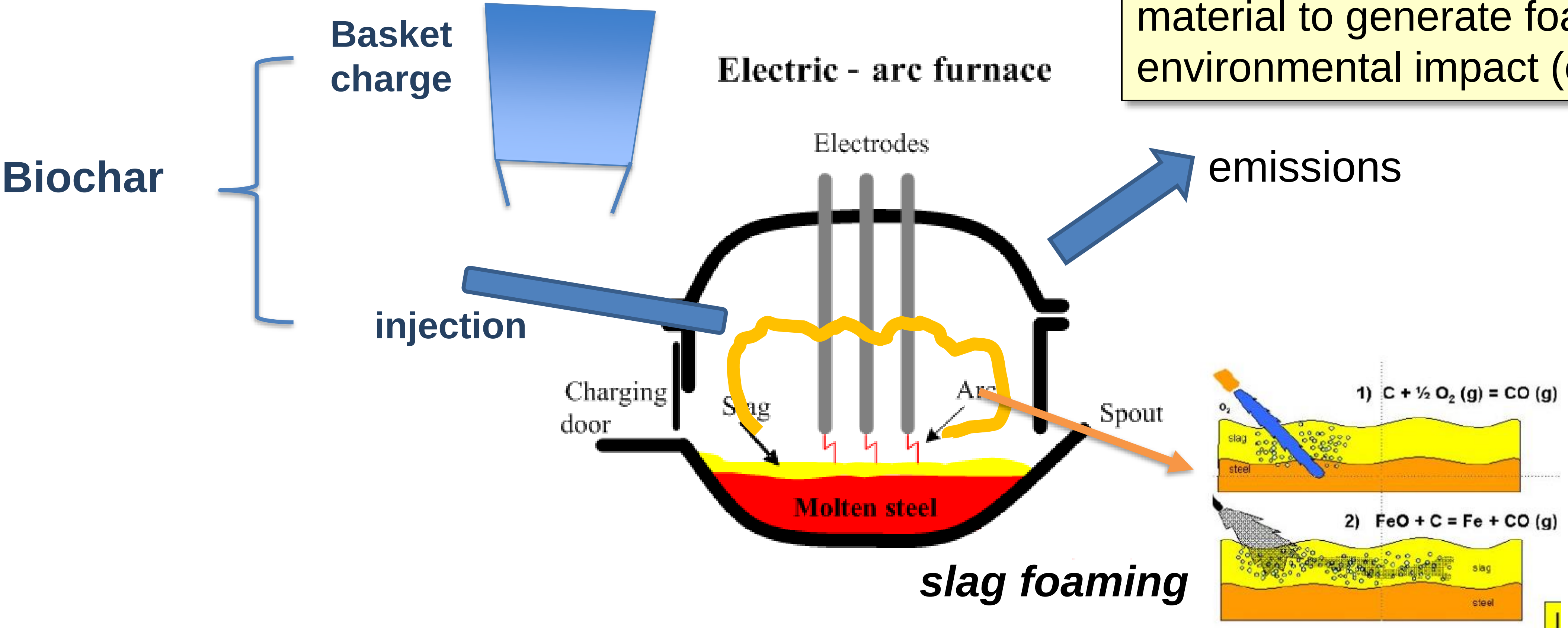
A serious issue for the industrial deployment of the biomass and derived products in steelmaking is the realization of a solid infrastructure for collection, pre-treatment and distribution of biomass

GreenEAF2 - Biochar for a sustainable EAF steel production, Final report

Decarbonization pathways – *The role of EAF*

EAF operating practice using alternative materials instead of coal

Investigation has been addressed to evaluate the ability of the new material to generate foam and on environmental impact (emissions)

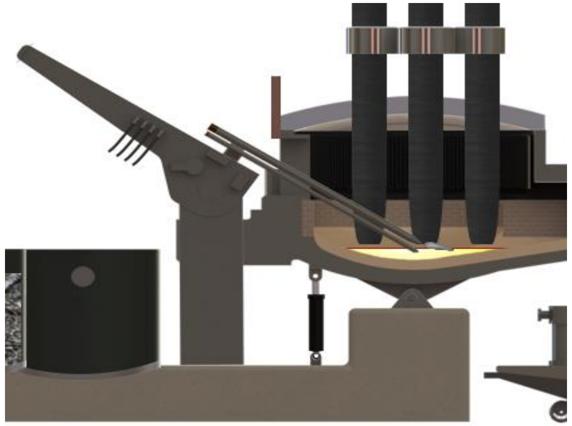


GreenEAF2 - Biochar for a sustainable EAF steel production, Final report

Decarbonization pathways – *The role of EAF*

charge in basket tests

Industrial tests have been performed in different EAF with different charging modalities



Injection inside slag tests

The projects demostrated the adequatness of the char to replace coal

GreenEAF2 - Biochar for a sustainable EAF steel production, Final report

Decarbonization pathways – *The role of EAF*

EAF behaviour was investigated in three steelworks (Ferriere Nord in Italy, Georgsmarienhütte in Germany and Marienhütte in Austria)

Charging trials gave positive results: EAF process was carried out with similar operating parameters (steel and slag analysis and productivity), after optimization of charging practice.

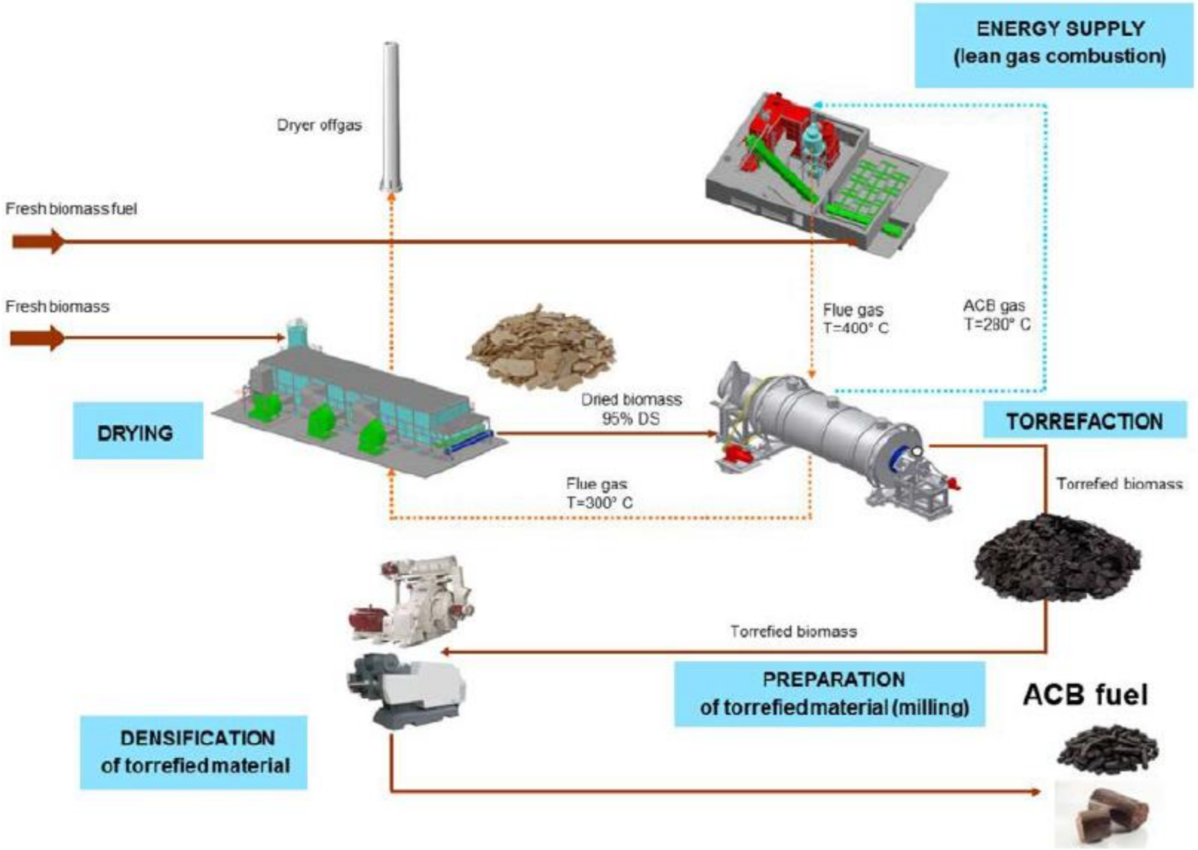
In case of the GMH furnace, equipped with oxygen diffusors, an energy saving of 6% has been measured

In a perspective view, *the installation of technologies of energy recovery from the EAF offgas will further increase the efficiency of the whole process.*

Techno-Economic evaluations: feasibility study for on-site char production plant

The torrefaction plant is composed by the following treatment stages:

- collection of biomass, grinding and homogenization,
- drying stage: the biomass is dried using the heat from hot gases in a conveyor belt, closed into a tunnel,
- torrefaction: biomass is thermally treated in a rotating drum with hot gas having a temperature in the range 250-350°C
- production of a hot gases stream; the boiler is heated up by the syngas from the torrefaction drum and from the gas developed in a second reactor in which an amount of residual biomass is burned,
- briquetting stage to compact material by pressure, obtaining a final product having a size according to final destination and a density of about 600 kg/m3.



Decarbonization pathways – *The role of EAF*

Techno-Economic evaluations: Example with torrefied biomass

Market price of torrefied material: 250-300 €/ton

Evaluation for on site production (taking into account torrefaction plant building, amortization, plant maintenance, employers costs)

biomass cost €/t	torr char €/t
70	310
50	244
15	104

Char cost as a function of biomass cost

GreenEAF2 - Biochar for a sustainable EAF steel production, Final report

Decarbonization pathways – *The role of EAF*

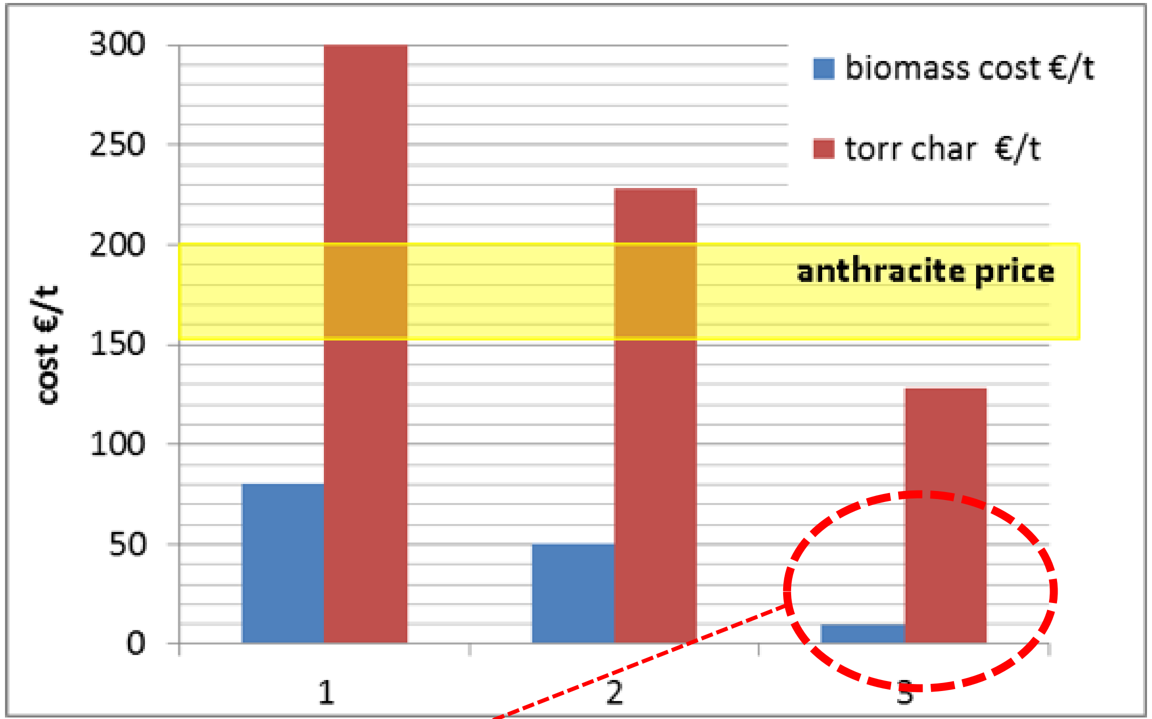
Techno-economical evaluation

In order to save resources all the flow of materials and energy of Iron & steel production processes must be considered

Sinergies with other production sectors are fundamental for application of circular economy

Continuous evolution of legislative, technological and social frame to be expected

Biomass cost includes: purchase, collection and transportation



Torrefaction cost for 3 different biomass cost

Ideal case: biomass nearby the steel factory (distance lower than 100 km)

GreenEAF2 - Biochar for a sustainable EAF steel production, Final report

Decarbonization pathways – *The role of EAF*

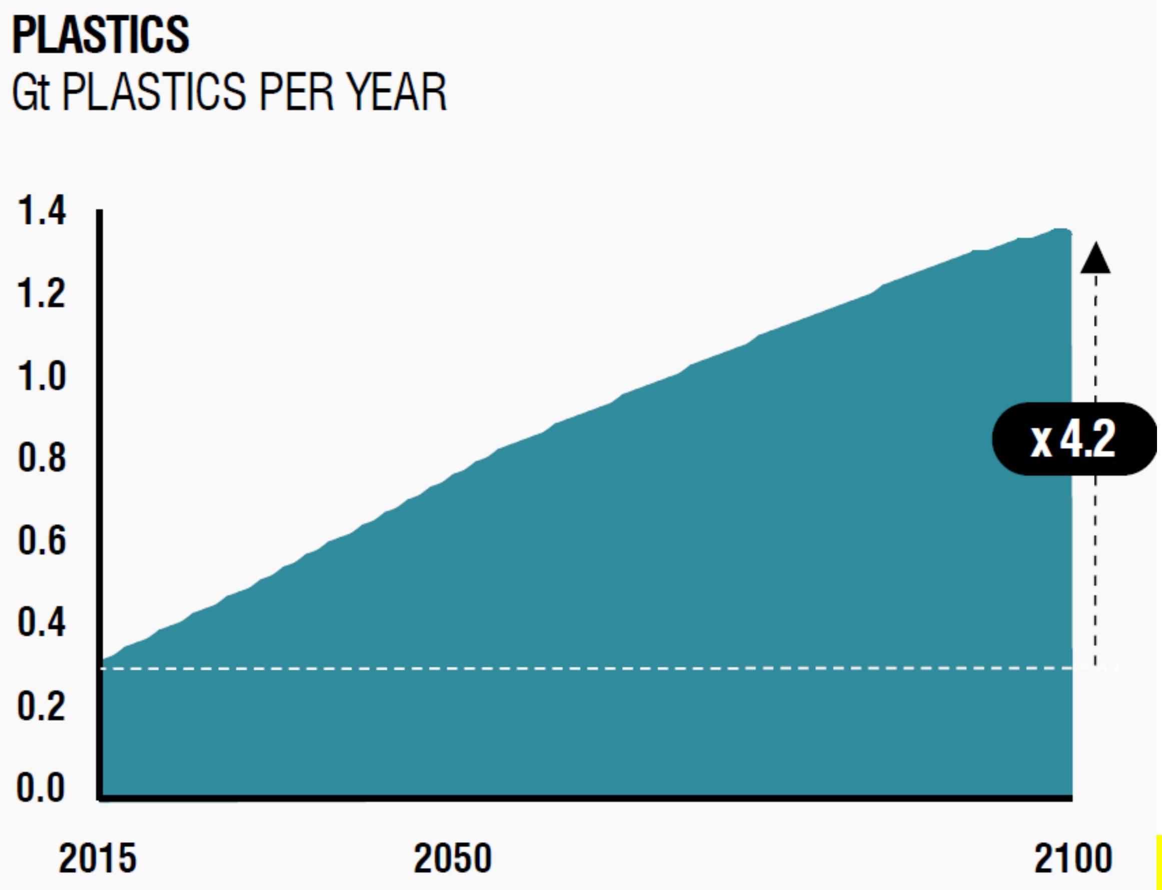
LCA analysis

LCA shows a reduction of ETS-relevant CO_2 emissions of about 10 % and 13%, respectively, for 100 % and 50 % substitution of charge carbon.

The theoretic consideration of a complete substitution of coal at Ferriere Nord leads to similar reductions of ETS-relevant CO_2 emissions of about 13%.

Decarbonization pathways – *The role of EAF*

A second case concerns the replacement of coal with plastics.



Plastics production has grown by 50% in the past decade, to just under 350 million tonnes per year.
In advanced economies, packaging is a major use, followed by construction and automotive. In Europe, current annual use of plastics is about 100 kg/person, while North America is at about 140 kg/person.

The scenario illustrates the outcome if all world regions converge to 120 kg/person.

From Material Economics Sverige AB Grev Turegatan 30, 114 38 Stockholm, Sweden materialeconomics.com

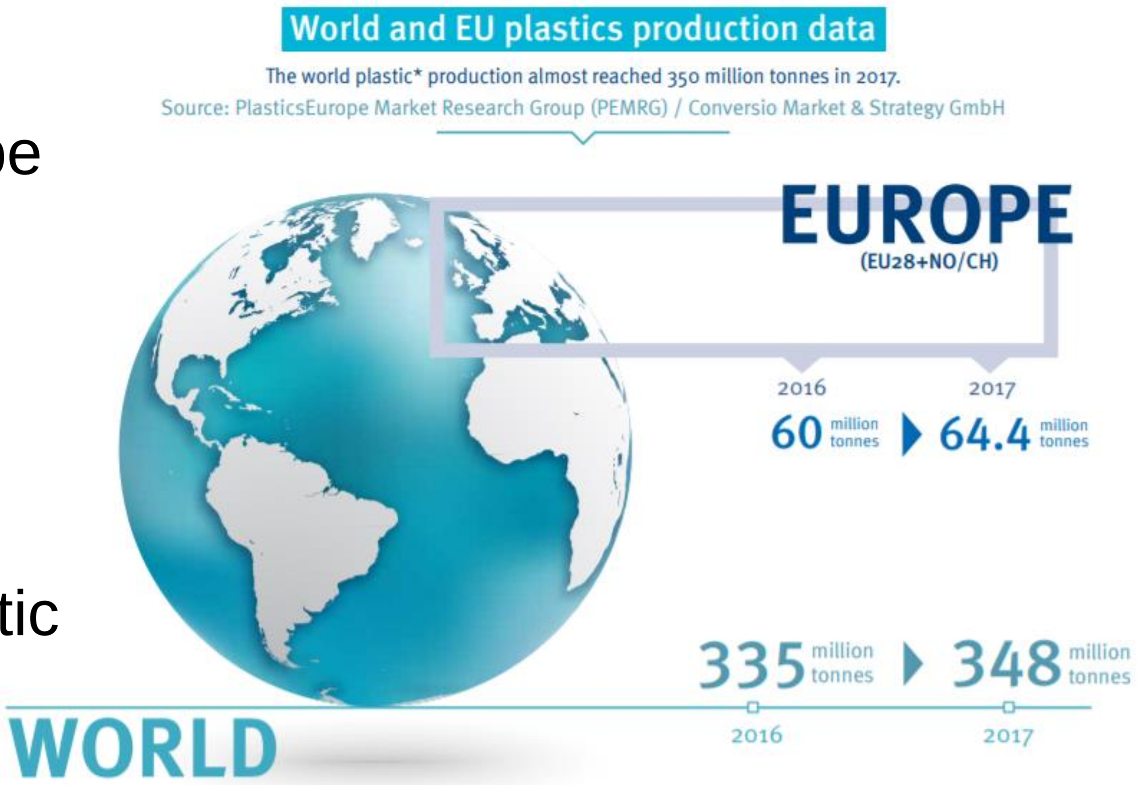
Decarbonization pathways – *The role of EAF*

A second case concerns the replacement of coal with plastics.

The annual amount of produced plastic in Europe is about 50 Mt.

From the collected waste plastics, about 27.3% is landfilled,
41.6% is used for energetic purpose

only 31.1% is recycled



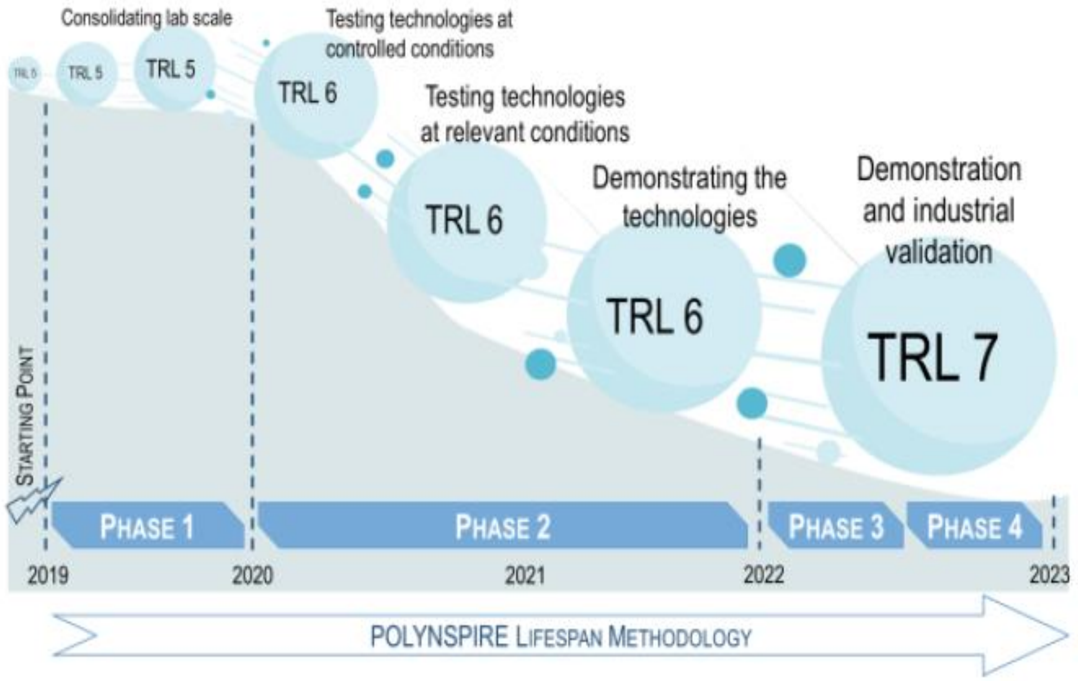
In Italy there are about 300 000 tons of low grade plastic (mixed plastic waste) with no market application

Data from report: Plastics – the Facts 2018, by the European plastic manufacturer association Plasticseurope

Decarbonization pathways – *The role of EAF*

The H2020 project ***POLYNSPIRE*** has been launched to demonstrate a set of innovative, cost effective and sustainable solutions, aiming at improving the energy and resource efficiency of post-consumer and post-industrial plastic recycling processes, targeting 100% waste streams. To reach this ambitious goal, three innovation pillars are addressed:

A. Chemical recycling to recover plastic monomers and valuable fillers
B. Advanced additivation to enhance recycled plastics quality
C. **Valorization of plastic waste as carbon source in steel industry**



The technological solution studied in **POLYNSPIRE** project will be validated with industrial trials, up to TRL 7 (Threshold Readiness Level).

Decarbonization pathways – *The role of EAF*

Replacement of coal with plastics.

Plastic grains have physico-chemical properties which differs significantly from anthracite

Parameter	Plastic residue	anthracite (reference material)
HHV** (MJ/kg)	32.37	26-30
Ash (% dry)	9.50	1-10
Cl (% dry)	0.38	<0.01
S (% dry)	0.03	0.5-1.5
H (% dry)	10	0.5-1.5
N (% dry)	1.1	0.2-0.3
C (% dry)	65.0	80-85
O (% dry)	14.88	0.1-0.5
Volatile matter (%)	88.50	1-10
Fixed carbon (%)	1.5	75-80

The major part of the plastic is constituted by volatile matter (88.89%). The carbon content in the plastic residue is 64% but only the 1.5% is fixed

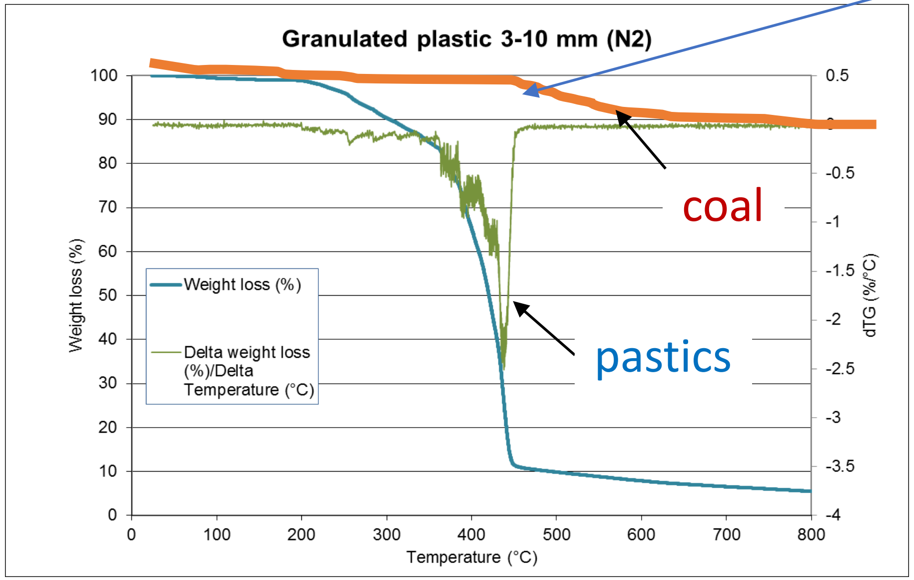
Tailored injection system is necessary

POLYNSPIRE project

Decarbonization pathways – *The role of EAF*

Replacement of coal with plastics.

To design the injection in EAF, laboratory investigation has been carried out to determine the thermal behaviour of the material.



Thermal analysis of granulated plastic 3-20 mm

In tests of carburization of metal bath plastic briquette is put in contact with molten steel measuring the C dissolution

In burning tests time of complete burning of a plastic grains is measured (test at 900°C)

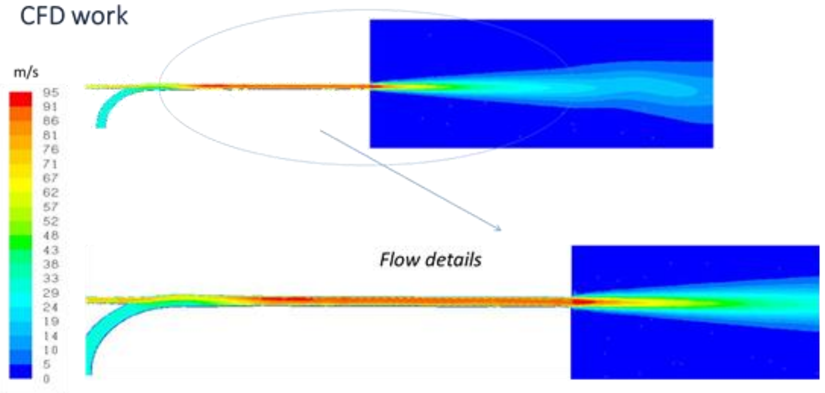
POLYNSPIRE project

The laboratory characterization indicated that the plastics is more suitable for injection under slag than for charging in basket

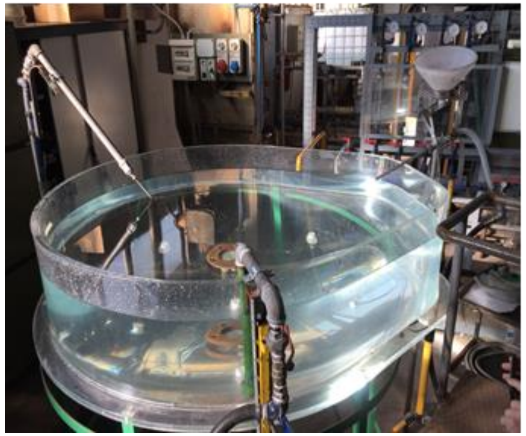
Decarbonization pathways – *The role of EAF*

Replacement of coal with plastics.

From the identified characteristics numerical and physical modelling have been used for tailoring injection system in EAF



Injector device designing supported by CFD simulations and by experimental tests with physical model



Characteristics of jet and penetration of the jet into the steel bath determined

POLYNSPIRE project

Decarbonization pathways – *The role of EAF*

Replacement of coal with plastics.

The thermal behavior of the plastic residue sample show that devolatilization is in two phases between 250°C and 450°C. Light organic matters (about 25%) volatilize in the first phase in the range of 250-350°C whereas heavy organic matters (about 75%) volatilize in the second phase in the range of 350-450°C.

Carburization tests showed dissolution efficiency of 15-20%. This means that during the injection process there is a large emission of gas beneficial for slag foaming

CFD and physical modelling allowed to design a tailored injector

Industrial tests on going

POLYNSPIRE project

The contents of this presentation and discussed examples are taken from following works funded by the European Union

1. Sustainable EAF steel production – GREENEAF, RFSR-CT-2009-00004
2. BIOCHAR FOR A SUSTAINABLE EAF STEEL PRODUCTION, GREENEAF2, Grant Agreement number: RFSP-CT-2014-00003, 01/07/2014-30/06/2016
3. H2020-NMBP-ST-IND-2018-2020 Demonstration of Innovative Technologies towards a more Efficient and Sustainable Plastic Recycling (POLYNSPIRE) (09/01/2018 – on going).
4. LowCarbonFuture, EXPLOITATION OF PROJECTS FOR LOW- CARBON FUTURE STEEL INDUSTRY, European Funded Project, GA-No. 800642, 2018-2020
5. Seventh Framework Program FP7/2007-2013 grant agreement n° ENER / FP7EN / 314596 http://pitagorasproject.eu/

Thank you for listening

Filippo Cirilli – filippo.cirilli@rina.org
Umberto Martini – umberto.martini@rina.org

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

Residual material for slag foaming in EAF

Johan Björkvall - Swerim

Research Fund for Coal & Steel

Day 3, 16.06.2021 Webinar on Refractory, Millscale, other residual material from inside and outside of the steelwork,

Recycling of industrial and municipal waste as slag foaming agent in EAF (RIMFOAM)

RFSR-CT-2014-00008

Reporting period: *01/07/2014 – 31/12/2017*

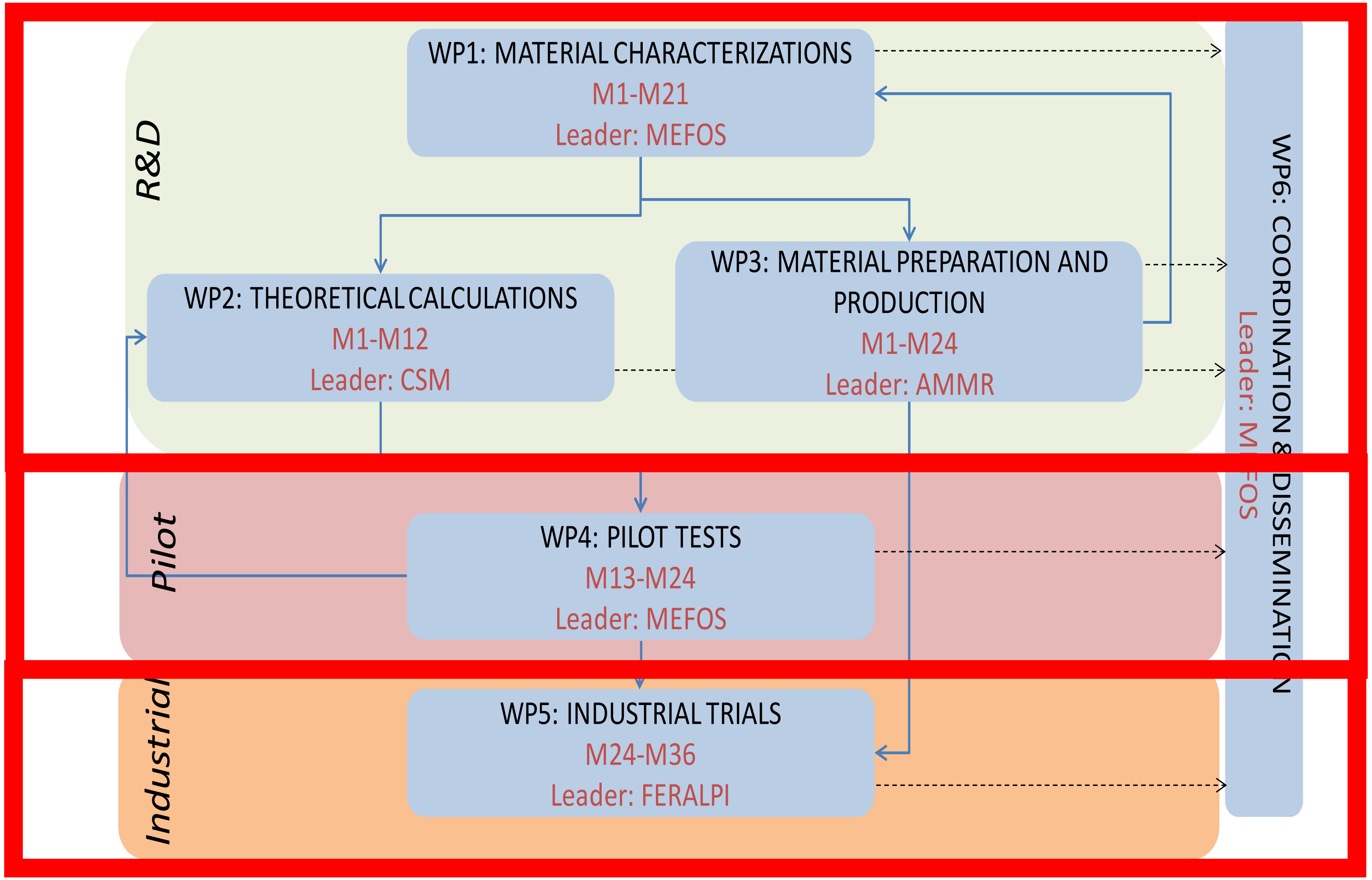
Jonas Alexis, Ida Heintz, Johan Björkvall - Swerim
Philippe Russo - ArcelorMittal Maizieres Research SA
Eros Faraci - Centro Sviluppi Materiali S.p.A (CSM)
Fredrik Cederholm - Höganäs Sweden AB
Peter Antoine - ArcelorMittal Belval & AMBD SA
Piero Frittella, Stefano Filippini - Feralpi Siderutgia S.p.A

Research Fund for Coal & Steel

Webinar on Refractory, Millscale, other residual material from inside and outside of the steelwork, 16.06.2021

The main objective of the project was to evaluate and utilise **waste material** blends containing both metal oxides and hydrocarbons **as slag foaming agents in the EAF**.

- **20 % replacement of carbon with recycled material**
- **5 % replacement of oxygen gas with recycled material**


R&D
WP1: MATERIAL CHARACTERIZATIONS
M1-M21
Leader: MEFOS
WP2: THEORETICAL CALCULATIONS
M1-M12
Leader: CSM
WP3: MATERIAL PREPARATION AND PRODUCTION
M1-M24
Leader: AMMR
Pilot
WP4: PILOT TESTS
M13-M24
Leader: MEFOS
Industrial
WP5: INDUSTRIAL TRIALS
M24-M36
Leader: FERALPI
WP6: COORDINATION & DISSEMINATION
Leader: MEFOS

CHARACTERISATION OF MATERIALS (WP1)

- *Carbon and hydrogen containing wastes*
- *Oxide containing wastes*
- *ASR fractions*

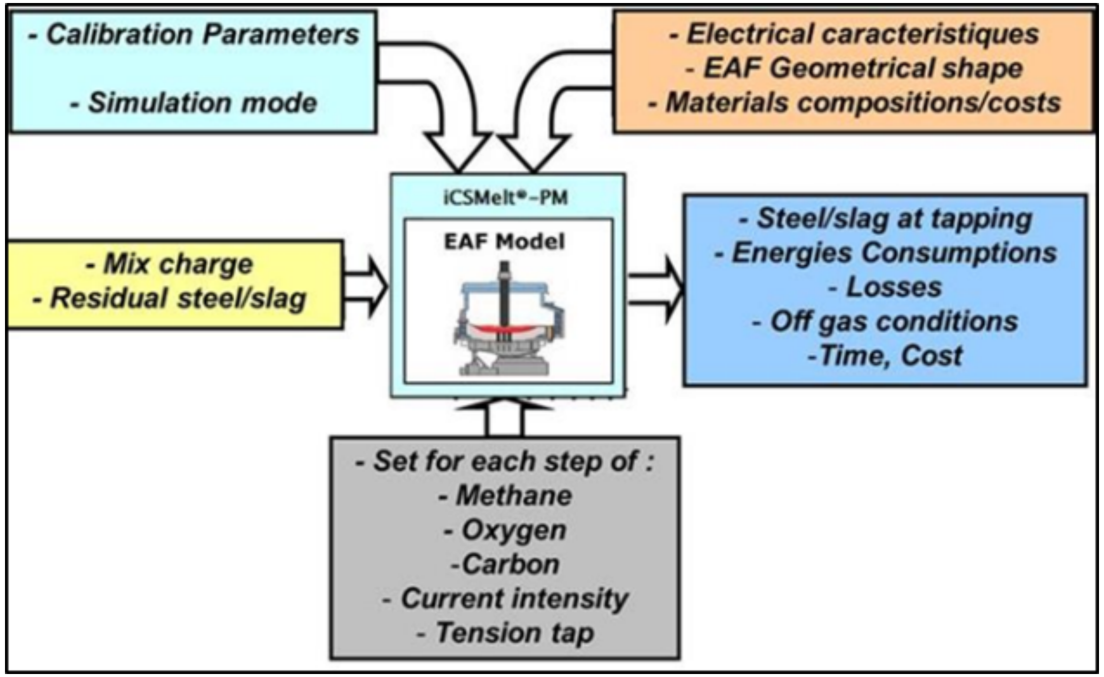
ASSESSMENT OF THE IMPACT OF CHARACTERISED MATERIALS ON THE EAF PROCESS (WP2)

- *Development of heat and mass balance model*
- *Calibration and validation of the model*
- *Identification of boundary conditions for use of materials*
- *Calculation of material blends*

MATERIAL PREPARATION AND PRODUCTION (WP3)

- *Identification and development of pre-treatment methods*
- *Agglomeration methods*
- *Definition and preparation of materials for laboratory tests*
- *Characterisation of pre-treated materials and material blends*
- *Production of material mixes*

WP 2 Theoretical calculation



Calibration of process model based on plant settings for partners' conditions and waste material characteristics.

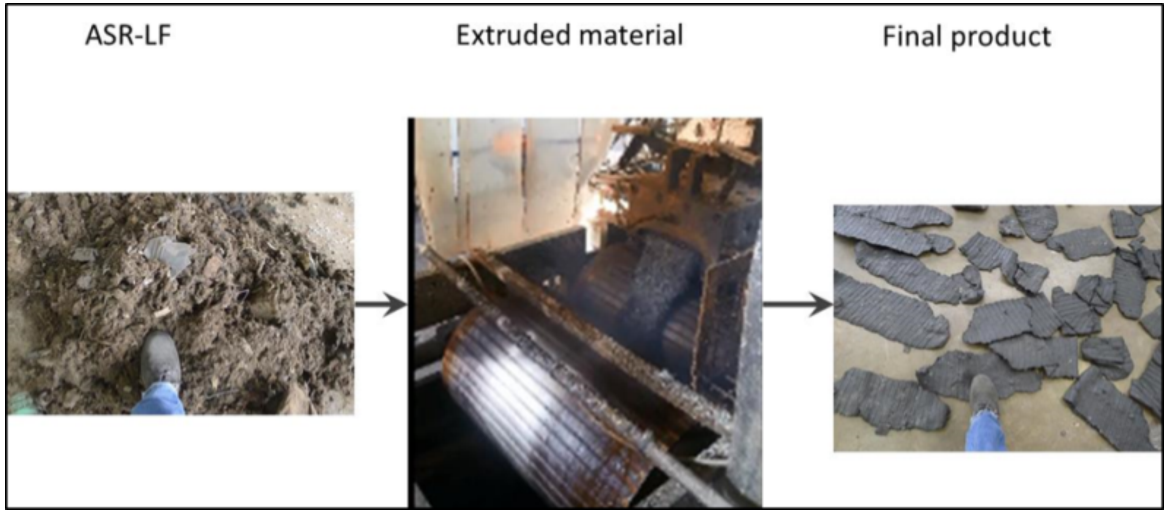
- Steel and slag conditions at tapping in terms of composition, temperature and weight.
- Off gas conditions at IV hole in terms of composition, flow rate and temperature
- Sources composition in terms of electrical energy, O2, CH4, C and time of the heat.

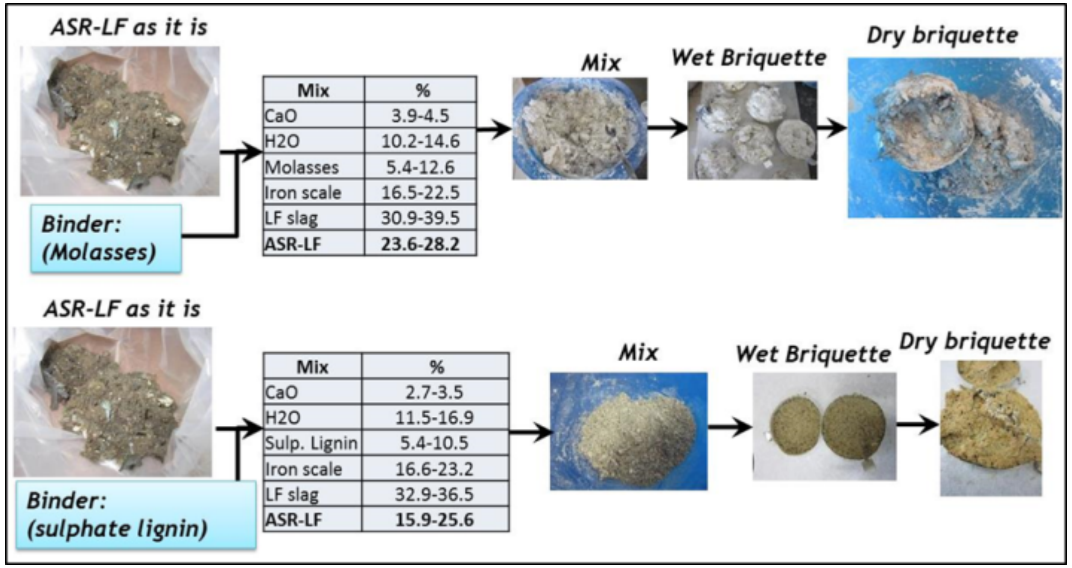
EAF site	Materials
Feralpi Lonato	ASR
Höganäs	PE/XLPE + EAF dust
AMDB	Rubber

MATERIAL PREPARATION AND PRODUCTION

- Ball sector valve for high flow rate (industrial trial)
- Roto-feeder valve for low flow rate (pilot trial)
- All materials could be injected but stirring is needed.
- Important to remove all material from dispenser

Agglomeration methods ASR





Advantages	Disadvantages
• Treatment costs	• High carbon yield • High material density • Low reactivity at low temperature

Advantages	Disadvantages
• Pre-treatment costs • Briquette fragility • Binders cost	• By-product recycling • Medium carbon yield • High material density

Pilot trials at two sites

The most promising material mixes for injection and charging were selected for pilot trials

Swerim (MEFOS)

- 15 slag foaming trials with six different material mixtures containing **anthracite**, **rubber**, **Petrit-t** and **EAF-dust**.
- Replacement ratio of anthracite varied from **20% to 50%**
- Replacement ratio oxygen varied from **2% to 10%** for the different material mixes.

AMMR (ArcelorMittal Maizieres Research)

- Investigated 7 residues injected with co-injection
- These materials include **plastic fines**, **fine rubber powder** from end-of-life tires, **wood sawdust pellets**, **petroleum coke**, a fraction of **ASR** from Feralpi and two shredder residue fractions from **plastic granules**.
- Replacement ratio of anthracite varied from **10% to 30%**.

Pilot trials: Slag foaming

MEFOS

- Most material blend shown good foaming

	A	B	C1	C2	I	J	C3
Replacement ratio anthracite %	20	20	10	50	50	50	50
Replacement ratio oxygen %	5	5	2	5	5	10	10
Anthracite wt%	30	34	53	14	22	14	32
Rubber wt%	0	2,8	0	0	12,9	5,4	0
Petrit T wt%	16	0	15,3	49,8	0	0	15,8
EAF dust wt%	54	63	32	36	66	81	53

AMMR

- The best foaming results was obtained with **rubber powder** and **petroleum coke** but good foaming was also observed for the **wood sawdust pellets** and one of the shredder residue fractions from **plastic granules**
- No slag foaming was obtained **plastic fines**

Foaming from MEFOS

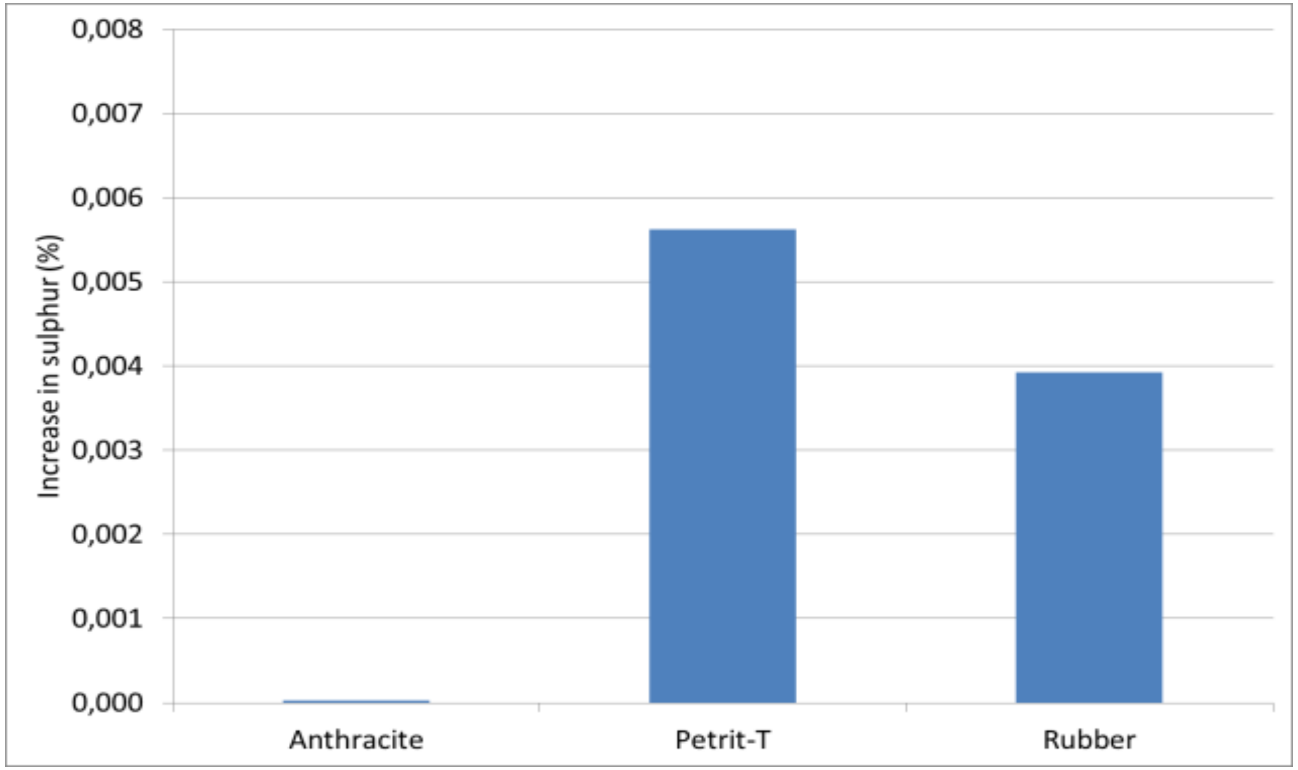
plastic fines from AMMR

Pilot trials: effect on steel composition

MEFOS and AMMR

- Similar results

Results from MEFOS



Pilot trials: Environmental impact

MEFOS

- Level of environmental impact of the off gas is probably more related to process parameters than the material in the slag foaming agents in the range of replacement.

AMMR

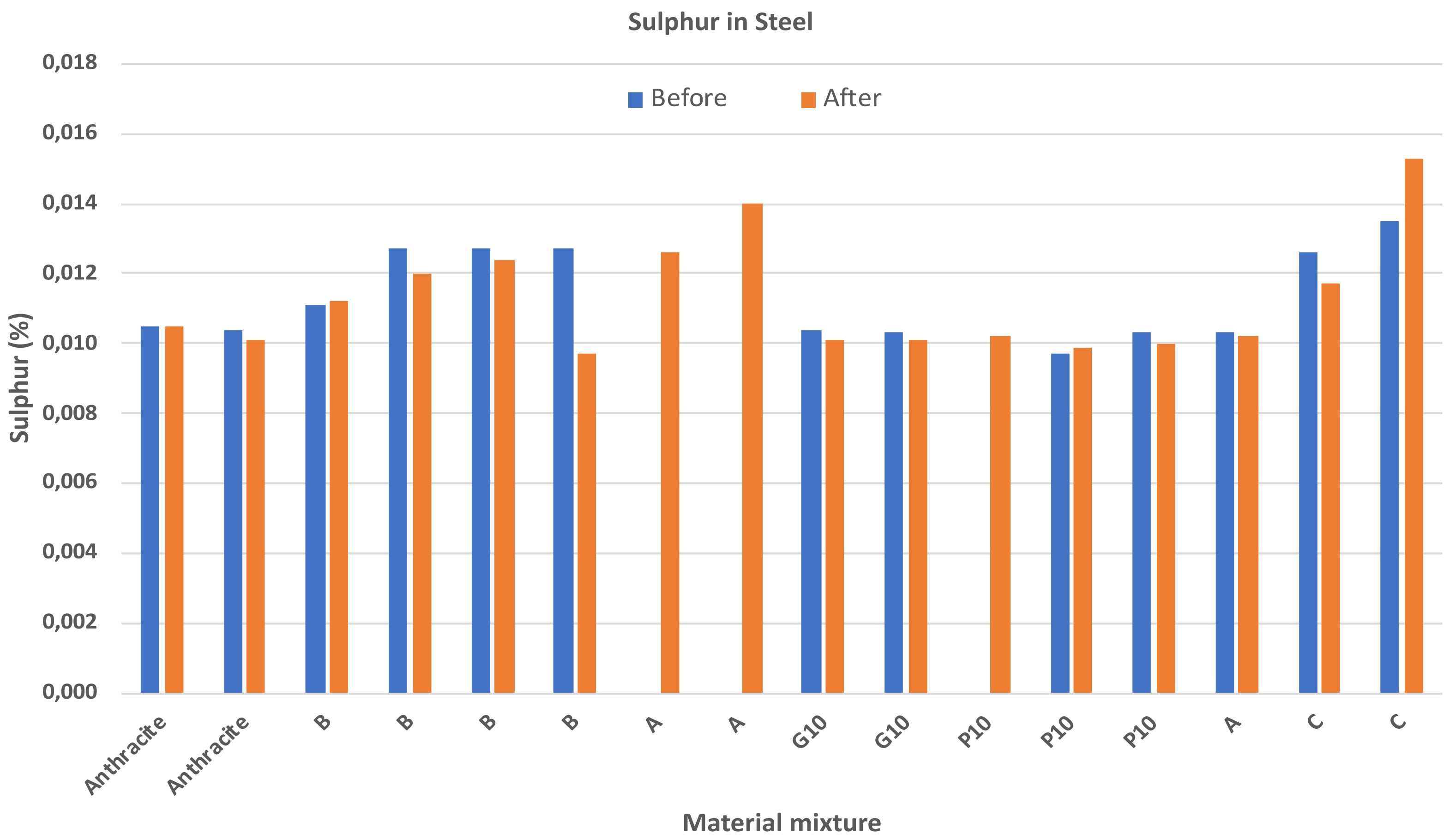
- Some increases have been measured with full replacement on the environmental impact during the trials.

Plant trials, Höganäs

Injected materials

Material	Anthracite	A	B	C	G 10	P10
Replacement anthracite (%)	100	10	10	20	10	10
Replacement oxygen (%)	0	2	2	5	0	0
Anthracite (wt%)	100	52.9	59.6	34,5	93	68,6
Rubber (wt%)	-	0	2.6	2,8	7	-
Petrit-T (wt%)	-	15.3	-	-	-	31,4
EAF dust (wt%)	-	31.8	37.8	62,7	-	-
%S	0.19	0.26	0.18	0,16	0.306	0,42

Sulphur content in steel at Höganäs



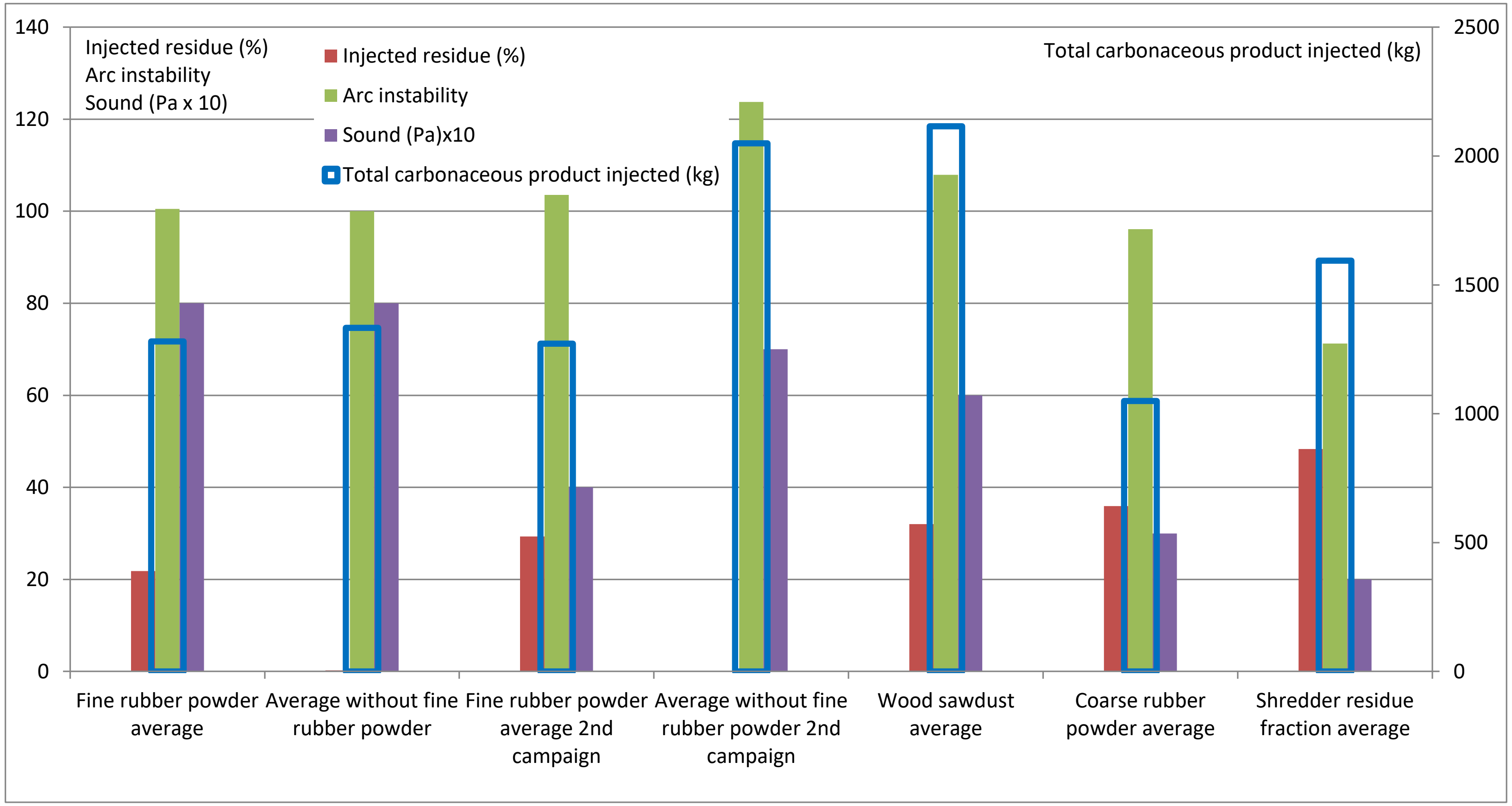
Industrial trials **ArcelorMittal Belval & AMBD SA** (AMBD)

Five different residues were tested in AMBD EAF:

- Fine rubber powder (0-1 mm)
- Coarse rubber powder (1-4 mm)
- Sawdust pellets
- Shredder Residue fraction obtained with Sicon technology
- Petroleum coke

Around 80 heats with partial injection of the 4 first residues and petroleum coke was tested on long term (from June to August 2017)

Arc stability and sound average values at AMBD



Results Industrial trials with injection

- The Höganäs trials show that it is possible to inject **EAF-dust**, **rubber** and **Petrit-T** together with anthracite and keep good foaming, at least qualitatively
- Injected material blends containing **EAF-dust** and **rubber** show promising results for both sulphur content in the steel and foaming capabilities.

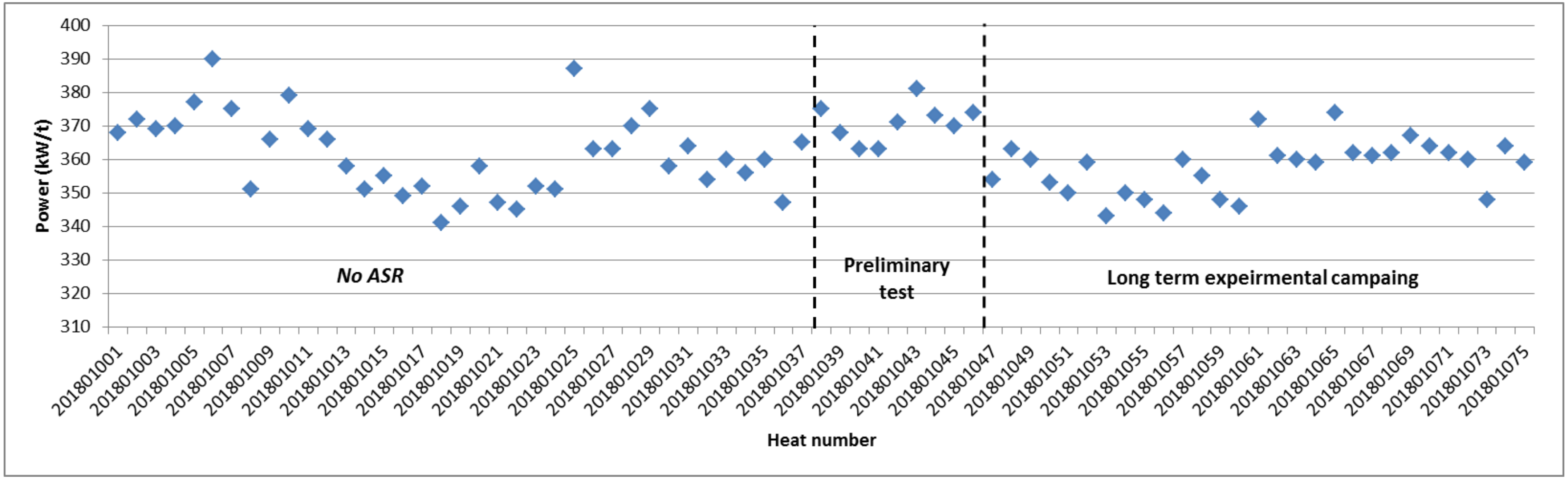
- At AMBD 3 residues containing carbon that can replace coal to make the slag foam were found:
  - coarse **rubber powder** from end of life tires
  - carbonaceous fraction extracted from shredder residue from **plastic granules**
  - **petroleum coke**

- More heats with full coal replacement are needed to validate the environmental impact and to evaluate, the potential extra cost from extra de-sulphurisation

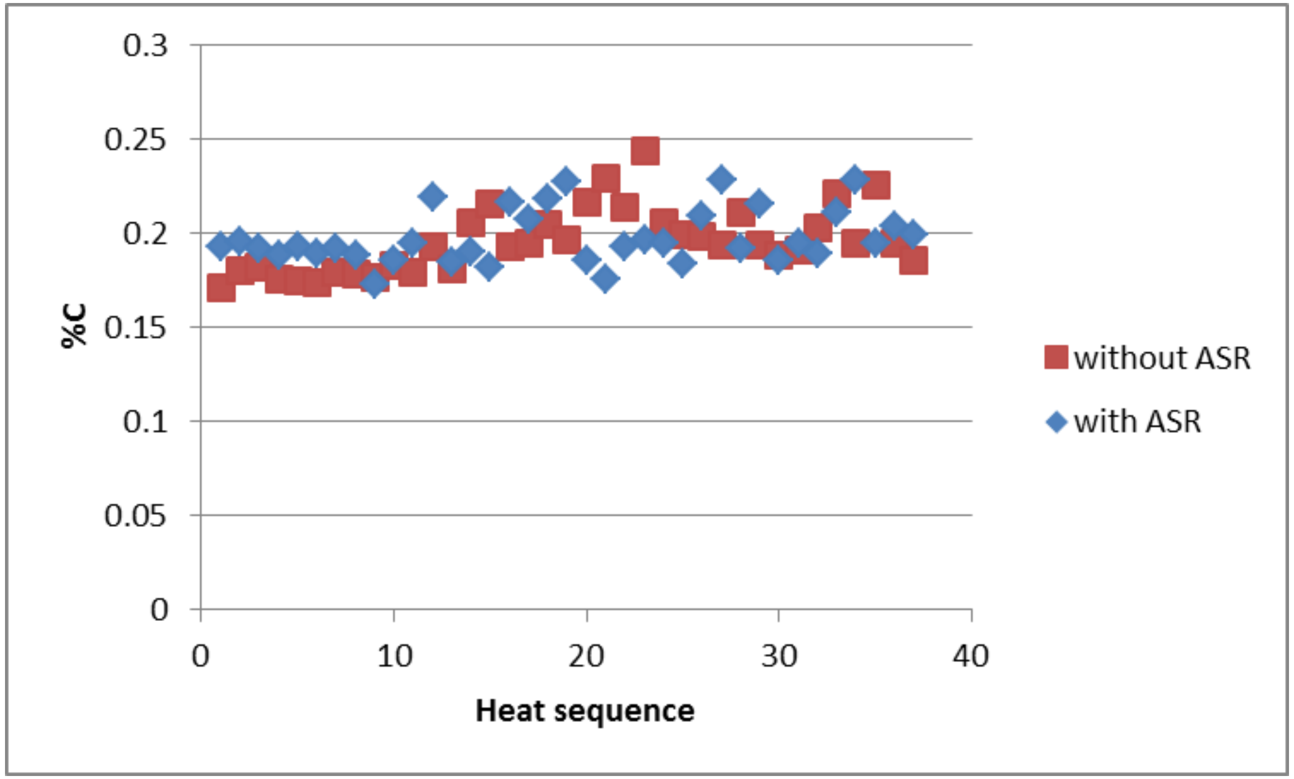
Industrial trials from Feralpi using ASR

Date	ASR (kg)	N° of heats	objective
06th February 2018	no	37 heats (201801001-201801037)	Test in standard condition to obtain a base line of reference
7th February 2018	450	9 heats (preliminary experimental trials) (2018010038-201801046)	Substitution of 100 kg of anthracite with 450 kg of ASR; comparison with standard practice. Stack analysis of Dioxins and furans
7th/8th February 2018	450	25 heats (Long term experimental campaign) (2018010047-201801075)	Substitution of 100 kg of anthracite with 450 kg of ASR comparison with standard practice. Stack analysis of Dioxins and furans
	900	4 heats (Long term experimental campaign) (2018010050-201801053)	Substitution of 200 kg of anthracite with 900 kg of ASR comparison with standard practice. Stack analysis of Dioxins and furans

Industrial trials from Feralpi using ASR
Power consumption



Industrial trials from Feralpi using ASR Carbon content



- The utilisation of ASR does not modify the main EAF process parameters
- ASR in the range of 450-900 kg per heat does not increase the bat carburization.
- The utilization of 450 kg per heat charged in first basket was found compatible with the stability of the process in normal continue production conditions.
- The utilization of 900 kg of briquette charged in 2 big bags in first basket was found not feasible for a stable production because of the difficulties to have a stable position of charged briquettes in the EAF.
- Supplementary off gas analysis of polluting agents (mainly dusts, chlorinated aromatic compounds, PCB, dioxins and furans) showe
  - The amount of dust did not vary with ASR utilization.
  - A slight increase of polycyclic aromatic compounds from the use
  - The dioxin level and heavy metal concentration in the off gas was not modified.

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

Processes and technologies for environmentally friendly recovery and treatment of scrap – PROTECT

Mikael, Larsson - Swerim

Outline

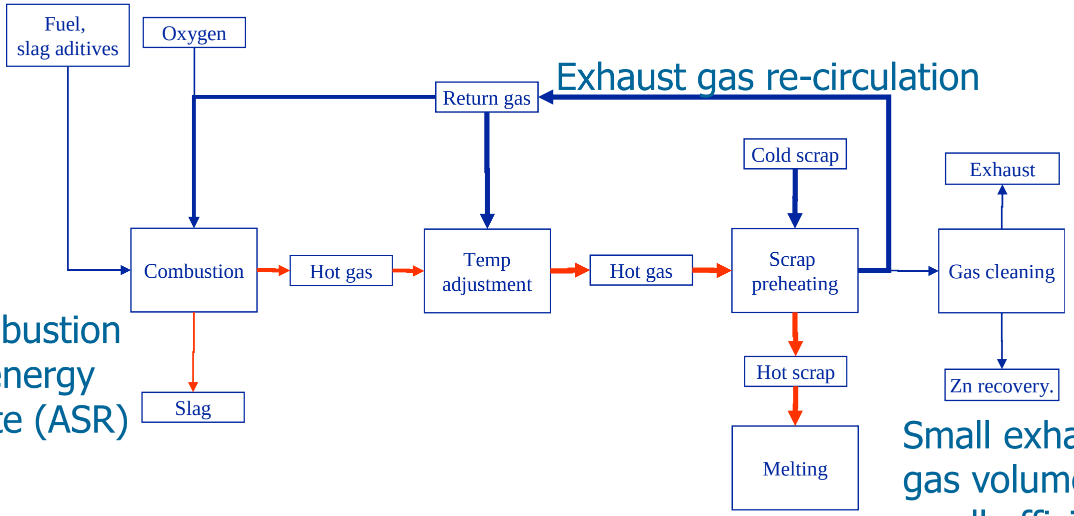
- Project overview
- Results
- Conclusions

Protect project overview

The stand-alone surface rinsing and preheating concept

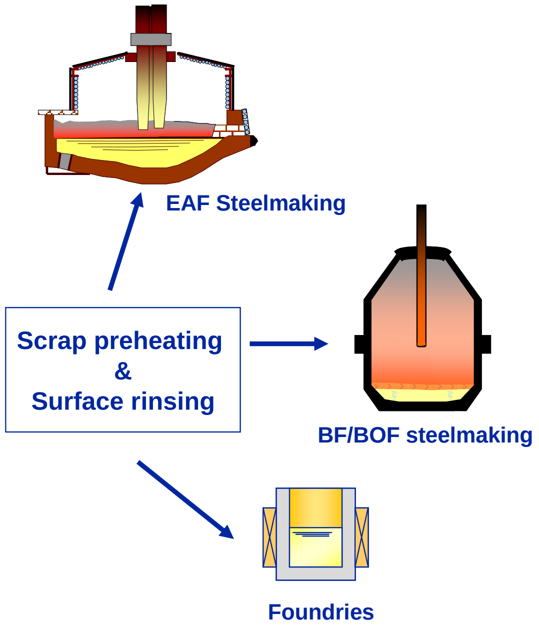
Oxygen

Exhaust gas re-circulation



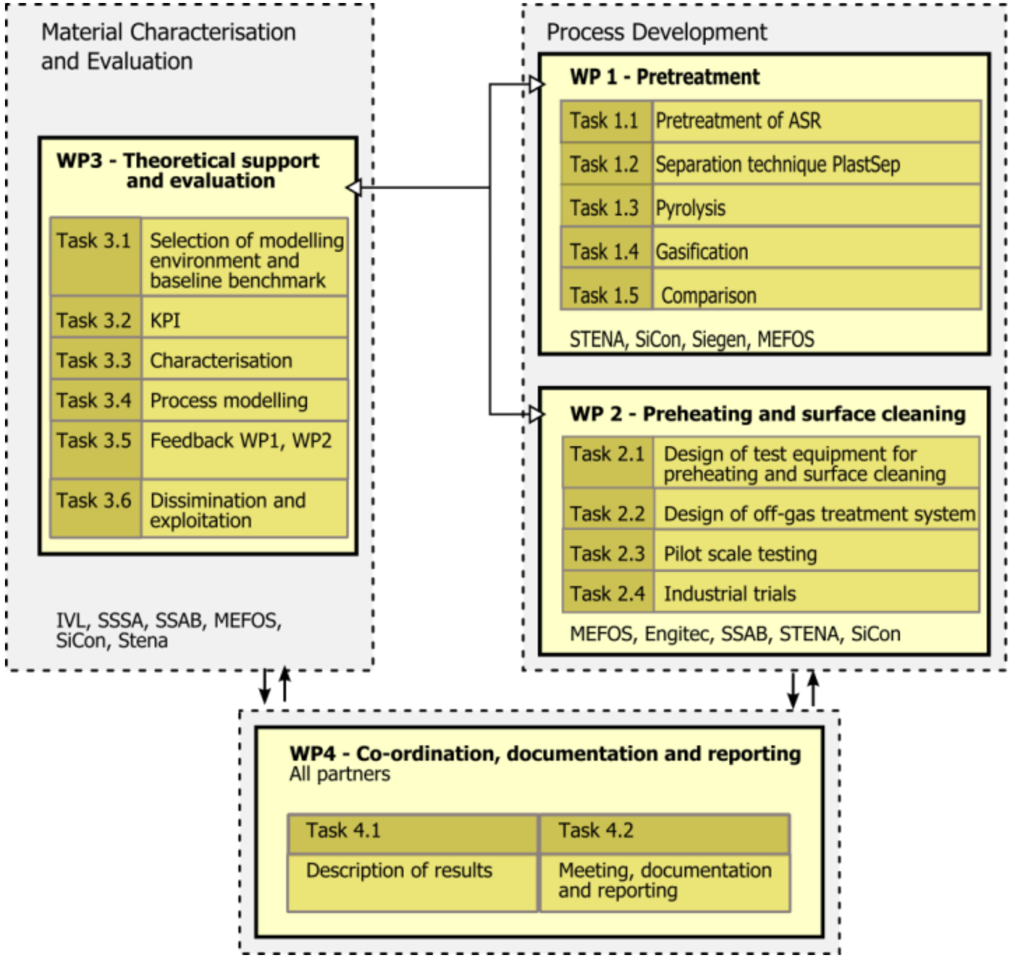
Combustion of energy waste (ASR)

Small exhaust gas volumes → small efficient gas filters



The main objective of the project is to develop a stand alone method for simultaneous preheating and surface cleaning of scrap utilising energy and chlorine containing waste as a resource.

Evaluation of effects, LCA and system modelling



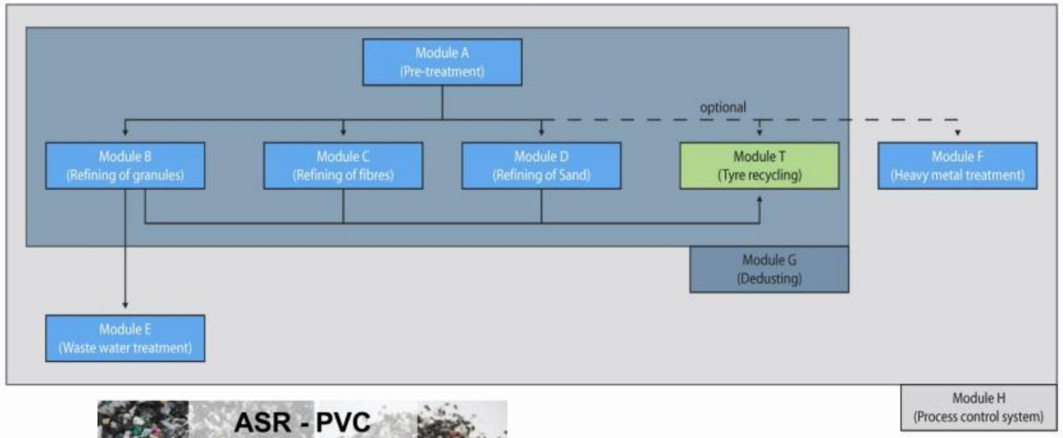
ASR – Preblematic material, Clorine rich
Gasification, pyrolysis

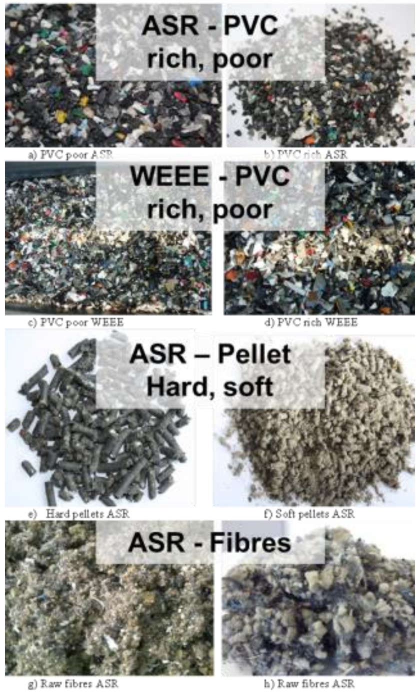
Preheating, harmful elements in flue gases requires expensive gas cleaning

Collaboration project between: Swerim, Stena, SSAB, Sicon, SSSA, Engitech, University of Siegen, IVL

Pretreatment

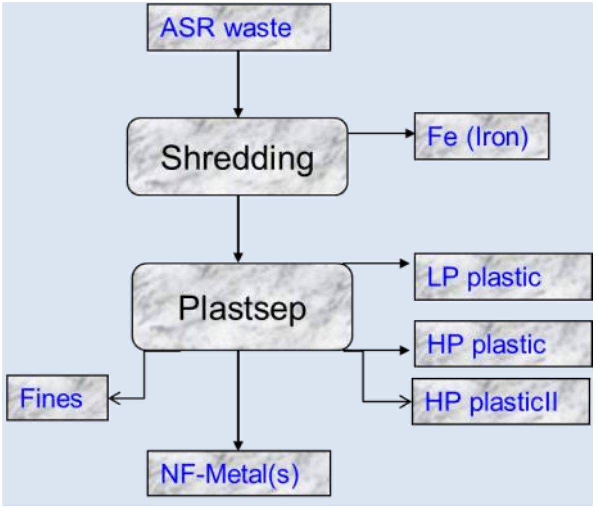
- Two different pre-treatment methods for separating and processing energy containing waste were adopted and tested,
  - possible to produce Cl rich fractions and Cl weak fractions.
- Development and experimental testing of thermo-chemical recycling of plastics containing Cl have been conducted,
  - possibility to treat and produce a highly energetic syngas.
  - Gasification and pyrolysis both have pros and cons, Different yields and products

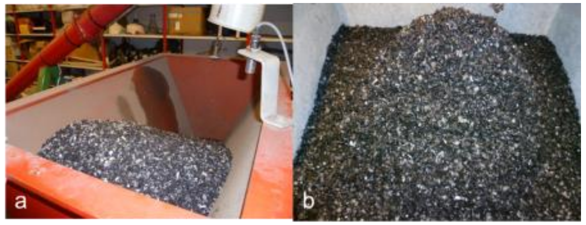




Sicon process and **Plastsep** process have been used to produce dedicated material fractions

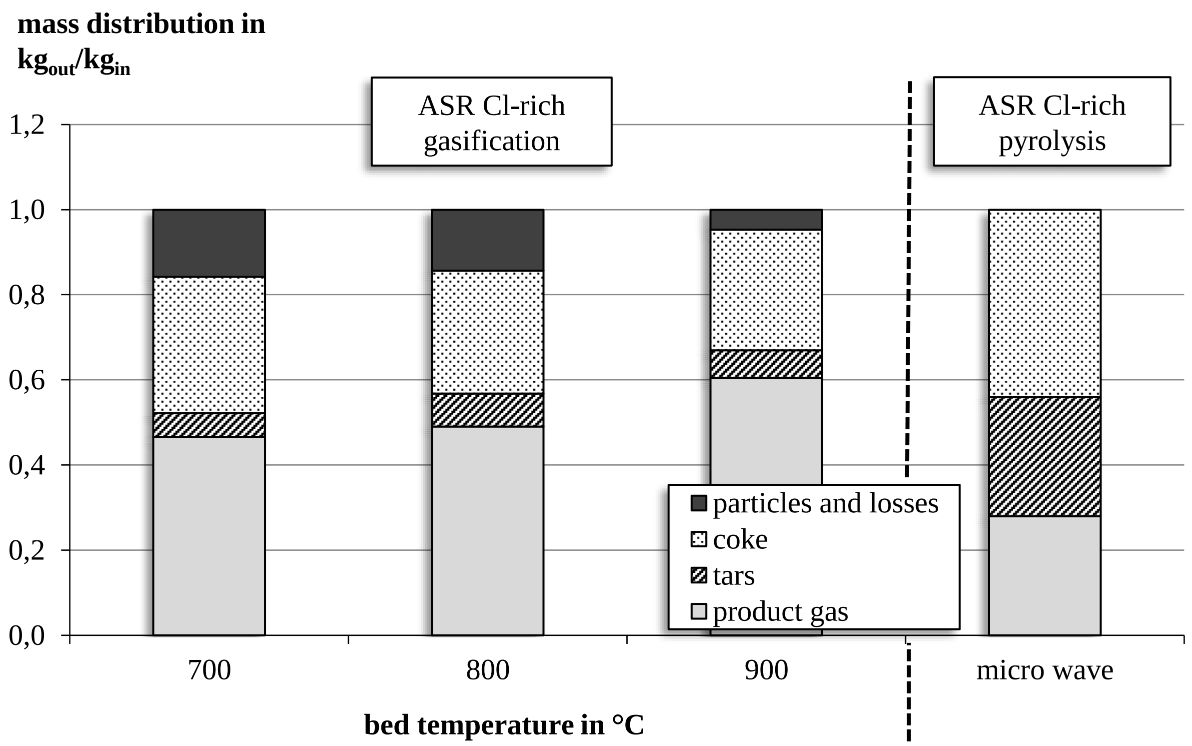
Good separation in low and high Cl contents fraction





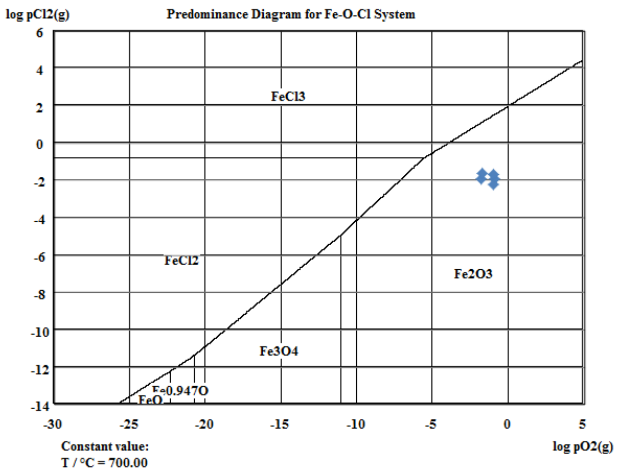
Microwave pyrolysis
Metalls in ash can be recovered
Possible ustilisation of oils

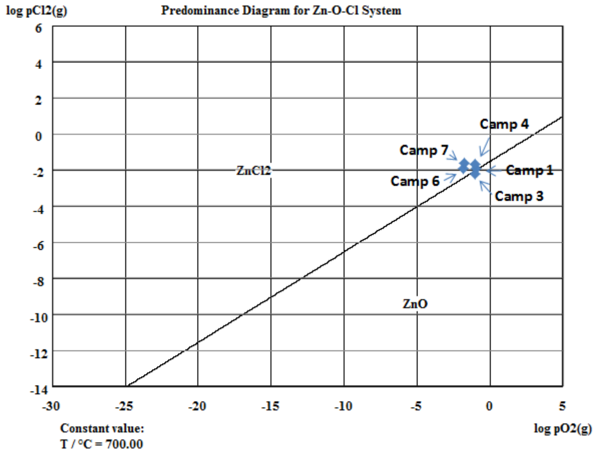
Gasification
Higher proces gas and Cl yield

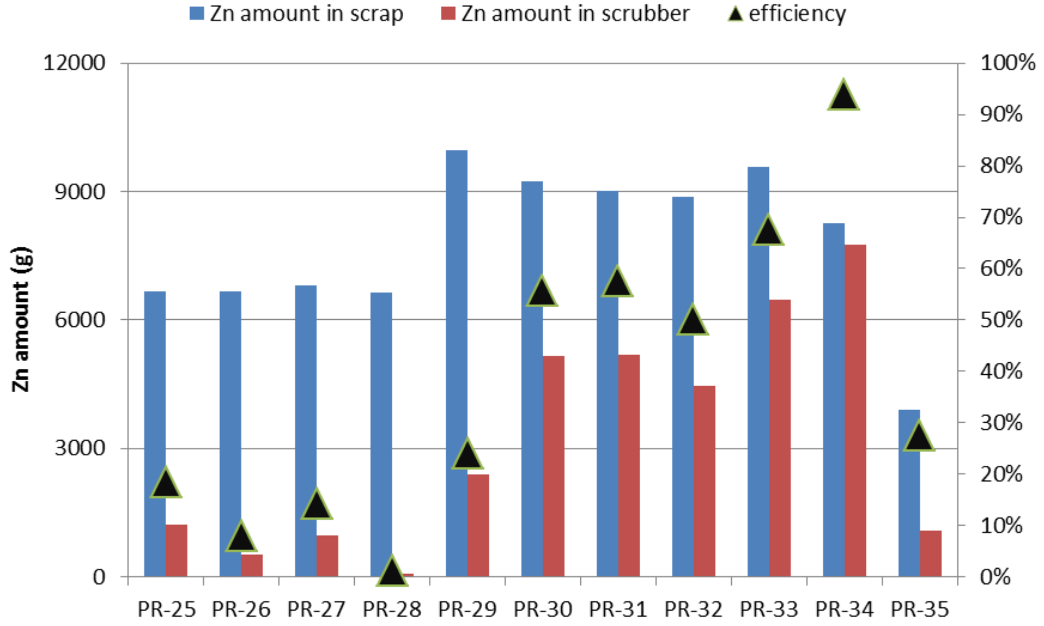


Preheating

- A scrap preheating pilot plant for simultaneous scrap preheating and surface cleaning has been designed, erected and test conductes.
- A dedicated recovery system for Zinc and other metals found in the scrubber solution have been developed. Tests have been made to evaluate process design, indicative cost estimates sensitive to size of equipment
- Industrial melting trials have been conducted







- Pilot designed and erected,
- 36 pilot trials conducted,
- High preheating temperature possible (>600C), low exhaust gas volumes vented (~100 nm3/t scrap), organic removal Ok, metallic (Zn) requires more work

- Calculation of Key Performance Indicators (KPIs) covering quality, economical and environmental values
  - Reference (BF/BOF, EAF) compared to new system with scrap preheating integrated
  - A general conclusion from the quantification of environmental KPI, is that the results indicate that the new proposed zinc recovery methods make it possible to recover the zinc in the steel scrap in the steel process without an increase of energy and environmental load
- Process simulations and Holistic modelling
  - Possibility to add PVC increases the Cl content in the plastic mix
- CFD modelling of the scrap preheating shaft
  - Operation praxis, energy efficiency about 75%, cleaning efficiency temperature dependant

Conclusion

- Possible to utilize low value waste streams, generating a combustible gas either gasification of pyrolysis, to be utilized as primary energy source for scrap preheating
- Its possible to minimize the off gas treatment through gas recirculation (minimized off-gas 100 nm3/t Scrap)
- It is possible to capture Zn as ZnCl. However more work is needed
- There are still some technological/metallurgical questions remaining open and more research to validate and improve before a large scale demonstration and implementation of the concept can be done is needed.

Industrial benefits

Cleaner off gases from the steel plant with existing gas cleaning system

Oil, plastics. Paint, Hg, Zn, etc in scrap can be removed

Widened scrap basis

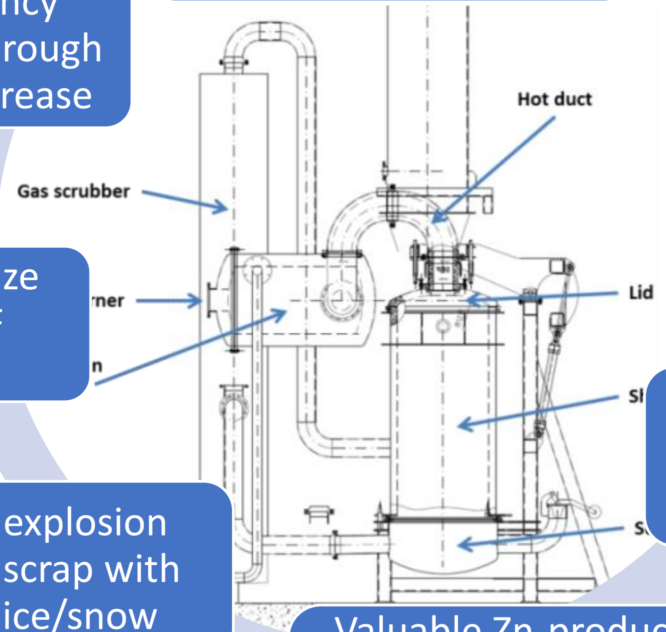
Increased possibilities for internal recirculation of dusts

Valuable Zn-products (concentrated ZnCl instead of diluted ZnO dust)

Elimination of explosion when charging scrap with moisture and ice/snow

Possibility to utilize hot heel in EAF operation

Energy efficiency improvement through productivity increase



ESTAD Symposium REUSteel

31 August 2021, 08:30 – 12:00

Moderators: Sara Rosendahl and Hanna Granbom, Swerim

Reuse and recycling of residual materials in iron and steelmaking: analysis of relevant results, trends and perspectives

Project members

Valentina Colla, TeCIP Institute, Scuola Superiore Sant'Anna, Via Moruzzi 1, Pisa, Italy, valentina.colla@santannapisa.it (coordinator)

Teresa Annunziata Branca, TeCIP Institute, Scuola Superiore Sant'Anna, Pisa, Italy, teresa.branca@santannapisa.it

Roland Pietruck, VDEh-Betriebsforschungsinstitut GmbH, 40237 Dusseldorf, Germany, roland.pietruck@bfi.de (presenter)

Agnieszka Morillon, FEhS-Institut für Baustoff-Forschung e.V., 47229 Duisburg, Germany, a.morillon@fehs.de

David Algermissen, FEhS-Institut für Baustoff-Forschung e.V., 47229 Duisburg, Germany, d.algermissen@fehs.de

Umberto Martini, RINA Consulting-Centro Sviluppo Materiali S.p.A. (CSM), 00128 Castel Romano (Rome), Italy, umberto.martini@rina.org

Hanna Granbom, SWERIM, 97125 Lulea, Sweden, hanna.granbom@swerim.se

Sara Rosendahl, SWERIM, 97125 Lulea, Sweden, sara.rosendahl@swerim.se

Abstract

The steel sector is deeply committed to sustainable management of its residual materials, in order to reduce the natural resources exploitation, reduce the environmental impact of the steel sector, and to achieve the steel sector's "zero-waste" goal.

The ongoing project titled "Dissemination of results of the European projects dealing with reuse and recycling of by-products in the Steel sector (REUSteel)", funded by the Research Fund for Coal and Steel (RFCS), is mapping the research done in this area. The project aims at a

valorisation of the most important research results on residual materials reuse and recycling, both internally within the steel sector and in other industrial sectors. This is based on an integrated critical analysis of many finalized EU-funded projects, in order to promote results exploitation and increase the synergies with other industrial sectors. The analysis will allow to identify the most urgent needs and ambitions of the European steel sector and define a sequence of future research topics in this field. The project is coordinated by SSSA and other partners are Swerim, BFI, FEhS, RINA-CSM.

The symposium will start with a presentation of the concluded and ongoing research within the REUSteel project. This will be followed by an in-depth look at three topics identified within the dissemination project. The three topics are slag use, residual material use in BF and sinter plant, residual material use in EAF. The symposium will be concluded with an outlook about the future of residual materials within steel industry. In connection to all the presentations there will be time for questions and comments from the audience. During the symposium we are also looking for the opinions and feedback from the audience.

Program

8.30-10.00 Two presentations including time for questions.

- General presentation of the REUSteel project and the symposium – Valentina Colla (SSSA)
- Research of use of slag from the steel industry – Agnieszka Morillon (FEhS)

10.00-10.30 Coffee break

10.30-12.00 Two presentations including time for questions followed by an outlook, together with the audience, on future use of and research on residual materials.

- Research of the use of sludge, dust, refractory, millscale, and other residual materials from the steel industry and external secondary raw material in the BF and Sinter – Roland Pietruck (BFI)
- Research of the use of sludge, dust, refractory, millscale, and other residual materials from the steel industry and external secondary raw material in the EAF – Umberto Martini (CSM)
- An outlook: How will the use of residual material change in the future? – Valentina Colla (SSSA)

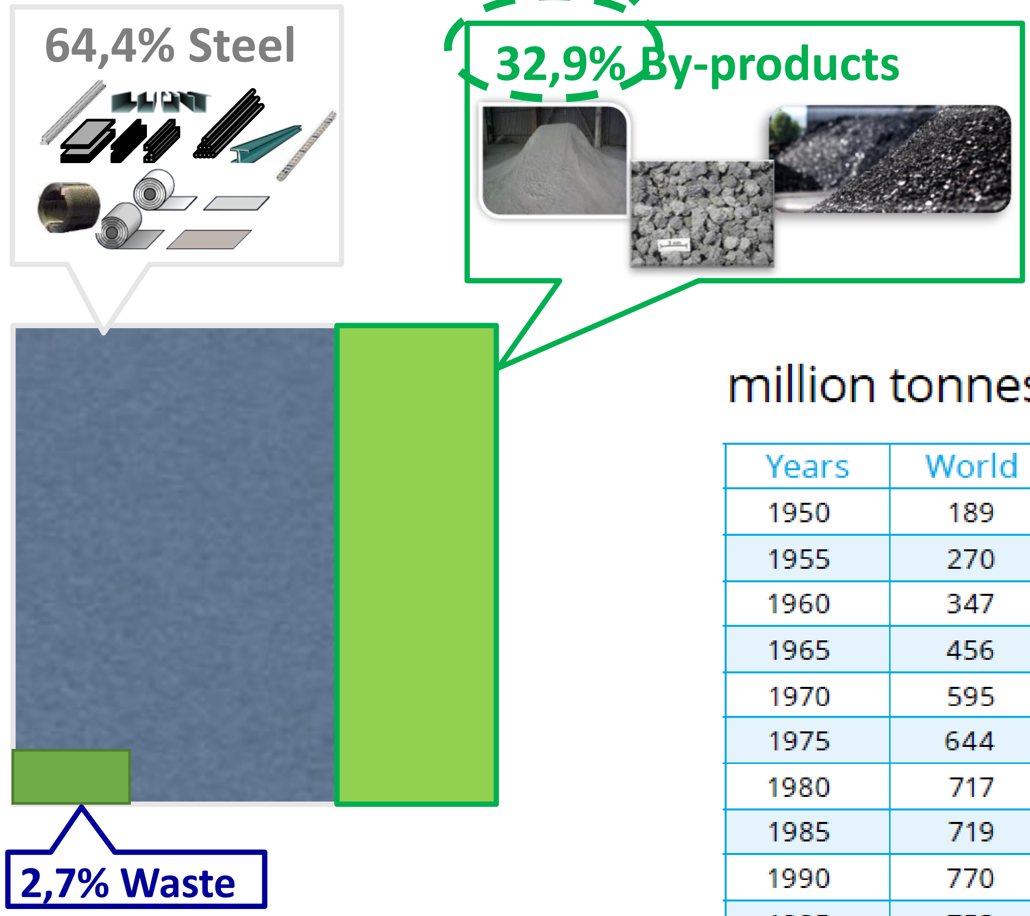
Dissemination of results of the European projects dealing with reuse and recycling of by-products in the Steel sector

Overview of the REUSteel project

Valentina Colla – Scuola Superiore Sant'Anna

Menti: 6141 4728

Goal & Main Objectives



The order is of hundreds of million tonnes per year

million tonnes, crude steel production

Years	World	Years	World	Years	World
1950	189	2000	850	2010	1 433
1955	270	2001	852	2011	1 538
1960	347	2002	905	2012	1 560
1965	456	2003	971	2013	1 650
1970	595	2004	1 063	2014	1 671
1975	644	2005	1 148	2015	1 621
1980	717	2006	1 250	2016	1 629
1985	719	2007	1 348	2017	1 732
1990	770	2008	1 343	2018	1 814
1995	753	2009	1 239	2019	1 869

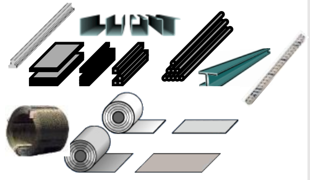
Source woldsteel.org, 2020

Menti: 6141 4728

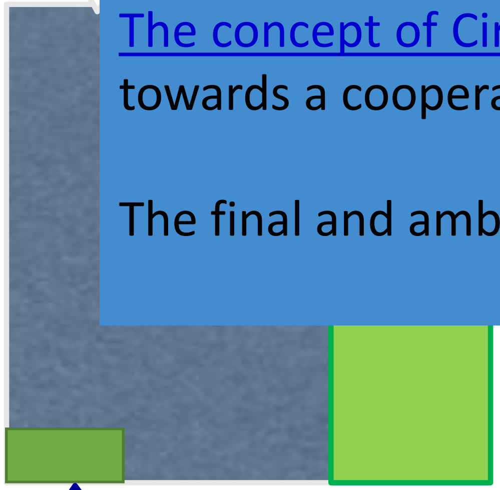
Goal & Main Objectives

Reuse of steel by-products concerns both their internal recycling in steelmaking route and their use for external applications.

64,4% Steel



32,9% By-products



2,7% Waste

The concept of Circular Economy drives several industrial sectors towards a cooperation in reuse and recycling of by products.

The final and ambitious goal is to reach the so called:

«zero waste»

Other by-products

- Pencil pitch
- Fertilisers
- Plastics
- Paints…

This "virtuous process" allows recovery of valuable elements and reuse of by products in different industrial sectors by limiting the need of landfill disposal.

Menti: 6141 4728

Goal & Main Objectives

Promoting the dissemination of the knowledge gained and the technological solutions introduced in relevant European projects on the reuse and recycling of by-products in the steel sector

Identifying present merits and limitations of the various technological solutions, as well as the spread of their implementation in the European steel plants

Evaluating the principal reasons of success and failure in the past projects, taking into account scientific, technical, economic and legislative aspects

Evaluating the impact of the results on the sustainability and the competitiveness of the European steel industry

Identifying the most promising and useful emerging development lines and encouraging the use of best results and innovative solutions, taking into account possible technological barriers

Identifying non-technological barriers to these innovations, research outcomes and other actions which can support the elimination of such barriers

Encouraging synergies with other industrial sectors in projects promoting industrial symbiosis and circular economy

Identifying a **future roadmap** and a sequence of research topics for the next years

The development of the wider improvement of by-products reuse and recycling in the future years

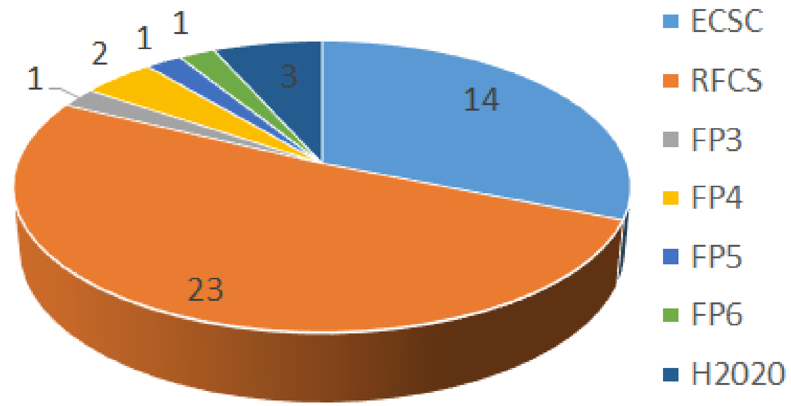
The basis of the pursued analysis

A list of relevant EU funded projects was compiled

Projects were subdivided based on the type of investigated by-product.

35 projects were kept for further dissemination

Exclusions due to inaccessible reports (report not available or confidential) or missing reports (for ongoing projects).



Slag
- BF
- EAF
- BOF
- LF

Sludge
- BF
- EAF
- BOF

Dusts
- BF
- EAF
- BOF

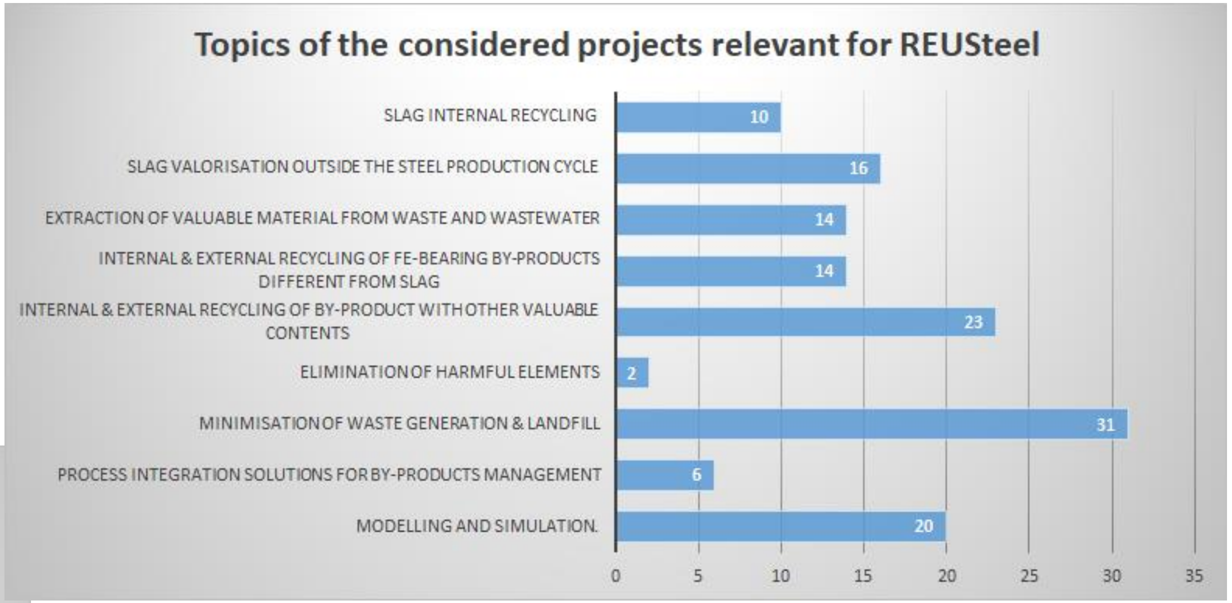
Refractory

Other by-products

Mill scale

Secondary raw materials

The basis of the pursued analysis



Menti: 6141 4728

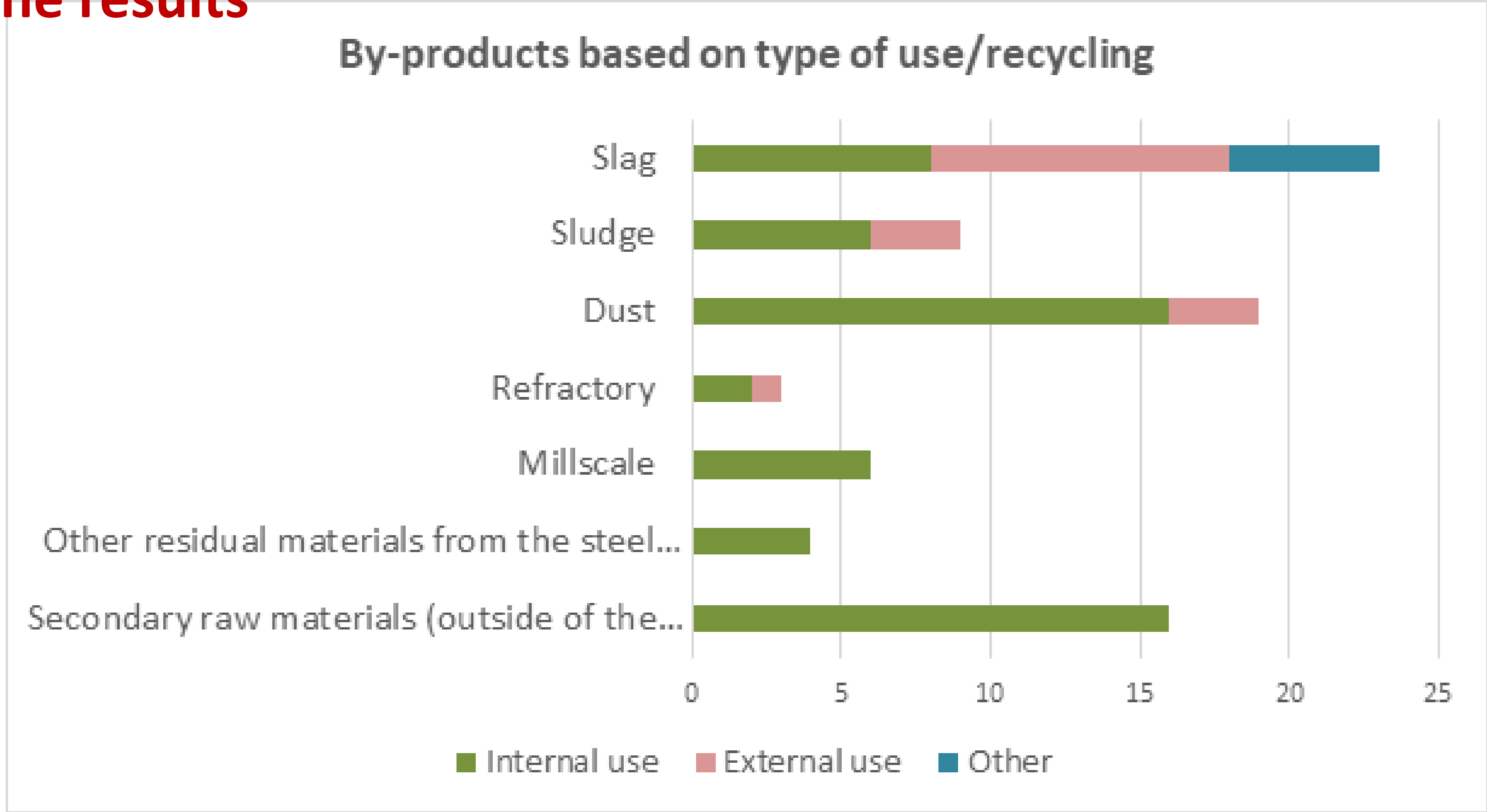
Criteria of the pursued analysis

Projects were analysed and the relevant information was collected:

- Type of by-product (e.g. slag, dust, sludges)
- Project duration
- Use (concerning the reuse of materials internally or externally steel production. Cases of IS are also considered here).
- Objective of the project (e.g. slag used as filter or as fertilizer, high purity Zinc for reuse from steelmaking dusts, etc.)
- Ideas investigated (technologies, processes, new operating practices, etc.)
- Test conducted (developed experimental activity)
- Main results (this includes techniques, processes, etc.)
- Successes (most successful outcomes)
- Failures (e.g. expected results not completely achieved).
- Achieved TRL
- Eventual follow up
- Things that were not clear
- Interesting ideas that could be further investigated
- Economical evaluation
- Environmental evaluation

Menti: 6141 4728

Overview of the results



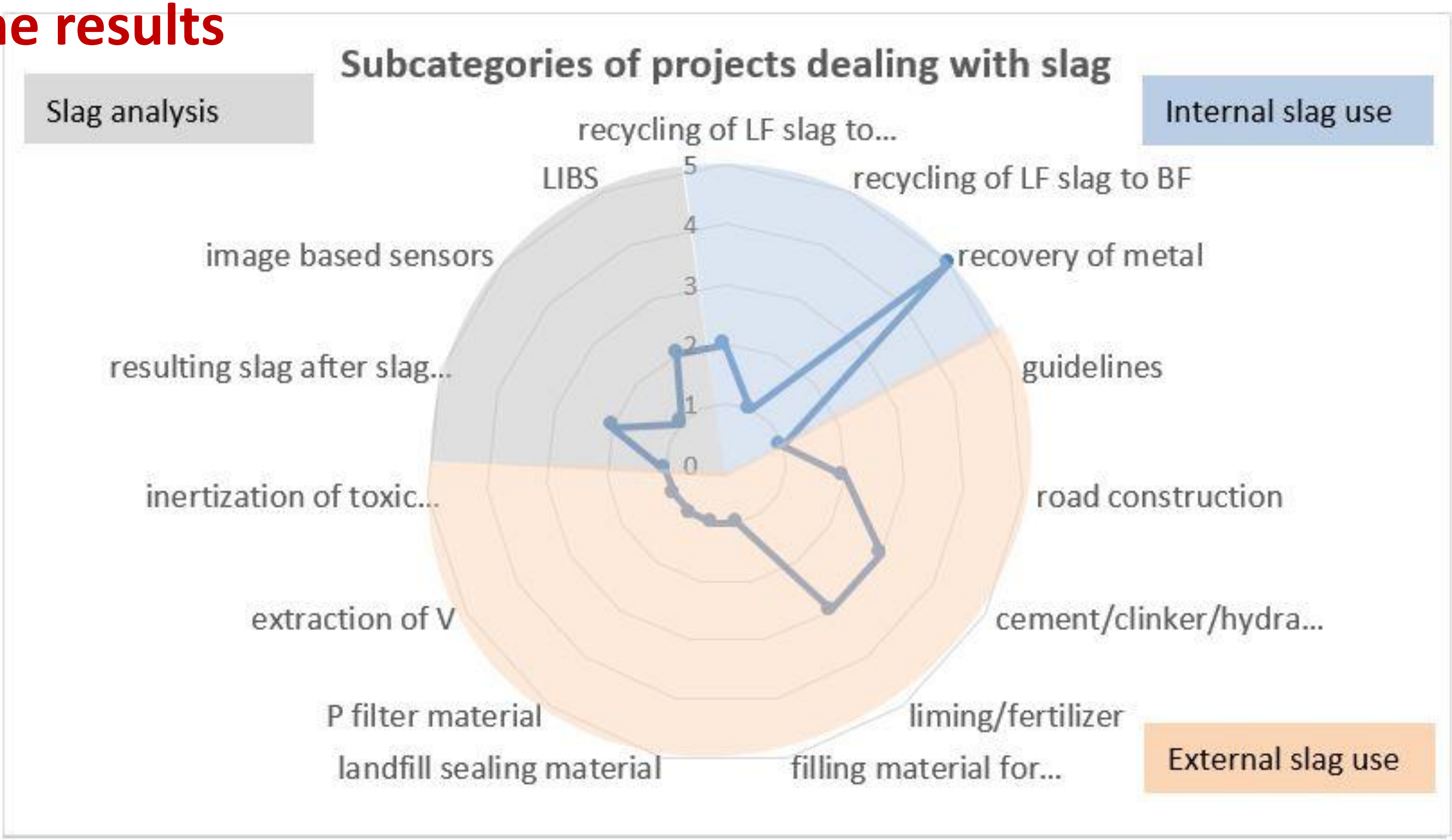
Research Fund for Coal & Steel

5TH ESTAD 2021

Menti: 6141 4728

REUSteel

Overview of the results



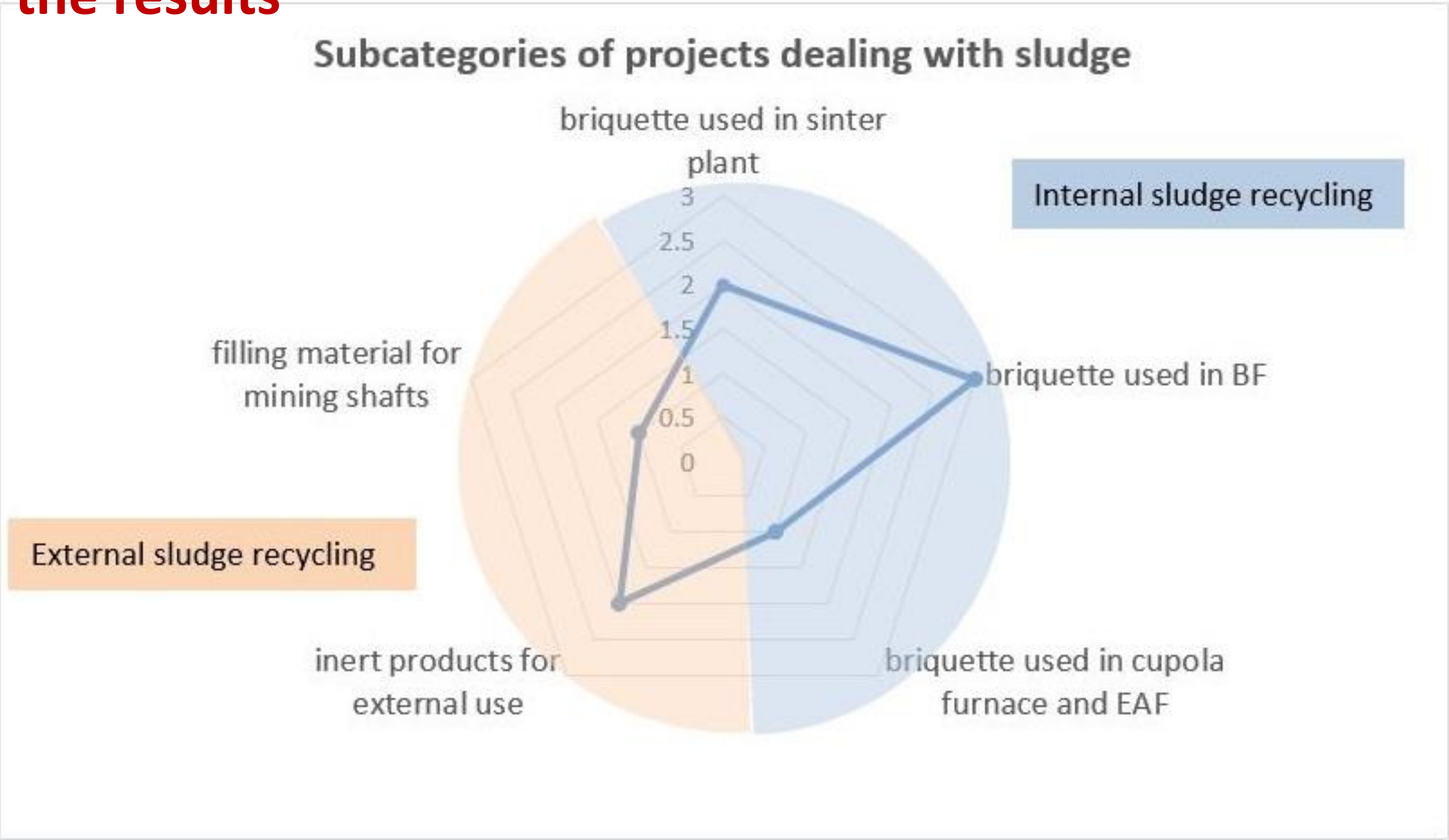
Research Fund for Coal & Steel

5TH ESTAD 2021

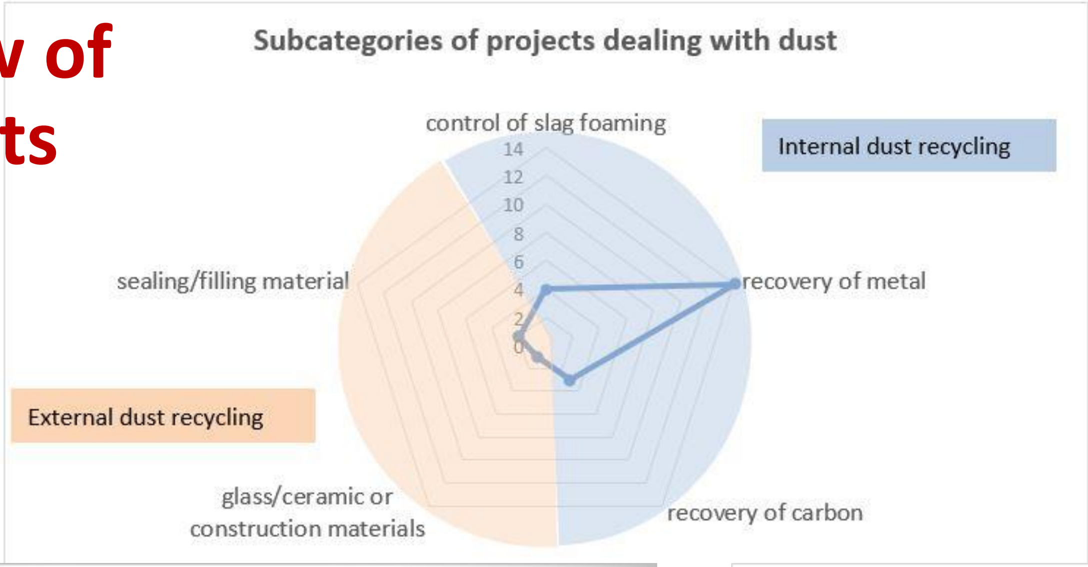
Menti: 6141 4728

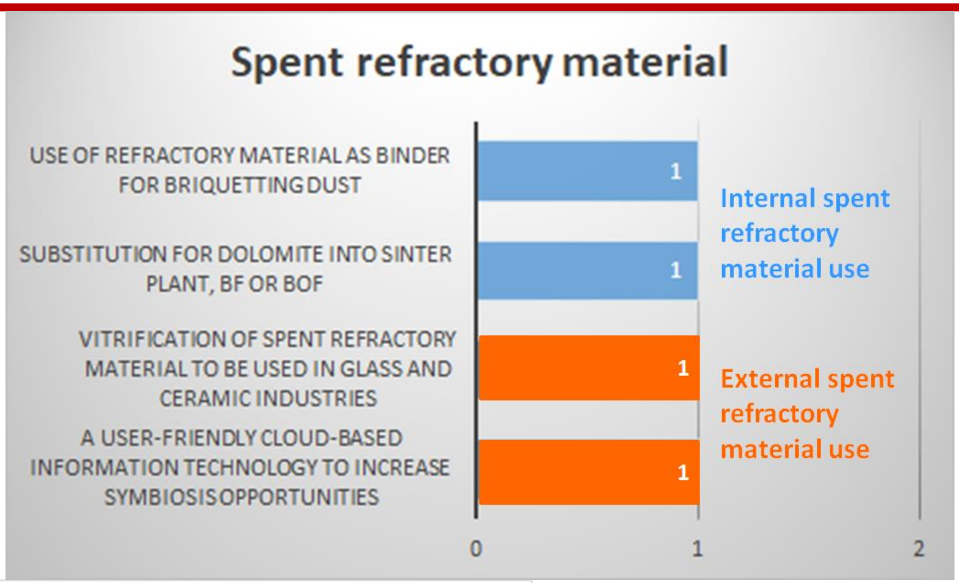
REUSteel

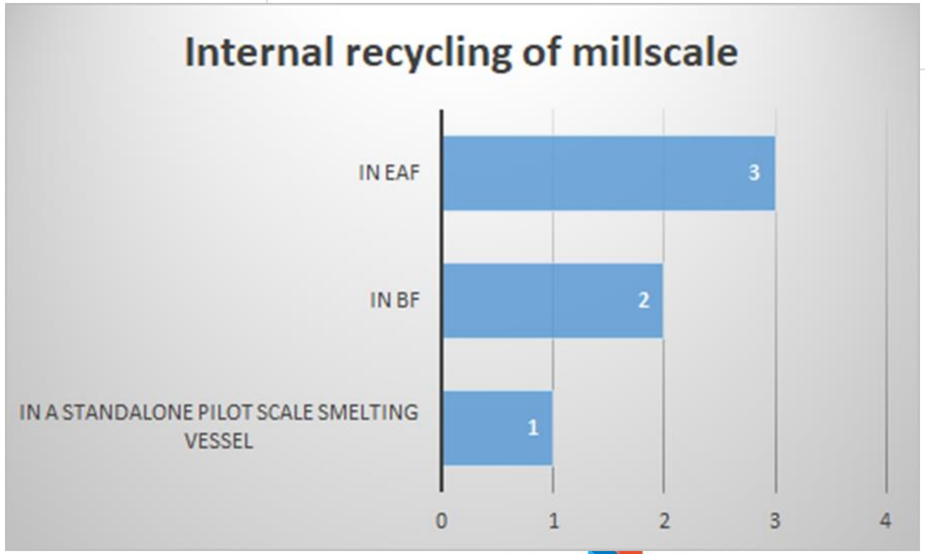
Overview of the results

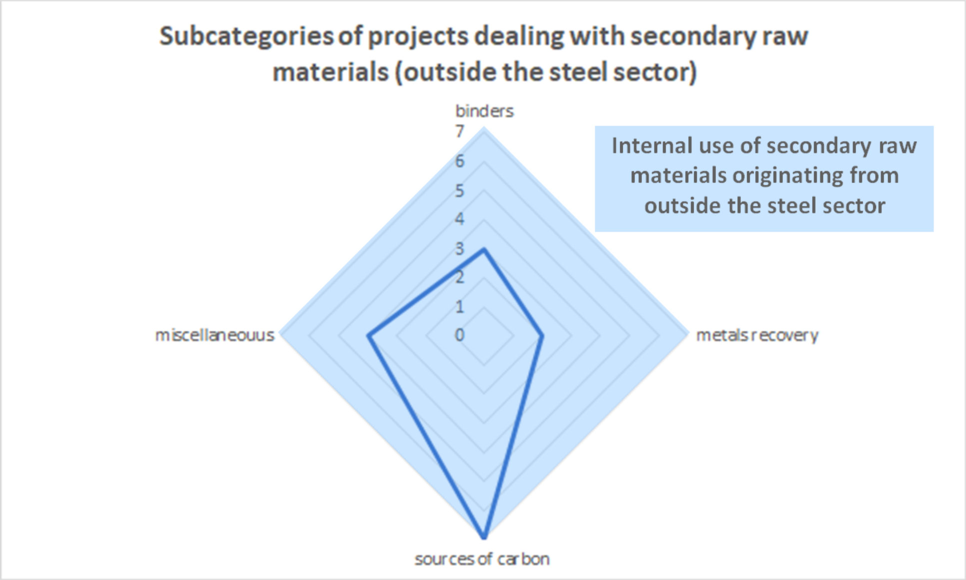


Overview of the results









Menti: 6141 4728

Preparing a Roadmap for by-products reuse and recycling in the steel sector

- Participation to workshops and conferences with presentation on specific topics
- Organization of webinars and seminars
- Organization of workshop

Dissemination of results

- Identification of industrial needs and technological trends
- Identification of technological challenges
- Identification of research needs

Roadmap

Menti: 6141 4728

Preparing a Roadmap for by-products reuse and recycling in the steel sector

Long term industrial needs in steel industry :

- Internal and external utilization of by products
- Zero Waste
- CO_2 mitigation technologies

Technological trends:

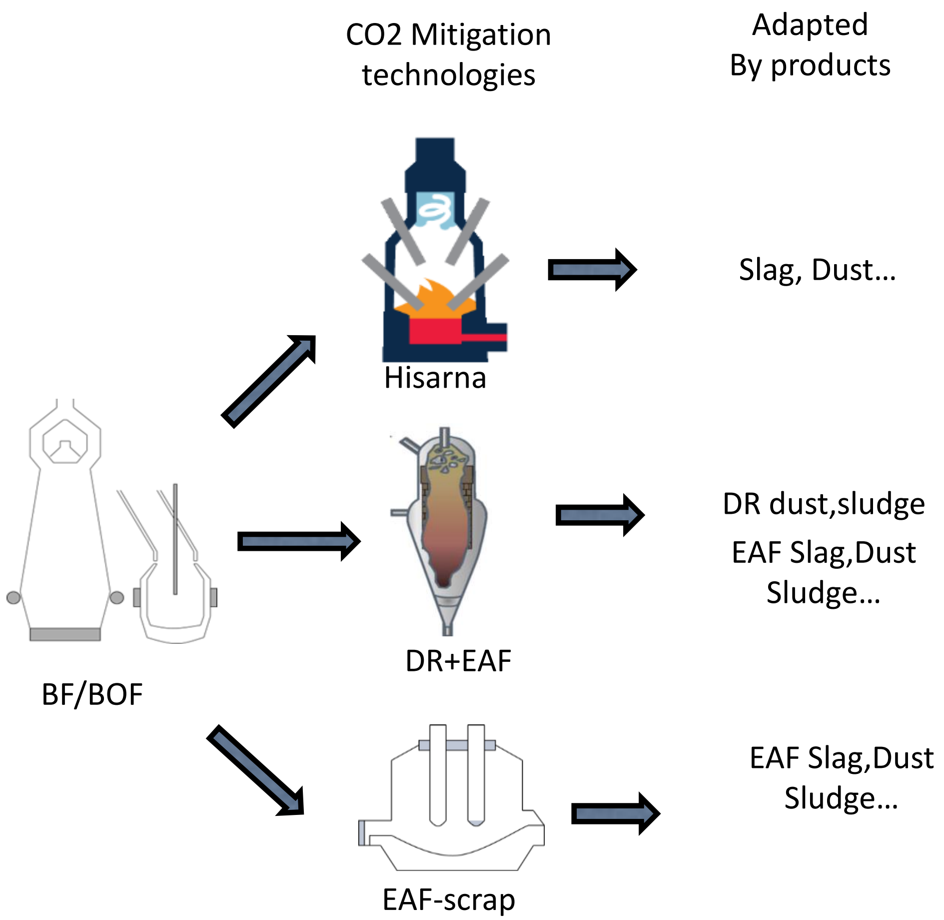
- Carbon Direct Avoidance (CDA)
- Smart Carbon Usage (SCU)

Challenges, Constraints:

- Structural barriers,
- EU and national regulatory framework

Research needs:

by-products reuse and recycling



Research Fund for Coal & Steel

5TH ESTAD 2021

Menti: 6141 4728

REUSteel

What is the future? An example

- Intensify cross-sectoral cooperation for implementing IS
- Improve accurate and fast characterization of by-products on a smaller lot scale
- Provide operators with easy-to-use tools to support IS and CE practices

- New production cycles → different by products features?

Menti: 6141 4728

Our Questionnaire

https://it.surveymonkey.com/r/P6728HB

Menti: 6141 4728


thank you
danke
謝謝
ngiyabonga
شكراً جزيلاً
teşekkür ederim
gracias
спасибо
рахмат
Баярлалаа
merci
obrigado
dziękuję
bedankt
go raibh maith agat
mochchakkeram
sukriya
kop khun krap
terima kasih
grazie
arigatô
dakujem
takk
мерси
감사합니다
ありがとう
ευχαριστώ
tapadh leat
dank je
hvala
mauruuru
köszönöm
mersi
barka
welalin
tack
spas
kia ora
faafetai lava
vinaka
спасибі
blagodaram
misaotra
matondo
paldies
grazzi
mahalo
хвала
asante
manana
obrigada
tenki
murakoze
djiere dieuf
tau
дякую
mamnun
chnorakaloutioun
gratias ago
gràcies
sulpáy
taiku
trugarez
kiitos
dankie
dhanyavad
nanni
nandri
bayarlalaa
gràcie
enkosi
sobodi
dekuji
mesi
didi madloba
sagolun
najis tuke
kam sah hamnida
rahmat
tanemirt
rahmet
diolch
dhanyavadagalu
shukriya
merce
xiexie
akun dankon
aciu

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

Research of use of slag from the steel industry
www.reusteel.eu

Agnieszka, Morillon - FEhS

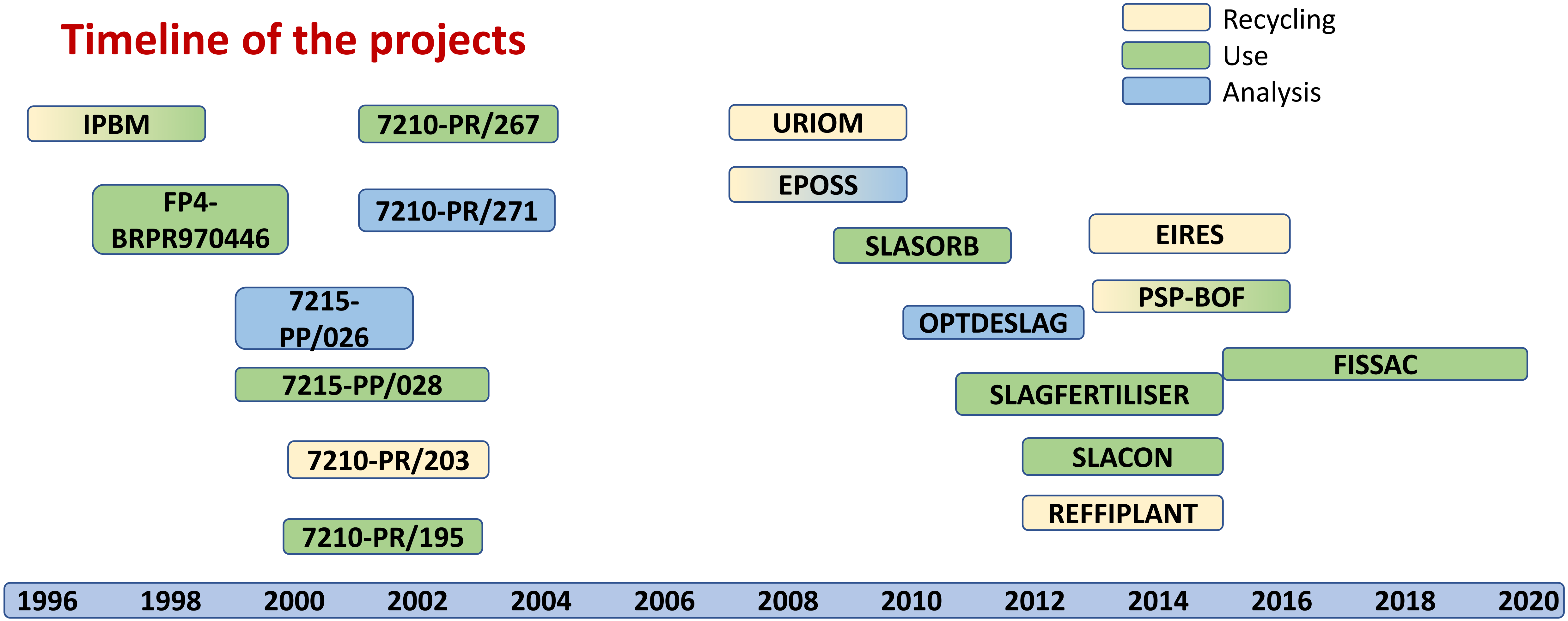
Research Fund for Coal & Steel

5th ESTAD 31st Aug 2021
Menti: 6141 4728

Projects dealing with slag

- 24 finished projects were taken into consideration

Timeline of the projects



Internal slag use

- 8 projects dealt with internal slag use/recycling

2 projects:
Recycling of LF slag to replace lime in EAF

1 project:
Recycling of BOF slag and LF slag to BF

5 projects:
Recovery of metal

Recycling of LF slag to replace lime in EAF

7210-PR/203

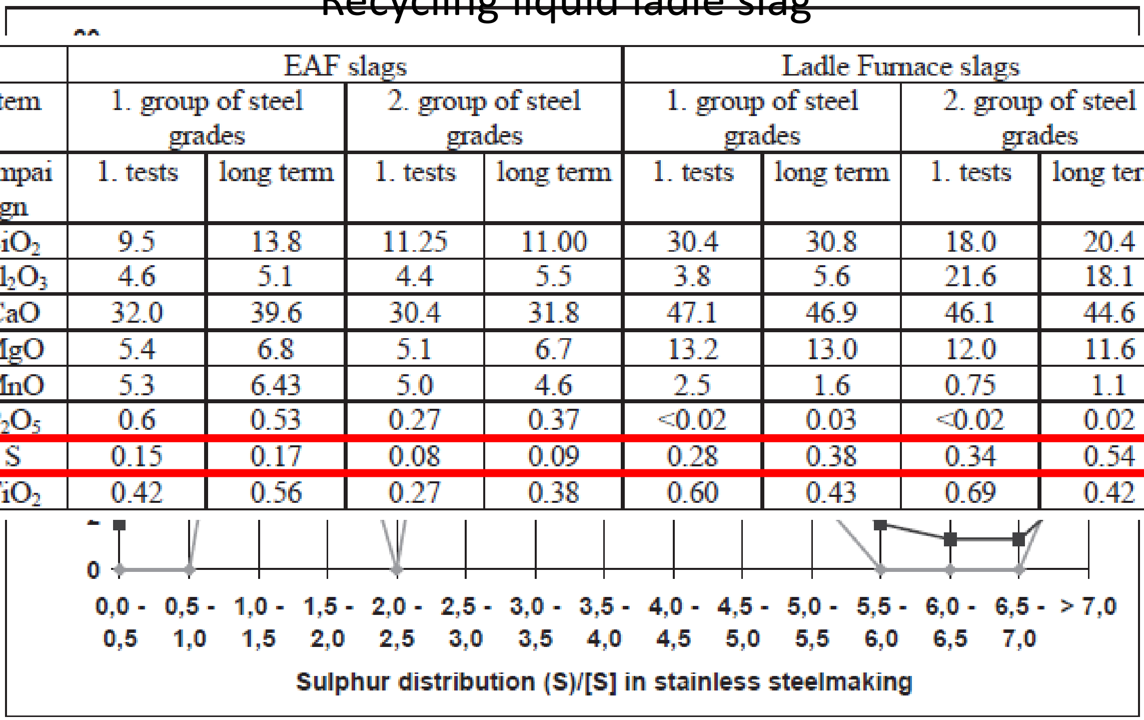
Liquid LF slag was recycled in an EAF (pilot scale)

- LF was able to replace lime, without increase in sulphur or negatively impacting the resulting composition of EAF slag
- At one steelwork, 80% of LF was recycled and the practice was transferred to daily operation
- Depending on the infrastructure of the steelwork this process can have limitations, e.g. not possible to transfer directly liquid slag or no time to calculate the amount needed

Optimal synthetic slag former was developed with LF slag and spent dolomite

- Development of optimal formula, including the binder, for palatalization
- The replacement of lime with optimized LF slag was successful and did not increase the energy
- This requires dry processing and handling

Frequency curve of sulphur distribution (S)/[S] in stainless steelmaking with and without recycling of ladle slag



Item	EAF slags				Ladle Furnace slags			
	1. group of steel grades		2. group of steel grades		1. group of steel grades		2. group of steel grades	
campaign	1. tests	long term	1. tests	long term	1. tests	long term	1. tests	long term
SiO_2	9.5	13.8	11.25	11.00	30.4	30.8	18.0	20.4
Al_2O_3	4.6	5.1	4.4	5.5	3.8	5.6	21.6	18.1
CaO	32.0	39.6	30.4	31.8	47.1	46.9	46.1	44.6
MgO	5.4	6.8	5.1	6.7	13.2	13.0	12.0	11.6
MnO	5.3	6.43	5.0	4.6	2.5	1.6	0.75	1.1
P_2O_5	0.6	0.53	0.27	0.37	<0.02	0.03	<0.02	0.02
S	0.15	0.17	0.08	0.09	0.28	0.38	0.34	0.54
TiO_2	0.42	0.56	0.27	0.38	0.60	0.43	0.69	0.42

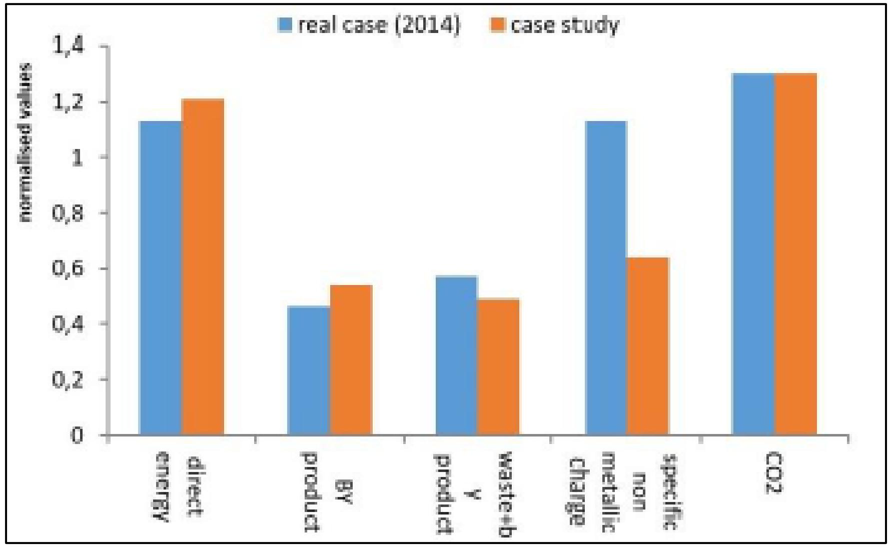
Recycling of LF slag to replace lime in EAF

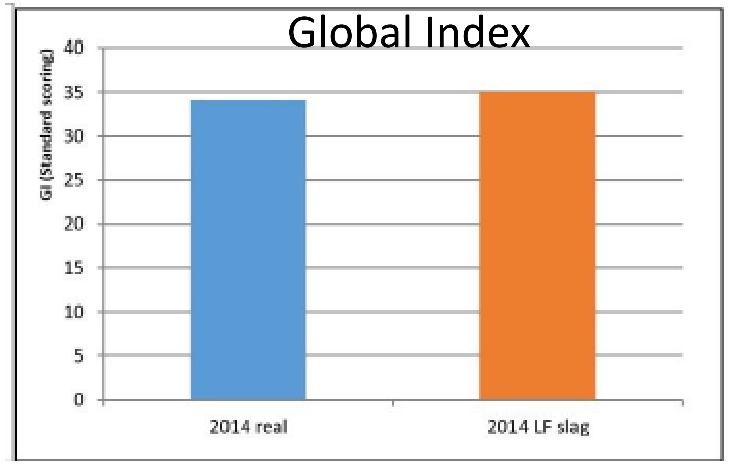
EIRES

Modeling of lime and dolimite replacement with LF slag in EAF (simulation, no physical tests)

- Different simulation environments (e.g. Aspen Plus and Matlab) needed to be used in order to comply with specific needs of all the partners, e.g. not possible to use a unique simulation system to take into account specific demands of the industrial partners
- Replacement of lime and dolime with LF slag is possible
- The energy increase is 2.5%

Key performance indicators

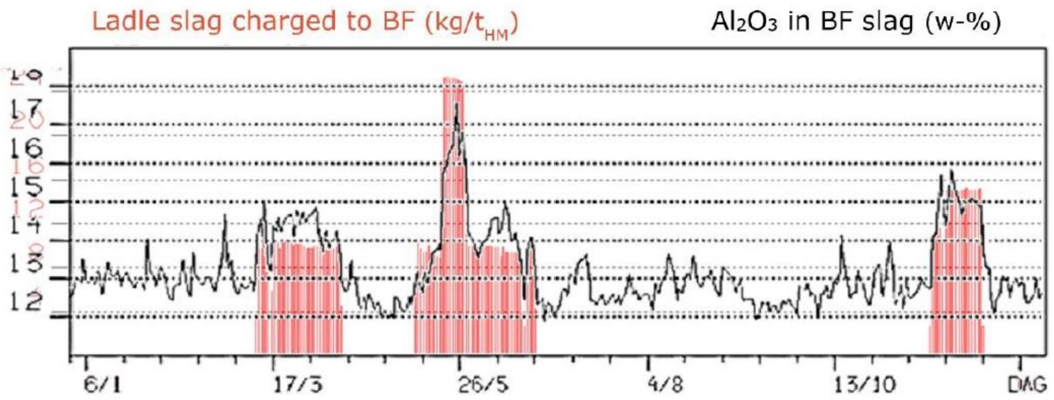




Recycling of BOF slag in sinter plant and LF slag in BF

REFFIPLANT

- Summery of by-products and waste management in the steel works
- On-site tests to use LF slag as slag former in BF to partially replace limestone
  - LF slag was able to replace partial amounts of limestone
  - The only effect seen was an increase in Al_2O_3 content in the BF slag

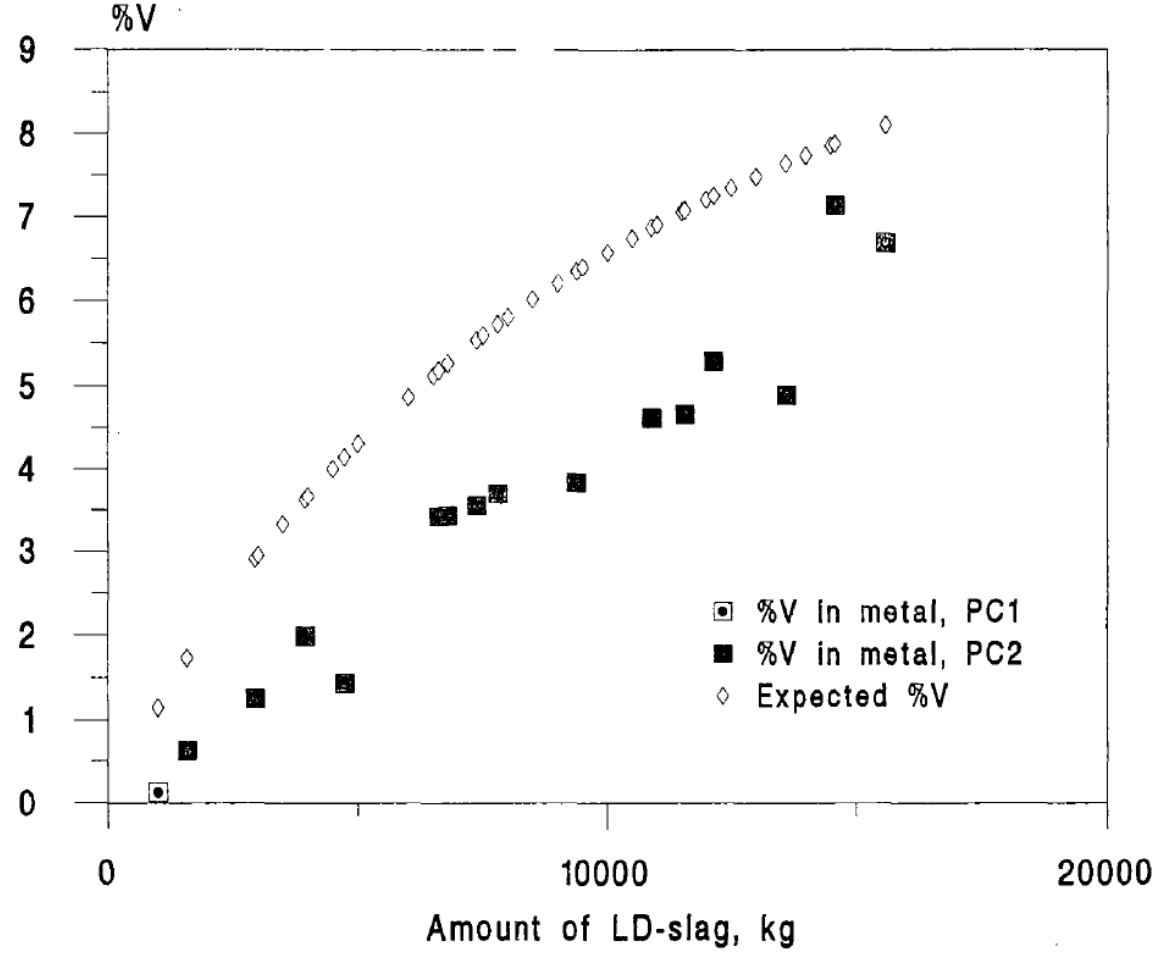


Recovery of metal

IPBM

DC furnace pilot plant to recycle BOF slag and EAF slag to recover metal (V) and to create valuable products from the remaining slag

- Stand-alone alternative gives possibilities to optimize slag and metal products
- The process still needed refining, but showed potential
- When the BOF-slag contained about 2 % of P_2O_5 the resulting metal was high in P and direct recycling of the metal into the steel production line would need a dephosphorization step.
- High operating costs (electricity) creates uncertainty and is dependent on V costs.



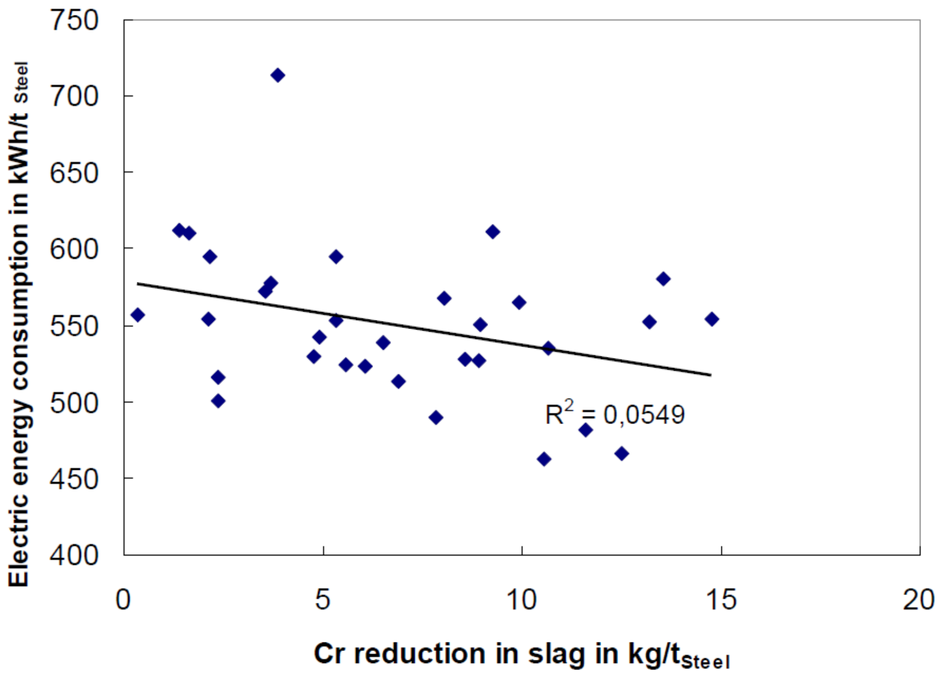
V-content in hot metal vs amount of treated BOF-slag, PC=pilot campaign

Recovery of metal

EPOSS

Increase energy efficiency in EAF and productivity by development of innovative slag conditioning techniques for slag foaming which result in less Cr going to slag

- Injection of CaC_2, FeSi, carbon/oxygen or Al granules
- Electricity was reduced by 13 % and Cr decreased in the slag by 22 %.



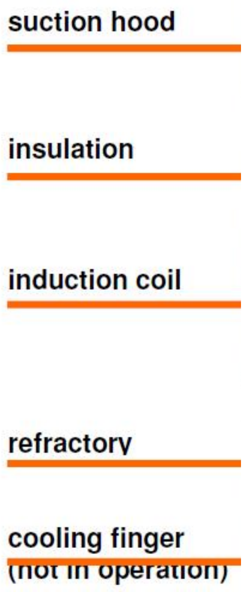
Electric energy consumption in dependency of the chromium reduction in the slag (in kg/t of liquid steel)

Recovery of metal

URIOM

Use of inductively heated coke bed reactor (ICBR) coupled with Flash reactor prototype to recover metal from EAF slag (Fe and Cr)

- The process almost completely removed metal from the slag
- The remaining 1.5 % of Cr_2O_3 and 1.2 % of FeO just amount to 3.7 and 0.5 % of the amount contained in the EAF slag



Recovery rates of the different metals and compounds into the different output streams (trial 8)

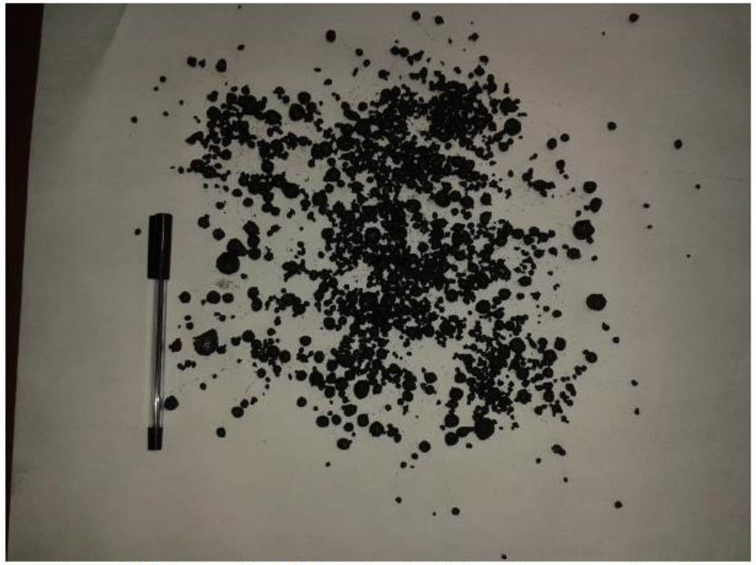
	carry over	slag		Fe alloy	
	[%]		[%]		[%]
ZnO	15,7				-
Pb	94,4				-
Cr_2O_3	3,2	Cr_2O_3	3,7	Cr	91,9
FeO	4,4	FeO	0,5	Fe	93,4
F	83,3				
Al_2O_3	-	Al_2O_3	95,4		
CaO	6,2	CaO	88,6		
Co	-			Co	95,5
C	-			C	287,7
Cu	-			Cu	94,1
MgO	2,2	MgO	89,9		
MnO	5,5	MnO	0,7	Mn	89,9
Mo	70,8			Mo	29,6
Ni	-			Ni	95,5
SiO_2	0,7	SiO_2	94,2	Si	2,5
V	-			V	93,3
W	4,8			W	92,7

INSTITUTE OF COMMUNICATION, INFORMATION AND PERCEPTION TECHNOLOGIES Scuola Superiore Sant'Anna | BFI Excellence in Applied Research | VDEh-Betriebsforschungsinstitut GmbH | RINA | INSTITUT FÜR BAUSTOFF FORSCHUNG FEhS | SWERIM | ESTEP

Recovery of metal

REFFIPLANT

- Integrated process optimization in the steelworks: case studies using holistic models for material treatment units
    - reMIND simulation was used to achieve optimal formula for BOF slag pellets which can be used as input into the sinter plant
    - The pellet formula was used to optimize palatalization which showed potential benefits related to reduction of waste amount
    - As the Italian law does not allow manufacturing industry to treat its own wastes without a special permission this solution was not tested



Low quality pellets produced with the mixture compositon n°1.

: High quality pellets produced following the "winning formula".

Recovery of metal

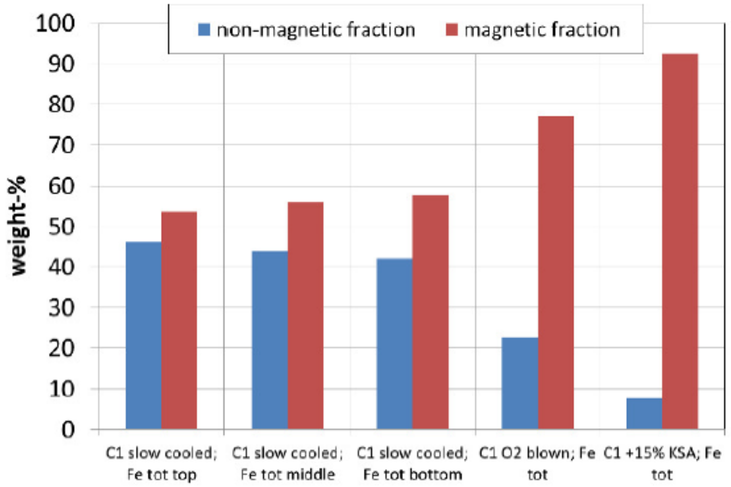
PSP-BOF

Separation of BOF slag into Fe-rich and P-rich fraction

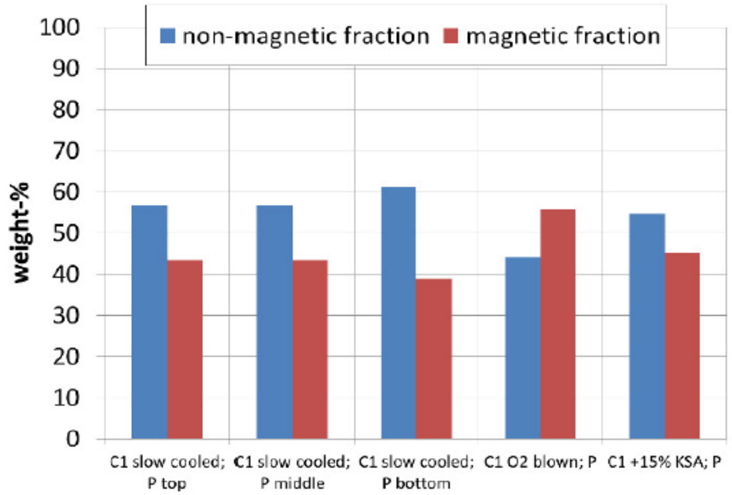
- Pretreatment of slag to facilitate separation of the slag fractions (grinding and magnetic separation)
- Treatment of liquid slag with P- and Fe-containing residues
- Different cooling rates were investigated in laboratory and industrial scale
- Fe-rich fraction was investigated in laboratory and pilot sinter plant

Laboratory tests

Yield of Fe in the magnetic and non-magnetic fractions after wet magnetic separation



Yield of P in the magnetic and non-magnetic fractions after wet magnetic separation



External slag use

- 15 projects dealt with external slag use/recycling

3 projects:
Use of slag in cement/clinker/ hydraulic binders

4 projects:
Use of slag as liming/fertilizer material

1 project:
Guidelines how to increase EAF slag use by solving environmental issues

2 projects:
Use of slag in road construction

1 project:
Use of slag as P filter material

1 project:
Inertization of toxic wastes

1 project:
Use of slag as filling materials for mining shafts

1 project:
Use of slag as landfill sealing material

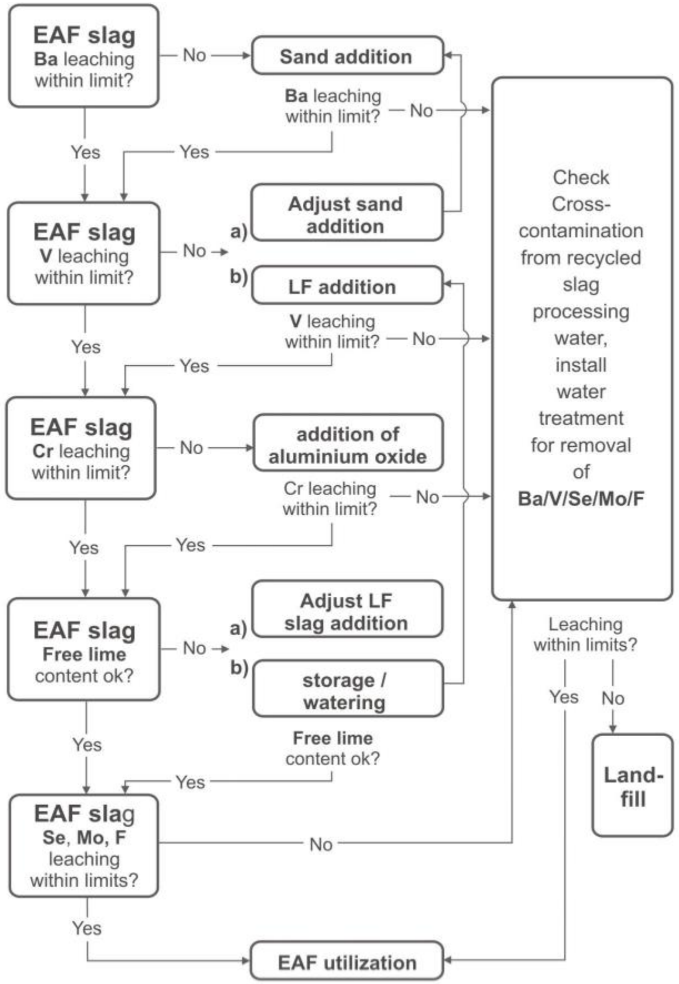
1 project:
Use of slag Fe-poor fraction as V source

Guidelines how to increase EAF slag use by solving environmental issues

SLACON

Solutions to specific environmental problems at different steelworks though laboratory and industrial trials

- Immobilization of leachable substances in EAF slag
  - As the quality of slag depends on different aspects, including which country it is produces (as different limiting values are implemented) in the project different ways to improve EAF slag were investigated.
  - Parameters investigated include Ba, V, Cr, Mo and free lime
- Elimination of leachable substances from slag washing/cooling water in a closed loop system
  - Design and tests of a filter that removes at the same time F, Mo and V from water



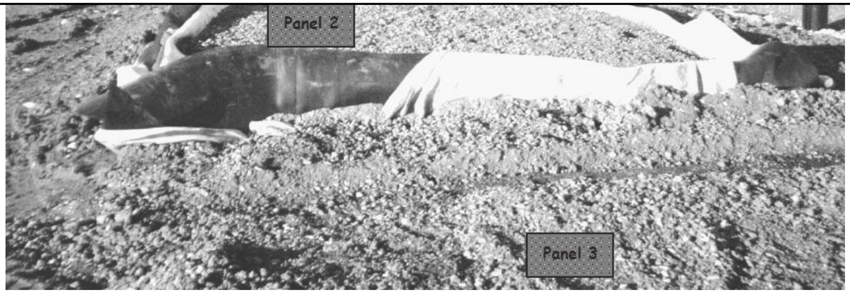
Use of slag in road construction

7210-PR/195

E.g. of conclusions

- In term of element, Ca (considering a recommended value which is not a limit value) and F are the most disadvantageous elements for the BOF slag
- To a minor extent , Cr for EAF slag, S for BF slag and Ba for BOF slag would be also disadvantageous elements
- In term of slag, BOF slag would be the most disadvantageous. The GBF slag seem to be the one which would generate the least impact on groundwater. EAF and BF slags would be in an intermediate situation.

were made



Use of slag in road construction

FP4-BRPR970446

Production of BOF and EAF slag with stable volume and good environmental behavior (reduced Cr content) was investigated to be used in road construction

- Pilot scale reduction tests in DC-furnace of slag with anthracite coal additions
- Addition of quartz sand, glass cullet and BOF-converter dust to liquid slag aiming to improve volume stability
- Different uses were investigated of treated slag:
    - road construction
    - armour stones in hydraulic engineering
    - paving stones

- Treatment of BOF-slag from carbon steelmaking with quartz sand and oxygen produces a highly valuable slag.
- Concrete paving-stones made with treated BOF-slag show the same development and final compressive strength as those made with natural aggregates. The same is valid with respect to the resistance against freeze-thaw attack.
- The exposure to traffic and environmental conditions reveals no differences between paving stones made with natural aggregates and those made with treated BOF-slag. Especially the polishing resistance against abrasion by traffic is at least the same

Use of slag in cement/clinker/hydraulic binders

IPBM

After extraction of metal from slag in a pilot smelting vessel (outside the main steel production), the remining slag was assessed towards use as clinker or hydraulic binders

Due to high content of Fe and Mn a clinker formula with only 10 % of slag was made that resulted in clinker cement material:

- 70.6% limestone
- 19.4% clay rock and
- 10% IPBM-slag

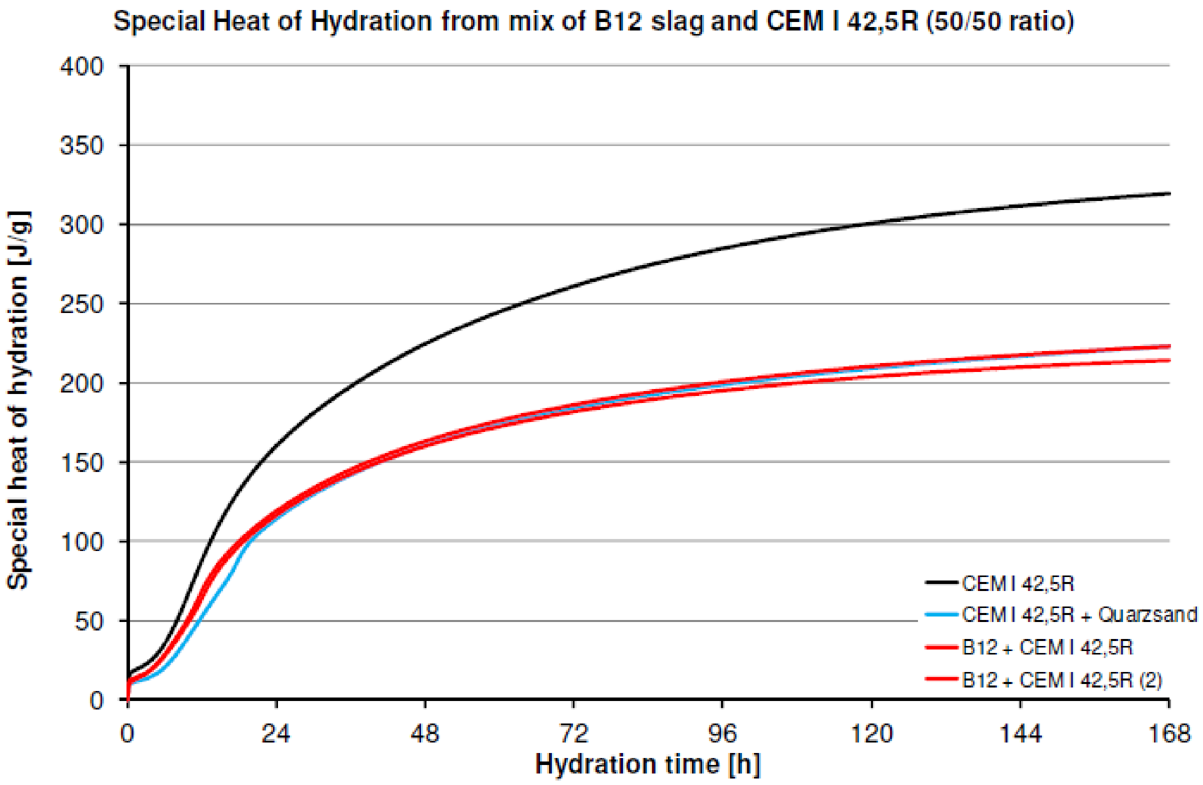
The initial resulting slag had only about 50 % glassy fraction.
Special water granulation device was used to increase the cooling rate which resulted in slag glassy fraction of > 95 %

Use of slag in cement/clinker/hydraulic binders

PSP-BOF

After separation of Fe-poor from Fe-rich fractions the Fe-poor fraction was assessed for applications towards the cement industry

- Due to wet magnetic separation that the slag was subjected to before cement tests, the heat of formation and reactivity are like that of quartz (which has none).
- As a substitute for clinker minerals, it will not contribute to development of compressive strength



Use of slag in cement/clinker/hydraulic binders

FISSAC

To establish a valorization scheme for EAF and LF slag similar to BF slag by incorporating it into cement industry

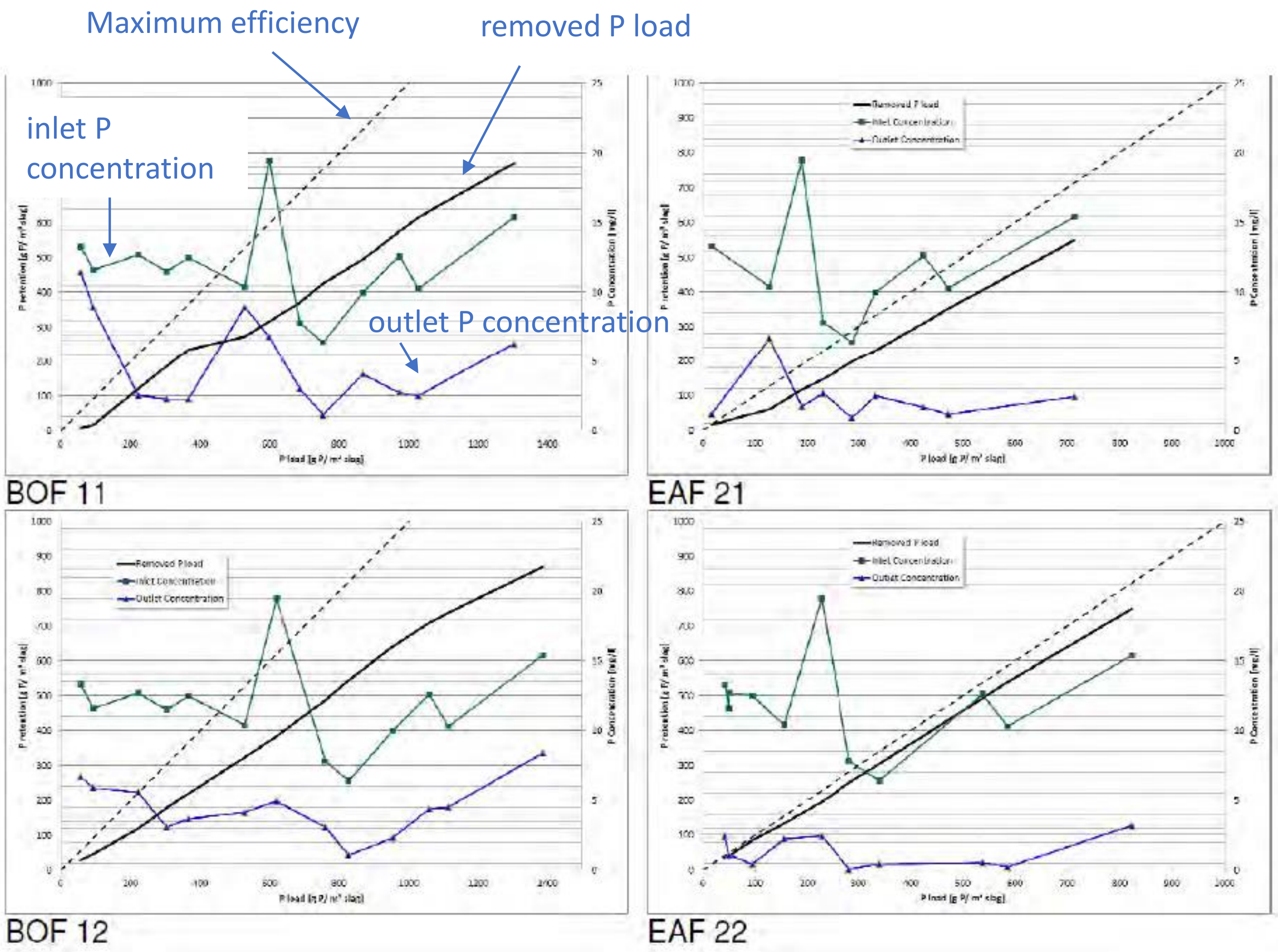
- Development of methodology and a software platform to implement the innovative industrial symbiosis model
- Case studies of using EAF slag or LF slag in different applications e.g. green concrete slag, pre-industrial production of CSA cement, industrial production of blended cement…

Use of slag as P filter material

SLASORB

Investigation of BOF and EAF slag to be used as a filter material to remove P from wastewater treatment plant in small communities

- Laboratory tests to investigate slag properties as filter material to remove P
- Two demonstration scale slag filters were installed at municipal wastewater treatment plants and tested



Removed Phosphorus load in g P per m³ slag (bed volume) compared to maximum efficiency (dotted line) and to in- and outlet TP concentrations

Use of slag as liming/fertilizer material

7210-PR/267

Investigation of slag as liming/fertilizing material

- Investigation of influence of different input materials into the metallurgical cycle of BF-BOF route on Cr and V content in slag
- Investigation of BF, BOF, LF and basic slag as liming/fertilizing and their effects on harvest yield of crops and hay.
- Cr and V content in soil after liming/fertilizing with slag

			Liming Material	Unlimed	Ladle Slag	Ladle Slag	Carbonate Limestone	
			kg CaO/ha	0	500	1000	1000	
	Year	Crop		Cr and V Contents (mg/kg D.M.)				$lsd_{5\%}$
Cr	2002	w.wheat	shoot EC 30	0,32	0,29	0,44	0,34	0,14
	2002	w.wheat	grain	1,24	0,63	0,52	1,08	0,24
	2002	w.wheat	straw	0,68	0,45	0,39	0,58	0,26
Cr	2003	w.barley	shoot EC 30	0,43	0,31	0,24	0,61	0,12
	2003	w.barley	grain	0,72	0,78	0,86	0,76	0,15
	2003	w.barley	straw	0,29	0,27	0,20	0,21	0,05
Cr	2004	w.rape	leaf	0,38	0,39	0,36	0,34	0,03
	2004	w.rape	grain	0,19	0,20	0,17	0,19	0,04
V	2002	w.wheat	shoot EC 30	0,23	0,20	0,18	0,19	0,02
	2002	w.wheat	grain	0,16	0,13	0,12	0,13	0,03
	2002	w.wheat	straw	0,41	0,28	0,31	0,43	0,13
V	2003	w.barley	shoot EC 30	0,19	0,21	0,14	0,14	0,07
	2003	w.barley	grain	0,03	0,03	0,03	0,03	0,01
	2003	w.barley	straw	0,09	0,09	0,10	0,11	0,01
V	2004	w.rape	leaf	0,22	0,17	0,16	0,16	0,03
	2004	w.rape	grain	0,02	0,02	0,02	0,02	0,01

Chromium and vanadium contents of wheat, barley and rape plants in the field experiment Kasseburg 2002-2004

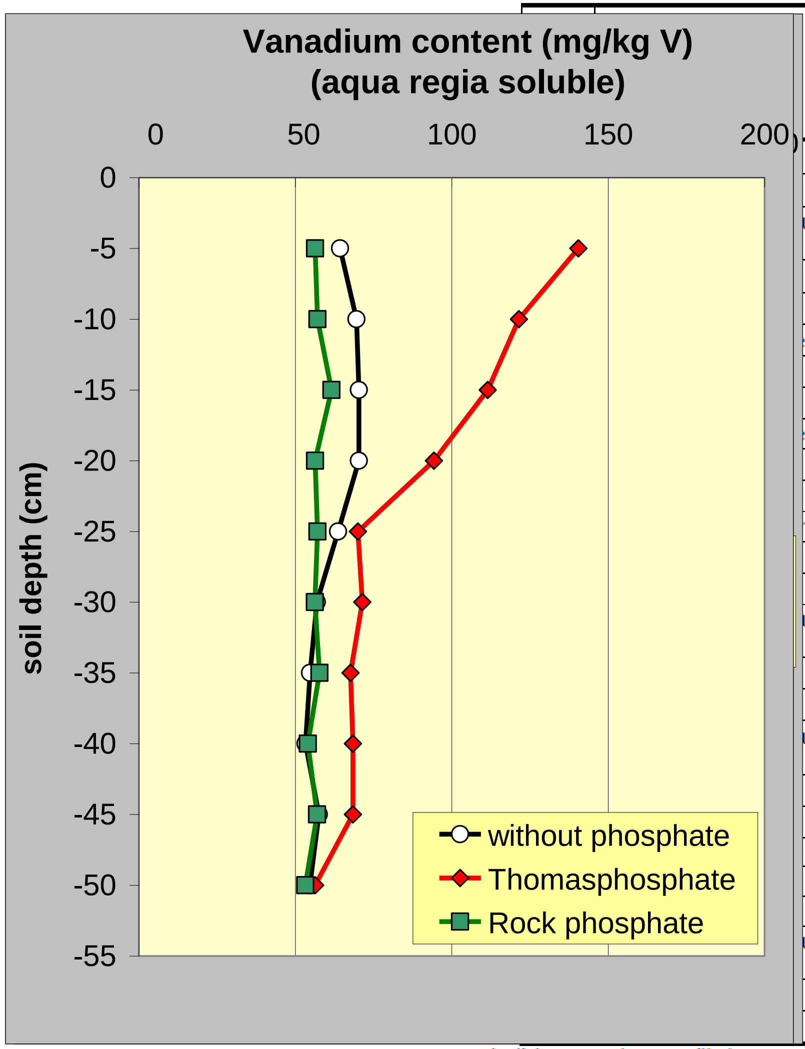
Use of slag as liming/ferti

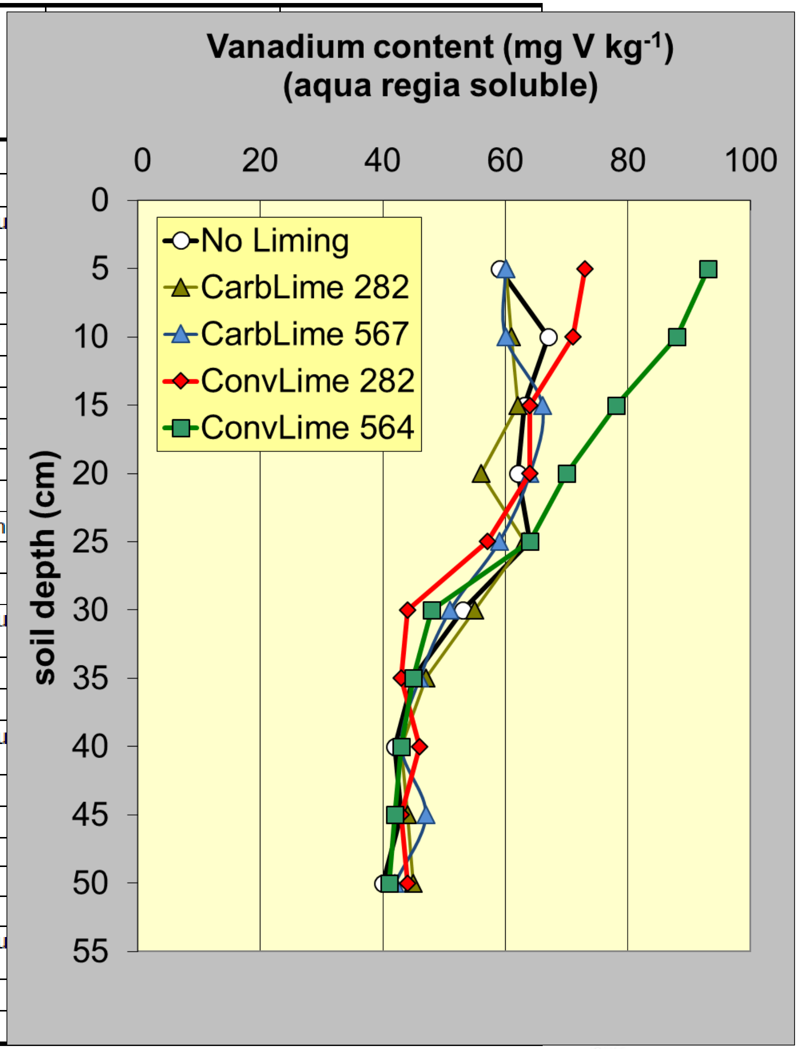
SLAGFERTILISER

Investigation of slag as liming/fertilizing material in long-term and short-term field trials

- Comparison of the effects of slag as liming/fertilizing material to products available on the market in short-term field trials in different climates (Finland, Germany, Austria and Italy)
- Evaluation of long-term slag utilization as liming/fertilizing material
- Evaluation of Cr and V in soil after liming/fertilizing with slag

Cr and V composition in soil before and after 3 years of fertilisation





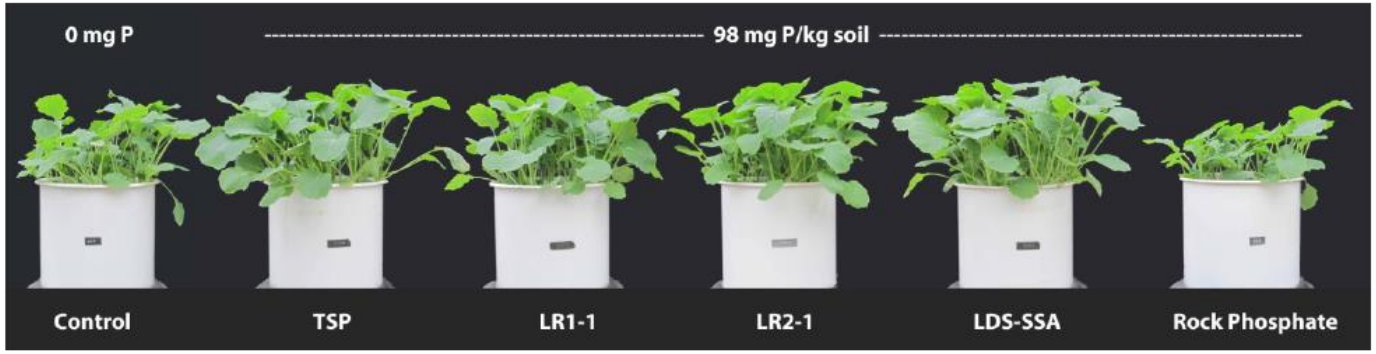
d=disintegrated; m 0 milled

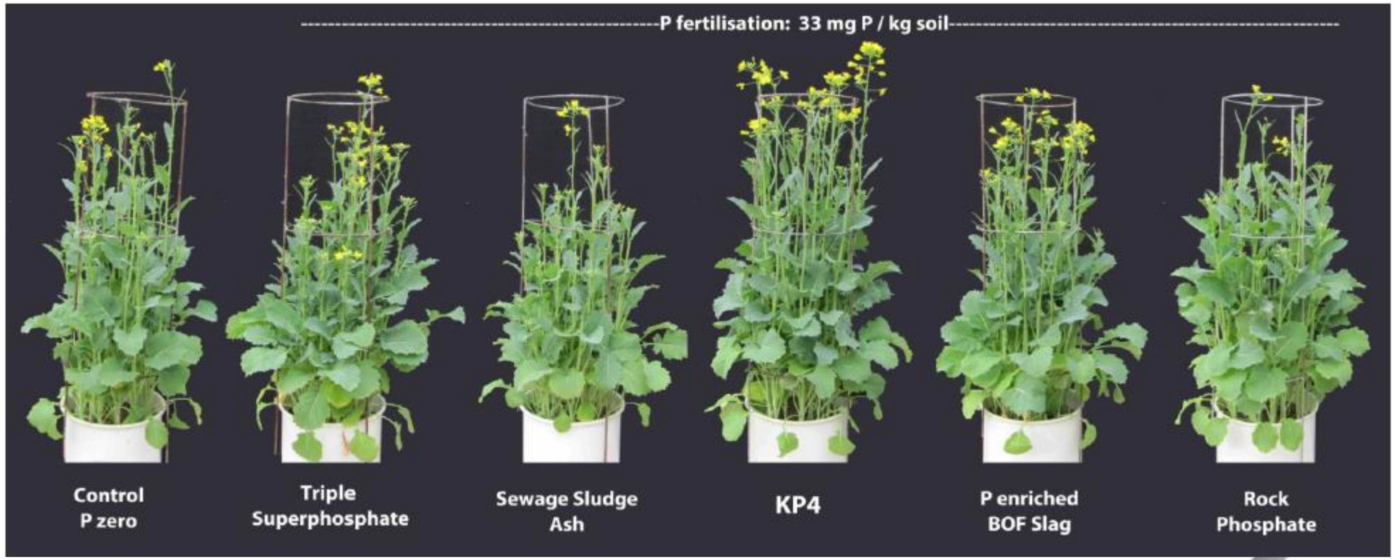
Use of slag as liming/fertilizer material

PSP-BOF

Remelting of sewage ash (high in P, but not bioavailable) with slag to create slag with high P content that is bioavailable

- Laboratory tests to assess use of slag after treatment as P fertilizer

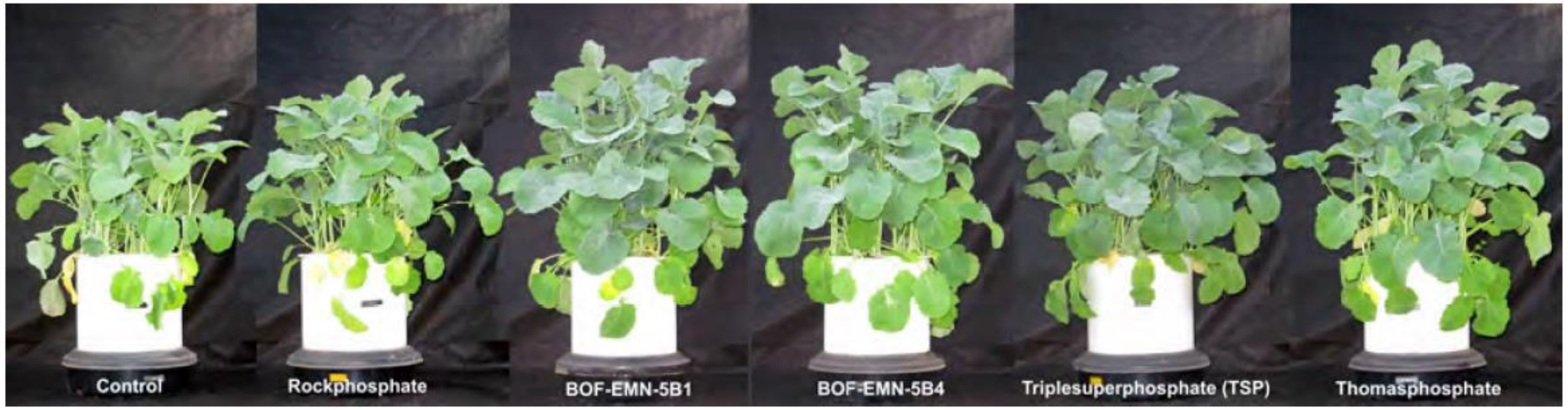




Use of slag as liming/fertilizer material

SLASORB

Pot trials to assess slag as a P fertilizer after slag was used as a filter material to remove P from municipal wastewater treatment plant



Use of slag as filling materials for mining shafts

FP4-BRPR970446

Refilling mixtures for mining shafts were investigated with BF slag.

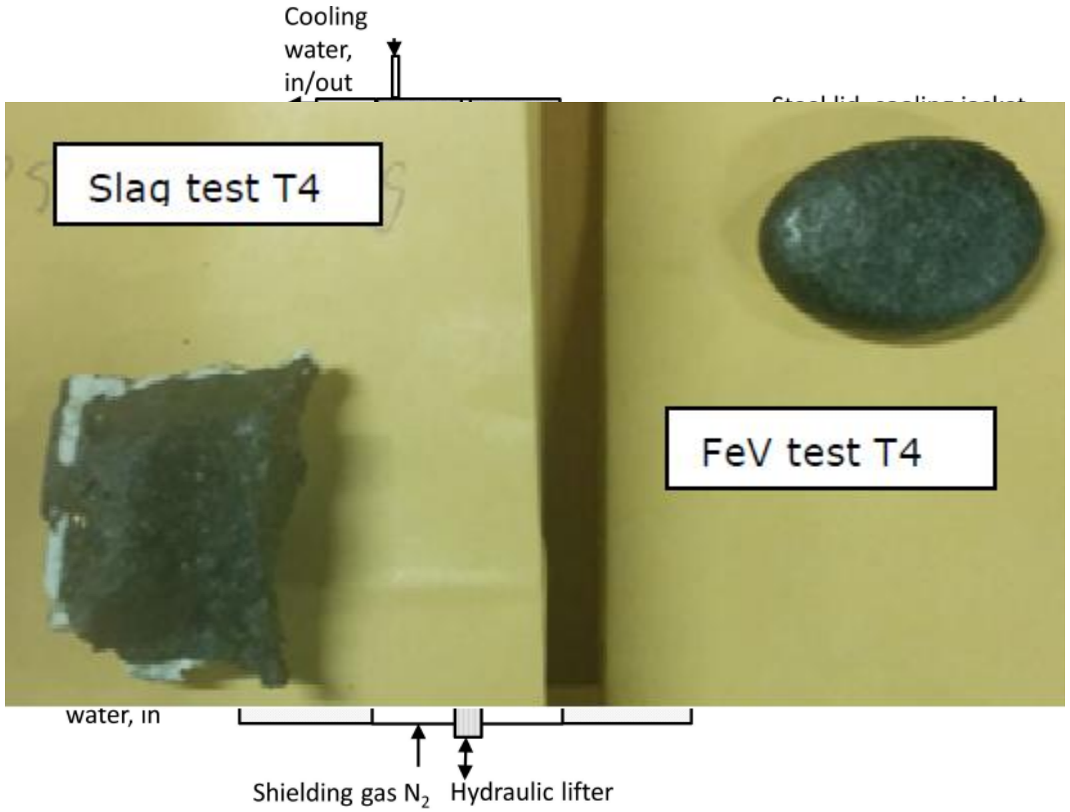
- Laboratory tests to investigate chemical and physical properties
- GBF slag mixed with different residuals was tested in lysimeters trials to evaluate efficiency.
- The trials lasted ~ 1 year
- High concentration of anions in the leaching water, especially chlorides and sulphates
- High concentration of elements shows that the mixtures have not hardened sufficiently
- Low concentration of heavy metals

Use of slag Fe-poor fraction as V source

PSP-BOF

After separation of Fe-poor from Fe-rich fractions the Fe-poor fraction was assessed as a source of V

- Laboratory smelting tests with up to 1 kg of slag were conducted to recover V
- Low grade alloy with up to 13% V can be produced from the slow-cooled slag sample. The low grade alloy that has earlier been produced from normal BOF-slag is about 10%
- After the low grade FeV product with 13% V can be converted into a high grade FeV



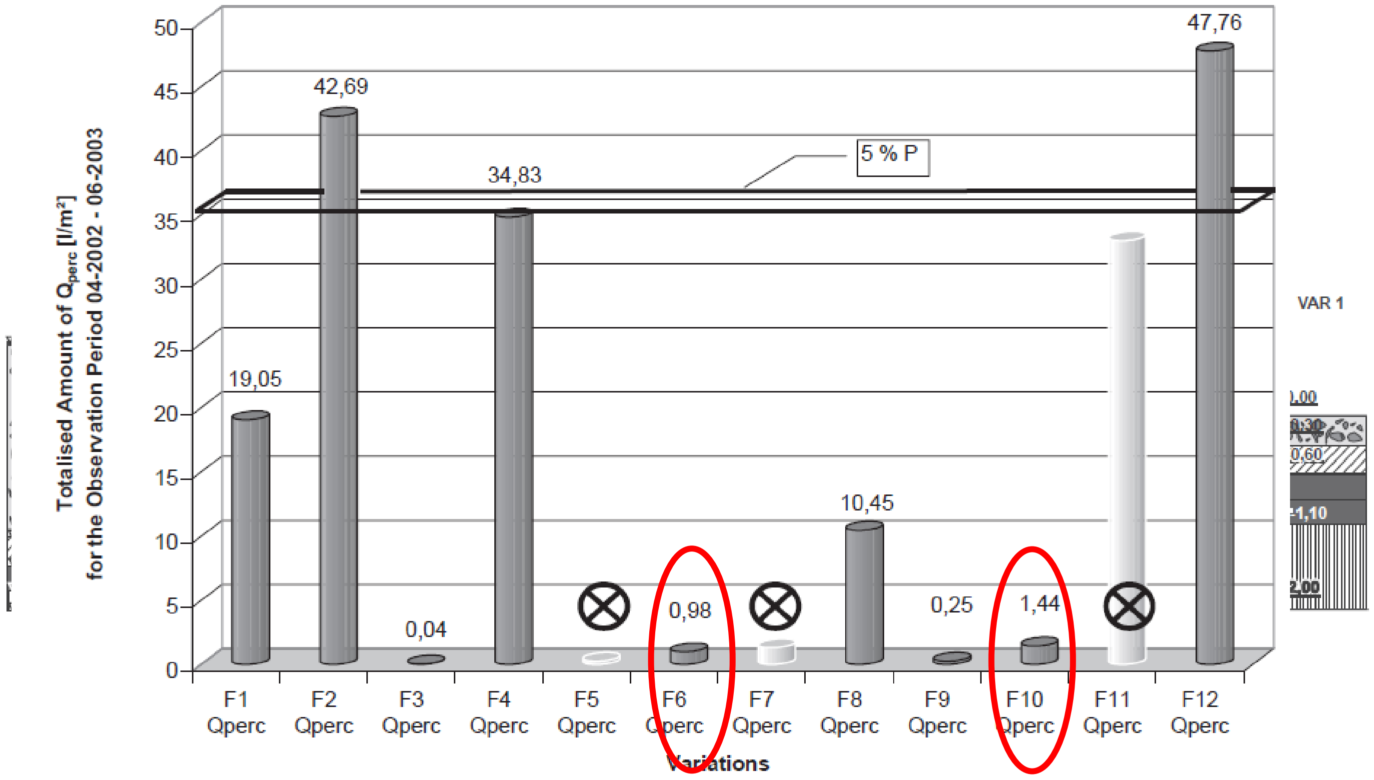
Experimental setup used for small scale FeV tests.

Use of slag as landfill sealing material

7215-PP/028

Investigation of slag (BOF, EAF and LF) with other by-products to create mixtures that preform as good or better than products used to seal landfills

- Laboratory tests to optimize sealing material
- Pilot scale tests with sealing materials on inhouse landfill that were tests for 15 months



Measured totalled quantities ‚Q_{perc}' to the end of the monitoring period in comparison of the system variations [l/m²] and 5 % of the precipitation 'P'.

Inertization of toxic wastes

IPBM

Development of a treatment process for vitrifying wastes such as spent refractory, zinc containing dust and sludge by using steel slags. Laboratory tests where liquid slag (BOF and EAF slag) was used to vitrify by-products

- Ground material was injected into melted slag.
- By this process inertization of toxic-noxious metals was obtained.

Leaching tests

	M3*$_1$	M3*$_2$ mg/l	319/65 Law limits
Pb	0.020	0.032	0.200
Zn	0.025	0.027	0.500
Cr VI	<0.010	<0.010	0.200
Cd	<0.010	<0.010	0.020
As	<0.010	<0.010	0.500

Slag analysis

- 5 projects dealt with slag analysis

2 projects:
Resulting slag after slag foaming optimization

1 project:
Image based sensors

2 projects:
LIBS

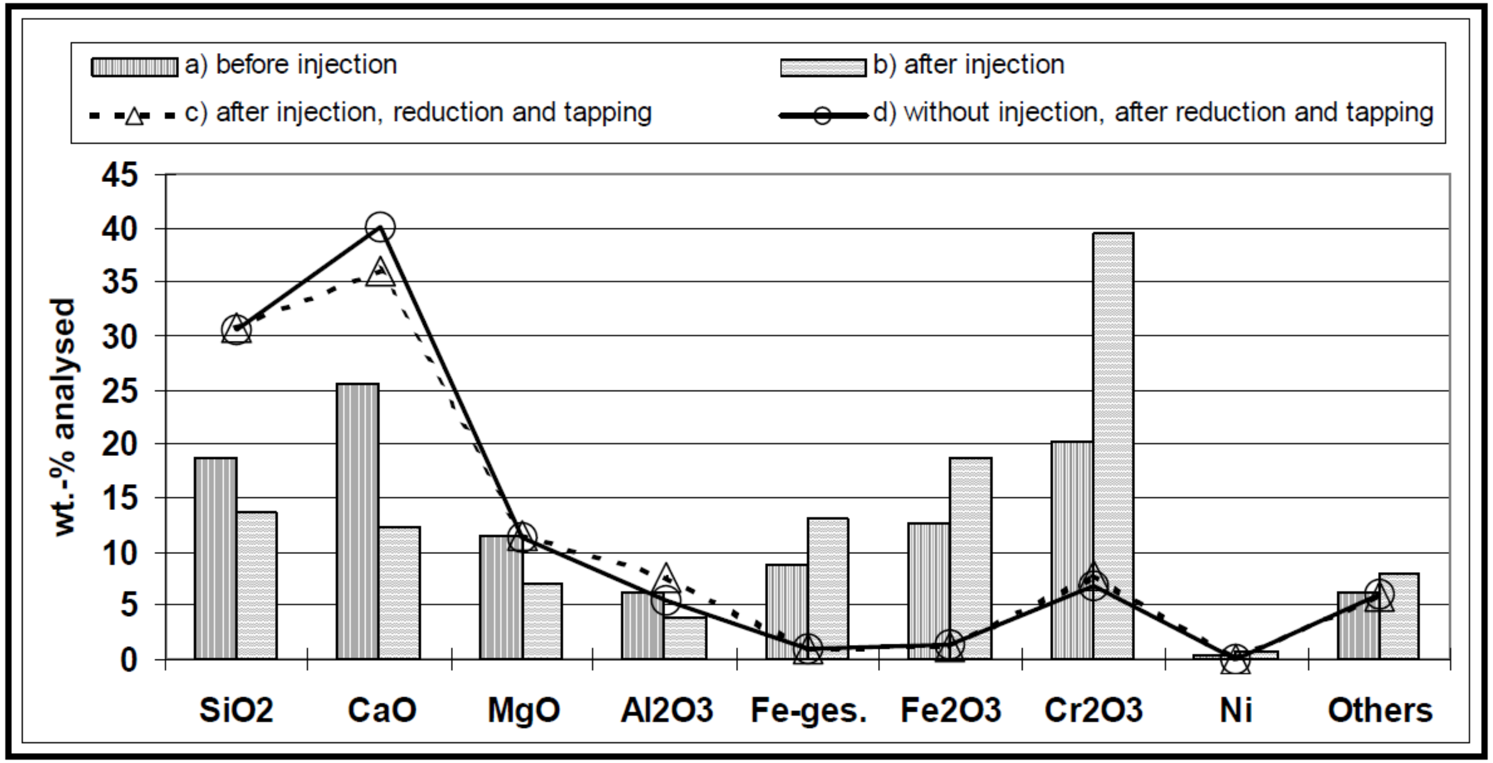
Resulting slag after slag foaming optimization

7215-PP/026

Analysis of slag after internal recycling of dust to reduce slag foaming in EAF

- EAF slag was investigated for chemical and mineral properties before and after dust injection to EAF to control its quality
- Comparing the average chemical composition of final slags from melts with and without dust injection might give the impression that dust recycling causes some higher concentration of Fe, Cr and Ni. But these differences are negligible compared to the scatter of data within each group.

1st trial on recycling dust from stainless steelmaking at KEP, changes in average chemical composition of EAF-slag production of austenitic steel qualities during different operational conditions

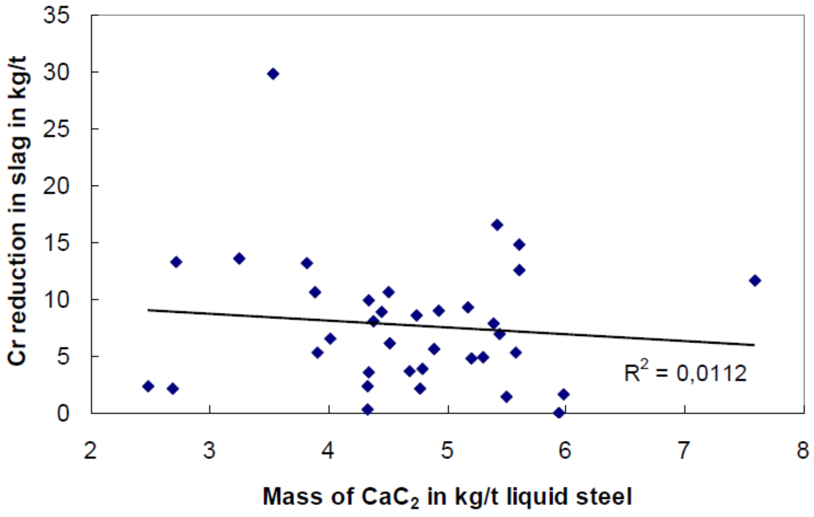


Resulting slag after slag foaming optimization

EPOSS

Analysis of slag after CaC_2 mix injection to reduce slag foaming in EAF

- EAF slag was investigated for chemical properties before and after dust injection to EAF to control its quality
- The EAF slag from CaC_2 injection as expected with 4.6 wt.% Cr_2O_3 contains much less Cr_2O_3 than the reference EAF slag (15.2 wt.% Cr_2O_3).
- The Cr concentration in the leachate of the EAF slag from CaC_2 injection is significantly higher than in the reference slag (Cr: 2.2 resp. 1.6 mg/kg) even though the Cr content in the EAF slag from CaC_2 injection is lower compared to the reference slag. Nearly all of the Cr in the leachate is present in the form of Cr(VI).
- The particle density and water absorption and the particle density of filler was found to be comparable for both reference slags. The BET surface area was higher for the reference slag than for EAF slag from CaC_2 injection.



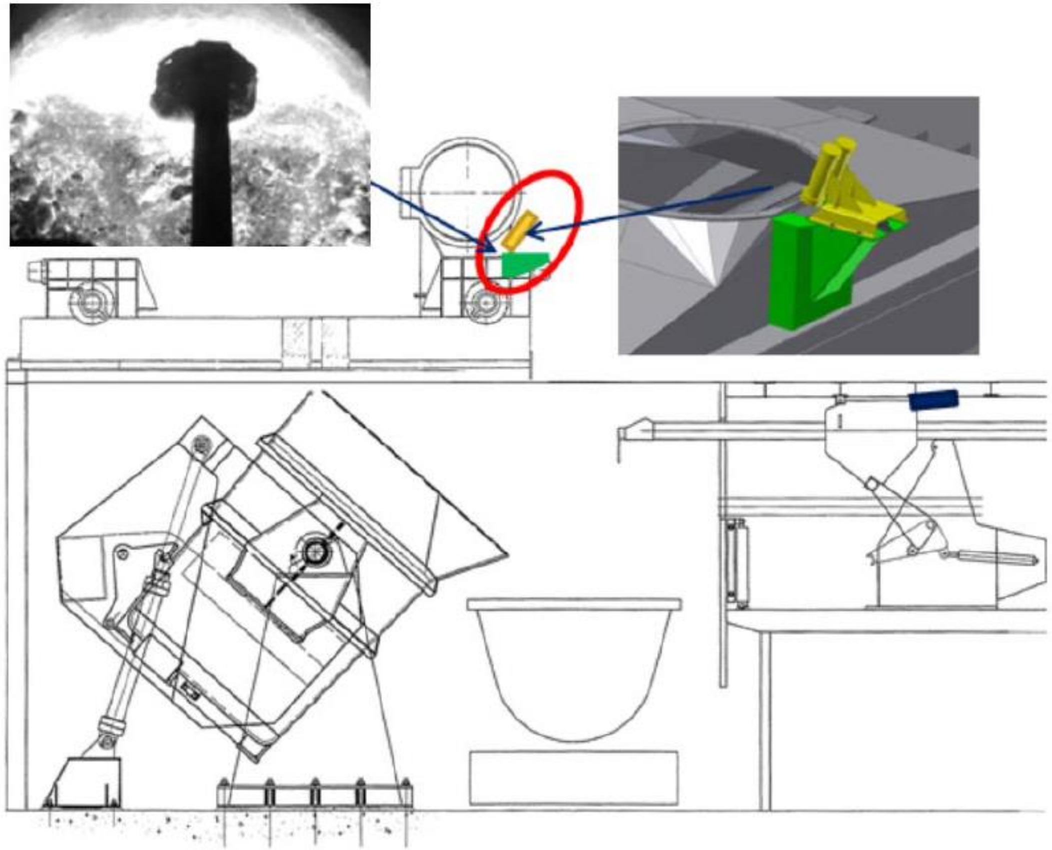
Chromium reduction in the slag (in kg Cr/t of liquid steel) in dependency of the mass of added CaC_2

Image based sensors

OPTDESLAG

Test of monitoring systems combining camera installations, image analysis, new senor information (stirring gas flow rate and pressure at EAF plant) and process models

- Monitoring and control of deslagging operations
- Dynamic online process models to monitor and control the slag properties throughout the production route of steelmaking
- Calculate set-point for slag conditioning



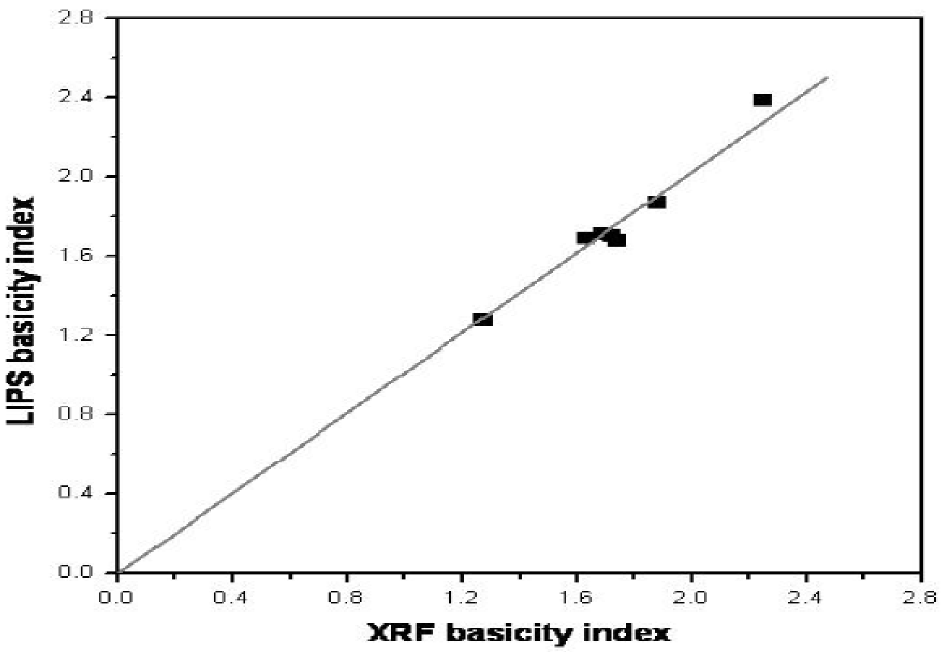
Placement of CCD camera system (to assess the amount of remaining slag on the hot metal surface on the off-gas hood) at SSAB

LIBS - laser induced breakdown spectroscopy

7210-PR/271

Investigation of adaptation of LIBS to EAF, converter and ladle units

- Detection of Fe, Ca, Si, Al, Mg, Cr and Mn by LIBS in solid and liquid slag, however it was very difficult in the melting range temperature
- Quick determination of oxidation potential, of slag foaming and basicity of the slag
- Prove of the online feasibility of the quick detection system
- Application of INQUISSS to support slag recycling measures by online detection of its recycling capacity



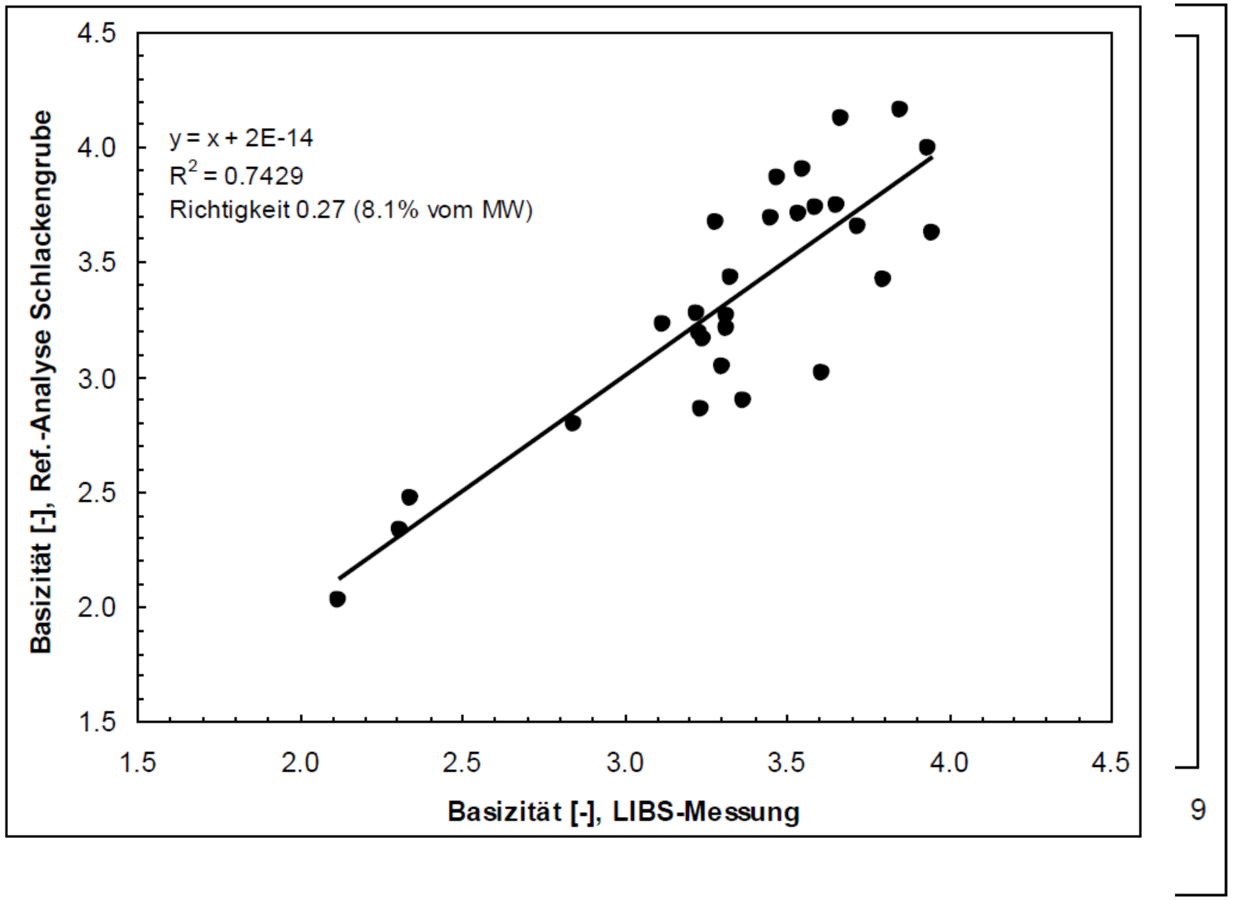
Predicted basicity index based on the LIPS results versus the nominal value as measured by XRF

LIBS - laser induced breakdown spectroscopy

SLAGFERTILISER

LIBS was used to measure the quality of BOF slag that was used in liming tests

- Testing of the LIBS system with small samples of slag in the laboratory
- Testing of the LIBS system in daily operation



Results for the tests with hot slags in the ladles

basicity)

Thank you for your attention

Agnieszka Morillon, PhD
Phone: +49 2065 9945-85
E-mail: a.morillon@fehs.de

web site: www.fehs.de

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

EU-Research on the use of sludge, dust, refractory, mill scale and other residual materials from the steel industry and external secondary raw material in the Blast furnace and Sinter plant

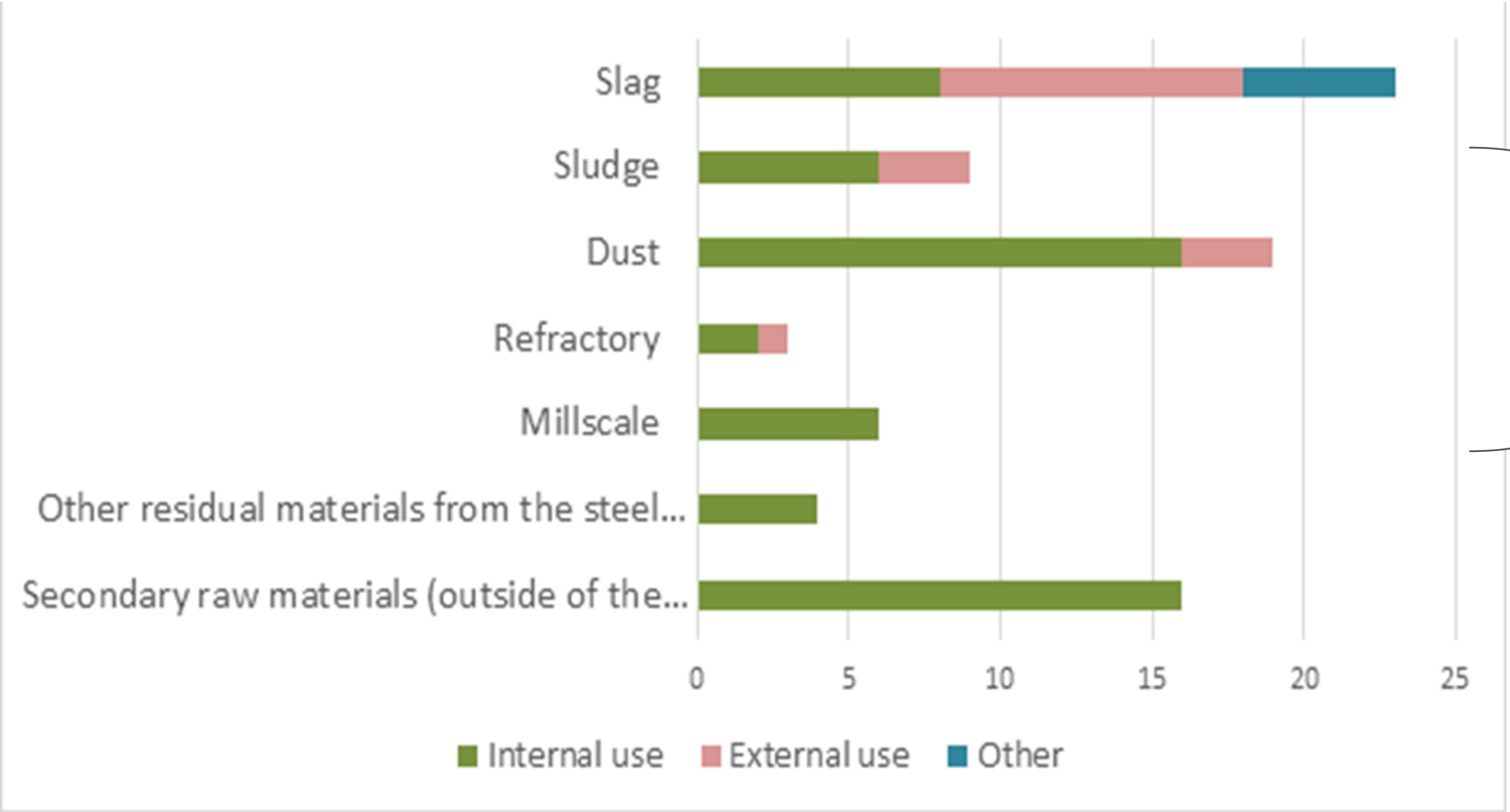
Roland Pietruck, BFI

Menti.com Code 6141 4728

Agenda

- Introduction
- Overview internal recycling
- Recycling of dust and sludge via the Sinter plant
- Recycling of dust and sludge via the BF burden
- Recycling of dust and sludge via the BF injection
- Summary
- Outlook

EU projects – Overview



11 EU research projects dealing with internal recycling of sludge, dust, refractory and mill scale

Sludge + Dust + Mill scale* :
13 % of steel making residues

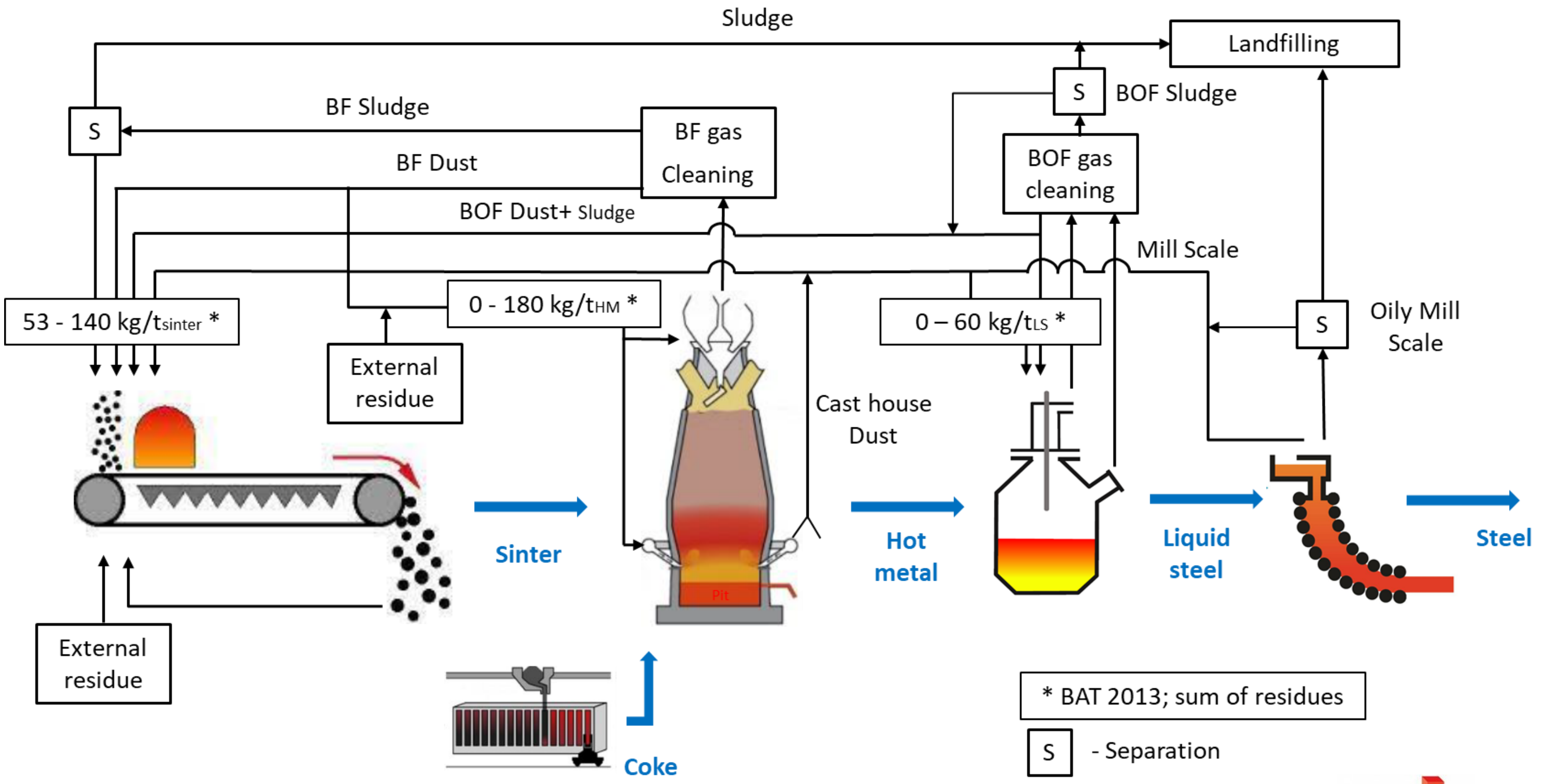
* DOI:10.1007/s40831-019-00220-2

Overview over internal recycling of sludge and dust at the BF route – Type and Composition

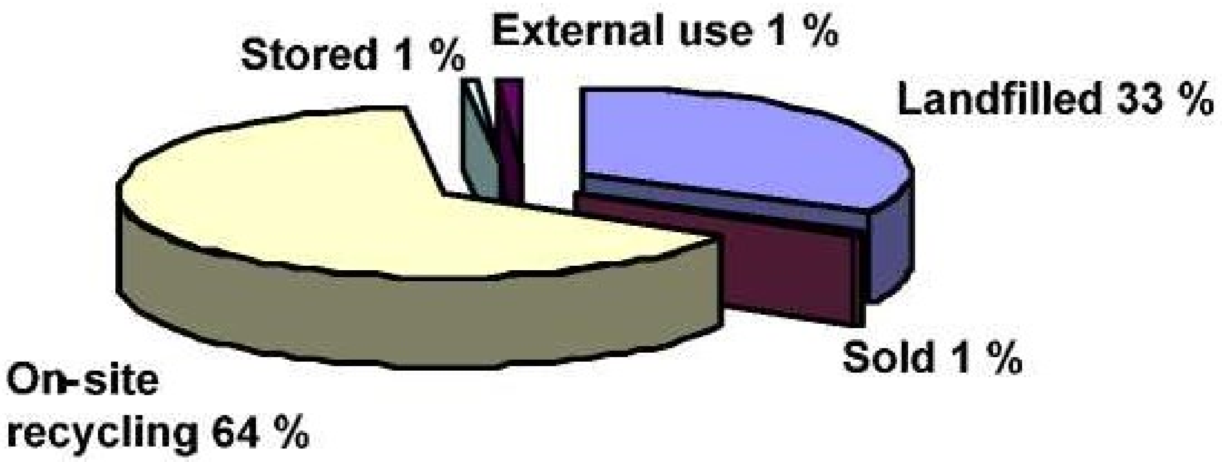
wt.%	Fe	C	CaO	SiO2	Al2O3	Zn	Pb
BF Dust [1]	15 - 40	25 - 40	2 - 8	4 - 8	0.2 - 3.7	0.1 - 0.5	< 0.07
BF Sludge[1]	7 - 35	15 - 47	3.5 - 18	3 -9	0.8 - 4.6	1 - 10	< 2.0
BOF Coarse dust[1]	30 - 85	1.4	8 - 12	-	-	< 0.4	< 0.04
BOF Fine dust[1]	54 - 70	0.7	3 - 11	-	-	< 3.2	< 1.0
BOF sludge[1]	48 - 70	0.7- 4.6	3 - 17			0.2 - 4.1	< 0.14
Mill Scale [2, 3]	56 - 72	0.6 - 0.8	0.2 - 5	0.7 - 7	< 2.2	< 0.04	-

[1] BAT 2013 EUR 25521 EN; [2] EUR 22974 EN; [3] DOI:10.1007/bf03403348

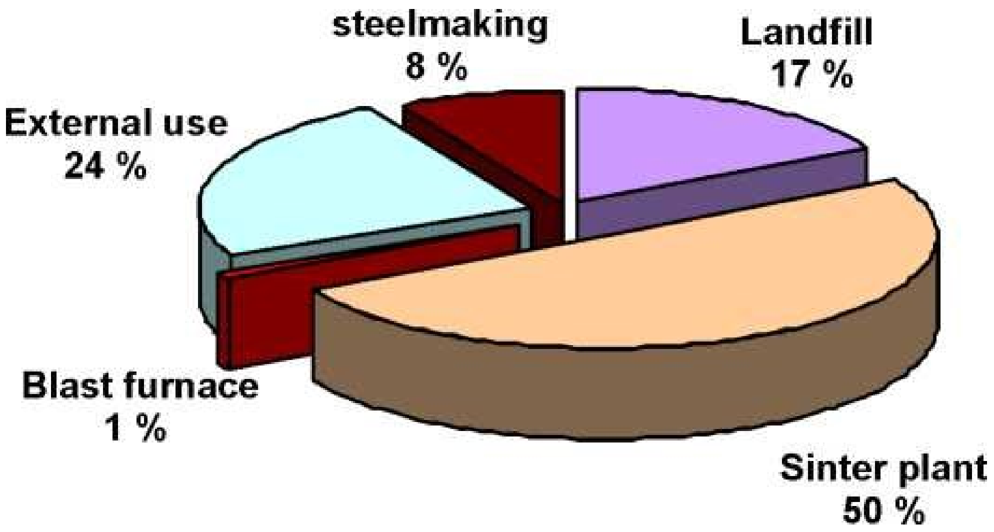
Overview over internal recycling of sludge and dust at the BF route – Material flow



Overview over internal recycling of sludge and dust at the BF route – Utilisation



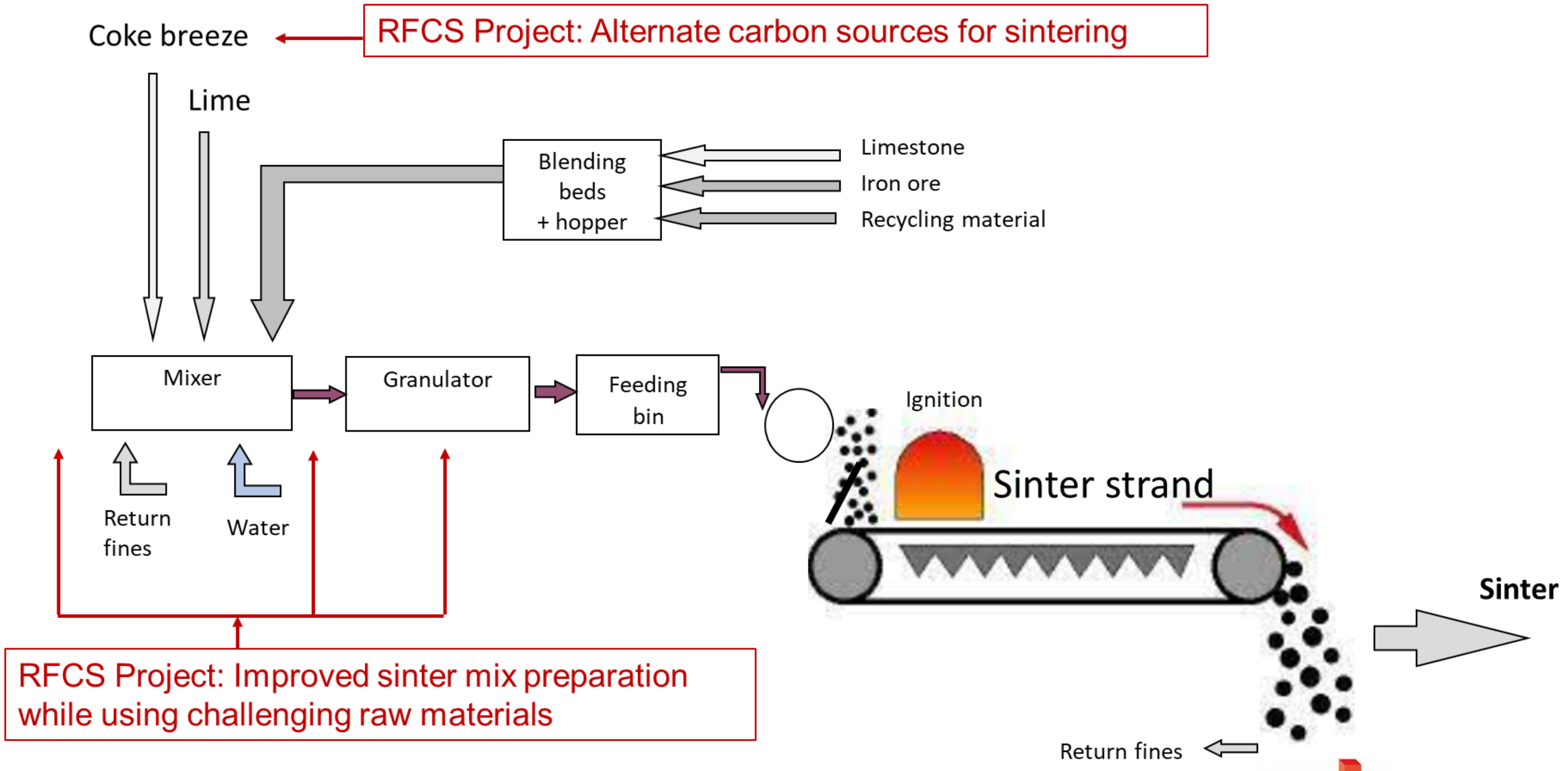
Fate of **dust and sludge** from **BF gas treatment** in the EU* (1998)



Use of **dust/sludge and mill scale** from **oxygen steelmaking*** (2007)

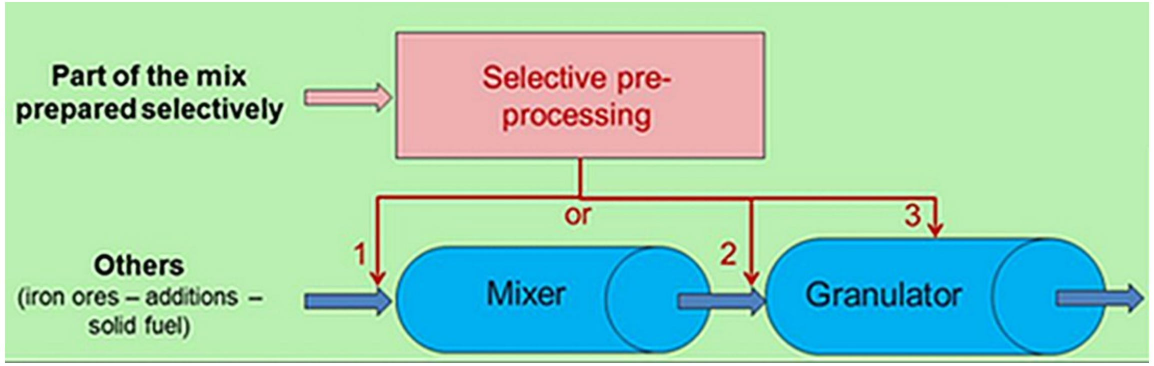
*BAT 2013 EUR 25521 EN

EU Projects - Recovery of dust and sludge in the sinter plant



RFCS: IMSIMI - Improved sinter mix preparation while using challenging raw materials; 2011-2014

Aim: Improvement of the sinter quality and performance by applying a selective pre-treatment while using high content of fine ores and residual materials



Pre-treatment :

- Non-/selective agglomeration with non-/intensive mixer
- Use of organic binder/water

Sinter pot tests and **Industrial sinter plant trials**

Main results of industrial tests:

- Intensive mixers improve productivity and flexibility when increasing fine iron ores/residues in the sinter feed,
- Adjustment of water and binders' content and of mixing with raw material necessary
  Parameter: size distribution and wettability of ores, moisture content

→ Follow up research projects (non RFCS) + Industrial application

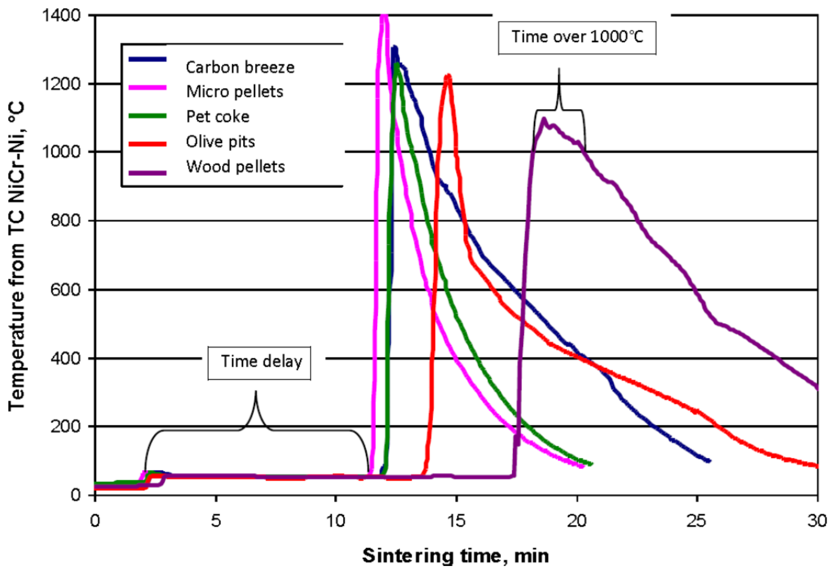
RFCS: Alternate Carbon Sources for Sintering of iron ore (ACASOS); 2007-2010

Aim: ACASOS as replacement for Coke breeze,

ACASOS: Biomass, BF sludge, BF dust, Petroleum coke

Pre-treatment : Grinding, Separation, Agglomeration, Drying

Sinter pot tests and **Industrial sinter plant trials →replacement factors**



Main results of industrial scale:

Carbon enriched BF sludge: 10 – 20% of the carbon breeze replaced by the carbon of a “Zn- and Pb-reduced” BF sludge; carbon replacement factor ~ 1; No enrichment of heavy metal content
→ Industrial application

Micro-pelletized and cured BF dust: ca 30% of carbon content replaced by carbon in BF dust - carbon replacement factor: 0.6 to 1; No changes in sinter quality

Research Fund for Coal & Steel

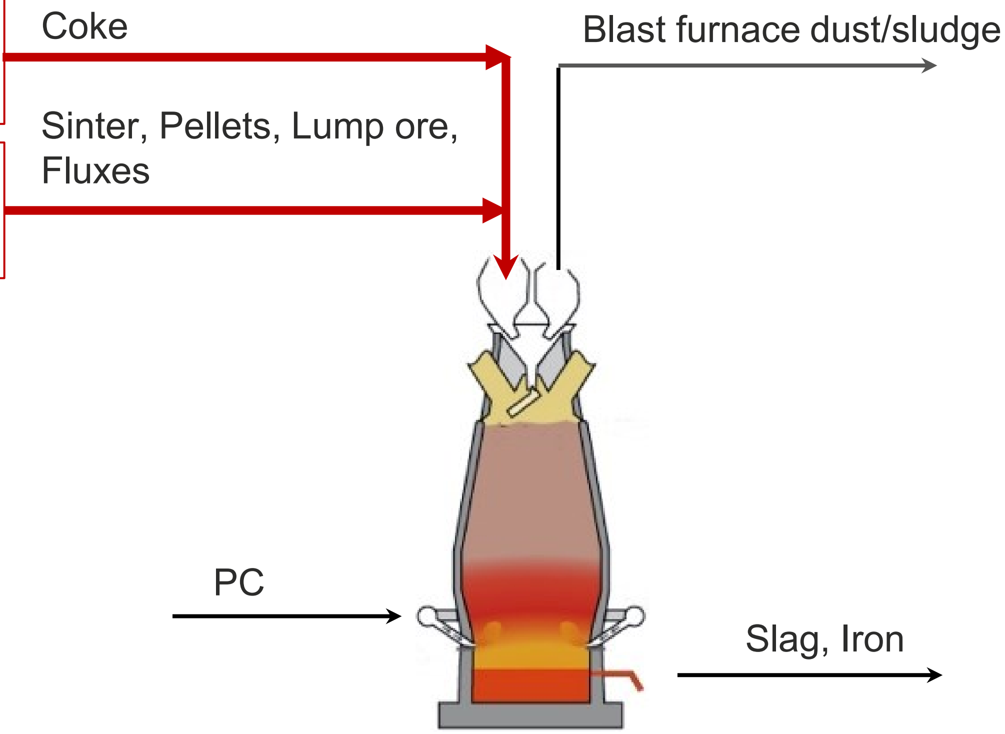
Menti Code: 6141 4728

Roland Pietruck, BFI

EU-Projects Recovery of dust and sludge via the BF burden

RFCS-Project: Innovative Carbon products for substituting coke on BF operation (Innocarb); 2013

RFCS-Project: Alternative Processing of Sinter Plant Recycling Materials; 2005



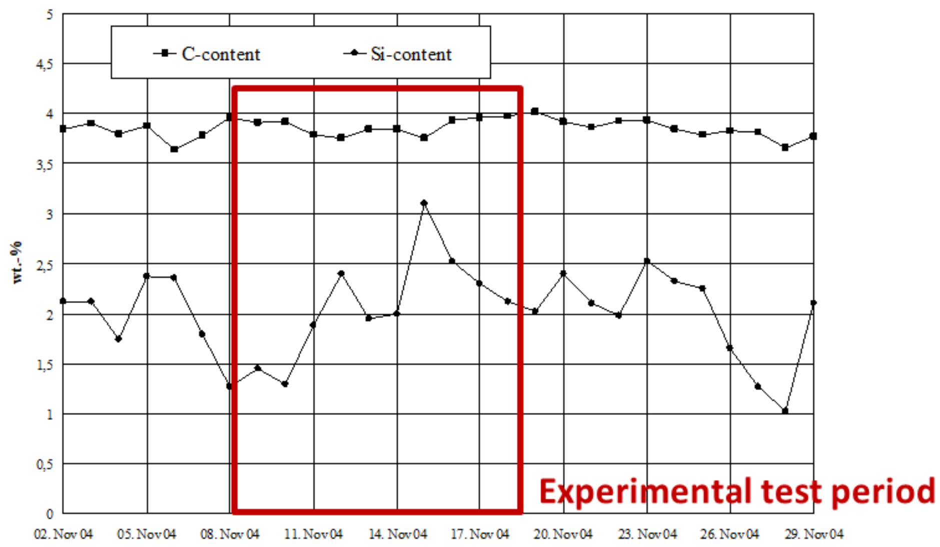
RFCS: Alternative Processing of Sinter Plant Recycling Materials; 2002-2005

Aim: Briquetting of Sinter Plant Recycling Materials for BF process

Residues: BF dust, BF sludge, mill scale, BOF sludge

Pre-treatment : Briquetting, Binder evaluation

Industrial trials to determine **influence on BF**



Main results of industrial BF tests:

- Briquette quality → Cold strength 1800 N (with 20 % cement as binder)
- Charging of 40 kg/t hot metal → no negative influences on BF operation
- Process evaluation→ no significant changes to normal operation

→ Follow up research projects (non RFCS) + Industrial application

Menti Code: 6141 4728

Roland Pietruck, BFI

RFCS: InnoCarb - Innovative Carbon Products for Substituting Coke on BF operation; 2010-2013

Aim: Substitution of metallurgical coke with residual carbon briquettes

Carbon sources: Carbon breeze, Pet coke, Coke dust

Pre-treatment : Briquetting, Binder evaluation

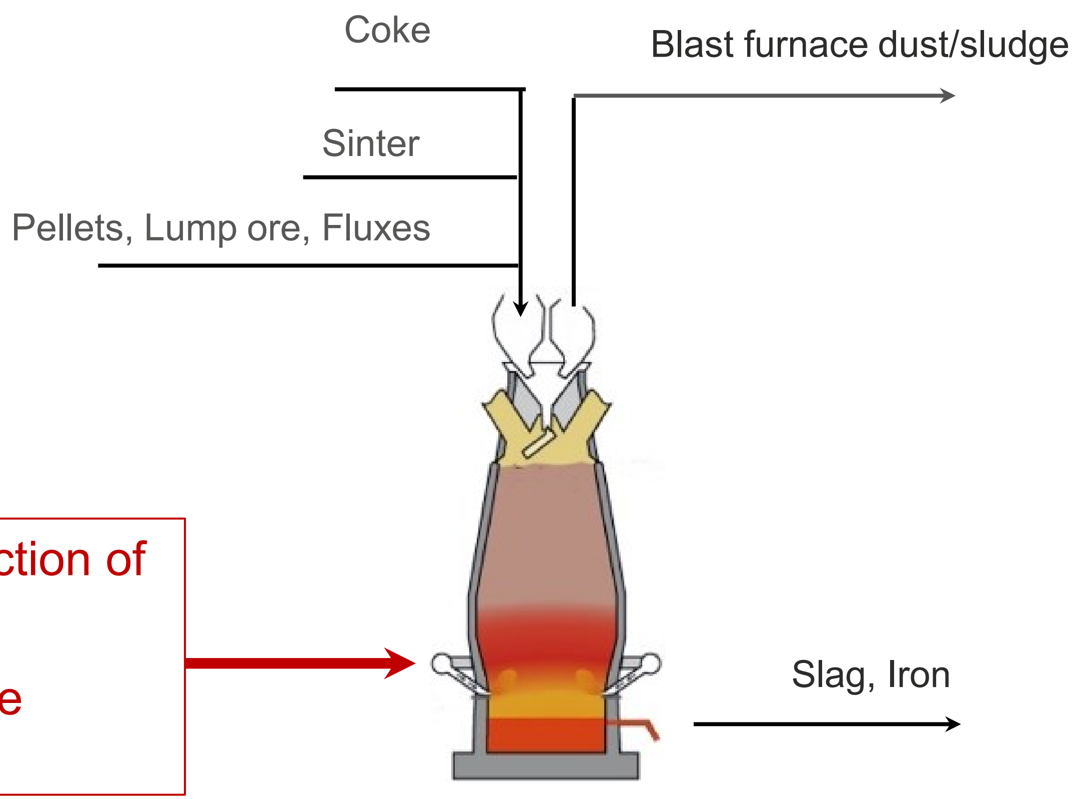
Industrial trials : 2000 t to determine **replacement factors** and influence on process at experimental blast furnace EBF and BF

Main results of industrial BF tests

- Strength of carbon briquettes sufficient at 15% cement; only slight increase of dust emission
- Reaction behavior is higher than BF-coke
- Exchange ratios for the carbon bricks are in the range of 0.65 - 0.70
- Coke substitution rate of about 10% in BF shows little influence on process

Menti Code: 6141 4728 Roland Pietruck, BFI

Recovery of dust and sludge via the BF injection



RFCS Project: Hearth protection in BF operation by injection of TiO2-materials; 2002-2005

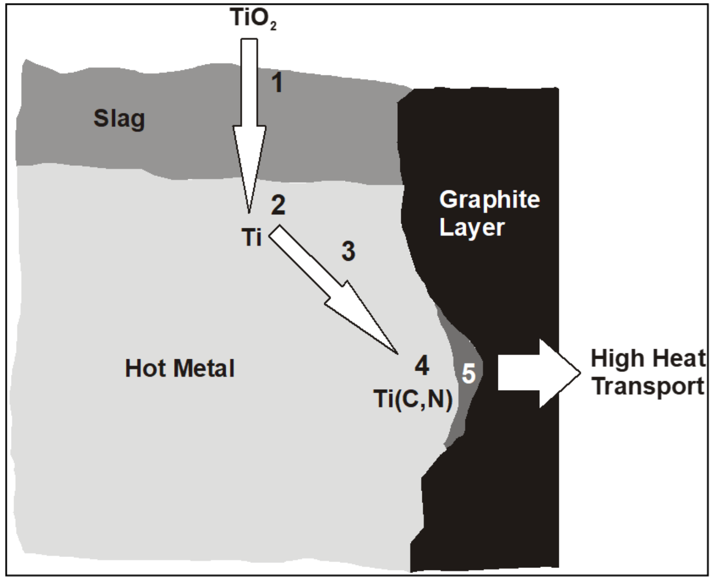
RFCS Project: FlexInject - Flexible injection of alternative carbon material into the BF; 2008-2011

RFCS: Hearth protection in BF operation by injection of TiO2-materials; 2002-2005

Aim: Influence tuyere injection of titanium materials on BF hearth protection

External by-product: Ti-rich by-product from Ti-production

Industrial BF trial: **Injection in** in a worn area in the transition zone → Transport of titanium along the worn area to the tap hole



Main results of industrial BF tests

- TiO2 rich residue suitable for the formation of TiCN layers
- TiO2 material injection at high temperature in the BF hearth → increasing titanium content in the HM and a decreasing in the slag, which support the formation of protective TiCN layers in the hearth
- High injection rate has to be preferred to a continuous injection at low intensity
- Injection start at mid or end of tapping -stop shortly after the tap hole is closed

→ in industrial application

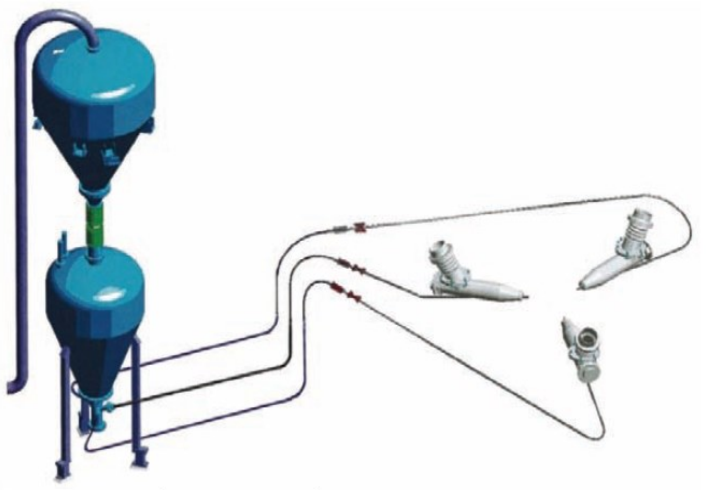
RFCS: FlexInject - Flexible injection of alternative carbon material into the blast furnace; 2008-2011

Aim: Use of alternative Carbon Materials as Carbon Resources

Residues: BF sludge, BF dust, Waste plastics, ASR

Pre-treatment : Tornado process

Pilot trial at EBF and industrial trials at BF



Main results of industrial BF tests

- Stable operation achieved up to the BF flue dust injection rate of 40 kg/tHM
- From process point co-injection and separate injection is possible,
- Abrasive coke particles makes wear resistant installation necessary
- Due to very fine particles and a content of iron oxide in the BF sludge there is a risk for segregation if co-injection with PC → Briquetting may be a favorable alternative for BF sludge

→ in industrial application

Summary

EU research projects are one part of a research agenda in Europe and contribute to the recycling of residues and by-products

Research topics are transferred to the industrial application

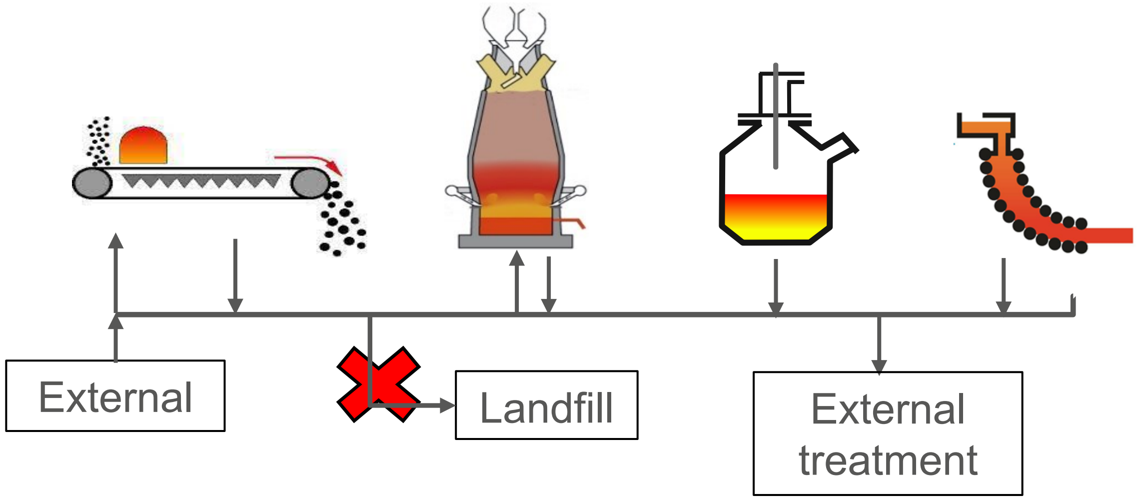
- Intensive mixer for fine ore and residue pre-treatment
- TiO2 injection for hearth protection
- Plastic injection in BF
- Top-charged cold-bonded briquettes in BF

Recycling of residues is limited due to product quality and process performance and emissions

Challenges for Recycling are increasing due to reduced input material quality (Zn, P, alkali, heavy metal)

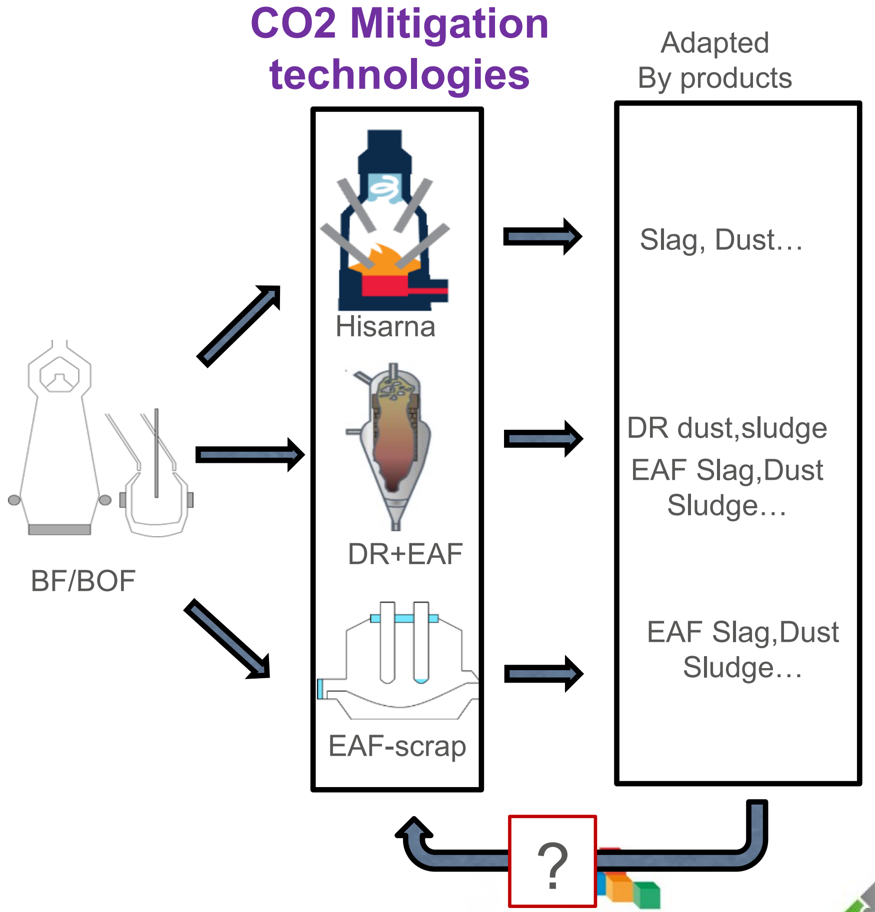
Outlook

Short and Mid term utilization of dust and sludge



Where do you see a need for research?

Mid and Long term utilization of dust and sludge



www.reusteel.eu

Please give us your feedback

REUSteel Online Questionnaire:
https://it.surveymonkey.com/r/P6728HB

www.reusteel.eu

Thank you

Roland Pietruck

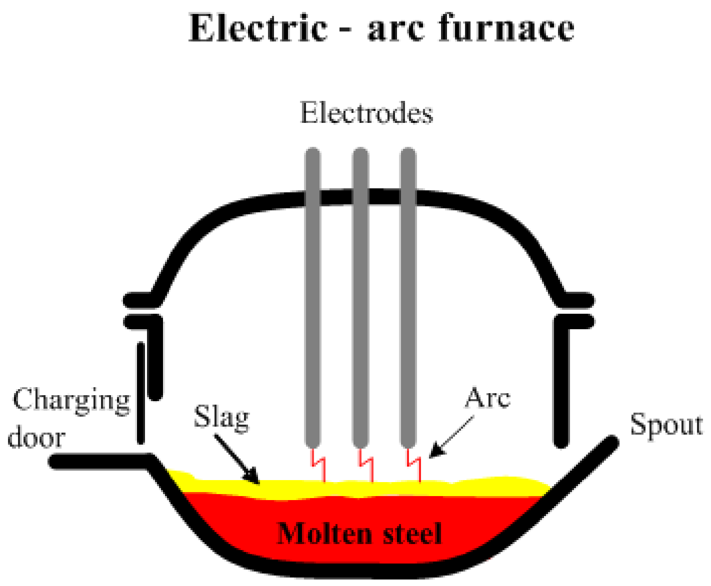
VDEh-Betriebsforschungsinstitut GmbH
Sohnstraße 69 · 40237 Düsseldorf
Telefon +49 211 98492 - 891, Fax: - 202
E-Mail Roland.Pietruck@bfi.de · www.bfi.de

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

Research of the use of sludge, dust, refractory, millscale, and other residual materials from the steel industry and external secondary raw material in the EAF

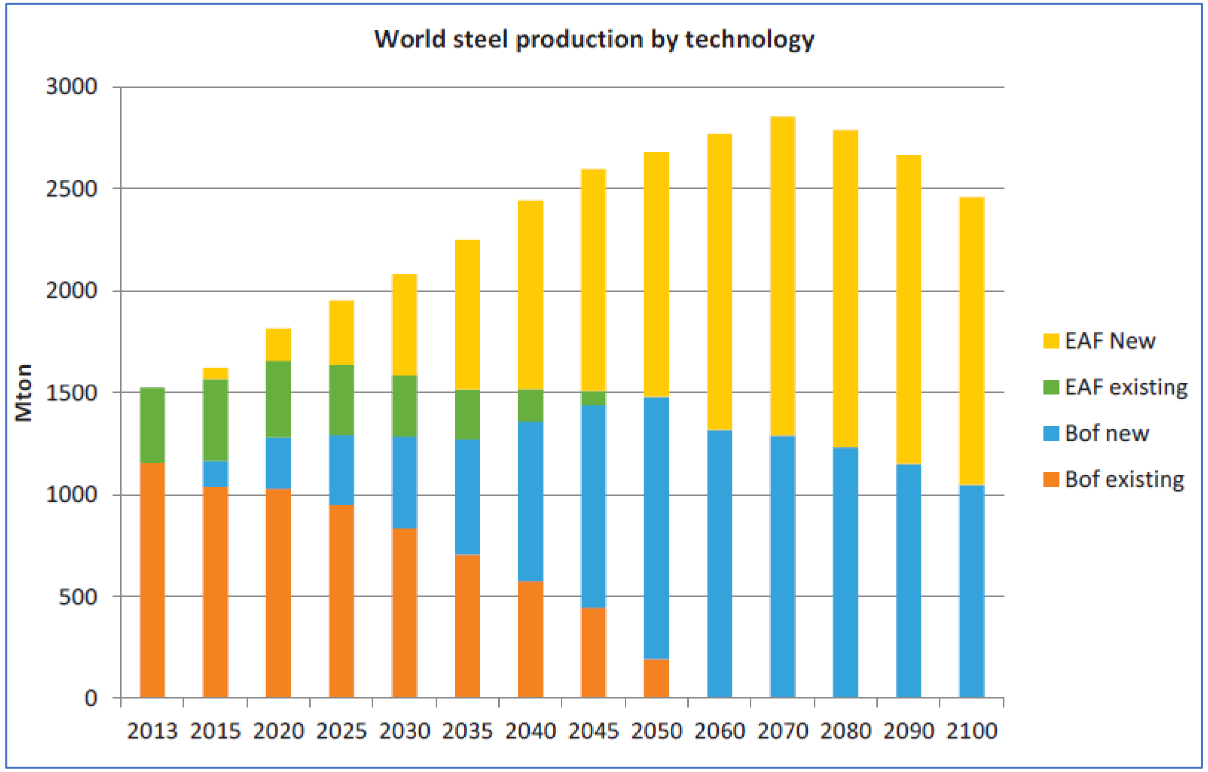
By: Umberto Martini (RINA-Consulting Centro Sviluppo Materiali SpA)

Menti: 6141 4728



The steel production by **E**lectric **A**rc **F**urnace (**EAF**) is expected to increase in the next years with a surge of growth from 2025-2030.

Production forecasts indicate the share of the global steel production by EAF route is expected to reach or even overpass the 45% worldwide in 2050 against the current 28%,



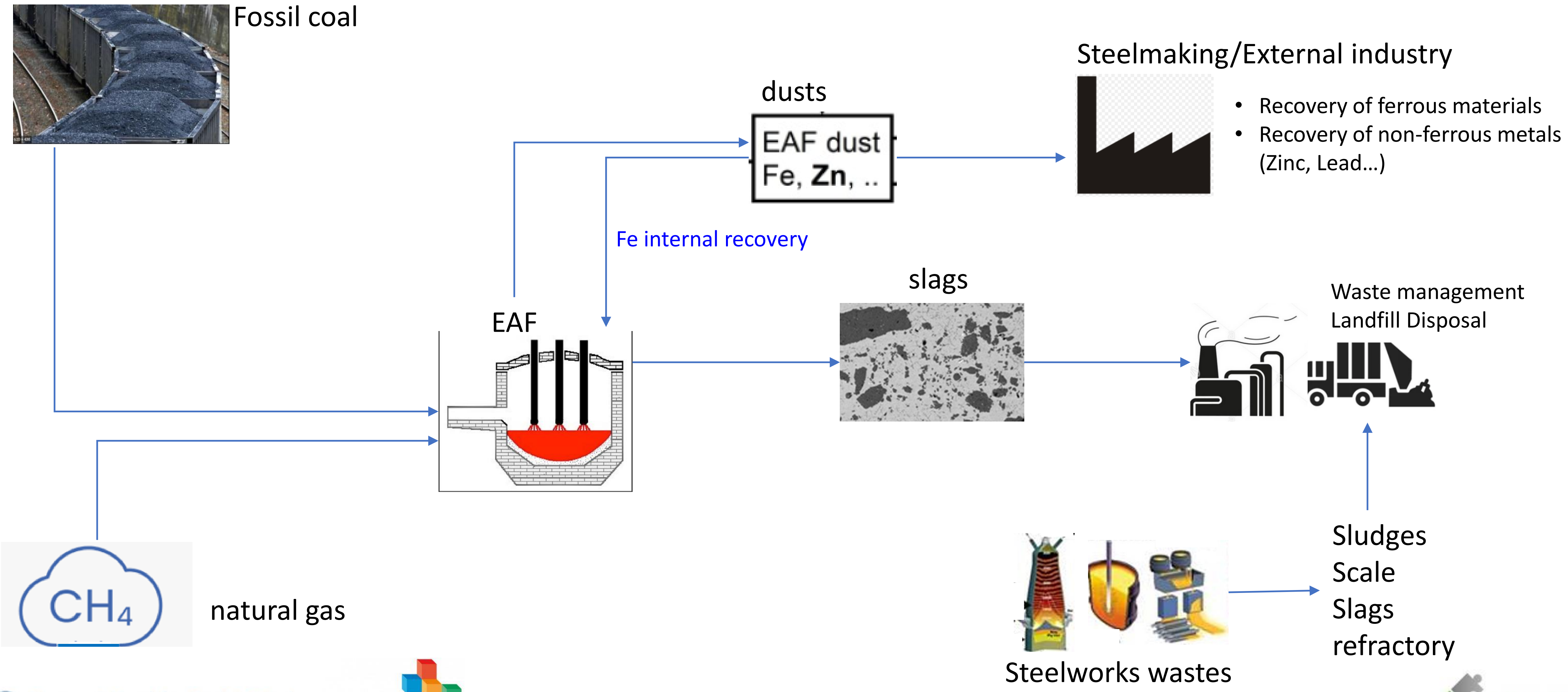
The EAF procedures are subjected to a change of paradigm that already started but that are still in a transition phase

Hypothetic scenario of world steel production divided according to the different routes.

Study 2012 KTH, Vito, ArcelorMittal

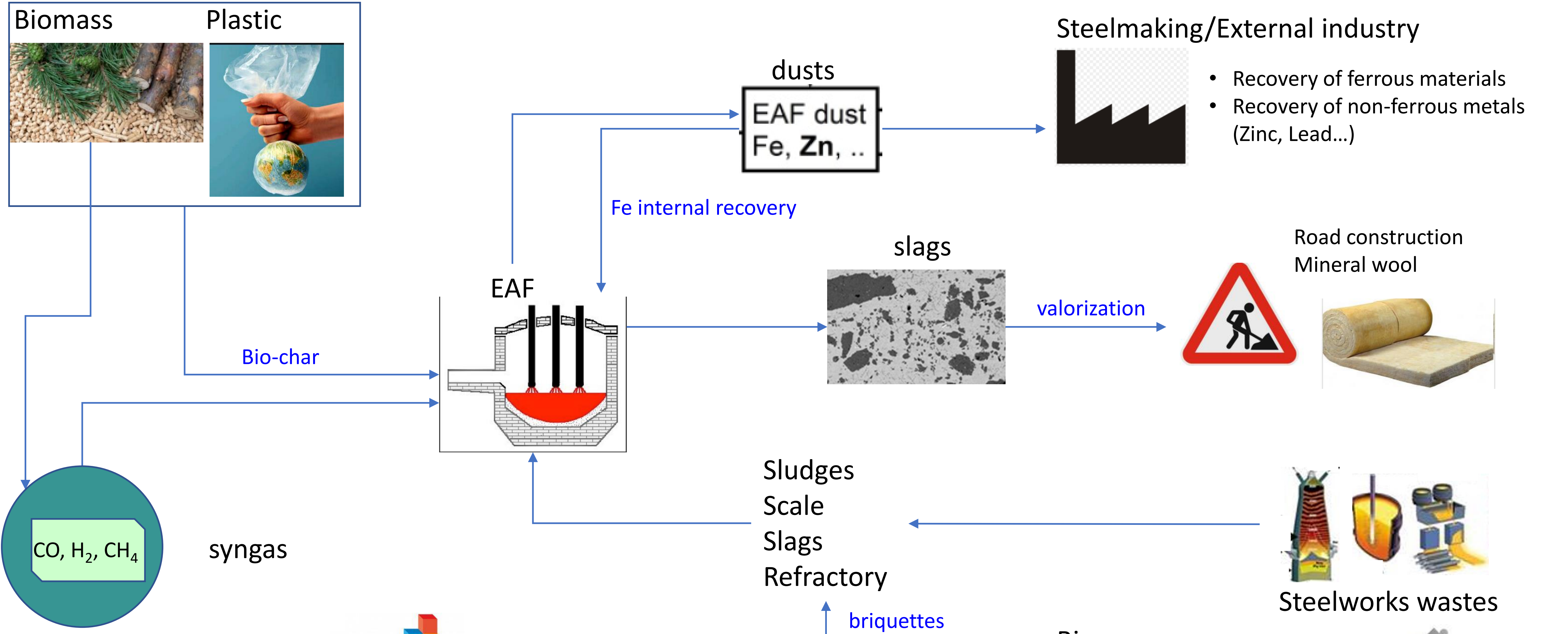
Menti: 6141 4728

EAF - old paradigm



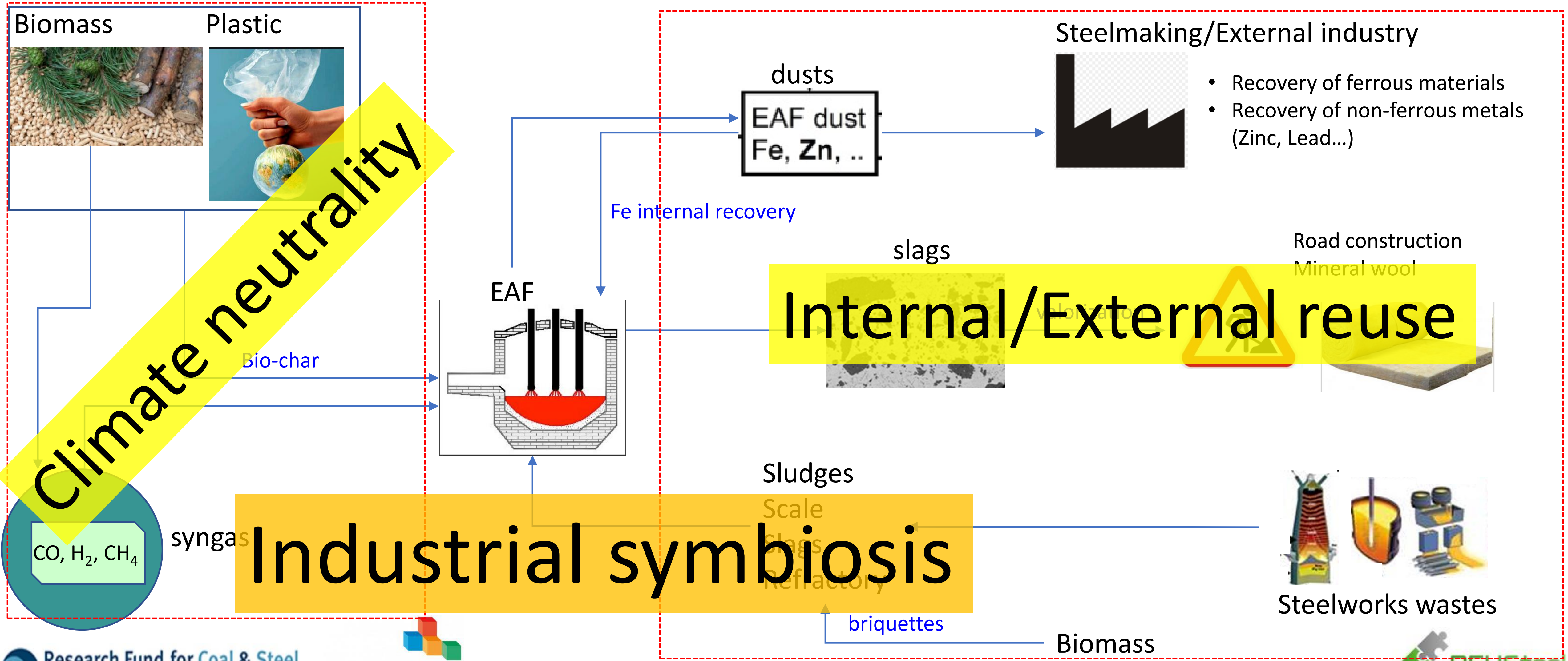
Menti: 6141 4728

EAF – new paradigm (already started but still in progress)



Menti: 6141 4728

EAF – new paradigm (already started but still in progress)



Menti: 6141 4728

EAF and dust recycling – aspects of interest (recent developments)

Zn recovery from EAF dust by thermal heating using the reduction/evaporation of zinc is the main used in the market (Waeltz process with >85% of the market)

The steelmaking dust (and also wastes) are *good microwave absorption materials*, so microwave heating can be considered as a possible alternative to the conventional one.

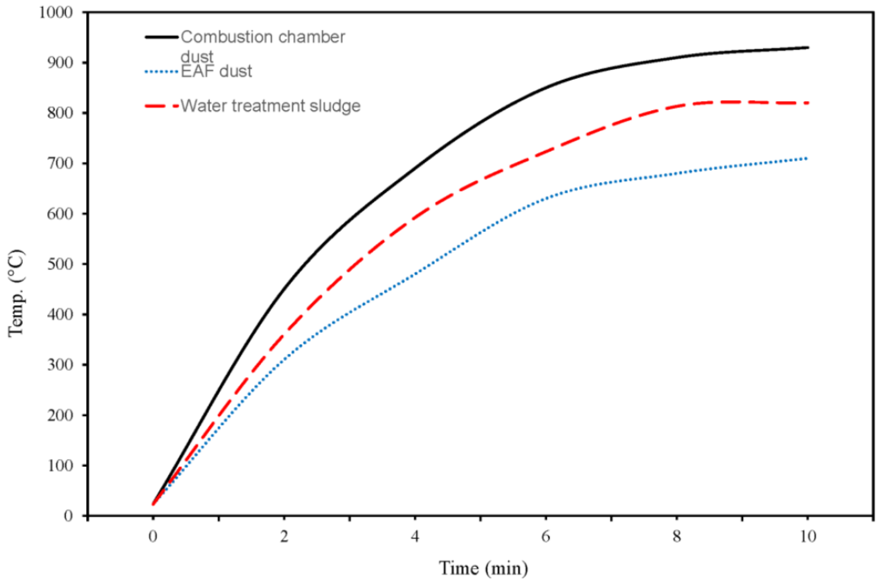
Potentiality of the microwave pre-heating for treating EAF dust and other steelmaking dusts

$$C + ZnFe_2O_4 = ZnO + 2\ FeO + CO\ (g)$$
$$CO\ (g) + ZnFe_2O_4 = ZnO + 2\ FeO + CO_2\ (g)$$
$$2CO \rightleftharpoons CO_2 + C$$
$$ZnO\ (s) + C\ (s) = Zn\ (g) + CO\ (g)$$

During the microwave heating, zinc ferrite decomposes to ZnO and FeO. FeO is a good microwave susceptor, so it increases the efficiency of the process.

The gaseous zinc is produced via a gas-solid reactions involving CO/CO2/C present in the system.

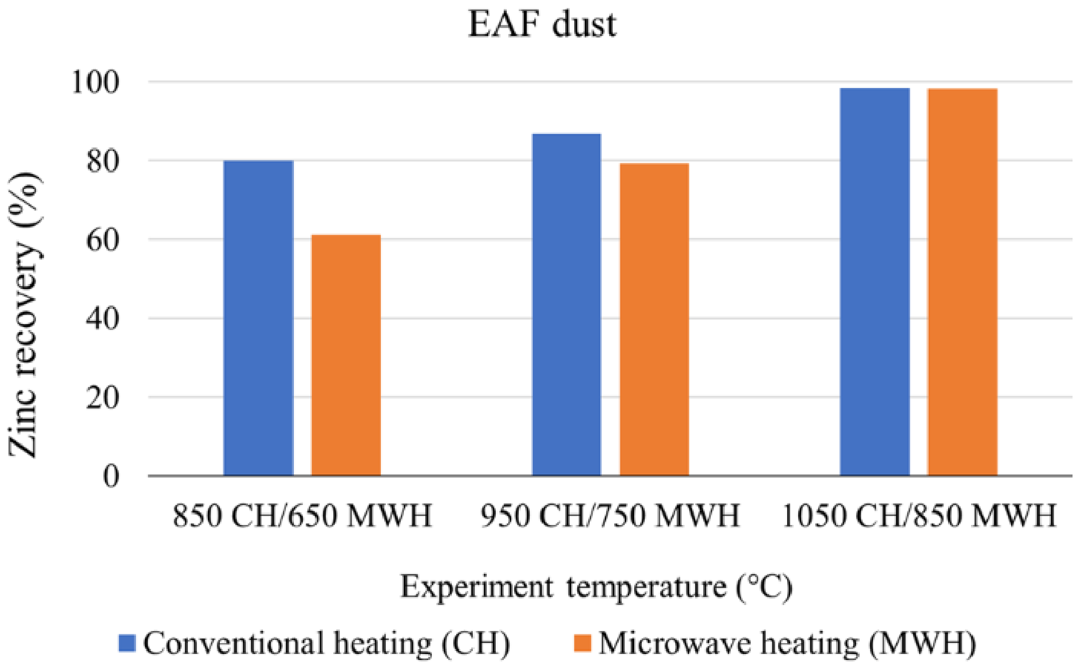
Combustion chamber dust, EAF dust and water treatment sludge can be classified as excellent microwave absorbers.



From: T. Echterhof, T. Willms, S. Preiß, M. Omran, T. Fabritius, D. Mombelli, C. Mapelli, S. Steinlechner, I. Unamuno, S. Schüler, D. Mudersbach, T. Griessacher, DEVELOPING A NEW PROCESS TO AGGLOMERATE SECONDARY RAW MATERIAL FINES FOR RECYCLING IN THE ELECTRIC ARC FURNACE – THE FINES2EAF PROJECT, CleanTech4_CT014 (document available on line)

EAF and dust recycling – aspects of interest (recent developments)

Comparison between conventional and microwave heating of EAF dust



Zn recovery through microwave heating of EAF and CRC (chromium converter) dusts.

At 850°C the microwave heating allows to obtain the same zinc recovery rate (proximate to 100%) of that with conventional heating at 1050°C

Hence…

Microwave heating looks promising but fundamental studies on the microwave cavity design and dielectric properties of treated materials are required in order to understand how *to perform the scaling up to an industrial level*.

From: M. Omran, T. Fabritius, Y. Yu, E.P. Heikkinen, G. Chen, Y. Kacar, Improving Zinc Recovery from Steelmaking Dust by Switching from Conventional Heating to Microwave Heating, Journal of Sustainable Metallurgy, https://doi.org/10.1007/s40831-020-00319-x

Menti: 6141 4728

EAF and dust recycling – aspects of interest

Optimization of EAF operations (pyro-metallurgy)

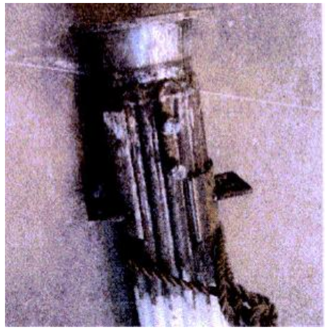
- Feeding systems
- Proper slag foaming
- Dust collection and treatment

FULLREC and FULLREC2

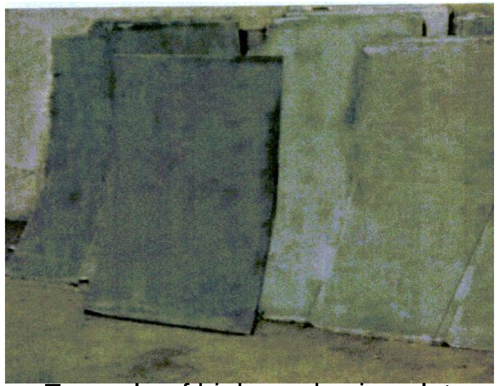
Collected dust on EAF filters

Hydrometallurgical process by sulphuric leaching of EAF dust.
Sulphuric leaching can dissolve zinc ferrite, too.

- Zn at high purity level (>99.98) obtained by electrolysis of leached and then purified solution
- Cements with high level of Pb and Fe



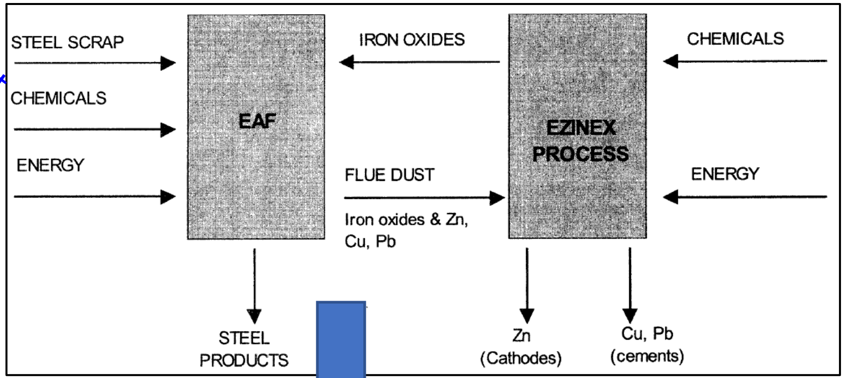
Example of modified snorkel for EAF dust injection at the slag level (FULLREC)



Example of high grade zinc plates (>99.9%)

7215-AA/403

Collected dust on EAF filters



Hydrometallurgical process by leaching of EAF dust using ammonium chlorine (EZINEX).
Zinc ferrite is not dissolved.

- Zn at high purity level (>99.5) obtained by electrolysis of leached and then purified solution
- Cements rich of Pb

Menti: 6141 4728

EAF and dust recycling – aspects of interest

Optimization of EAF operations (pyro-metallurgy)

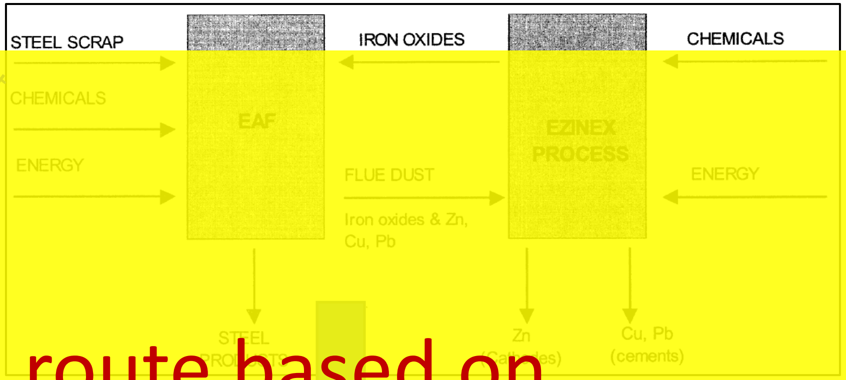
- Feeding systems
- Proper slag foaming
- Dust collection and treatment

FULLREC and FULLREC2

7215-AA/403

Collected dust on EAF filters

Collected dust on EAF filters



Recent related developments:

Zn recovery through hydrometallurgical route based on sulphuric acid is done using an ultrasound-assisted acid leaching that facilitates the dissolution of zinc-ferrite at lower acid concentration

Hydrometallurgical process by sulphuric leaching of EAF dust.
Sulphuric leaching can dissolve zinc ferrite, too.

- Zn at high purity level (>99.98) obtained by electrolysis of leached and then purified solution
- Cements with high level of Pb and Fe

Example of modified snorkel for EAF dust injection at the slag level

dust using ammonium chlorine (EZINEX).
Zinc ferrite is not dissolved.

- Zn at high purity level (>99.5) obtained by electrolysis of leached and then purified solution
- Cements rich of Pb

Example of high grade zinc plates (>99.9%)

EAF to reuse various steelmaking by-products

FINES2EAF project (still in progress)

An innovative approach in making agglomeration that allows to use a wider range of by-products

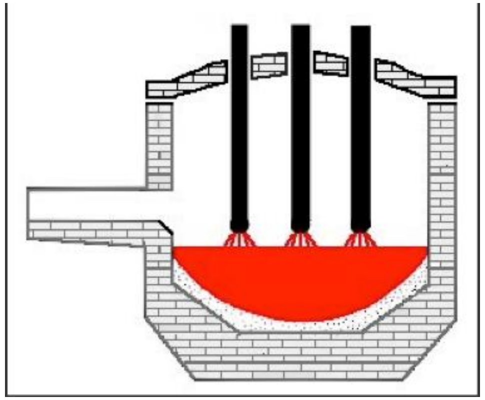
Not only dust but also fines from various steel by-products:

- Fines produced by steel industry include secondary materials (dusts, sludges, scales)
- primary materials like iron ore fines
- sieved undersize alloying materials
- sieved undersize lime or dolomitic lime

Agglomeration

- Briquettes, pellets, bricks
- Self reducing briquettes

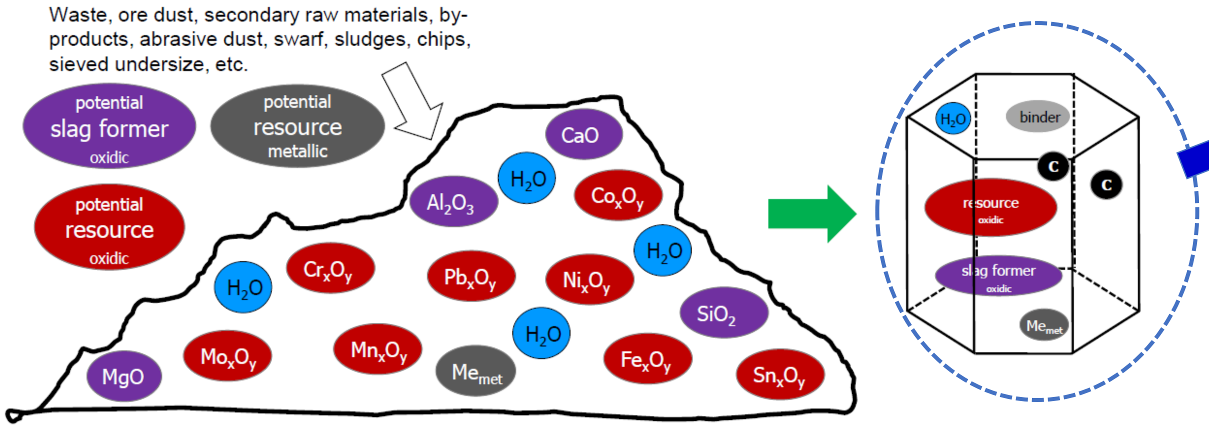
Use in EAF



Menti: 6141 4728

EAF to reuse various steelmaking by-products

The innovative way followed in **FINES2EAF** project approach regards the optimization of the production and then the use in EAF of cement-free bricks with binders and reducing agents that allow a high flexibility in terms of the size of particles in the brick itself.



How the problem is approached

Use of cement-free bricks in EAF

Requires:

- Behavior of bricks under heat-up
- Influence of bricks on slag, metal and process energy
- Control of volatile components in the fines

The **cement-free bricks** with binders allow to have in the same matrix very fine material (<0.02 µm) and coarser material (>18 mm) overcoming the typical limitation concerning this aspect of the *briquetting* and *conventional cement brick*.
The reducing agents that can be used include (apart fossil carbon), biomass or char coal and, considering also an inter-sectorial recycling approach, it can be suitable to use also materials like SiC abrasive dust.

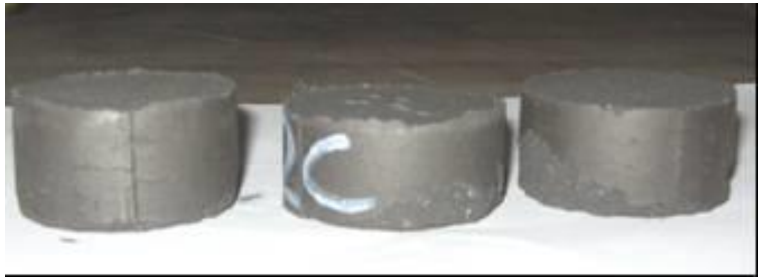
The microwave heating is considered as a proper way to perform a brick pre-treatment in order to reduce the excess of volatiles (e.g. Zn oxides or alkali metals) that can cause problems in off-gas channel or in filter baghouse.

From: T. Echterhof, T. Willms, S. Preiß, M. Omran, T. Fabritius, D. Mombelli, C. Mapelli, S. Steinlechner, I. Unamuno, S. Schüler, D. Mudersbach, T. Griessacher, DEVELOPING A NEW PROCESS TO AGGLOMERATE SECONDARY RAW MATERIAL FINES FOR RECYCLING IN THE ELECTRIC ARC FURNACE – THE FINES2EAF PROJECT, CleanTech4_CT014 (document available on line)

Menti: 6141 4728

EAF to reuse Fe and other heavy metals residue from steel industry

An approach based on the production of briquettes containing high Fe and Cr concentrations from stainless steel production has been used in **URIOM** project.

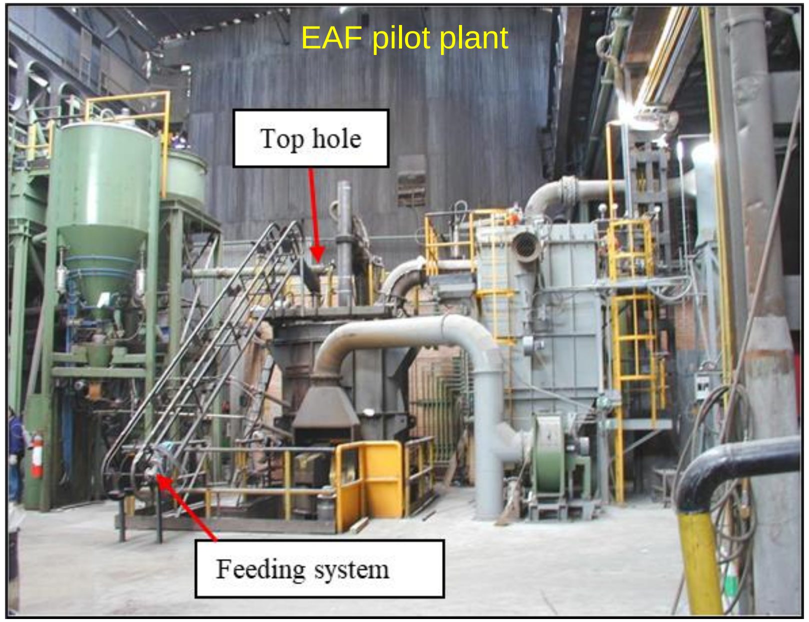


Briquettes

- Wheat flour (binder)
- EAF residues Fe rich (>70%)
- Optimized density (2.7-3.1 g/cm^3, to prevent floating on slag surface)
- Mechanical resistance to handling and long preservation of characteristics during storage (> 3 months in a dry environment).

Tests have been done in pilot scale.
The possibility explored are:

- Briquette charging in a pre-formed bath
- Briquette charging together with scrap



Fe yield more than 90% in both cases

Research Fund for Coal & Steel

5TH ESTAD 2021

REUSteel

Menti: 6141 4728

EAF to reuse Fe and other heavy metals residue from steel industry

The approach of URIOM project includes also a parallel way (respect to the direct recycle in EAF) to recover Fe and Cr from stainless steelmaking residue:

Use of an **inductively heated coke bed reactor** coupled with two possible variants aimed these lasts at pre-treating the oxidic residues

- flash smelter (pre-melting)
- cupola furnace (pre-melting and pre-reduction)

- Fe and Cr recovery from EAF dust
- The residual slag is inert (1.5% Cr, 1.2% Fe)

From testing

- Feasibility of the process for high-Cr EAF slags Fe and Cr recovery.

From modelling

InduCarb reactor and the Flash Reactor tapping during the coupled trials

Menti: 6141 4728

EAF new paradigm and a new attention for the scrap

The limitation due to the availability of scrap with the right quality is a potential problem for the increasing production through EAF route.

The presence of tramp elements in the scrap might limit the use for producing certain steel grades.

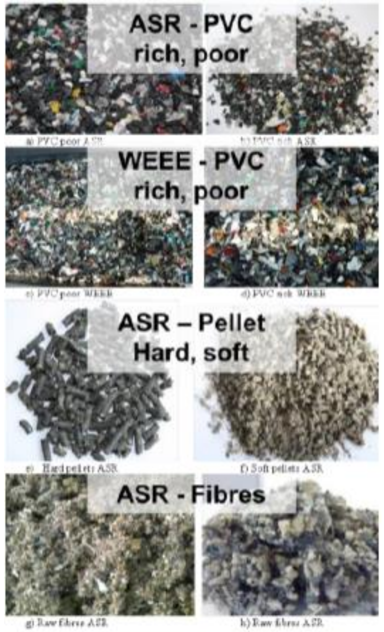
Furthermore, a recover from the scrap of non-ferrous elements such as zinc, tin, copper is also another opportunity to increase the transition towards a greener steel production.

Hence, research efforts on this topic are necessary an are expected as one of the topic of interest for the next years.

Menti: 6141 4728

EAF new paradigm and a new attention for the scrap

The approach of PROTECT project is to use low-value energy rich wastes (plastic fractions) as fuel/reagent combining preheating and surface cleaning of zinc-containing scrap for zinc recovery.



Plastic fractions produced by devoted process

Pyrolysis of waste plastics for a combined scrap pre-heating and surface cleaning process.

A dedicated recovery system for zinc and other metals found in the scrubber solution has been developed

Results:

- ASR can be used for generating a Cl-rich syngas to be used as primary source for scrap pre-heating
- Cleaner off gases from the steel plant
- The surface of scrap is cleaned (no oil, paint etc.)
- The capture of Zn and ZnCl is possible but some difficulties have been found so more work is still needed for this topic. In a similar way, the capture and removal of Hg is possible as well.

Pilot plant

Menti: 6141 4728

EAF new paradigm and new possibilities of synergies with other sectors

The approach of RINFOAM project opens the way to new perspectives. The basic idea is to use waste material blends containing both metal oxides and hydrocarbons as slag foaming agents in the EAF.

Pilot trials

Site 1→ different material mixtures containing anthracite, rubber, Petrit-t and EAF dust

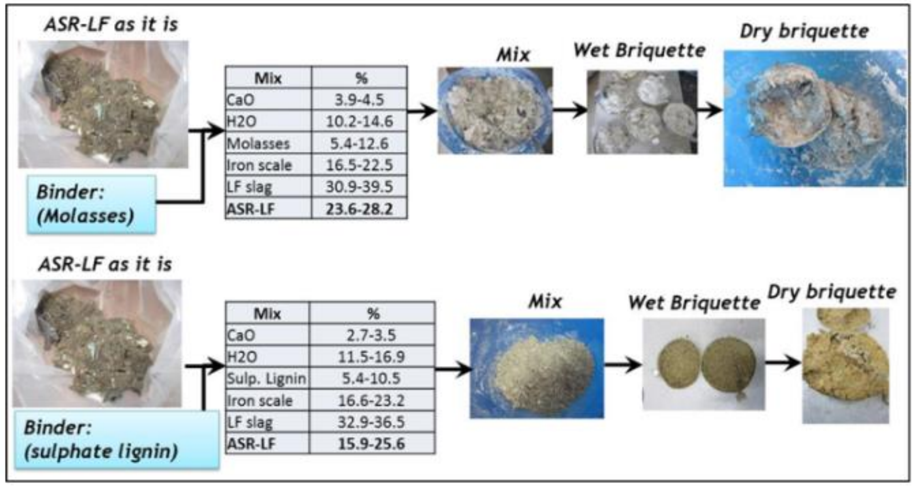
Replacement ratio of anthracite from 20% to 50%

Replacement ratio of oxygen from 2% to 10%

Site 2→ plastic fines, fine rubber powder (end of life tyres), wood sawdust pellets, petroleum coke, ASR, plastic granules

replacement ratio of anthracite from 10% to 30%

Material preparation and production for pilot and industrial tests



Mix	%
CaO	3.9-4.5
H2O	10.2-14.6
Molasses	5.4-12.6
Iron scale	16.5-22.5
LF slag	30.9-39.5
ASR-LF	23.6-28.2

Mix	%
CaO	2.7-3.5
H2O	11.5-16.9
Sulp. Lignin	5.4-10.5
Iron scale	16.6-23.2
LF slag	32.9-36.5
ASR-LF	15.9-25.6

EAF new paradigm and new possibilities of synergies with other sectors

The approach of RINFOAM project opens the way to new perspectives. The basic idea is to use waste material blends containing both metal oxides and hydrocarbons as slag foaming agents in the EAF.

Pilot trials

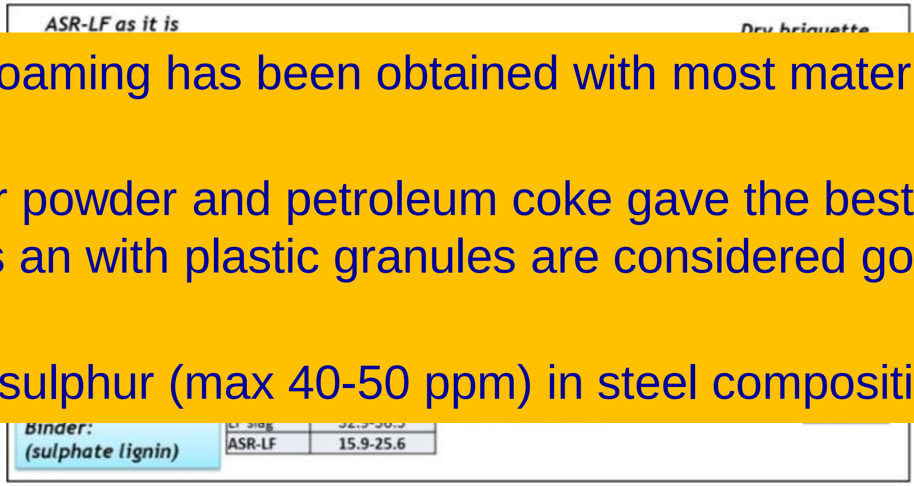
Site 1→ different material mixtures containing anthracite, rubber, Petrit-t and EAF dust

Replacement ratio of anthracite from 20% to 50%
Replacement ratio of oxygen from 2% to 10%

Site 2→ plastic fines, fine rubber powder (end of life tyres), wood sawdust pellets, petroleum coke, ASR, plastic granules

replacement ratio of anthracite from 10% to 30%

strial tests



(**Site 1**) Good foaming has been obtained with most material blends

(**Site 2**) Rubber powder and petroleum coke gave the best foaming results. The results with wood sawdust pellets an with plastic granules are considered good.

An increase of sulphur (max 40-50 ppm) in steel composition is noticed in both cases

EAF new paradigm and new possibilities of synergies with other sectors

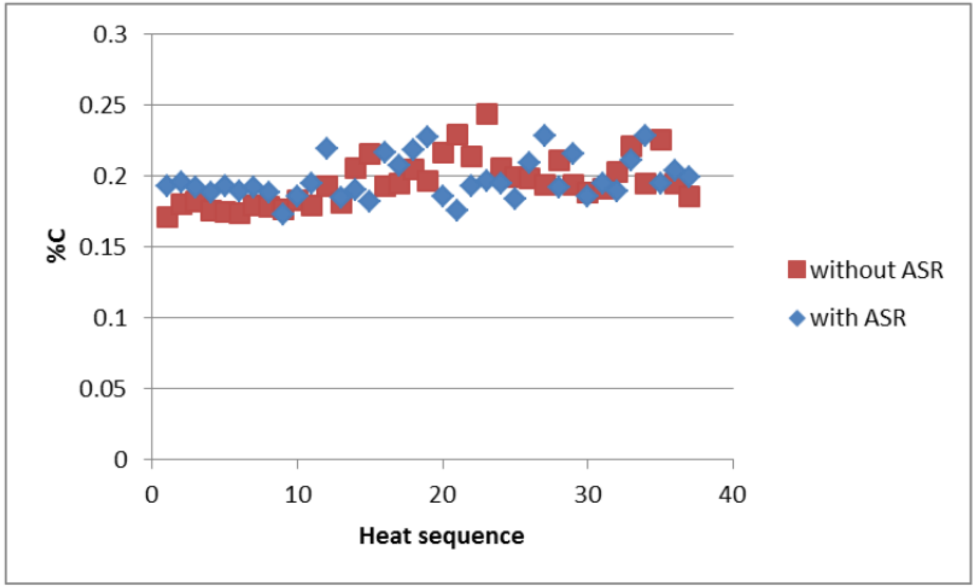
The approach of RINFOAM project opens the way to new perspectives. The basic idea is to use waste material blends containing both metal oxides and hydrocarbons as slag foaming agents in the EAF.

Plant trials in 2 different sites (industrial EAF) gave encouraging results by injection of the selected blends or materials:

- Promising results for both foaming and sulphur content injecting blends containing rubber and EAF-dust
- Good solutions for achieving slag foaming are: coarse rubber powder, petroleum coke, carbonaceous fraction extracted from shredder residue from plastic granules

Plant trials in one additional site (industrial EAF) using ASR

- Found optimal conditions for quantities of ASR per heat charged to have stable EAF operations
- ASR is charged in the first basket. No increase of dust, dioxin level and heavy metal concentration. However, a slight increase of polycyclic aromatic compounds is found.



Industrial trials using ASR in EAF

Research Fund for Coal & Steel

5TH ESTAD 2021

REUSteel

Menti: 6141 4728

EAF new paradigm: towards the CO_2 neutrality

The approach of GreenEAF/GreenEAF2 projects is to use the bio-char and syngas obtained by the biomass pyrolysis as carbon sources for the EAF process

Ideas investigated

BIOMASS

(e.g. forest residue, agriculture residue)

Pyrolysis

Charcoal, tar, syngas

Use in EAF in substitution of

- Coal (charging and injection)
- Natural gas

Menti: 6141 4728

EAF new paradigm: towards the CO_2 neutrality

The approach of GreenEAF/GreenEAF2 projects is to use the bio-char and syngas obtained by the biomass pyrolysis as carbon sources for the EAF process

The study concerned not only the technical aspects related at obtaining the bio-char and the syngas but also the biomass availability preferably near the zones of production.

biomass type	ton	energy (tep*/year)	CO_2 avoided (t/year)
forest residues	218100	40100	93000
ligneous species	66200	12200	28000
agricultural residues	355100	100200	233000
biomass from cultivation	300000	95000	220000
tot	**939400**	**247500**	**574000**

****Equivalent Tons of Petrol: 1 tep=10,000,000 kcal=11,600 kWh***

Example of biomass types and availability in a given zone (Friuli, Italy)

Choice of the technology for char production:

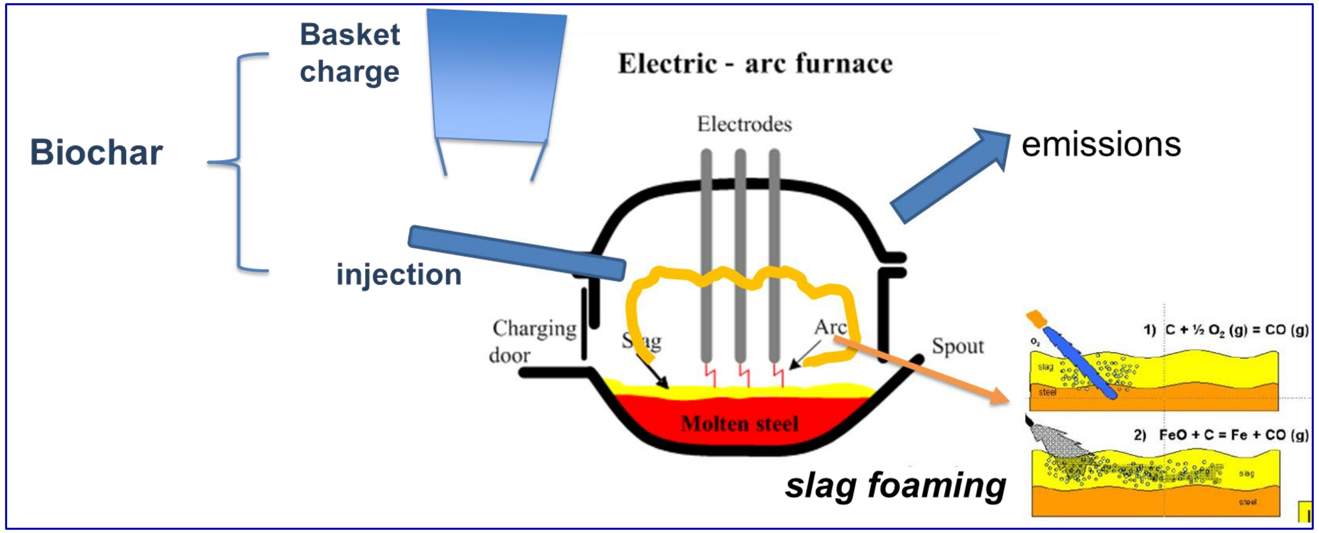
- Pyrolysis
- Torrefaction
- HTC (hydrothermal conversion)

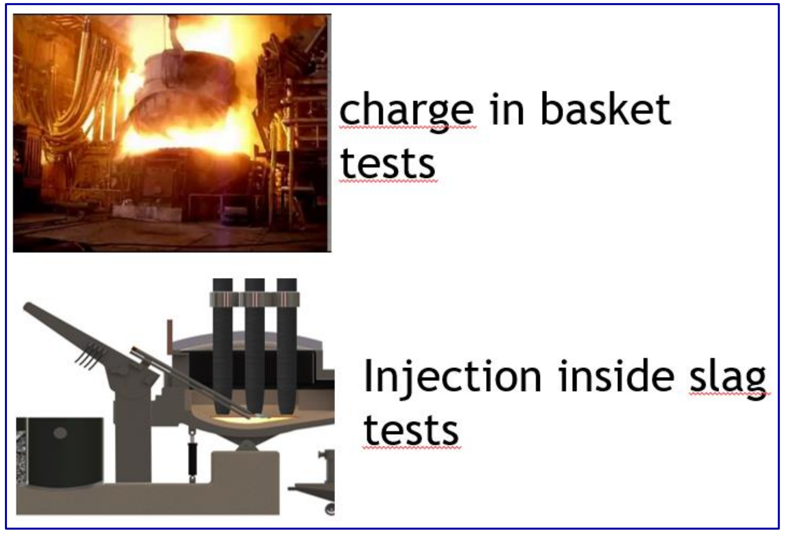
Realisation of an adequate infrastructure

Menti: 6141 4728

EAF new paradigm: towards the CO_2 neutrality

The approach of GreenEAF/GreenEAF2 projects is to use the bio-char and syngas obtained by the biomass pyrolysis as carbon sources for the EAF process





Industrial tests performed in 3 different EAFs with different modalities for using biochar

- Satisfactory results in terms of EAF operations.
- In a perspective view, the installation of technologies of energy recovery from the EAF offgas will further increase the efficiency of the whole process.
- The substitution of 50 to 100% of charge carbon is expected to lead to a reduction of ETS-relevant CO_2 emissions in the range 10-13%
- The economic benefits in substituting fossil coals with torrefied biomass depend on the anthracite price but also on the continuous evolution of legislative, technological and social frame as expected in the next years.

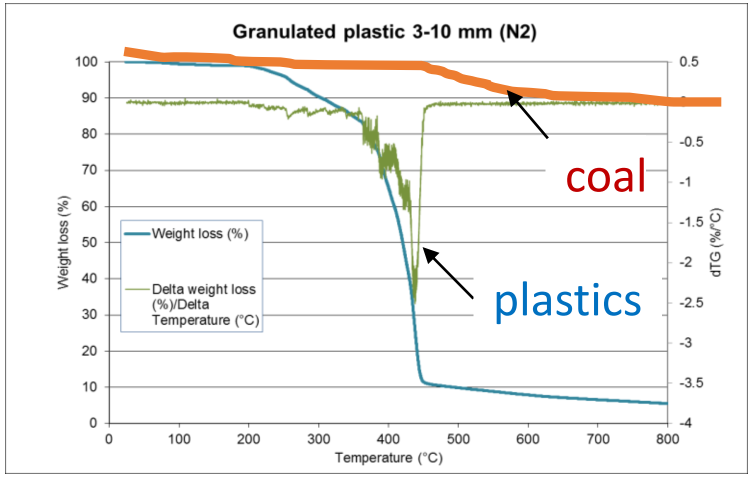
Menti: 6141 4728

EAF new paradigm: towards the CO_2 neutrality

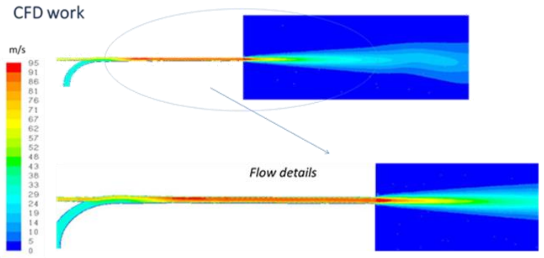
The approach of POLINSPIRE project (in progress) is to use plastic in replacement of fossil coal for EAF operations

The use of plastic has the difficulty related with its thermal behaviour

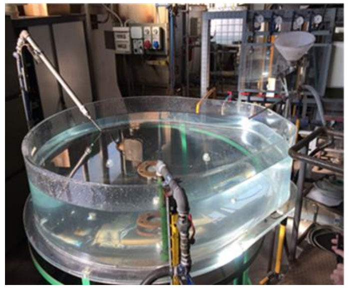
The thermal behavior of the plastic residue sample show that devolatilization is in two phases between 250°C and 450°C. Light organic matters (about 25%) volatilize in the first phase in the range of 250-350°C whereas heavy organic matters (about 75%) volatilize in the second phase in the range of 350-450°C.

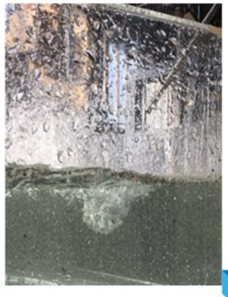


Thermal analysis of granulated plastic 3-20 mm



Injector device designing supported by CFD simulations and by experimental tests with physical model





Characteristics of jet and penetration of the jet into the steel bath determined

Plastic is more suitable for injection under slag rather than for charging in basket

A suitable injection system must be designed. CFD and physical modelling help in designing such system

Research Fund for Coal & Steel

5TH ESTAD 2021

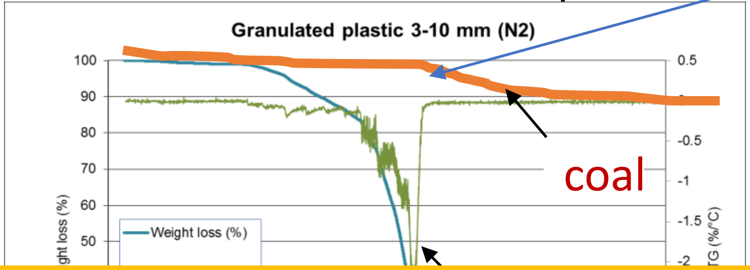
REUSteel

Menti: 6141 4728

EAF new paradigm: towards the CO_2 neutrality

The approach of POLINSPIRE project (in progress) is to use plastic in replacement of fossil coal for EAF operations

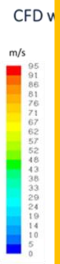
The use of plastic has the difficulty related with its thermal behaviour

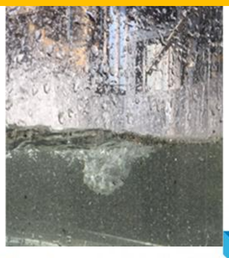


The thermal behavior of the plastic residue sample show that devolatilization is in two phases between 250°C and 450°C. Light organic matters (about 25%) volatilize in the first phase in the range of 250-350°C whereas heavy organic mat

Preliminary results indications from the laboratory indicated that Carburization tests showed dissolution efficiency of 15-20%. This means that during the injection process there is a large emission of gas beneficial for slag foaming.

Industrial testing are on-going





Characteristics of jet and penetration of the jet into the steel bath determined

charging in basket

Concluding remarks

The Electric Arc Furnace, EAF, has an important role in the evolution/revolution of the steel industry.

Recycling is in DNA of the EAF, which was born to produce new steel melting scraps.

From a simple melting machine, the EAF evolved, becoming a complex flexible reactor, able to handle alternative materials and fuels, promoting circular economy in the steel industry and the first fundamental step of the decarbonization.

Projects like FINES2EAF, URIOM, RINFOAM, GREENEAF demonstrated the possibility to perform adequate EAF operations having at the same time the chance to recycle and reuse different steel by-products and external by-products giving also the possibility to organize synergic activities with other industrial sectors, human communities and moving at the same time towards a lower environmental impact.

Menti: 6141 4728

Thank you for listening

Umberto Martini – umberto.martini@rina.org

Menti: 6141 4728

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

Merging our ideas for improving and enhancing residual materials valorization in the steel sector: final discussion.

Menti: 6141 4728

Preparing a Roadmap for by-products reuse and recycling in the steel sector

Long term industrial needs in steel industry :

- Internal and external utilization of by products
- Zero Waste
- CO_2 mitigation technologies

Technological trends:

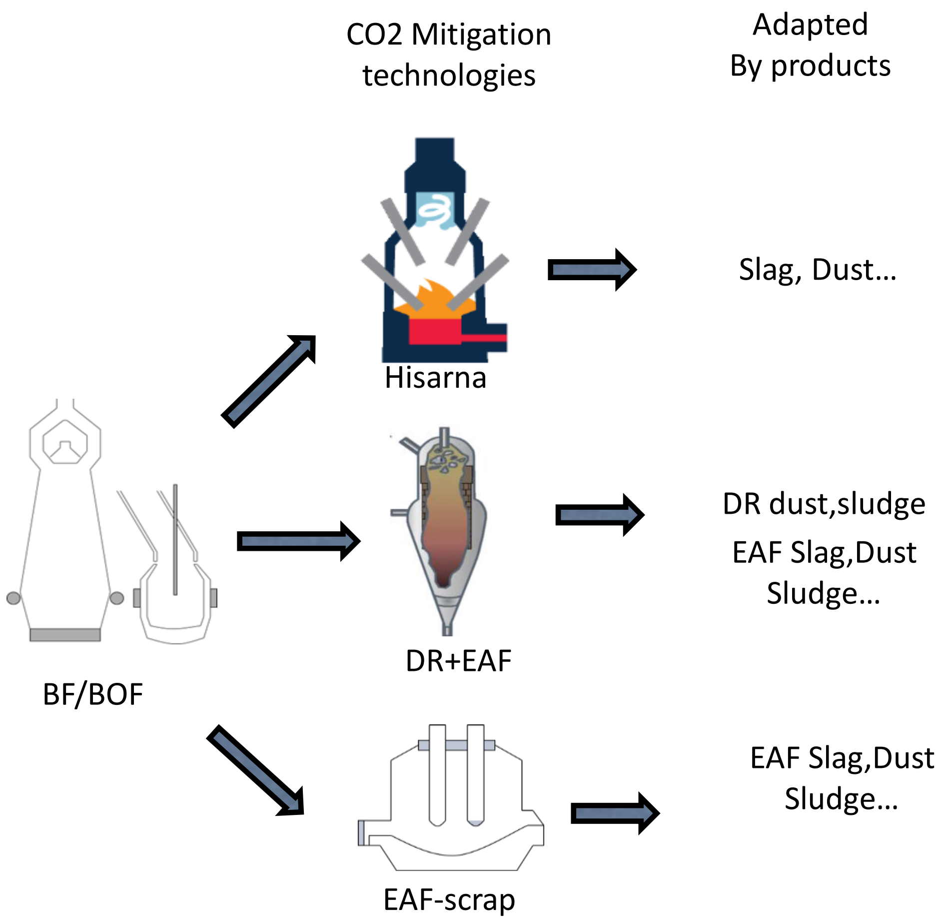
- Carbon Direct Avoidance (CDA)
- Smart Carbon Usage (SCU)

Challenges, Constraints:

- Structural barriers,
- EU and national regulatory framework

Research needs:

by-products reuse and recycling



Research Fund for Coal & Steel

5TH ESTAD 2021

Menti: 6141 4728

REUSteel

What major obstacles do you see for reuse and recycling of residual materials?

Contamination

Melting yield

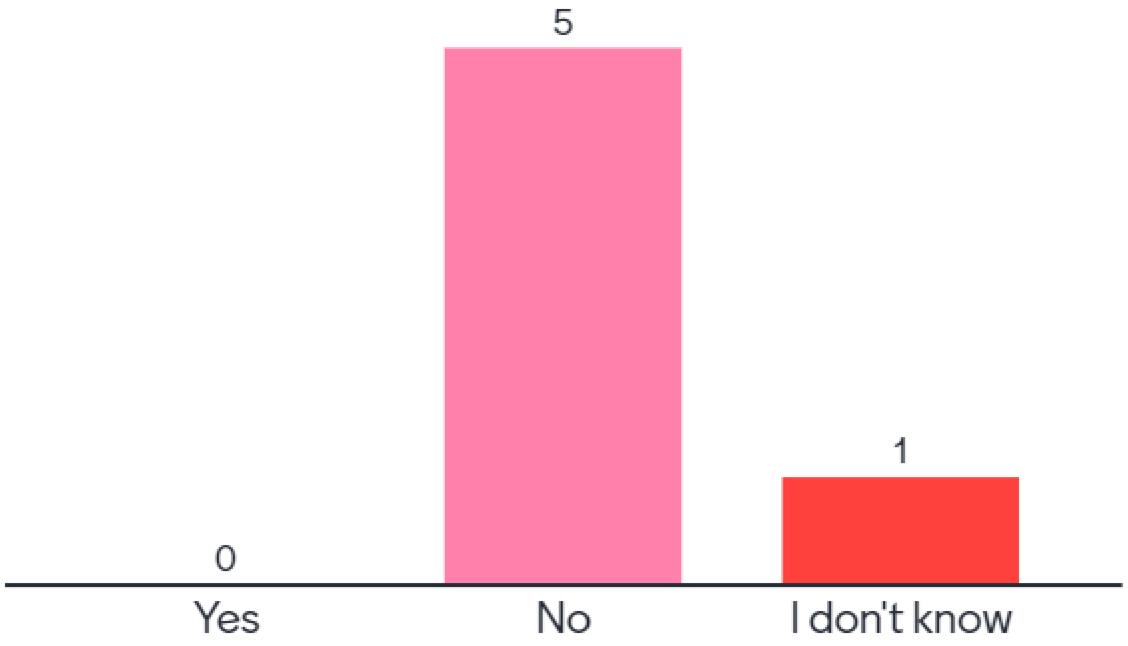
Customer and authority knowledge/education

Answer to the question regarding obstacle : main obstacle is meltling yield of low sized scraps (lots of oxide)

Quality of Input material is getting worser so recycling will be more difficult

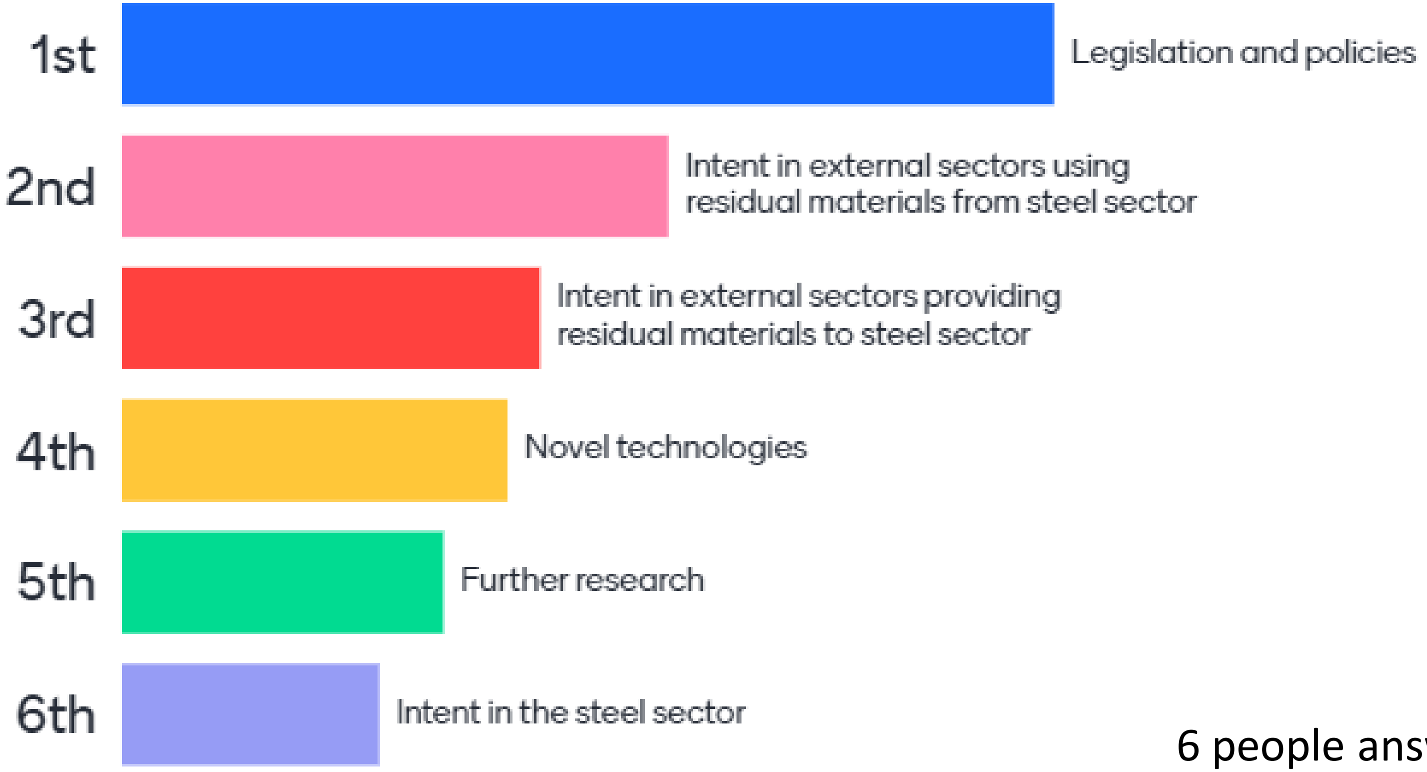
Menti: 6141 4728

Is the legislation in your country supporting use of residual materials?



Menti: 6141 4728

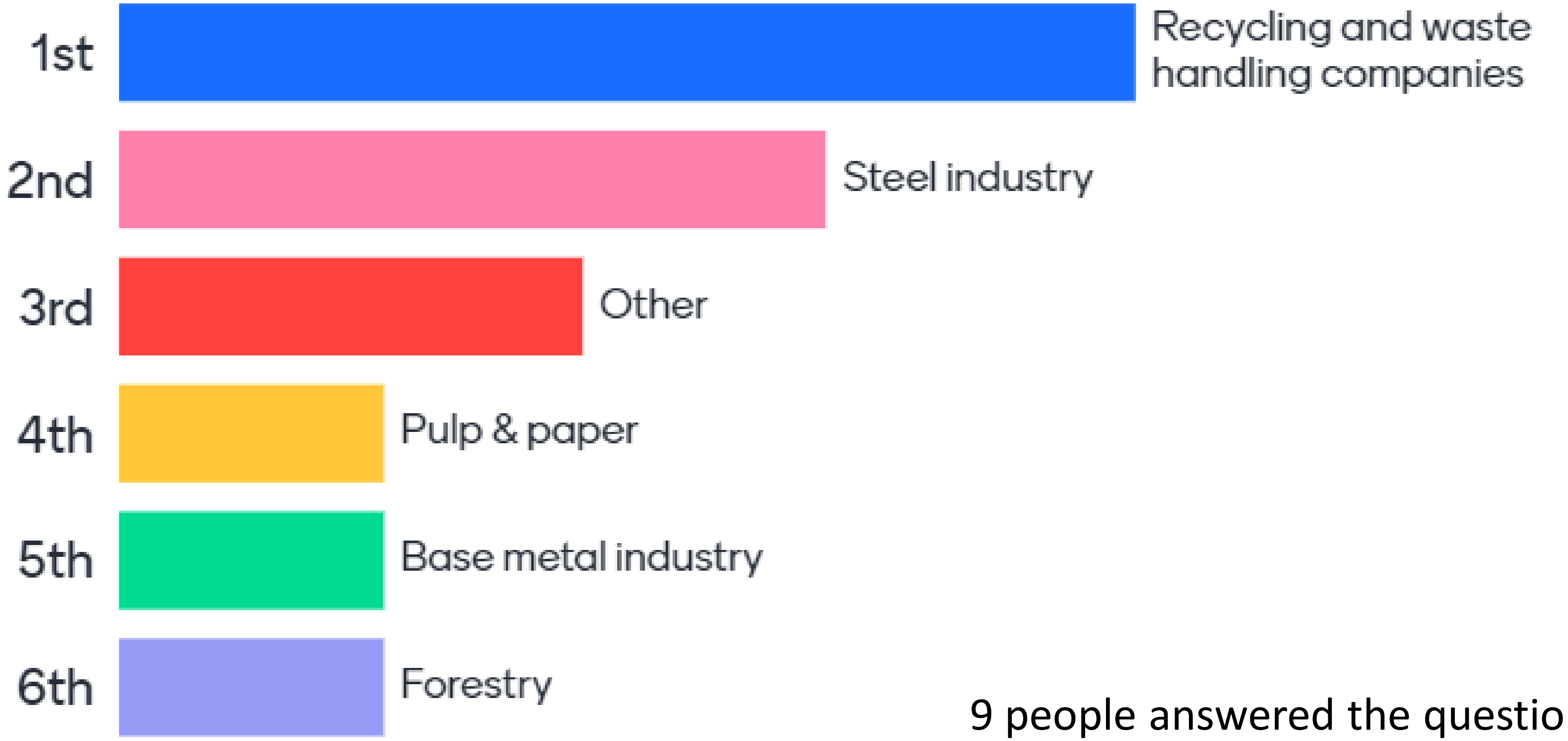
How important are the following factors for promoting reuse and recycling in the steel industry?



6 people answered the question.

Menti: 6141 4728

Who benefits most from use of external residual materials in steel making?



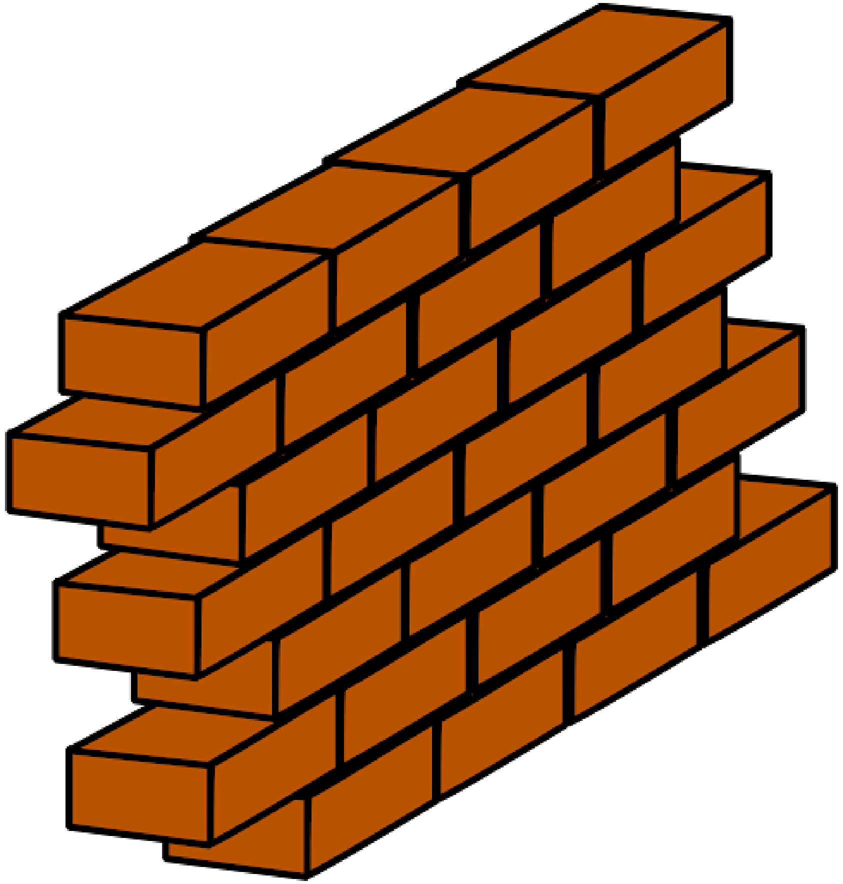
9 people answered the question.

Menti: 6141 4728

What is the greatest possibility for novel reuse and recycling in the steel industry in the near future?

Menti: 6141 4728

What are the non-technical barriers to the diffusion of novel reuse and recycling practices in EU of steel industry by-products /residual materials ?



Menti: 6141 4728

Can digital technologies and tools be effective in enhancing reuse and recycling of residual materials?

Menti: 6141 4728

Our Questionnaire

https://it.surveymonkey.com/r/P6728HB

Menti: 6141 4728

www.reusteel.eu

Menti: 6141 4728