Project[1] Number: 709740

Project Acronym: DissTec

Project title: Valorisation and dissemination of technologies for measurement, modelling and control in secondary metallurgy

Periodic Technical Report

Part B

Period covered by the report: from 01/07/2016 to 31/12/2017

Periodic report: 1st

[1] The term 'project' used in this template equates to an 'action' in certain other Horizon 2020 documentation

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1. Explanation of the work carried out by the beneficiaries and Overview of the progress

The evolution of secondary steelmaking processes, starting in the 1960s on a broad basis, brought about the effective production of high quality steel grades. The processes of ladle metallurgy determine the properties of liquid steel in terms of chemical composition, cleanness and also casting temperature, and thus to a large extent also of the final steel products.

The importance of secondary steelmaking processes is also reflected in the European research activities. Within the framework of the ECSC and RFCS steel research programme, in the last 20 years around 60 projects with focus on secondary metallurgy have been funded. They provided a significant contribution towards the present high level of technology within secondary metallurgy processes, aiming at improving process performance, with particular focus on technologies for measurement and control of liquid steel properties within tight tolerances, with high reliability and under minimum energy and resource consumption.

However, because of the large variety of subjects, distributed within the different projects and shared among many research and industrial partners with poor synergy, the impact of the project results on industrial practice is much lower than potentially achievable. Also so far no clear indication of the most useful future developments and requirements for research activities was provided.

The basic idea is that an action of dissemination and valorisation of the most important research results, based on an integrated critical analysis of funded ECSC and RFCS projects, is useful to valorise, distribute and promote the exploitation of the results. Also this action is a necessary step for preparing and communicating a roadmap for future research activities and priorities. The enhanced dissemination of RFCS project results is also recommended in the recently published monitoring and assessment reports on RFCS programme [61]. A RFCS dissemination project on Electric Arc Furnace technology called VALEAF [62] has been successfully completed by the end of 2015. So far, this was the only dissemination project that has been organised to valorise the immense work carried out on steelmaking process developments. Thus, a complementary dissemination project focussing on Secondary Metallurgy technologies is a logical continuation of the work of spreading the results of European research in this field among the steelmaking community.

1.1 Objectives

The objectives of the dissemination project DissTec were to analyse, valorise and disseminate the most important results obtained in ECSC and RFCS research on technologies for the different secondary metallurgy processes. Based on a critical analysis of the project results, the most promising development lines and innovative solutions were to be identified, and the industrial exploitation of gained knowledge and successful technological solutions in the European steel plants was to be encouraged. Also future technological developments and priorities for research subjects and activities in Secondary Metallurgy technology were to be identified.

These general objectives can be broken down as follows:

- To promote the dissemination of the knowledge gained and the technological solutions introduced in relevant projects on Secondary Metallurgy
- To identify present merits and limitations of the various technological solutions, as well as the spread of their implementation in the European steel plants.
- To identify most promising and most useful emerging development lines and to encourage the use of best results and innovative solutions, taking into account possible technological barriers
- To identify future developments, to produce a clear and realistic picture of the future trends to be expected in Secondary Metallurgy technology
- To supply guidelines for the next developments of Secondary Metallurgy technologies, to give indications on priorities for research subjects and activities
- To suggest a clear road map for the technological development in this field.

The dissemination activities comprised the following actions:

- Set-up of a web site to allow the access to the results of the project analysis, the presentations of seminars and workshops and the road map for future developments
- Seminars on dedicated topics
- Webinars with demonstration of successful applications
- A workshop for information exchange and open discussion, especially regarding the identification of future developments and definition of a road map

The dissemination project dealt with the different secondary metallurgy processes being used in the steel plants of the European Union to produce high quality steel via the oxygen and electric steelmaking route. Thus it covered the production of carbon and stainless steel grades as well as low, medium and high alloyed quality steel grades via the different aggregates and processes of secondary metallurgy, as:

- Ladle Furnaces
- Ladle Stirring stations
- Vacuum tank degassing plants
- RH degassing plants
- CAS(-OB) plants
- VOD plants
- AOD converters
- Tundishes at the continuous casting plant

The project partners of the DissTec project were the main steel research institutes in Europe:

- VDEh-Betriebsforschungsinstitut (BFI), Düsseldorf, Germany (Coordinator)
- Centro Sviluppo Materiali (CSM), Rome, Italy
- Centre de Recherches Metallurgiques (CRM), Liege, Belgium
- Swerea MEFOS, Lulea, Sweden
- Materials Processing Institute (MPI), Teesside, UK

1.2 Explanation of the work carried out per WP

1.2.1 Bar chart with comparison of actual project performance with initial planning

The project was performed according to the project bar chart (**Table 1**) which had been defined in the DoA.

Table 1: Project bar chart

Work package	*Work package title*	*Delive-rables*	1st year				2nd year	
			I	II	III	IV	I	II
WP 1	**Project coordination**							
Task 1.1	Organisation of project meetings							
Task 1.2	Reporting	D 1.1						
Task 1.3	Supervision of the project							
Task 1.4	Preparation of publications	D 1.2						
WP 2	**Collection of information**							
Task 2.1	Collection and assessment of research projects	D 2.1						
Task 2.2	Identification and categorisation of project results	D 2.2						
Task 2.3	Analysis and evaluation of project results	D 2.3						
WP 3	**Preparation and support of dissemination actions**							
Task 3.1	Documentation of project analysis results	D 3.1						
Task 3.2	Generation of a web site	D 3.2						
Task 3.3	Preparation of material for dissemination	D 3.3						
WP 4	**Performance of seminars, webinars and workshops**							
Task 4.1	Planning and promotion of dissemination events	D 4.1						
Task 4.2	Preparation and holding of seminars	D 4.2						
Task 4.3	Preparation and holding of webinars	D 4.3						
Task 4.4	Organisation and holding of workshop for road map	D 4.4						
Task 4.5	Evaluation of dissemination events							
WP 5	**Preparation of road map**							
Task 5.1	Identification of industrial needs and trends							
Task 5.2	Evaluation of technological challenges							
Task 5.3	Identification of research needs							
Task 5.4	Preparation of a road map	D 5.1						

For most of the tasks deliverables were defined. **Table 2** shows the list of deliverables with their title, lead beneficiary, type, dissemination level as well as due and actual date. Most of the deliverables were submitted in due date. Some delays in D4.2 and 4.3 occurred, as seminars and webinars were held later than originally scheduled. Also the road map definition was performed with a slight delay, in conjunction with the periodic report, as among others the feedback of a questionnaire, which was set up after the final workshop, was evaluated for this purpose.

Table 2: Table of deliverables

Deliverable Number	Deliverable Title	WP Number	Lead Beneficiary	Type	Dissemination level	Due Date (in months)	Actual Date (in months)
D1.1	State of the art	WP1	1 - BFI	Report	Confidential	3	3
D1.2	Abstracts for publication in journals and conferences	WP1	1- BFI	Report	Confidential	18	19
D2.1	List of projects of interest for valorisation and dissemination	WP2	1- BFI	Report	Public	3	3
D2.2	Report with classification of issues and topics for secondary metallurgy technology	WP2	5 - MEFOS	Report	Confidential	6	6
D2.3	List with categorisation of the impact of the research results	WP2	2 - CSM	Report	Confidential	9	9
D3.1	Project database set up	WP3	5 - MEFOS	Websites, patents filling, etc.	Public	9	9
D3.2	DissTec Web site generated	WP3	1 - BFI	Websites, patents filling, etc.	Public	6	6
D3.3	Dissemination material prepared	WP3	2- CSM	Websites, patents filling, etc.	Public	9	9

Deliverable Number	Deliverable Title	WP Number	Lead Beneficiary	Type	Dissemination level	Due Date (in months)	Actual Date (in months)
D4.1	Schedule of dissemination events	WP4	1 - BFI	Report	Public	6	6
D4.2	Holding of seminars completed	WP4	1 - BFI	Websites, patents filling, etc.	Public	15	17
D4.3	Holding of webinars completed	WP4	2 - CSM	Websites, patents filling, etc.	Public	15	17
D4.4	Holding of workshop completed	WP4	1 - BFI	Report	Public	17	17
D5.1	Road map for future research and development directions in secondary metallurgy	WP5	4 - MPI	Report	Public	18	20

1.2.2 Work Package 1: Project coordination

The dissemination project DissTec was carried out in a short time with a limited budget. To carry out the activities rapidly and in strong collaboration among the partners, the work had to be accurately coordinated and continuously monitored. Also the schedule of the dissemination events had to be kept up to date continuously. The coordination work was split into 4 tasks.

a) Task 1.1 Organisation of project meetings (Lead BFI, with involvement of all partners)

Meetings to favour the exchange of information and to distribute the work among the partners were organized, in order to define the European projects that must be collected, evaluated and prepared for the dissemination events, in order to valorise the results achieved in the projects. After a face-to-face kick off meeting, which was held at BFI on the 05.07.2016, several further face-to-face meetings were organised in connection with the seminars and the workshop which were held within the project. Furthermore several telephone conferences and WebEx meetings were held to discuss the analysis results and to decide on the next actions and the schedule of the dissemination events.

An important coordination work was to precisely distribute the tasks for study and evaluation of the various projects to disseminate and the responsibility for dissemination among the partners. For this purpose each project partner took care of a subset of projects, in terms of identification of merits and results as well as target audience for dissemination.

b) Task 1.2 Reporting (All partners)

Reports were written in connection with the various deliverables (see Table 2), in order to describe project activities and progress, as well as the obtained results. The partners' responsibility for the different deliverable reports is also indicated in Table 2. The coordinator BFI had to assign to the various partners the sections of the documents to be prepared, to guarantee the due times for preparation and to check the suitability of the contribution to the objectives and programme of the project. The deliverable reports were submitted by the project coordinator.

The objectives and first results of the DissTec project were presented and discussed at the TGS 2 expert meeting held in Castellanza, Italy on the 30.-31. of May 2017.

Finally the Periodic Technical Report was prepared by all partners and will be presented at the next TGS 2 spring meeting to be held in Brussels on the 24.-25. of April 2018.

c) Task 1.3 Supervision of the project (BFI)

A tight supervision of the project was required to avoid overlapping of activities and the compliance with the objectives foreseen in the scheduled periods of time. For this purpose the coordinator organised a continuous exchange of information and documents, and supplied clear indications for the next steps of work. This was of high importance, as the project

intended to disseminate the results of a large number of projects, carried out by several different consortia.

The supervision task also included the management of the project web site, for documentation of the project results, collection of information and publication of presentations at the seminars, webinars and workshops. Also the time schedule of the dissemination events had to be kept up to date throughout the whole project duration.

d) Task 1.4 Preparation of publications (All partners)

The results of the DissTec project, with focus on the performed dissemination events and the definition of a road map for future developments and research activities in secondary metallurgy, shall be presented at technical / scientific conferences as well as in technical journals. For this purpose, in parallel to the elaboration of the final report an abstract of the project results was already drafted:

Abstract for publication in journals and conferences

'Disseminating results of RFCS supported research projects on Secondary Metallurgy Technology'

In the frame of the European Research Fund for Coal and Steel (RFCS programme), in the last 20 years many research and demonstration projects have been carried out on different aspects of Secondary Metallurgy technology, aiming at improving the process performance in terms of liquid steel quality, energy and resource optimisation and flexibility. This effort contributed to the development of a number of technological solutions in terms of process modelling, measurement systems and process control.

Within the RFCS programme, in 2016 and 2017 the project "Valorisation and dissemination of technologies for measurement, modelling and control in secondary metallurgy" (DissTec) was carried out in the frame of an "accompanying measure" project. This project aimed at analysing and promoting the most important results of European research projects dealing with the different aspects of Secondary Metallurgy technology.

The paper will present the applied methods as well as the achieved results and deliverables of the dissemination work performed in the DissTec project.

It will cover the critical analysis of the results obtained in 60 EU funded projects with respect to the following topics:

- *measurement technologies for the quality relevant parameters of liquid steel*
- *process models*
- *on-line control approaches*
- *connected auxiliary materials (refractories, stirring plugs, ...)*
- *clean steel aspects*

The most important results in these fields were selected for valorisation and dissemination within a series of seminars, webinars and workshops, which turned out to be a useful step forward to promote the exploitation of the findings, and to provide a clear picture of the current status of European SecMet technology. Finally future industrial targets and requirements for further research activities were identified, and a roadmap for future developments of Secondary Metallurgy technology was defined.

The DissTec consortium intends to present the project results at the following conferences to be held within the next two years:

- Clean Steel 2018
- 8th European Oxygen Steelmaking Conference (EOSC) 2018
- 4th European Steel Technology & Application Days (ESTAD) 2019
- 12th European Electric Steelmaking Conference (EEC) 2020

Furthermore the results are intended to be published in the following technical journals:

- Stahl & Eisen
- Steel research
- La Metallurgia Italiana
- Steel Times International
- Ironmaking & Steelmaking

1.2.3 Work package 2: Collection, analysis and organisation of available information of research results in secondary metallurgy

The main objectives of Work Package 2 were the:

- Final definition of the list of ECSC and RFCS projects on secondary metallurgy which are of interest for dissemination and valorisation within the defined scope of topics
- Assignment of the projects to different sub-topics according to their main results
- Selection and categorisation of the knowledge achieved and the innovative technological solutions derived from the selected projects
- Identification of reasons for success or failures of the research activities carried out in the selected projects

a) Task 2.1 Collection and assessment of the relevant projects of secondary metallurgy (All)

The first step of work was to finalise a list of ECSC and RFCS projects which shall be the basis for the evaluation and dissemination work. For this purpose, the preliminary list of projects which had already been set up within the state of the art description of the proposal was completed by adding further projects and by removing projects which turned out to be not relevant with respect to the scope of the selected topics.

In total 60 European projects which have been performed in the time period from 1990 until today have been selected. 35 of them were ECSC projects (1990 – 2005) [1 - 35], and 25 were RFCS projects (2006 – today) [36 - 60]. A table of the selected projects with key data was set up and provided as deliverable D 2.1, see **Table 3**.

Table 3: List of evaluated ECSC and RFCS projects [1-60]

Nr	Number of contract	Title	Acronym	Report number	Participants	Start date	End date	Abstract
1	7210-CB/107	Development of process technology and metallurgy for extremely low and strictly limited nitrogen contents	/	EUR 14483 DE	BFI	1989-01-01	1990-12-31	To satisfy requirements for steel with low nitrogen contents and steels with very precise nitrogen contents, fundamental data on denitrogenation in liquid steelmaking were applied to develop a thermodynamic and kinetic model.
2	7215-CA/107	On-line analysis of molten steel for automated steel production (1st phase)	/	EUR 15184	TK Nirosta, ARBED, KRUPP Elektronik, Krupp Forschung, Univ. Madrid	1989-04-01	1991-03-31	The objective of this pilot project was to build and test an on-line analysis system for monitoring and measuring the change in concentration of various elements in liquid steel by laser-induced spectroscopy. The measurement system was tested for monitoring the carbon content in an AOD converter.
3	7210-CC/104	Development of a model for the vacuum circulating process		EUR 16186 DE	BFI	1990-08-01	1994-01-31	The objective of this project was to develop a detailed dynamic model for decarburisa-tion in the RH process, which can be used for on-line monitoring of the process behaviour.
4	7210-GD/109	Fast multi-element on-line analysis of steel melts by means of laser technology - Development of a novel method for laser emission spectrometry (Phase I)	/	EUR 16632	Inst. Siderugie Francais, Fraunhofer, TKSE	1991-12-01	1993-11-30	This project intended to develop the use of a modulated laser to excite specific emission peaks for certain elements over wavelengths compatible with the use of optical fibres. The results were to be used to develop a rapid system for analysing liquid steel bath composition.
5	7210-GD/409	Direct trace element analysis by AES with a high energy source (Phase II)	/	EUR 16702 IT	CSM	1991-07-01	1993-12-31	This project intended to continue previous development work and produce an AES source for increased accuracy and sensitivity of element analysis in liquid steel of at least an order of magnitude compared with classic analytical techniques.
6	7210-CC/805	Optical sensing of temperature and stirring conditions in ladle furnaces	/	EUR 18365 EN	British Steel	1992-07-01	1995-06-30	The aim of this project was to develop new techniques for the measurement of stirring, inclusion entrainment and steel temperature in a ladle furnace and to exploit these techniques with the aim of balancing demands for fast working with steel cleanness and energy efficiency.
7	7215-EB/10	Continuous measurement and analysis of liquid steel (BOF)	/	/	DH, CRM, Inst. Siderugie Francais, Klöckner Stahl	1993-07-01	1996-06-30	Within this project a device was installed at a BOF converter, which is capable of continuously measuring temperature using pyrometry techniques as well as analysing the carbon and phosphorus contents of the liquid metal. Excitation will be based on laser beam techniques.
8	7210-CC/109,110,701	Process Modelling, Process Measurements and Control to Optimise Secondary Steeelmaking in the Production of Super Clean Steels	/	/	GMH, British Steel, RWTH, BFI, Sidenor, CSM, Uni Patras, VDEh	1993-07-01	1996-12-31	This project improved the performance of secondary steelmaking vessels by developing techniques of process modelling, measurement and control of slag, vacuum and temperature parameters. Bubbling and vacuum techniques were employed for production of super-clean steels.
9	7210-CB/122,312,941	Low Nitrogen in EAF steelmaking	/	EUR 19349 EN	Inst. Siderugie Francais, ACENOR, RWTH	1995-07-01	1998-12-31	The low nitrogen content required for highly ductile steel grades (strips, bars, wire) is not usually achieved in conventional, 100% scrap-based EAF steelmaking. The aim of the research was to establish the feasibility and the features of an industrial process for producing low nitrogen (50 ppm and less) steels in the EAF, using scrap as iron source.
10	7210-MA/319, 320	High nitrogen stainless steels by AOD / VOD process	/	EUR 19417	IRSID, Creusot-Loire Industrie	1995-07-01	1998-12-31	Within this project, the thermodynamics of nitrogen alloying in stainless steelmaking by bottom stirring during ladle treatment under atmospheric pressure were investigated, and a model for description of the nitrogen behaviour was developed.

Nr	Number of contract	Title	Acronym	Report number	Participants	Start date	End date	Abstract
11	7210-CC/116,407,117	Improvement of vacuum circulation plant operation on the basis of the BFI simulation model	/	EUR 19488 EN	BFI, Voest Alpine, CSM	1995-07-01	1999-06-30	Within this project a simulation model of the vacuum circulation process (RH) for decarburization of steel was extended to include further metallurgical operations such as stirring, gas input, oxygen blowing, dehydrogenation and nitrogen control and to improve process control of RH plants.
12	7210-CC/121/122/936	Dynamic modelling and control of the vacuum degassing process	/	EUR 19484 EN	Buderus, Sidenor, BFI	1996-07-01	1999-06-30	Within this project a process control system for vacuum treatment in ladle degassing stations or similar facilities was developed. By means of dynamic process models for decarburization, desulphurisation, denitrogenation and dehydrogenation, the vacuum treatment time was predicted.
13	7210-CC/114	Improvement of cleanness and fine-grain structure of Ca-treated and Al-deoxidised steels with a high S content made by continuous casting of billets and blooms	/	EUR 19486	TU Bergakademie	1995-07-01	1999-06-30	In this research project the process routes: - EAF-LFV; - LD-RH-degassing, were optimized for production of Al-deoxidized steel grades with S- contents. Ladle metallurgy and process engineering were investigated for the production of these critical steels with high cleanness requirements.
14	7210-GD/120	Sensitivity enhanced laser analysis of steel melts for fast multi-element on-line analysis during ladle processing in secondary metallurgy	SELA	EUR 19411	Fraunhofer, RWTH, RAUTAUUKKI, TKSE	1996-07-01	1998-06-30	The goal of this research project was the performance evaluation of fast multi-element, on-line laser analysis during ladle processing in steel metallurgy with determination limits of less than 10 ppm, especially for carbon, phosphorus, sulphur and nitrogen.
15	7210/CC/302/303/809	Development of techniques to minimise ladle/slag interaction and prevent uncontrolled inclusion modification	/	EUR 19485	IRSID, British Steel, SOLLAC	1996-07-01	1999-06-30	The main goals of this project were to identify detailed mechanisms of mass transfer from refractory lining of ladles towards steel regarding carbon pick-up by ultra-low carbon steels and contamination by glazed ladle lining from previous casts, to improve process practices in ladle that minimise both aspects and thus to contribute to a better control of steel inclusion populations and of steel composition.
16	7210-PR/009	Control of inclusions in RH degassing processes	/	EUR 20179	IRSID, Corus UK, CRM, BFI	1997-07-01	2000-12-31	The main aim of this project was to develop, test and validate physical and CFD modelling techniques for the evaluation of RH vacuum degasser performance with respect to steel cleanness.
17	7210-PR/011	Dynamic process control of AOD converter	/	EUR 20177	CSM, AST, KTN, BFI	1997-07-01	2000-12-31	A dynamic model for decarburisation and temperature behaviour within the AOD process was developed, based on balance calculations for carbon, oxygen and energy and used off-gas analysis and flow rate values to determine the decarburisation rate and the current carbon content.
18	7210-PR/010	The use of artificial intelligence to control secondary steelmaking practices	/	EUR 28178	British Steel, CSM, Krupp, BFI	1997-07-01	2000-12-31	The objective of this project was to develop tools and techniques based on artificial intelligence to monitor the performance of heat treatment and to calculate alloy material requirements throughout the complete secondary steelmaking route.
19	7210-PR/207	Operation and control of vacuum circulation (RH) process with lance oxygen input	/	EUR 21435	BFI, voestalpine, Sollac Fos, Technometal	1997-07-01	2000-12-31	The objective of this project was to develop dynamic models for decarburisation and steel temperature behaviour within the RH degassing process with oxygen top lance, and to use these models for on-line observation and control of the lance oxygen input.
20	7210-PR-080	Desulphurisation of liquid steel with refining top slags	/	EUR 20474	Voest, CSM, DH, BFI	1997-07-01	2000-12-31	The objective of this project was to investigate the influencing parameters of the desulphurisation reaction via the ladle top slag in detail, and to optimise the process with respect to slag control and refining kinetics.

Nr	Number of contract	Title	Acronym	Report number	Participants	Start date	End date	Abstract
21	7210-PR/079	Control of inclusion, slag foaming and temperature in vacuum degassing	/	EUR 20562	MEFOS, ACCIAERIE, OVAKO Sidenor, BFI	1998-07-01	2001-06-30	The objective was to develop a new concept for on-line control of the vacuum degassing process. The concepts were based on techniques as the modified OES method, radio-wave interferometry technology for slag level measurements and temperature measurements by thermovision camera.
22	7210-PR/135	Production of EAF steels with low contents in N2 and S through vacuum treatment	/	EUR 20945 EN	Sidenor, ProfilARBED, IRSID, MEFOS, BFI	1999-07-01	2002-06-30	Development of dynamic models for denitrogenation and desulphurisation in vacuum degassing for production of low-alloyed steels via the electric steelmaking route.
23	7210-PR/136	Characterisation and optimisation of ladle stirring systems for the steelmaking industry	/	EUR 20946 EN	voestalpine, TKS, Sidenor, DIFK, BFI	1999-07-01	2002-06-30	The project's aim was to improve the reliability and efficiency of the ladle stirring process. Different stirring systems were investigated with regard to their reliability, efficiency and wear.
24	7210-PR-168	Improved production control through rapid characterisation of non-metallic inclusions in steel	/	EUR 21627 EN	TKSE, Boehler, EKO, Fraunhofer, Inst. Siderugie Francais	1999-07-01	2002-06-30	Aim of the project was to develop a fast and robust laser- method characterising inclusions over a large area or volume that can be integrated into the process control.
25	7210-PR/138	Chromium-free alternative refractory for the lining of RH/DH vessels	/	EUR 21335	Arcelor, Corus NL	1999-09-01	2002-08-31	The goal of this project was to find solutions to avoid the dumping of RH refractory wastes in special costly landfills by substituting magchrome bricks by chromium-free materials among the magnesia-spinel group.
26	7210/PR/206	The Determination and elimination of the effect of Anti-Oxidants in Magnesia-Carbon bricks on steel composition and inclusion formation	/	EUR 21446 EN	Corus UK, CSM, DIFK, Saarstahl	2000-07-01	2003-12-31	This project investigated the effects of anti-oxidant materials in MgO-C bricks on steel clearness and ladle life. A rapid analysis technique, using Laser Induced Breakdown Spectroscopy (LIBS), to detect trace elements and inclusions was also developed. LIBS was successful in mapping element distributions in refractory, slag and metal. Inclusion detection is compared with SEM methods and advantages of LIBS in speed of analysis are defined.
27	7210-PR-204	Innovative continuous on-line determination of the steel melt temperature by direct optical measurement in the melt	/	EUR 21428 EN	ACERALIA, CRM, BFI	2000-07-01	2003-12-31	In this project a new method for a continuous temperature measurement of liquid steel by pyrometer with optical fibre measurement technology was developed. The new system was tested and optimised on several steel plants including EAF furnaces, BOF converters, ladles and tundishes.
28	7210-PR-270	Improvement of inclusion flotation during RH treatment	/	EUR 22388 EN	Inst. Siderugie Francais, CSM, RWTH, BFI	2001-07-01	2004-06-30	The objective of this project was to develop a validated model of prediction of the evolution of the inclusion population during RH treatment, to evaluate the effect of ladle slag composition on the capture of inclusions and finally to propose an optimised flotation process at the RH unit.
29	7210-PR-271	In situ, quick sensing system for measurements of process-critical components in steelmaking slags	INQUISS	EUR 22818	Aceralia, Acerinox, Helliniki, Inst. De Soldadura e Qualidade, Unv. Malaga, Univ. Patras, RWTH	2001-07-01	2004-06-30	The aim of this project was the adaptation and optimisation of laser-based sensing (LIBS) in plant processing conditions, to develop a quick/on-line, in-situ measurement system of process-critical components of molten slags. Different metallurgical slags in steelmaking (EAF, Converter and Ladle) were used, and the determination oxides was achieved by detection of their elemental concentration.
30	7210-PR/300	In-line assessment of steel cleanness during the secondary steelmaking process	/	EUR 22032 EN	AM Reserach, CREAS, CRM, Sidenor	2001-07-01	2004-06-30	The aim of this project was to work out an appropriate steel cleanness index, to be used for in-line quality assessment during secondary steelmaking process. Another objective was to complete the information obtained in this way with a more precise knowledge of the inclusion size and distribution using statistical/stereological tools and distribution models. This ladle treatment in-line control was based on the fast and simultaneous determination of the steel and slag chemistry.

Nr	Number of contract	Title	Acronym	Report number	Participants	Start date	End date	Abstract
31	7210-PR/269	Improvement of process control and refractory performance of the AOD converter	/	EUR 21974	Terni, CSM, TK Nirosta, BFI	2001-07-01	2004-06-30	This project was the continuation of work performed within the previous ECSC project 7210-PR/011. To improve the accuracy in on-line observation of the carbon content, a thermodynamic decarburisation model was developed. Furthermore the process observation system was extended by a thermodynamic model for the nitrogen content. On the basis of this model, a control concept for the nitrogen inert gas supply was developed, to adjust the aim nitrogen content under minimum costs.
32	7210-PR/329	De-oxidation practice and slag ability to trap non-metallic inclusions and their influence on the castability and steel cleanliness	/	EUR 23194 EN	ACERALIA, CSM, RWTH, Sidenor, Inst. Siderugie Francais	2002-07-01	2005-06-30	The aim of this research was to evaluate the inclusion properties and final steel cleanness regarding deoxidation practice and the slag ability to trap non-metallic inclusions.
33	7210-PR/330	Development of advanced methods for control of the ladle stirring process	/	EUR 22988 EN	ACERALIA, MEFOS, Saarstahl, Sidenor, BFI	2002-07-01	2005-06-30	Development of innovative methods for continuous on-line monitoring of ladle stirring processes by means of digital image analysis applied to melt surface, and by means of vibration measurements
34	7210-PR/331	Improved control of inclusion chemistry and steel cleanness in the ladle furnace	/	EUR 23593	MEFOS, CORUS, CSM, UDDEHOLM, BFI	2002-07-01	2005-06-30	The objective of the project was to enhance the control of inclusion chemistry and steel cleanness in the ladle furnace, regarding the process operation practice with respect to stirring patterns and slag practice.
35	7210-PR-332	Optimisation and evaluation of different secondary metallurgy routes to achieve high quality strip steel	/	EUR 23888	Voest, Corus, TKSE, HKM, BFI	2002-07-01	2005-06-30	The proposed research project aims at the optimisation and evaluation of different production lines to achieve high quality steel grades for strip production. The possibilities of Ca treatment in the production of these steel grades were clarified. Several secondary metallurgy lines were considered and practices for an optimised treatment by ladle furnace, RH degassing and tank degassing combinations in-line with vertical-bending slab casters and thin slab casters were worked out.
36	RFSR-CT-2003-00008	Investigations and measures to reduce emissions and energy consumption during preheating of steel ladles	IMSTEELLAD	EUR 23175 EN	Terni, CSM, Gerdau, TK Nirosta, BFI	2003-09-01	2006-12-31	The goal of this research project was to optimise the ladle preheating procedure for emissions and energy consumption. For that purpose also a ladle temperature control model was developed.
37	RFSR-CT-2003-00016	Cost efficient metallurgy for the production of novel ultra high strength deep drawable steel grades with high Mn contents from 10 to 25 wt.-%	PROMS	EUR 22991 EN	SZFG, Mefos, TU Clausthal	2003-09-01	2006-12-31	The aim of the project was the selection and development of suitable technologies of primary and secondary metallurgy for the production of ultra-high strength deep-drawable steels with high manganese contents these steels with an emphasis on the BOF route.
38	RFSR-CT-2003-00043	Feasibility of a fast vacuum slag analysis by laser OES in secondary steelmaking	AVAS	/	DH, AM Maizieres, Fraunhofer, Saarstahl	2003-09-01	2006-08-31	The feasibility of a fast slag analysis at the vacuum degasser for better production control in secondary steelmaking was demonstrated with the emphasis on SiO2, CaO and Al2O3. The comparability with XRF measurements (directly on casted slags and/or after preparation) was investigated by performing a round robin trial within the partners.
39	RFSP-CT-2004-00006	Application of direct optical temperature measurement in steelmaking process	DOT Application	EUR 23736 EN	DH, BFI	2004-07-01	2007-06-30	In this P&D project the temperature evolution in the BOF converter during oxygen blowing was continuously monitored to improve end point control. Therefore a measurement system was developed using an optical fibre which is continuously fed into the melt.
40	RFSR-CT-2005-00013	Innovative tundish management for final steel thermal and chemical adjustment	TUNDJUST	EUR 24348 EN	CSM, BFI	2005-07-01	2008-06-30	Alloying techniques were defined and applied via CaSi/FeS wire injection; inclusion engineering was performed via material poured into a pad. For temperature control, local reheating was successfully achieved with exothermic powders at the surface above the exits; a model for online control of steel temperature was set up and validated with plant data for operational purposes. The innovative character of the work consisted of the application in a 'continuous' reactor (tundish) of metallurgy operations typically exploited in a ladle ('batch' reactor). The application leads to cost savings allowing further steel composition/temperature control after ladle treatment.

Nr	Number of contract	Title	Acronym	Report number	Participants	Start date	End date	Abstract
41	RFSR-CT-2005-00005	Improvement of purging plugs performances by investigations on the materials, process analysis and continuous monitoring	ImPurgingAr	EUR 24987 EN	CSM, Terni, Calderys Italia, BFI	2005-07-01	2009-06-30	The objective of this research project was the improvement of the purging plugs performance for ladle Ar stirring. The objective is to improve the plugs selection and management in order to enhance their performances. Overall result was to set up a model of general application of the correlations between the process and the behaviour of the plugs.
42	RFSR-CT-2005-00006	Prediction of inclusions in the slabs from the process characteristics	PREDINC	EUR 24992 EN	AME, ILVA, Politecnio Milano, RWTH, Scuola Superiore Sant´Anna, Aalto, U. Oviedo	2005-07-01	2008-12-31	The aim of this project was to develop a system capable to determine the quality in the field of inclusions of steel before and during its production, in order to change the setups to improve it. Two ways of model development were carried out: classical thermodynamic calculation and data-based analysis.
43	RFSR-CT-2006-00018	Grain size control in steel by means of dispersed non-metallic inclusions	GRAINCONT	EUR 24993 EN	KTH, AM Maizieres, Comdicast, CRM, Aalto U.	2006-07-01	2009-06-30	Within this project research work was carried out to control steel composition and temperature in the tundish, and to perform inclusion engineering. The research work was supported by fluid dynamics management, aimed at favouring dissolution of materials for alloying and inclusion modification, and at allowing the identification of injection techniques. A model for online control of steel temperature was set up and validated with plant data for operational purposes.
44	RFSR-CT-2006-00005	Cost efficient metallurgy for the production of novel ultra high strength deep drawable steel grades with high Mn contents from 10 to 25 wt.-% by using EAF steel making route	EAF-PROMS	EUR 24225 EN	SZFG, Mefos, TU Clausthal	2006-09-01	2008-12-31	The aim of the work was the selection and development of suitable technologies of primary and secondary metallurgy for the production of ultra high-strength deep-drawable steels with high manganese contents with emphasis on the EAF route.
45	RFSR-CT-2007-00004	Online control of desulphurization and degassing through ladle bubbling under vacuum	ONDECO	EUR 25091 EN	AM Maizieres, DH, Voestalpine	2007-07-01	2010-06-30	Development of image and vibration sensors to qualify the stirring state during LF treatment and VD degassing and use it as input for a desulphurisation model
46	RFSR-CT-2007-00009	Improvement of ladle stirring to minimise slag emulsification and reoxidation during alloying and rinsing	STIMPROVE	EUR 25068 EN	KTH, Saarstahl, Aalto Univ. BFI	2007-07-01	2010-06-30	Development of digital infrared image analysis and theoretical models to assess stirring process parameters and clarify their interaction with steel metallurgy
47	RFSR-CT-2007-00011	Development of steel grade related slag systems with low reoxidation potential in ladle and optimised ladle glaze technique for improving steel cleanness	STEEL-CLEAN-CONTROL	EUR 25076 EN	TU Freiberg, KTH, SSAB, TK Nirosta, Uddeholm	2007-07-01	2010-06-30	Investigation of interaction between deoxidised steel melts and oxidic materials during ladle metallurgy. Development and practical verification of optimised slag compositions and treatment strategies for inclusion voidance and removal for improved steel cleanness.
48	RFSR-CT-2007-00007	Resource-saving operation and control of stainless steel refining in VOD and AOD process	OPCon-Stainless	EUR 25087 EN	Kobolde, KTH, Outokumpu, SMS Mevac, Arconi, BFI	2007-07-01	2010-06-30	The objective of the project was to improve the operation and control of stainless steel refining within the VOD and the AOD process with respect to the main metallurgical operations. This was achieved by detailed investigations with CFD based process models, and by application of dynamic models for on-line observation and control of the process.
49	RFSR-CT-2008-00006	Active tundish metallurgy	AcTuM	EUR 25875 EN	Aalto U., DEW, Technalia, Gerdau Investigation, OVAKO BAR, TATA UK, Bergakademie Freiberg	2008-07-01	2011-06-30	The project aimed at improved, better guaranteed steel cleanness by applying tailored tundish slag with high capacity to efficiently absorb macro- and micro-inclusions from different steels. Fundamental studies on factors influencing inclusion removal and inclusion cleanliness in tundish as well as thermodynamic calculations showed that more basic slag would lead to a more effective tundish slag having higher capacity to absorb inclusions compared to standard practice.
50	RFSR-CT-2008-00003	Optimized production of low C and N steel grades via the steelmaking route	LOWCNEAF	EUR 25869 EN	BFI, AM Olaberria, CRM, Gerdau, PTG, Riva	2008-07-01	2011-12-31	Within this project through process control strategies were developed for the reliable achievement of low C and N contents within the EAF route under minimum costs. In this context dynamic process models for the EAF for on-line calculation of C and N content, and for the VD plant regarding degassing and temperature behaviour were applied at several plants.

Nr	Number of contract	Title	Acronym	Report number	Participants	Start date	End date	Abstract
51	RFSR-CT-2008-00044	Enhanced reliability in ladle refining processes (VD, VOD and LF) by improved on-line process monitoring and control	LAREFMON	EUR 25947 EN	AMR, Gerdau Voestalpine, BFI	2008-12-01	2011-11-30	The objective of this project was to improve the reliability of vacuum degassing and ladle furnace treatment by joint application of new thermal imaging-based evaluation of stirring efficiency and improved dynamic process models. Enhanced online monitoring and control systems were developed and applied for reliable control and improved performance of the main metallurgical ladle refining processes. Among others, an IR-camera was successfully applied to monitor the melt bath surface during VD treatment.
52	RFSR-CT-2009-00003	Enhanced steel ladle life by improving the resistance of lining to thermal, thermomechanical and thermochemical alteration	Ladlife	EUR 26689 EN	Gerdau I+D, CSM, BFI, Lucchini	2009-07-01	2012-06-30	Ladle refractory wear is an important concern for steelmakers, not only for the material cost but also for its influence on plant productivity and safety. This project aims at enhancing ladle lining life, helping steelmakers in decisions about materials to use and in scheduling of maintenance operations. This will be achieved by model based soft sensors and laboratory work. The wear of ladle lining is mainly due to its cyclic interaction with steel and slag during its normal operation. The understanding of the chemical, thermo-chemical and thermo-mechanical reactions in the metal-slag-refractory system is the key to reach the planned goal.
53	RFSR-CT-2010-00003	Multi-criteria through-process optimisation of liquid steelmaking	TOTOPTLIS	EUR 26931 EN	CSM, AME, Lucchini, PTG, BFI	2010-07-01	2013-12-31	Main objective of this on-going project is the development of a through-process optimisation for the liquid steelmaking route. Real-time monitoring and predictive models, using process and sensor data from different aggregates, shall be integrated for a multi-criteria optimisation of material and energy input regarding quality, productivity and costs. A dynamic modification of the planned process route will be suggested in case of deviations in quality relevant parameters.
54	RFSR-CT-2010-00005	Increased yield and enhanced steel quality by improved deslagging and slag conditioning	OPTDESLAG	EUR 27438 EN	Mefos, Saarschmiede, SSAB, BFI	2010-07-01	2013-06-30	In this project, CCD and infrared cameras and imaging systems were installed to monitor and improve ladle deslagging operations. Based on the image analysis the amount of remaining slag on the melt bath was estimated. The latter information was used as additional input for a slag balance model, to calculate slag amount and composition throughout ladle treatment and to derive set-points for slag former additions.
55	RFSR-CT-2011-00004	Intelligent cleanness control in secondary steelmaking by advanced off-line and on-line process models	IntCleanCon	EUR 27832 EN	Tecnalia, Gerdau, DEW, BFI	2011-07-01	2014-12-31	Within this project CFD and on-line prediction models were developed and applied for advanced industrial control strategies and practices in secondary metallurgy, in order to guarantee highest steel cleanness levels for high quality steels. On-line control strategies, based on a combination of through-process models and new monitoring and control techniques for stirring during ladle metallurgy processes, were used for reliable achievement of improved cleanness and castability
56	RFSR-CT-2012-00005	Stirring plug monitoring system for improvement of plug availability and stirring performance	PlugWatch	not yet published	Terni, CSM, DEW, Gerdau, BFI	2012-07-01	2015-06-30	The aim of this research project is the development and installation of online monitoring systems for stirring plugs in steel ladles in order to determine and predict their availability and performance for stirring processes.
57	RFSR-CT-2013-00030	Environmental impact evaluation and effective management of resources in the EAF steelmaking	EIRES	still running	Scuola Superiore Sant´Anna, CSM, Dalmine, DEW, Gerdau, Ori Martin, RIVA, Tecnalia, BFI	2013-07-01	2016-12-31	This ongoing project aims at defining a methodology for the assessment of the environmental impact of EAF steelmaking plants. Emissions into air, water and soil, as well as energy, water and wastes management, properly measured and weighted, will contribute to the definition of a global index. Moreover, simulation models for the plants of the EAF steelmaking route will be developed to predict the environmental impact of process modifications.
58	RFSR-CT-2014-00006	Improving steelmaking processes by enhancing thermal state ladle monitoring	LADTHERM	still running	AMB, Gerdau, KTH, BFI	2014-07-01	2017-12-31	This project aims to monitor the thermal state of steelmaking ladles during secondary steelmaking operations. Refractory temperature measurements will provide online information to accompanying thermal models for the ladle lining. This is a new input parameter for ladle thermal state monitoring systems to optimize the use of thermal energy stored in the ladle lining.
59	RFSR-CT-2015-00004	Dynamic stirring for improvement of energy efficiency in secondary steelmaking	DYNSTIR	still running	CSM, GMH, KTH, Udeholm, BFI	2015-07-01	2018-06-30	The project objective is to improve ladle stirring by developing dynamic stirring policies in secondary steelmaking at different treatment stations (CAS-OB, VD and FT). In heat-individual dynamic stirring, the stirring process will be tailored to the individual need of each treated steel melt, based on metallurgical fundamentals, with the aim to improve the energy efficiency of the ladle stirring processes while maintaining the cleanness of the final product. Imaging and vibration measurement systems will be used to monitor the actual stirring, compare it to the ideal treatment according to the stirring policies and advise correct stirring accordingly.
60	RFSP-CT-2015-00026	Plant wide control of steel bath temperature	PlantTemp	still running	GMH,BFI	2015-07-01	2018-06-30	The objective of this P&D project is to develop an operator advisory system for through-process monitoring and control of the liquid steel temperature in order to improve the accuracy in meeting the target casting temperature with minimisation of energy and material consumptions. The through-process control system shall be based on enhanced dynamic models and measurement procedures covering the complete process chain of electric steelmaking from the superheating phase in the EAF up to the end of the casting process in the tundish.

The review work of these selected projects, to prepare a solid basis of knowledge and technologies to valorise and disseminate, was shared among the project partners. In most of the projects on Secondary Metallurgy carried out in ECSC and RFCS at least one of the DissTec project partners was involved, so that the distribution of the evaluation work was

obvious. The projects where none of the project partners was involved were distributed among the partners according to their main expertise (measurement, modelling, control) in the field of secondary metallurgy.

b) Task 2.2 Identification and categorisation of the most significant results (All partners)

The dissemination of the research results was limited to the technologies which allow a relatively easy transfer to various plants throughout the European steel industry, i.e.:

- measurement technologies for the quality relevant parameters of liquid steel (temperature, composition of steel and ladle slag, concentration and composition of non-metallic inclusions)
- process models (analytical, thermodynamic, statistical, CFD-based, off-line simulation, on-line dynamic for monitoring and control, …)
- on-line control approaches (manufacturing execution systems, set-point and alloy calculations, regulation and control, through-process control for the whole chain of secondary steelmaking, ….)
- connected auxiliary materials (refractories, stirring plugs, …)
- environmental aspects (reduction of emissions, re-use of by-products, …)

Investigations which were purely focussed on fundamental research or metallurgical quality issues were excluded from the dissemination activities, as the direct transferability of such results to industrial application was expected to be limited.

The list of topics has been divided into the five above mentioned categories where each category comprises a number of sub-topics with respect to the main topic. The five main topics have been broken down into the following sub-topics:

1. **Measurement technologies for the quality relevant parameters of liquid steel**
   1.1. Temperature
   1.2. Composition of steel and ladle slag
   1.3. Concentration and composition of non-metallic inclusions
   1.4. Ratio of steel and slag at melt bath surface
2. **Process models**
   2.1. Analytical thermodynamic
   2.2. Statistical
   2.3. CFD- and physical-modelling
   2.4. Off-line simulation
   2.5. On-line dynamic for monitoring and control
3. **On-line control approaches**
   3.1. Manufacturing execution system
   3.2. Set-point and alloy calculation
   3.3. Regulation and control
   3.4. Through-process control for whole chain of secondary steelmaking
   3.5. Online monitoring of process conditions

4. **Connected auxiliary materials**
   4.1. Refractories
   4.2. Stirring plugs
   4.3. Slag formers and slag control
5. **Resources efficiency and environmental aspects**
   5.1. Reduction of emissions
   5.2. Energy efficiency
   5.3. Resource efficiency and alloy yield improvement
   5.4. Re-use of by-products

The 60 ECSC and RFCS projects on secondary metallurgy processes which had been selected for evaluation and dissemination within the DissTec project (see Table 3) were evaluated and categorised regarding the relevant topics and sub-topics.

Figure 1 shows the percentage of each main relevant topic with respect to the total number of projects. As can be seen, the focus of more than 40% of the projects is on Topic 1, (measurement technologies), which is in line with the current trends on plant management (see also the findings of the Dissemination Project VALEAF, RFSR-CT-2014-00002, on EAF technology). In contrast to that the subject of "resource efficiency and environmental aspects" (Topic 5) is covered by just 3% of the projects. This was different in the VALEAF project, where this topic was of higher importance for EAF technology.

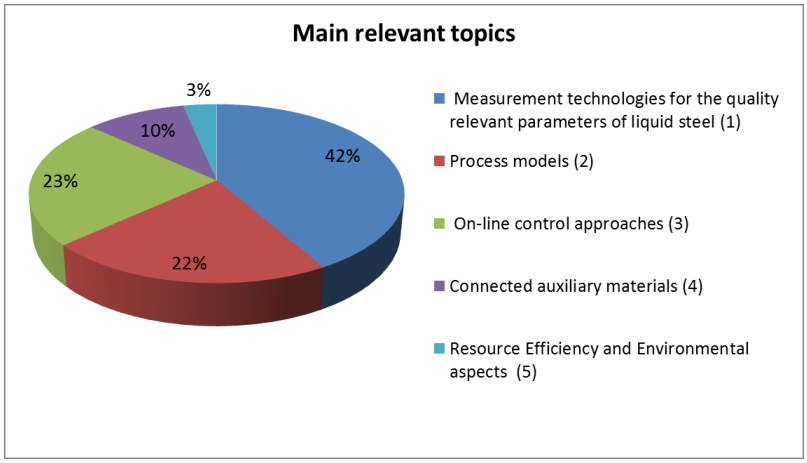


Figure 1: Distribution of main relevant topics

Furthermore, as many projects were investigating more than one topic, the major objective of that project was identified and tagged as "main relevant topic", and other topics were considered as "further relevant topics". **Figure 2** shows the distribution of "further relevant topics" covered by the projects. The figure shows that the topic of "process models" has the largest frequency as a supportive subject followed by "on-line control". It also shows that the "resource efficiency and environmental aspects" is more favoured as a supportive subject (10%) compared to the main topic (figure 1). However, the "resource efficiency and environmental aspects" is still the least among all the topics even as a supportive subject. As a consequence, it was decided that, different to the preliminary schedule, the topic "resource

efficiency and environmental aspects" seems not to be suitable to be treated in one of the seminars.

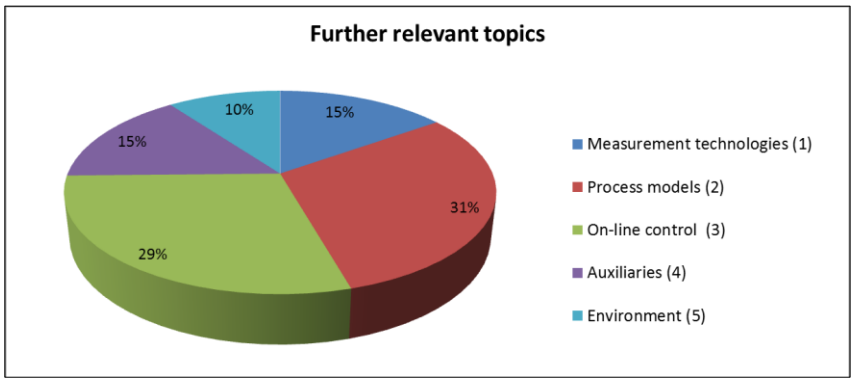


Figure 2: Distribution of further relevant topics

In addition, the 60 ECSC and RFCS projects on secondary metallurgy processes have been classified regarding the involved aggregates of secondary metallurgy. It should be mentioned that the project scope was also extended to the tundish practice as well. For this purpose the aggregates and processes were categorized as follows:

- Ladle furnace (LF)
- Ladle stirring station (AS)
- Vacuum tank degassing plant (VD)
- RH degassing plant (RH)
- CAS(-OB) plant (CAS)
- VOD plant (VOD)
- AOD converter (AOD)
- Tundish (TUN)

As can be seen in **Figure 3**, the evaluated projects on secondary metallurgy processes were assigned to seven out of the 8 different main aggregates. The most relevant was found to be the Ladle Furnace. Additionally it should be mentioned that almost 20% of the projects which have been evaluated were relevant, on a more general level, for all of the secondary metallurgy process steps and aggregates listed above.

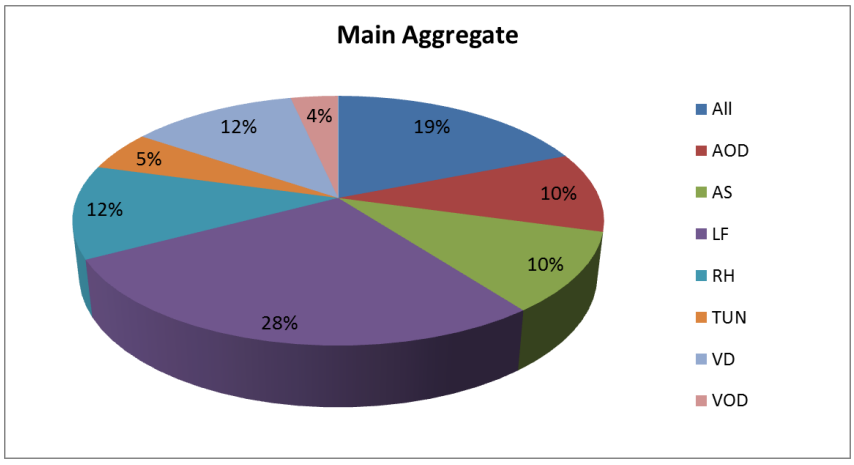


Figure 3: Distribution to the main secondary metallurgy aggregates

Furthermore, as many projects were dealing with more than only one secondary metallurgy aggregate, these were considered as "further aggregate". **Figure 4** shows the distribution of "further aggregates" covered by the projects. In this view on the projects, the vacuum degassing plant (VD) has the largest relevance.

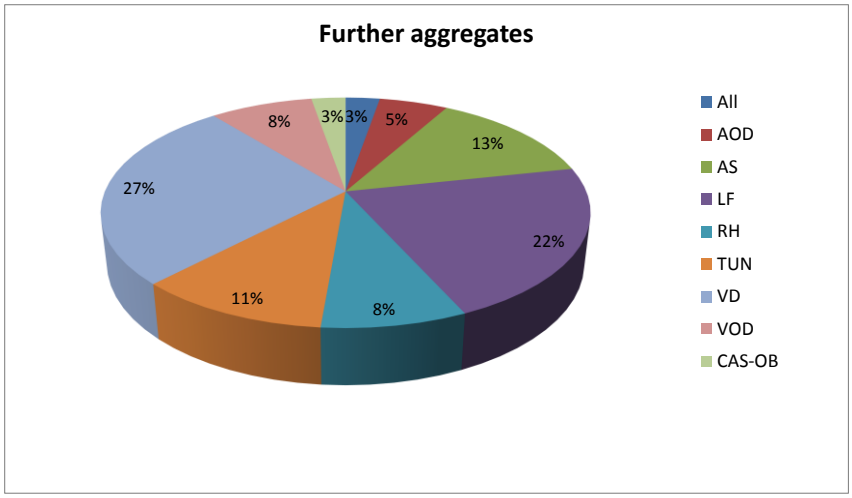


Figure 4: Distribution to further secondary metallurgy aggregates

c) Task 2.3 Analysis, evaluation and judgement of the project results (All partners)

An assessment of the project results was performed with regard to the achieved level of practical application and value among the community of steelmakers, with indication of reasons for success or failure of the projects. Furthermore a scheme was set up for evaluation and judgement of the project results as shown in the section below.

The evaluation was performed by the project partners, after assignment of each project to the partners according to their expertise in the relevant topics (e.g. measurement systems, process models, on-line control) and their involvement in the respective projects.

For this task in some cases other partners (besides those involved in this dissemination project) of past projects were contacted for selected project information, in order to better assess the relevance of information to be disseminated and to assist in deepening the evaluation of the results achieved in the past projects.

The following four criteria for scoring the relevance of the project results for industrial application were defined, for evaluating to what extent a project was successful and ensured a real progress in secondary steelmaking:

- A project scores "zero" if "the project idea did not work at all".
- A project scores "one" if "the project idea was in principle good, but industrial implementation was not possible at the time".
- A project scores "two" if "the project idea is applied in at least one industrial plant".
- A project scores "three" if "the project idea is state of the art and is applied in many plants."

As shown in **Figure 5,** only 3% of the projects (two projects) were scored "zero", meaning the project idea was not applicable at all. The figure also shows that more than 70% of the evaluated projects were scored "two" or "three", which suggests that most of the projects have already led to applications on an industrial scale. Most of the applications were, at least at the time of the project, only implemented at the project partners' plants, which encourages the project consortium to focus the dissemination actions especially to these project results.

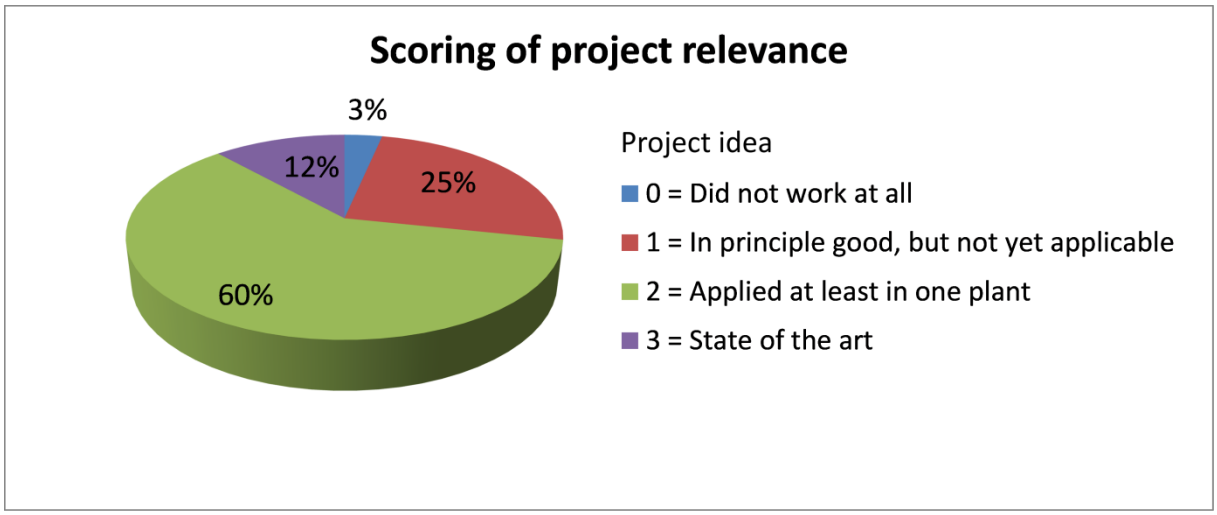


Figure 5: Distribution of scoring results regarding project relevance

However, it should be noted that some of the difficulties associated with transferring the outcomes of the projects result directly from the large variations in processing equipment and processing capabilities of developed steel plants and their dissimilar configurations, and this often limits the application of generically-designed systems to be transposed from one steel plant to another without extensive and costly restructuring.

In addition the scoring also was performed according to the relevant topics and subtopics, which have been documented under Task 2.2. For each project, a main topic was identified (see **Figure 1**). In some cases also a further relevant topics (as in secondary steelmaking problems faced and actions caused are very often interrelated) and a correspondent group of subtopics was assigned. **Figure 6** shows the scoring for the most important four topics separately.

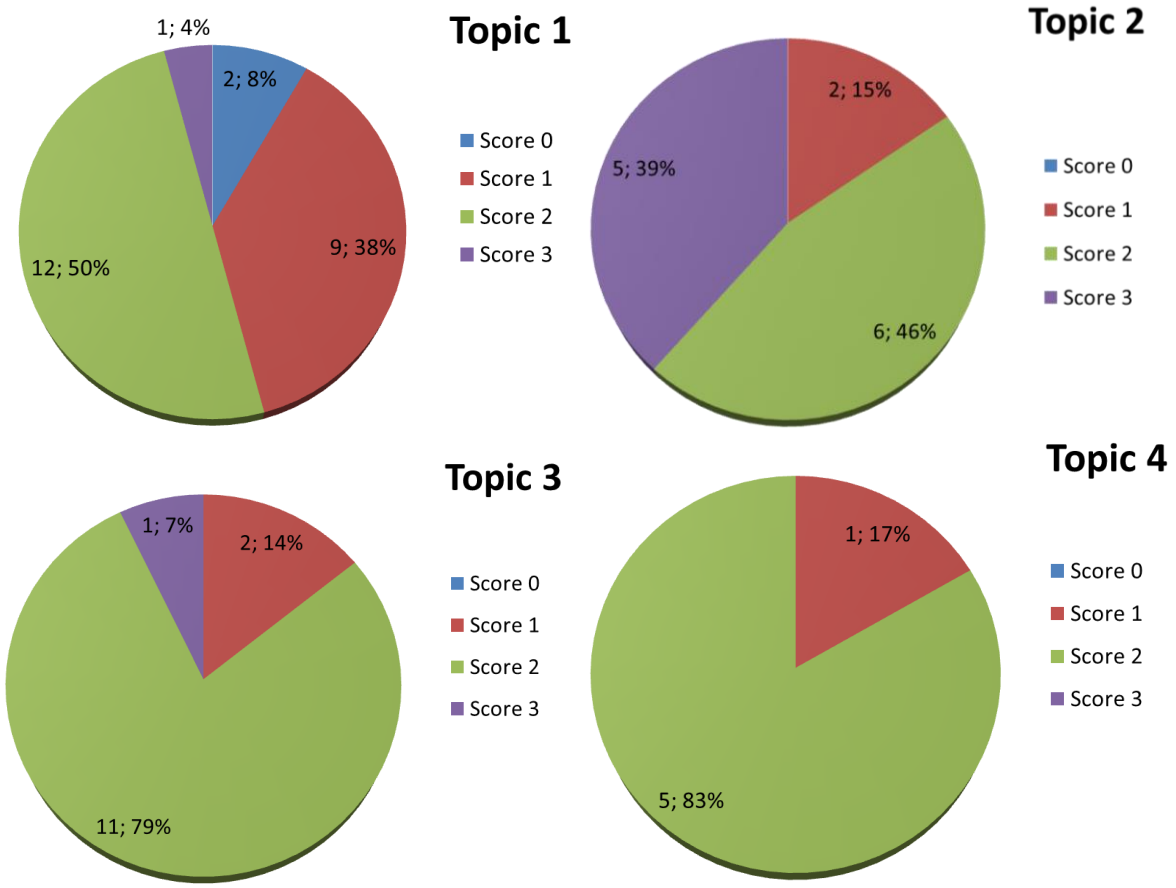


Figure 6: Score distribution per topic.

As a general comment, from the largely prevailing score '2' it seems that the findings were applied mostly in one plant – the direct beneficiary of the research project. The most successful topic for a wider industrial application of the project outcomes concerns Topic 2 (process models), to which the highest incidence of the maximum score (3) was achieved. This was mainly due to sub-topic 2.1 (Analytical & Thermodynamic models) and 2.5. (on-line dynamic models for monitoring and control).

These statistics can be interpreted as follows:

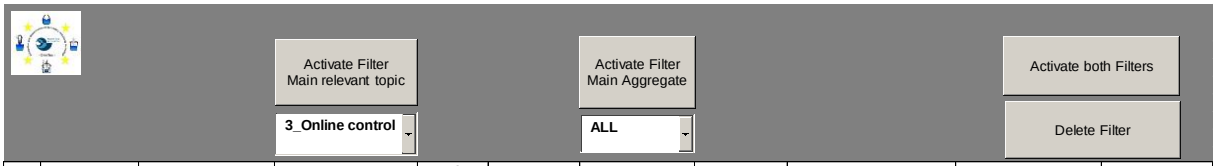
- concerning the success of subtopic 2.1, the need of steelmakers and stakeholders in general is reflected to gain deeper knowledge of fundamental aspects of metallurgy, also in view of the ever increasing demands on product quality, causing an increasingly relevant role of chemistry management
- concerning the success of subtopic 2.5, the stakeholders need - already noticed from the VALEAF [62] project analysis - to support production with continuous monitoring and control tools, to provide on-line information on the process status and its evolution, and to take controlling countermeasures in due time if needed and possible.

The information reported above allowed partners to define guidelines for addressing the technical presentations in the frame of the dissemination events to be held in the project, in order to better highlight the most relevant points of the findings of the EU-supported research

in secondary steelmaking, and to favour the involvement of all stakeholders in this dissemination work.

The categorisation of the projects regarding topics, sub-topics and secondary metallurgy aggregates, as well as the assessment and scoring of the project results was added within new columns of the project overview table (see Table 3). Two further columns entitled "Main project results" and "Level of industrial / practical application" were added, to document the project outcome in terms of industrial application with some further details. This extended list of projects is shown in **Table 4**. It also includes a filter function, which was added in the project data base table described within Task 3.1.

Table 4: ECSC and RFCS projects with categorisation and scoring of impact



Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
1	7210-CB/107	Development of process technology and metallurgy for extremely low and strictly limited nitrogen contents	2		2.1, 2.4	AOD		General process indications were given on hot metal, plain carbon steel, high-alloy steels, vacuum treatment and a thermodynamic and kinetic model was developed to characterize the elimination or fixing of nitrogen.	Findings applied on benficiary plant.	EUR 14483 DE
2	7215-CA/107	On-line analysis of molten steel for automated steel production (1st phase)	1		1.2, 3.5	AOD		The carbon content of liquid melt was measured online at an AOD converter using LIBS, but freezing of metal at the gas purged measurement tuyere in the converter bottom limited availability	After testes at laboratory furnaces the measurement system was successfully applied for 6 month at an industrial AOD converter	EUR 15184
3	7210-CC/104	Development of a model for the vacuum circulating process	2	3	2.1, 2.5	RH		Dynamic process model for description of decarburisation behaviour during RH process	Process model was provided as simulation model with validation by industrial process data. On-line application was possible, but not foressen within the project.	EUR 16186 DE
4	7210-GD/109	Fast multi-element on-line analysis of steel melts by means of laser technology - Development of a novel method for laser emission spectrometry (Phase I)	1	3	1.2, 3.3	All		Improvement of laser-based multi-element analysis thanks to laser modulation approach.	Validation of the measurement mean efficiency at laboratory-scale. Pilot scale validation to be done in phase II.	EUR 16632
5	7210-GD/409	Direct trace element analysis by AES with a high energy source (Phase II)	1		1.2	LF	AS	Fundamental work. The best performance was obtained with the dual chamber source. The effects of microwave irradiation on glow discharge and on emission were checked by analyzing forged hollow cathode samples. Some elements were found to be extremely sensitive to microwaves, while on others microwave irradiation either had no effects at all or, in some cases, even harmful effects.	None	EUR 16702 IT
6	7210-CC/805	Optical sensing of temperature and stirring conditions in ladle furnaces	1	3	1.1, 1.3, 3.3	LF		(1) Optical temperature measurement possible but not proved. (2) Optical steel velocities measurement proved impractical. (3) Ultrasound to measure steel velocity feasable but not proved within the project.	(1) Measurement method effective in laboratory conditions but not industrially. (2) Not feasable. (3) Method worked in water but not in steel, reason is supposed to be US source not powerfull enough and this couldn't be solved in the course of the project.	EUR 18365 EN
7	7215-EB/10	Continuous measurement and analysis of liquid steel (BOF)	1		1.2	LF	All	Measurements trials were not satisfactory, project was stopped.	Measurements trials were not satisfactory, project was stopped.	/
8	7210-CC/109,110,701	Process Modelling, Process Measurements and Control to Optimise Secondary Steeelmaking in the Production of Super Clean Steels	2	1, 3, 4	1.1, 2.1, 2.3, 2.4, 3.3, 4.2	All		This project improved the performance of secondary steelmaking vessels by developing techniques of process modelling, measurement and control of slag, vacuum and temperature parameters. Bubbling and vacuum techniques were employed for production of super-clean steels.	The findings were applied to partners plant (details were given in form of general process management indications) and also taken as reference by producers with the same aims.	/

Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
9	7210-CB/122,312,941	Low Nitrogen in EAF steelmaking	1	3	1.2, 3.4	VF	TUN	(1) Carbon addition at EAF tapping decreases nitrogen content for high C steel. (2) Improved vacuum sequence decrease nitrogen content but increase process time.	Results were obtained on industrial tools and were still applied by the plants after the end of the project.	EUR 19349 EN
10	7210-MA/319, 320	High nitrogen stainless steels by AOD / VOD process	2		2.1	AOD	VOD	To improve the nitrogen alloying during the steelmaking practice, a validated model describing the nitrogen gas dissolution kinetics during bottom stirring in ladle was adapted to stainless steels. A good agreement was obtained between nitrogen yields predicted by the model and obtained during industrial heats.	For industrial purpose, the dissolution kinetics model can be used to improve the efficiency of nitrogen bubbling during the steelmaking practice.	EUR 19417
11	7210-CC/116,407,117	Improvement of vacuum circulation plant operation on the basis of the BFI simulation model	2	3	2.1, 2.3, 2.5	RH		Dynamic process model for description of degassing and temperature behaviour during RH process	Process model was provided as simulation model with validation by industrial process data. On-line application at one industrial RH plant within the project, today state of the art within RH process control systems.	EUR 19488 EN
12	7210-CC/121/122/936	Dynamic modelling and control of the vacuum degassing process	2	3	2.1, 2.5	VD		Dynamic process model for description of degassing and temperature behaviour during VD process	Process model was provided as simulation model with validation by industrial process data. On-line application at one industrial VD plant within the project, today state of the art within VD process control systems.	EUR 19484 EN
13	7210-CC/114	Improvement of cleanness and fine-grain structure of Ca-treated and Al-deoxidised steels with a high S content made by continuous casting of billets and blooms	1	3	1.2, 1.3, 3.1	RH	LF, VD	(1) Corrected Ca treatment to form liquid inclusions for very high and low S contents (2) Successful demonstration of the use of Oxide metallurgy i.e. use of fine dispersion of oxides to improve castability and the microstrutcure using alternate deoxidation technology	The findings are implented by the project partners at the industrial scale by indicating the existence of inclusion path during ladle metallurgy which influences the effectiveness of Ca-treatment	EUR 19486
14	7210-GD/120	Sensitivity enhanced laser analysis of steel melts for fast multi-element on-line analysis during ladle processing in secondary metallurgy	1		1.2, 3.5	All	AS	Online chemical analysis based on LIBS was succcesfully demonstrated at a steel melt and limits of detection for C, P, S, Ni, Cr with 10ppm were improved by factor of 10	Measurement system was calibrated at 350g small scale furnace and applied to 100kg steel melt in a laboratory induction furnace	EUR 19411
15	7210/CC/302/303/809	Development of techniques to minimise ladle/slag interaction and prevent uncontrolled inclusion modification	4		4.1	LF		Mechanisms were identified of mass transfer from refractory lining of ladles towards steel in the two situations: carbon pick-up by ultra-low carbon steels from C-bearing refractories at slag line, contamination of metal by glazed ladle lining from previous casts, (b) to improve process practices in ladle that minimise both aspects; (c) to contribute to casting higher quality steels by better control of steel inclusion populations and of steel composition (carbon in ultra-low carbon steel) at ladle stage of the elaboration.	Findigs relevant to steelmakers is the occurrence of C pick-up by ULC steel after vacuum treatment, mainly controlled by slag wear. Decrease in C pick-up occurs when using low-C developed MgO-C bricks. Moreover, pilot plant trials showed that liquid steel/glaze reactions predominate in glaze formation and heat transfer is a major mechanism in the removal of ladle glaze from refractory walls.	EUR 19485
16	7210-PR/009	Control of inclusions in RH degassing processes	2	1, 3	2.3, 2.4, 1.3, 3.2, 3.3	RH		CFD model of RH degasser (interactions between melt, inclusions and gases), model of inclusion coalescence phenomena, injection of powder reagent to improve steel internal quality.	Models were provided as simulation model with validation by industrial process data.	EUR 20179
17	7210-PR/011	Dynamic process control of AOD converter	2	3	2.1, 2.5, 3.2	AOD		Dynamic process model for description of decarburisation and temperature behaviour during AOD process	Process model was provided as simulation model with validation by industrial process data. On-line application at one industrial AOD plant within the project, today state of the art within AOD process control systems.	EUR 20177

Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
18	7210-PR/010	The use of artificial intelligence to control secondary steelmaking practices	3		3.2, 3.4	LF	VD	Main results were : retrospective diagnosis of through-process control, optimisation of alloying strategy for manufacturing success at low cost and improvement in process control of steelmaking unit operations. Research related to each of these themes has been successful in creation of new tools directly applicable to one of the three steelmaking plants at which development has been focused.	Findings applied on partners 'plants.	EUR 28178
19	7210-PR/207	Operation and control of vacuum circulation (RH) process with lance oxygen input	3	2	2.1, 2.5, 3.2, 3.3	RH		Dynamic process model for description of decarburisation and temperature behaviour during RH process with oxygen top lance	Process model was validated by industrial process data from two RH plants. On-line application at one industrial RH plant within the project, today applied within few RH process control systems.	EUR 21435
20	7210-PR-080	Desulphurisation of liquid steel with refining top slags	1	2, 4	1.2, 2.3, 4.3	LF	AS, VD	(1) Development of a numerical model to trace the desulphurisation (2) Optimisation of various parameters related to slag composition for effective desulphurisation	The work consisted of operational trials and helped in optimizing the desulphurisation process through optimization of slag chemistry and slag-metal mixing	EUR 20474
21	7210-PR/079	Control of inclusion, slag foaming and temperature in vacuum degassing	2	1	2.1, 2.5, 1.1, 1.4	VD		Dynamic process model for description of temperature behaviour and inclusion removal during VD process. Application of IR camera to monitor temperature evolution.	Process model was provided as simulation model with validation by industrial process data of two VD plants, no on-line application within the project. Monitoring of T evolution by IR camera failed, but stirring behaviour can be monitored.	EUR 20562
22	7210-PR/135	Production of EAF steels with low contents in N2 and S through vacuum treatment	2		2.1, 2.2, 2.3	VD		Dynamic process model for description of denitrogenation and desulphurisation behaviour during VD process	Process model was provided as simulation model with validation by industrial process data of two VD plants, no on-line application within the project. Today applied within some VD process control systems.	EUR 20945 EN
23	7210-PR/136	Characterisation and optimisation of ladle stirring systems for the steelmaking industry	4		4.2	AS		From the experiences of all partners, proposals for the further improvement of stirring systems are made which point out the main objectives for the equipment, operation and maintenance. In addition, proposals for the standardisation of stirring systems are derived, which should be used by producers and by users	Practical recommendations were given to avoid blocked stirring plugs or gas leakage. Findings applied in two partners' plants.	EUR 20946 EN
24	7210-PR-168	Improved production control through rapid characterisation of non-metallic inclusions in steel	1		1.3	All		(1) Development of a laser-OES technique to provide quantitative and qualitative information about the non-metallic inclusions in steel	The LIBS technique has been developed using the industrial steel samples so can be implemented on an industrial scale	EUR 21627 EN
25	7210-PR/138	Chromium-free alternative refractory for the lining of RH/DH vessels	4	5	4.1, 5.1	RH		Development of a Chromium-free refractory recipe to reduce the enviromental impact of hexavalent chromium	An alternative recipe was developed and tested for an industrial application with successful results, however, it was not implemented.	EUR 21335
26	7210/PR/206	The Determination and elimination of the effect of Anti-Oxidants in Magnesia-Carbon bricks on steel composition and inclusion formation	4	1	4.1, 1.2, 1.3	All		The generation of potentially harmful inclusions, such as spinel and corundum, has been shown by the thermodynamic and kinetic models. The presence of those species has been shown in laboratory experiments and in plant samples.	The development of the LIBS rapid analysis system has shown to be a powerful investigation tool capable of analysing soluble concentrations, inclusion composition, position and size. Areas for further development have been identified and it is recommended that LIBS systems be considered for both research and production applications.	EUR 21446 EN

Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
27	7210-PR-204	Innovative continuous on-line determination of the steel melt temperature by direct optical measurement in the melt	1	3	1.1, 3.3	LF	TUN	Continuous temperature measurement of liquid steel by pyrometer with optical fibre measurement technology.	The new system was succesfully tested and optimised on several steel plants including EAF furnaces, BOF converters, ladles and tundishes.	EUR 21428 EN
28	7210-PR-270	Improvement of inclusion flotation during RH treatment	2	1	2.1, 2.3, 1.3	RH		(1) Development of process models using experimental and numerical modelling techniques to improve the removal of non-metallic inclusions during the RH process	The project has covered the performance of industrial RH degasser in terms of inclusion population, and its separation from liquid steel	EUR 22388 EN
29	7210-PR-271	In situ, quick sensing system for measurements of process-critical components in steelmaking slags	1	3, 4, 5	1.2, 3.3, 4.1, 5.4	LF		EAF and BOF slag analysis by LIBS system.	LIBS measurements were performed off-line on sampled slag at EAF plant. On-line trials at BOF plant haven't been done due to practical problems.	EUR 22818
30	7210-PR/300	In-line assessment of steel cleanness during the secondary steelmaking process	1	2, 3, 4	1.3, 2.2, 3.4, 4.1	LF	RH, TUN	Tool for steel cleanness in-line assessment during secondary steelmaking process based on PDA-OES measurement.	Preindustrial demonstration has been conducted, in real time, during one shift.	EUR 22032 EN
31	7210-PR/269	Improvement of process control and refractory performance of the AOD converter	3	2, 4	2.1, 2.5, 3.3, 4.1	AOD		Dynamic process model with thermodynamic description of decarburisation and nitrogen content behaviour during AOD process	Process model was provided as simulation model with validation by industrial process data. Pilot application at one industrial AOD plant within the project, today applied in some AOD process control systems.	EUR 21974
32	7210-PR/329	De-oxidation practice and slag ability to trap non-metallic inclusions and their influence on the castability and steel cleanliness	1	2, 4	1.3, 2.3, 4.3	LF	VD	(1) Study of (a) deoxidation and (b) slag conditioning practices using laboratory experiments, modelling and pilot/plant trials to improve castability and cleanness (2) Detailed description of one of the fundamental aspects of ladle refining i.e. inclusion nucleation and growth phenomenon	The main results obtained in the framework of this project show that more work need to be done to develop a complete and satisfying model of various reactions in a ladle. The main difficulty was the coupling of thermodynamics, kinetics and fluid dynamics.	EUR 23194 EN
33	7210-PR/330	Development of advanced methods for control of the ladle stirring process	3	2	3.3, 2.3, 2.5	AS		Development of an on-line control of gas stirred ladle treatment to improve the steel quality with respect to refining, inclusion removal, homogenization, slag entrapment and reoxidation.	A labratory work has been conducted to investigate the effect of different parameters on the process. Moreover, image process, CFD and vibration measurement have been conducted and validated with the industrial trials. However, the image analysis hasn't been a compelete success.	EUR 22988 EN
34	7210-PR/331	Improved control of inclusion chemistry and steel cleanness in the ladle furnace	1	2, 3	1.3, 2.1, 2.3, 3.4	LF	VD, AS	Investigation of stirring and heating strategies for inclusion chemistry and cleaness of the steel melt in ladle furnace station	The project investigate effects of stirring (gas and/or induction) on cleanness and composition of inclusions in the melt. A state-of-the-art guidline has been adopted and suggested to improve the process which has been implemented in mutiple plants.	EUR 23593
35	7210-PR-332	Optimisation and evaluation of different secondary metallurgy routes to achieve high quality strip steel	1	5	1.3, 5.3	LF	VD, RH	(1) Evaluated and optimized the secondary metallurgy production lines to achieve high quality strip for ULC/IF steel (2) Evaluated the possibility of Ca treatment to the strip grades which helped in optimizing the important process parameters to Ca treatment such as Ca yield, its amount and injection rate etc.	The slag metallurgy and Ca treatment practices for strip grades have been optimized at an industrial scale	EUR 23888

Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
36	RFSR-CT-2003-00008	Investigations and measures to reduce emissions and energy consumption during preheating of steel ladles	**5**	**3, 4**	**5.1, 4.1, 3.3**	**LF**		A new burner with heat recovery system has been implemented, with heat exchanger performance for Thermal efficiency of 70% and energy savings of 35%. A new regenerative heat recovery system was installed at a heating station at TKLNR. An increased fuel-efficiency (the natural gas consumption had been reduced by more than 20 % for both) The ladle control model for the ladle thermal tracking was implemented in the Sidenor-Basauri meltshop in 2006 and is since then in operation.influence.	See results. Partners have directly benefited from the project findings.	EUR 23175 EN
37	RFSR-CT-2003-00016	Cost efficient metallurgy for the production of novel ultra high strength deep drawable steel grades with high Mn contents from 10 to 25 wt.-%	**3**	**1, 2,4**	**2.1, 1.1, 4.1**	**VOD**	**LF, AOD**	Investigation into a cost effective industrial process technology within the primary and secondary metallurgy to produce a novel ultra high-strength high Mn-content steel.	The project studied and compared multiple routes in production of high-strength high Mn-content steel with successfully identifying the most effective approach within different process which was implemented in an industrial plant.	EUR 22991 EN
38	RFSR-CT-2003-00043	Feasibility of a fast vacuum slag analysis by laser OES in secondary steelmaking	**1**		**1.2**	**VD**		Investigation of the feasibility of fast slag analysis for a better control during the secondary metallurgy process	The project was unable to produce reliable results regarding the fast slag analysis using laser OES method. Furthermore, the obtained results in some cases were also irreproducible.	/
39	RFSP-CT-2004-00006	Application of direct optical temperature measurement in steelmaking process	**1**		**1.1, 3.5**	**AOD**		Evolution of liquid steel temperature in LD converter can be measured online during blowing to determine end point, but availability is limited by availability of bottom tuyere	Measurement system was applied at one LD converter	EUR 23736 EN
40	RFSR-CT-2005-00013	Innovative tundish management for final steel thermal and chemical adjustment	**1**	**3**	**1.3, 3.1**	**TUN**		Alloying techniques were defined and applied via CaSi/FeS wire injection; inclusion engineering was performed via material poured into a pad. For temperature control, local reheating was successfully achieved with exothermic powders at the surface above the exits; a model for online control of steel temperature was set up and validated with plant data for operational purposes.	The findings were applied and used on plant partners facilities. They can be applied to all steel routes with the same needs. The innovative character of the work consisted of the application in a 'continuous' reactor (tundish) of metallurgy operations typically exploited in a ladle ('batch' reactor). The application leads to cost savings allowing steel composition / temperature control after ladle treatment.	EUR 24348 EN
41	RFSR-CT-2005-00005	Improvement of purging plugs performances by investigations on the materials, process analysis and continuous monitoring	**4**		**4.2**	**AS**	**LF**	Link between thermo physical and thermo chemical models was achieved, together with exploiting measuring system to produce continuous wear data.	Settled a methodology with measuring and investigation instruments able to support the steelmaking industry on both the selection of the most suitable purging plugs to use in specified working conditions and on the enhancement of plug use and maintenance procedures, suitable to improve their performances.	EUR 24987 EN
42	RFSR-CT-2005-00006	Prediction of inclusions in the slabs from the process characteristics	**2**	**1**	**2.1, 2.2, 2.3**	**All (except VOD, AOD)**		(1) Inclusion prediction models using (a) Data based and (b) Thermodynamic modelling have been developed (2) Data based models have been developed with two different approaches using (i) Parsytec data and (ii) the direct information of the steel.	The methodologies used for the data based models have proven to reliable and the generic information about the most significant variables affecting the steel quality can be used in the industries with similar facilities with the same production characteristics	EUR 24992 EN

Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
43	RFSR-CT-2006-00018	Grain size control in steel by means of dispersed non-metallic inclusions	**2**	**3**	**2.3, 3.1**	**TUN**		Grain refining in steel by addition of suitable inoculants systems and selection of proper addition technique was proven to be possible, both for low-alloy and stainless steel. Different types of inoculants systems were produced and tested by both continuous injection technique and batch additions in molten steel.	A potential was shown for master alloying design aimed at grain refining under industrial conditions, also in view of enhancing material properties such as weldability and mechanical strength without compromising the ductility. On the basis of the promising results obtained during the experimental activity, TK AST steel plant intended to improve the system and the procedures to enhance the purging plug performances of its steel ladle.	EUR 24993 EN
44	RFSR-CT-2006-00005	Cost efficient metallurgy for the production of novel ultra high strength deep drawable steel grades with high Mn contents from 10 to 25 wt.-% by using EAF steel making route	**3**	**2**	**2.1, 3.2, 3.4**	**not applicable**		Investigation into a cost effective industrial process technology within the primary and secondary metallurgy with the EAF as an initial point to produce a novel ultra high-strength high Mn-content steel.	The project investigated the possibility to apply scarp based production routes to produce the high-strength high Mn-content steel. Unfortunately, the results of the project were not able to identify an economical and practical approach. However, the scrap based production routes of this type of steels maybe further investigated in the future.	EUR 24225 EN
45	RFSR-CT-2007-00004	Online control of desulphurization and degassing through ladle bubbling under vacuum	**1**	**2, 3**	**1.4, 2.1, 2.5, 3.2**	**VD**	**LF**	Online measurement systems based on VIS camera and on accelerometers to be evaluate stirring efficiency and its effect on desulphurization and degassing at LF and VD.	Cameras and vibration sensors were installed and are used for evaluating stirring efficiency. A correlation between the measured camera index and the sulphur reduction as well as the degree of desulphurisation has been established (at LF). Available offline desulphurisation and degassing models have been modified and are now used online, with the gas flow rate estimated by the measured vibration index is used as a relevant input parameter (at VD).	EUR 25091 EN
46	RFSR-CT-2007-00009	Improvement of ladle stirring to minimise slag emulsification and reoxidation during alloying and rinsing	**1**	**2, 3**	**3, 1.4, 2.1, 2.3, 3**	**AS**		Investiagtion of stirring conditions and cleannes of product suggested a reduction of stirring gas flow rate during alloying and rinsing.	Online monitoring of stirring by camera and image analysis applied at rinsing station. Reduced stirring gas flow rates applied with no influence on steel quality.	EUR 25068 EN
47	RFSR-CT-2007-00011	Development of steel grade related slag systems with low reoxidation potential in ladle and optimised ladle glaze technique for improving steel cleanness	**1**	**2, 4, 5**	**1.3, 2.1, 4.1, 4.3, 5.3**	**All (except RH)**		(1) The project work lead to the improved understanding about reoxidation and ladle glaze impact on steel quality which enabled (i) Improved steel cleanness (ii) Precise process control and (iii) Increased productivity	The results of this project lead in a longer perspective to an increased product quality and productivity in European steelmaking industries, thus enhancing its competitiveness	EUR 25076 EN
48	RFSR-CT-2007-00007	Resource-saving operation and control of stainless steel refining in VOD and AOD process	**3**	**2**	**2.1, 2.3, 2.5, 3.3**	**VOD**	**AOD**	Dynamic process model with thermodynamic description of decarburisation and temperature behaviour during AOD and VOD process. Process control algorithms provided as simulation tools.	Process models were validated by industrial process data. On-line applications at one industrial AOD and VOD plant within the project, today applied in some process control systems.	EUR 25087 EN
49	RFSR-CT-2008-00006	Active tundish metallurgy	**1**	**2**	**1.2, 1.3, 2.1**	**TUN**		Fundamental studies as well as thermodynamic calculations showed that a more basic slag would lead to a more effective tundish slag having higher capacity to absorb inclusions compared to standard practice. Based on these results better slags and practices were proposed for industrial trials.	Experimental tests at steel plants with the new proposed tundish powders showed improvement in steel cleanness compared to standard practice.The new tundish practices developed in this project have been successfully implemented at two of the plant partners works (Sidenor and Ovako).	EUR 25875 EN

Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
50	RFSR-CT-2008-00003	Optimized production of low C and N steel grades via the steelmaking route	**3**	**2**	**3.4**	**VD**	**LF, TUN**	Dynamic through process model for evolution of nitrogen and carbon content along the process route of electric steelmaking. Control algorithms to achieve the target values provided as simulation tools.	Process models were validated by industrial process data of two plants. Models and control algorithms were partailly implemented on-line within the project. Today the solution is applied in few through process process control systems.	EUR 25869 EN
51	RFSR-CT-2008-00044	Enhanced reliability in ladle refining processes (VD, VOD and LF) by improved on-line process monitoring and control	**1**	**2, 3**	**1.4, 2.1, 2.5, 3.3**	**VD**	**VOD, LF**	Joint application of new (thermal) imaging based evaluation of stirring efficiency to overcome the problems caused by an undefined stirring intensity during VD, VOD and LF treatment and to improve the process reliabilities.	Camera-based monitoring systems were implemented at VD, VOD and LF. Process models for all metallurgical operations which are relevant for secondary steelmaking in VD / VOD and LF plants were developed and validated within off-line calculations. The on-line application of the models focused on monitoring of degassing and melt temperature during VD treatment, as well as on melt temperature at the LF.	EUR 25947 EN
52	RFSR-CT-2009-00003	Enhanced steel ladle life by improving the resistance of lining to thermal, thermomechanical and thermochemical alteration	**3**	**2, 4, 5**	**2.1, 2.4, 3.4, 4.1, 5.3**	**All**		Investigations on degradation and wear of ladle refractory material by laboratory studies as well as thermo-chemical and thermo-mechanical simulations to improve ladle lining life.	The results of the project work are being used by the two industrial partners in the consortium. The trials about refractory materials, refractory configuration and industrial practices have been evaluated and many of them left as standard. Improvement in ladle lining life was obtained regarding increment of number of heats per campaign.	EUR 26689 EN
53	RFSR-CT-2010-00003	Multi-criteria through-process optimisation of liquid steelmaking	**3**	**2**	**3.4**	**LF**	**VD, AS**	Dynamic through process model for evolution of temperature, slag composition, desulphurisation and degassing along the process route of liquid steelmaking. Coupling with optimisation algorithms for process control.	Process models were validated by industrial process data of three plants. Models and control algorithms were partially implemented on-line within the project. Today the solution is partially applied in few through process control systems for liquid steelmaking.	EUR 26931 EN
54	RFSR-CT-2010-00005	Increased yield and enhanced steel quality by improved deslagging and slag conditioning	**3**	**1, 2**	**1.4, 2.5, 3.2, 3.3, 3.5**	**All**		Online monitoring of deslagging process after EAF tap and after desulphurisation of hot metal using camera based image analysis and online models	CCD cameras permanently installed and connected with image analysis software for monitoring of purging gas/slag rake movements, slag area and slag amount. The online application of the models focused on calculation of slag conditions and to provide recommendations for the amount of slag forming agents to be added, and on calculation of the amount of slag that can be transferred into BOF.	EUR 27438 EN
55	RFSR-CT-2011-00004	Intelligent cleanness control in secondary steelmaking by advanced off-line and on-line process models	**3**	**1, 2**	**1.4, 2.1, 3.4**	**AS**	**LF, RH**	CFD, on-line prediction models and on-line control strategies, based on a combination of through-process models and new monitoring and control techniques for stirring during ladle metallurgy processes	The project has combined many modelling tools, new index definitions and plant data to increment the knowledge about inclusions inspired by two practical objectives: cleanliness in final product and castability in microalloyed steels. The overall balance is that practical improvements and theoretical knowledge have been gained in both cases and interesting exchange between partners has been promoted.	EUR 27832 EN

Nr	Number of contract	Title	Main relevant topic	Further relevant topics	Relevant Sub-Topics	Main Aggregate	Further Aggregates	Main project results	Level of industrial / practical application	Report number
56	RFSR-CT-2012-00005	Stirring plug monitoring system for improvement of plug availability and stirring performance	4	2, 3	2.1, 2.4, 3.5, 4.2	LF	AS, VD, VOD	Measurement techniques for plug refractory temperature, numerical simulation of process induced changes in stirring plugs, software engineering to determine and predict stirring plug availability and performance	Discontinuous measurement of stirring plug temperature was realised and performed. Wireless data transmission was not possible due to high temperatures and low signals. Models were developed to describe heating and cooling procedures during stirring plug life. Software tools were developed for the management of process data and the new temperature information in the stirring plug.	not yet published
57	RFSR-CT-2013-00030	Environmental impact evaluation and effective management of resources in the EAF steelmaking	5	3	1, 5.2, 5.3, 5.4, 3	All		Key Performance Indicators were selected in order to monitor the environmental performance of the whole steelmaking process in terms of energy consumption, water and air emissions, by-products and waste management.	To support stakeholders, a tool was implemented in order to follow the temporal evolution of the defined KPIs on both real and simulated data, and suitable simulation models have been developed for scenario analyses.	still running
58	RFSR-CT-2014-00006	Improving steelmaking processes by enhancing thermal state ladle monitoring	1	2, 3, 4, 5	1.1, 2.4, 2.5, 3.4, 3.5, 4.1, 5.2	All		still ongoing project	still ongoing project	still running
59	RFSR-CT-2015-00004	Dynamic stirring for improvement of energy efficiency in secondary steelmaking	3	1, 2, 5	1.4, 2.3, 2.4, 5.2	AS	VD, CAS-OB	still ongoing project	still ongoing project	still running
60	RFSP-CT-2015-00026	Plant wide control of steel bath temperature	3	1, 2	3.4, 1.1	All	LF, VD	Operator advisory tool for through process monitoring and control of liquid steel temperature based on dynamic process model, novel sensors, and adapted measurement routines	Implementeation of operator adisory system in one pilot application at electric steel plant	still running

1.2.4 Work package 3: Preparation and support of dissemination actions

The main objectives of Work Package 3 were the:

- Documentation of the project analysis results
- Set-up, implementation and continuous updating of a project web site
- Preparation of texts, presentations and videos for dissemination actions
- Publication of information on the project via the web site and presentations

a) Task 3.1 Documentation of project analysis results (All partners)

The list of projects, which have been analysed, evaluated and categorised according to relevant topics and secondary metallurgy aggregates has already been described under Task 2.2. In Task 2.3, this list has been extended by two further columns entitled "Main project results" and "Level of industrial / practical application". Within these columns the assessment of the project results with regard to the achieved level of practical application and value among the community of steelmakers, with indication of reasons for success or failure of the projects is included.

To set up an appropriate data base, filter functions were added to allow an easy access to the results per topic (measurement, modelling, control, etc.) and secondary metallurgy aggregate. **Table 4** already showed the graphical user interface of the project list with the filter functions. This extended project list can be downloaded as Excel data base from the project website at the address www.bfi.de/en/projects/disstec respectively www.bfi.de/de/projekte/disstec.

b) Task 3.2 Generation of a web site (BFI, MPI)

The DissTec project web site was generated inside the home page of VDEh-Betriebsforschungsinstitut (BFI). The web site was made accessible in the second week of January 2017. The address of the web site is

www.bfi.de/en/projects/disstec

Later, also a German version of this web site was created under

www.bfi.de/de/projekte/disstec

The layout of the web site is shown in **Figure 7**.

Within the web site all information on the project has been made available. In the first version the initial situation, the work programme of the project as well as its objectives and expected results are described. Later on, the list of evaluated ECSC and RFCS projects, which has been set up as Deliverable 2.1, and the project data base, which has been provided as Deliverable 3.1, were provided as download from the web site.

In addition the web site was used as a platform for advertisement of the different dissemination events and for download of all presentations which were given during the events. The time schedule for the dissemination events was updated every time when further dates and places for the dissemination events had been fixed.

Via the web site, furthermore links were provided to allow an easy access to useful information, such as related knowledge, innovative solutions, technical data and possibility of further improvements.

In general, the web site was continuously updated throughout the project, always providing the most actual information on project evaluation, dissemination events and related information.

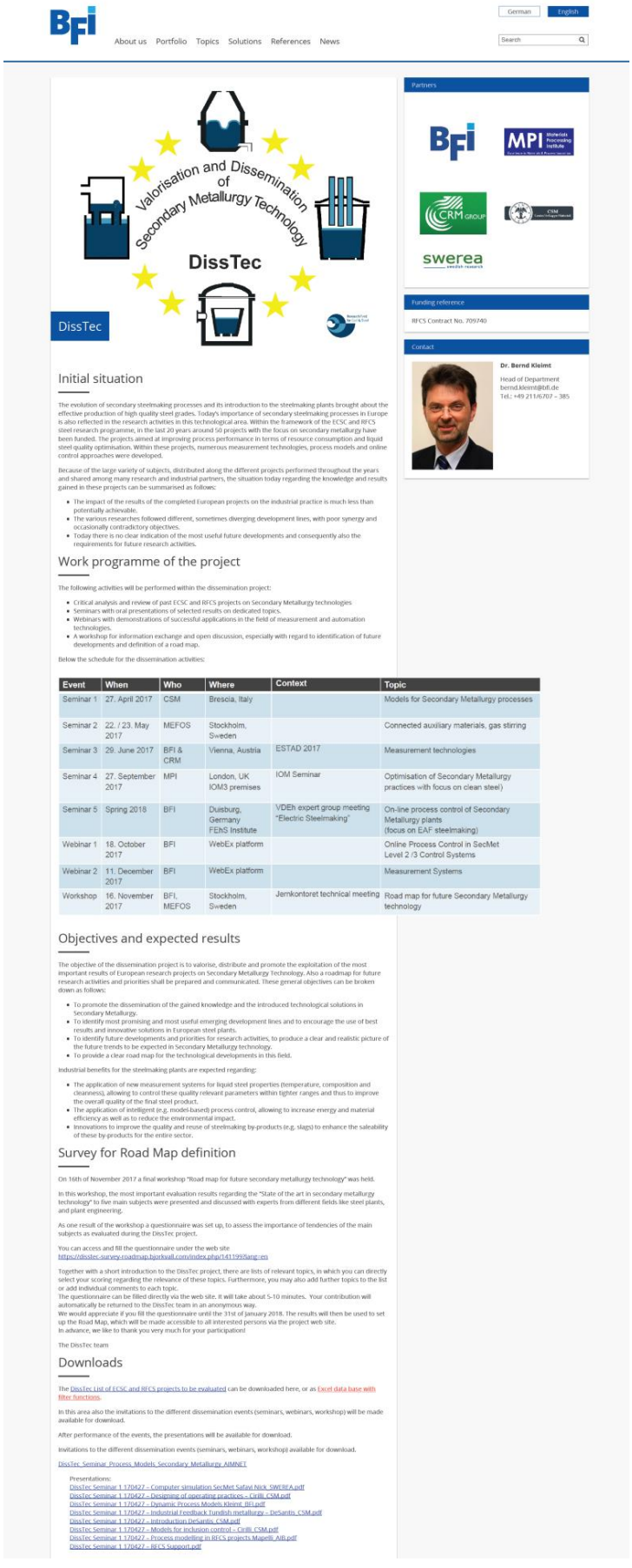


Figure 7: Layout of DissTec web site

c) Task 3.3 Preparation of material for dissemination actions (BFI, CSM, MPI, MEFOS)

To support the dissemination actions regarding the seminars to be performed, illustrative material has been derived from projects where the partners of the DissTec project were directly involved. Focus has been laid on those projects where results have already been applied on industrial level, i.e. which were scored in the project evaluation with 2 or 3 (cf. to Deliverable 2.3 "Categorisation of the impact" with respect to the scoring scheme). The material intended to demonstrate, on one side, the high scientific values of the researches, on the other side the practical usefulness in industrial applications.

Selected graphics and photos were also uploaded on the DissTec Web site. **Table 5** shows a selection of these projects from where illustrative material was derived.

Table 5: Examples of successful projects with relevant illustrative material

Contract number	Nr.	Title	Abstract
7210-CC/116,407,117	11	Improvement of vacuum circulation plant operation on the basis of the BFI simulation model	Within this project a simulation model of the vacuum circulation process (RH) for decarburization of steel was extended to include further metallurgical operations such as stirring, gas input, oxygen blowing, dehydrogenation and nitrogen control and to improve process control of RH plants.
7210-PR/011	17	Dynamic process control of AOD converter	A dynamic model for decarburisation and temperature behaviour within the AOD process was developed, based on balance calculations for carbon, oxygen and energy and used off-gas analysis and flow rate values to determine the decarburisation rate and the current carbon content.
7210-PR/331	34	Improved control of inclusion chemistry and steel cleanness in the ladle furnace	The objective of the project was to enhance the control of inclusion chemistry and steel cleanness in the ladle furnace, regarding the process operation practice with respect to stirring patterns and slag practice.
RFSR-CT-2010-00003	53	Multi-criteria through-process optimisation of liquid steelmaking	Main objective of this project was the development of a through-process optimisation for the liquid steelmaking route. Real-time monitoring and predictive models, using process and sensor data from different aggregates, shall be integrated for a multi-criteria optimisation of material and energy input regarding quality, productivity and costs. A dynamic modification of the planned process route will be suggested in case of deviations in quality relevant parameters.

In the following, some pictures and graphics from the example projects listed in Table 5 are reported. Some examples directly refer to industrial applications. For instance, the AOD model (Material 2, Figure 2) and the thermal model (Material 4, Figure 7) are real software packages running in industrial plants. From some of these software applications, also demonstration videos have been derived. These videos, supported by illustrative animations, were used, together with other software demonstrators and animations for measurement

systems, in the two webinars for Measurement Technologies and Level 2 / 3 control systems, which were performed in October and December 2017.

Material 1 - 7210-CC/116,407,117 (Project No. 11)

Improvement of vacuum circulation plant operation on the basis of the BFI simulation model

The aim of this project was to develop, to apply and to validate numerical and experimental modelling techniques, in order to improve the removal of non-metallic inclusions and therefore enhance steel cleanliness.

The project was focused on operation in RH vacuum operations.

In the project, sophisticated multi-physics models were developed an applied. The results were validated with comparison with industrial data.

Figure 8 shows examples of physical a numerical modelling.

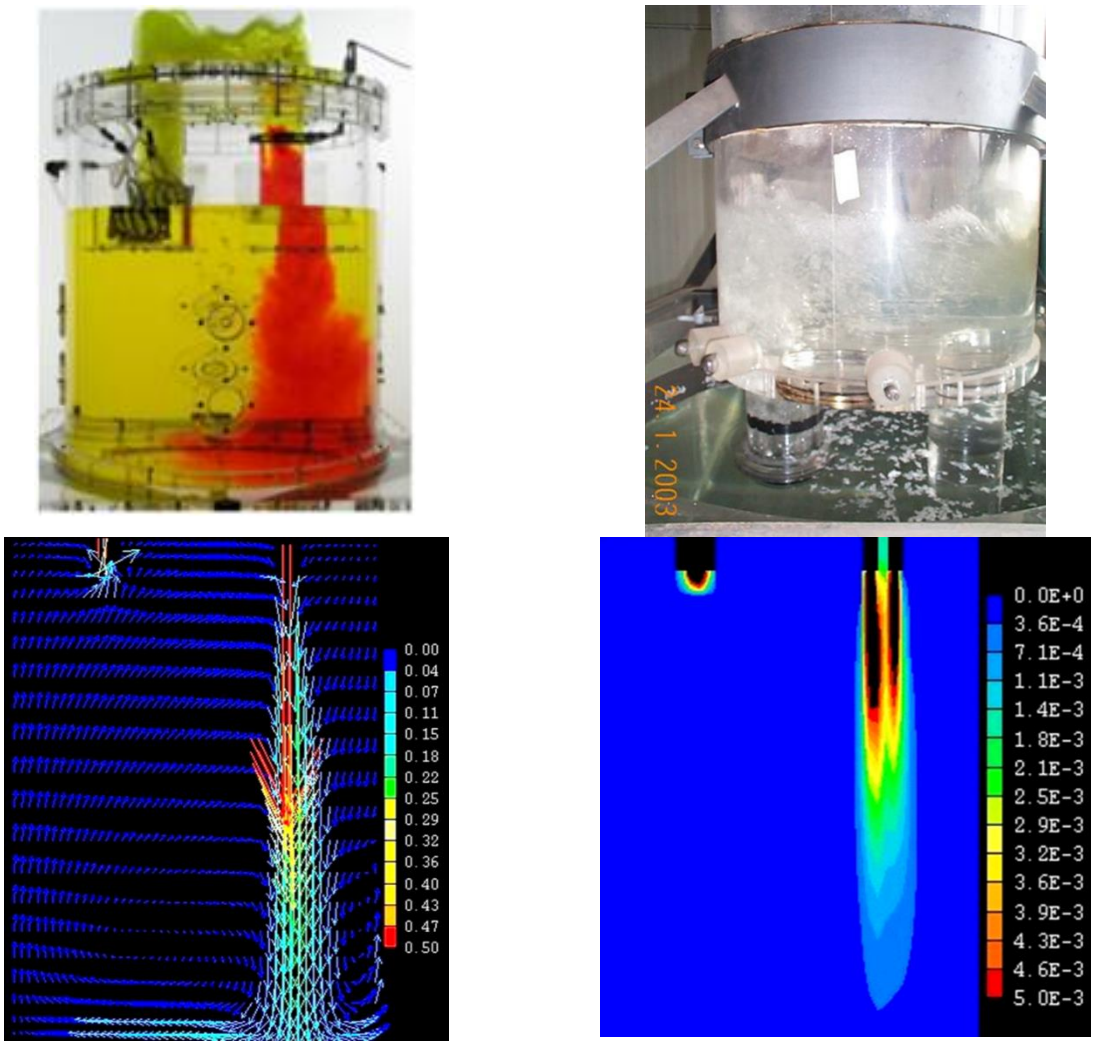


Figure 8: Physical (top) and numerical (bottom) modelling of the process in RH.
The simulations with the models allowed to have the flow field and turbulent energy distribution useful to evaluate the coalescence probability of particles dispersed in steel.

Material 2 - 7210-PR/011 (Project No. 17)

Dynamic process control of AOD converter

A dynamic model for decarburisation and temperature behaviour within the AOD process was developed, based on balance calculations for carbon, oxygen and energy and used off-gas analysis and flow rate values to determine the decarburisation rate and the current carbon content.

In this project, dynamic models of AOD process have been coupled with continuous measurements of off gas composition and model based control systems have been developed. The integrated models are used to support the off-line design of practice and for the on.-line control of the process.

The results of this project were successfully applied for routine industrial operations.

Figure 9 shows the application concept, example of output and graphical the graphical interface of the industrial implementation in TK-AST workshop in Terni.

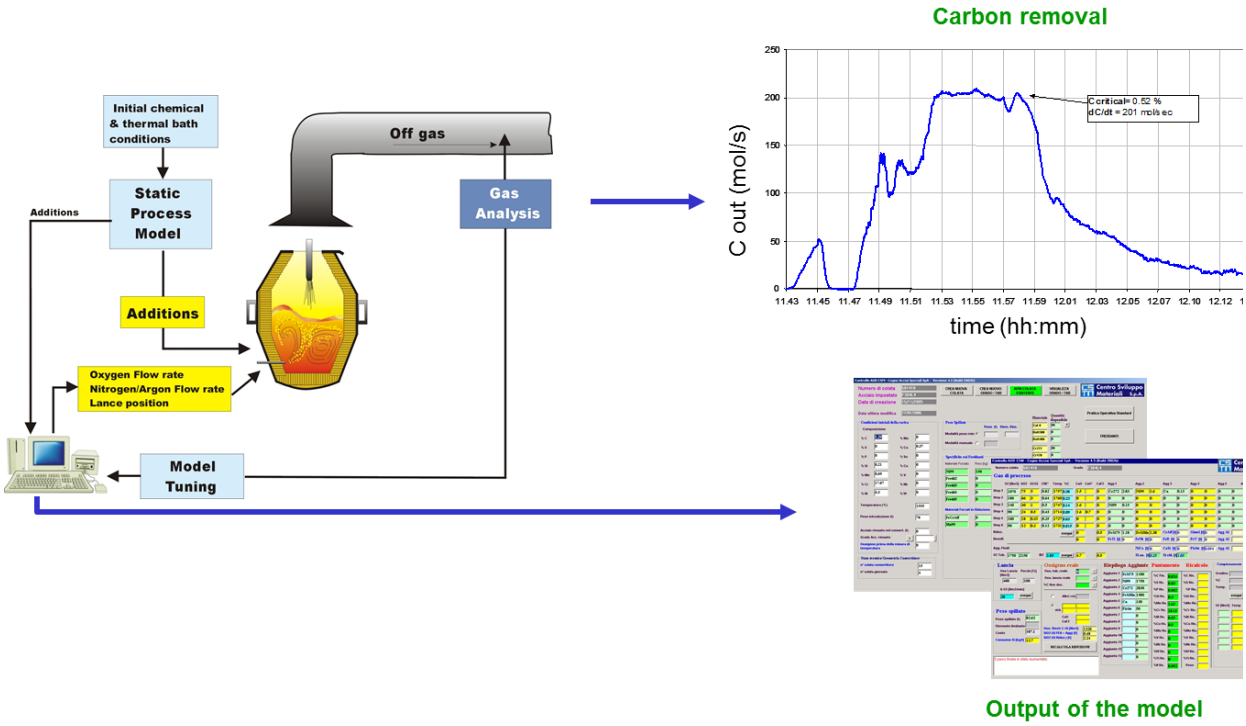


Figure 9: The process control is based on a model, which calculates process parameters such as decarburization velocity and related gas production rate.

On the basis of on-line continuous measurement of carbon in off-gas, the C content in steel bath is calculated at real-time. The operating parameters can be adjusted to guide the process.

Material 3 - 7210-PR/331 (Project No. 34)

Improved control of inclusion chemistry and steel cleanness in the ladle furnace

The objective of the project was to enhance the control of inclusion chemistry and steel cleanness in the ladle furnace, regarding the process operation practice with respect to stirring patterns and slag practice.

In the project both fluid dynamic and thermodynamic calculations were used to define best operation practice for inclusion control. The focus of the project was the operations in ladle.

In the project both gas and magnetic stirring was investigated. The fluid dynamic modelling was performed at the state-of-the art and included the interaction between steel and slag.

Thermodynamic and fluid dynamic models were integrated and applied to evaluate the impact of slag composition and stirring strategy on inclusion mass and composition and inclusion removal. The integrated models were used to define innovative stirring strategy favouring final steel cleanliness.

Figures 10 and 11 show examples of advanced fluid dynamic model of the system steel-slag, stirred with induction and gas.

Figure 12 shows an example of stirring practice developed with the help of calculation with an integrated thermodynamic and fluid dynamic model.

The simulations with the model suggested the use of an asymmetric stirring practice, using different gas flow rates in the two porous plugs of the ladle.

This practice facilitates steel de-oxidation and inclusion entrapment in slag. The measurements of dissolved and total oxygen concentration confirmed the model prediction

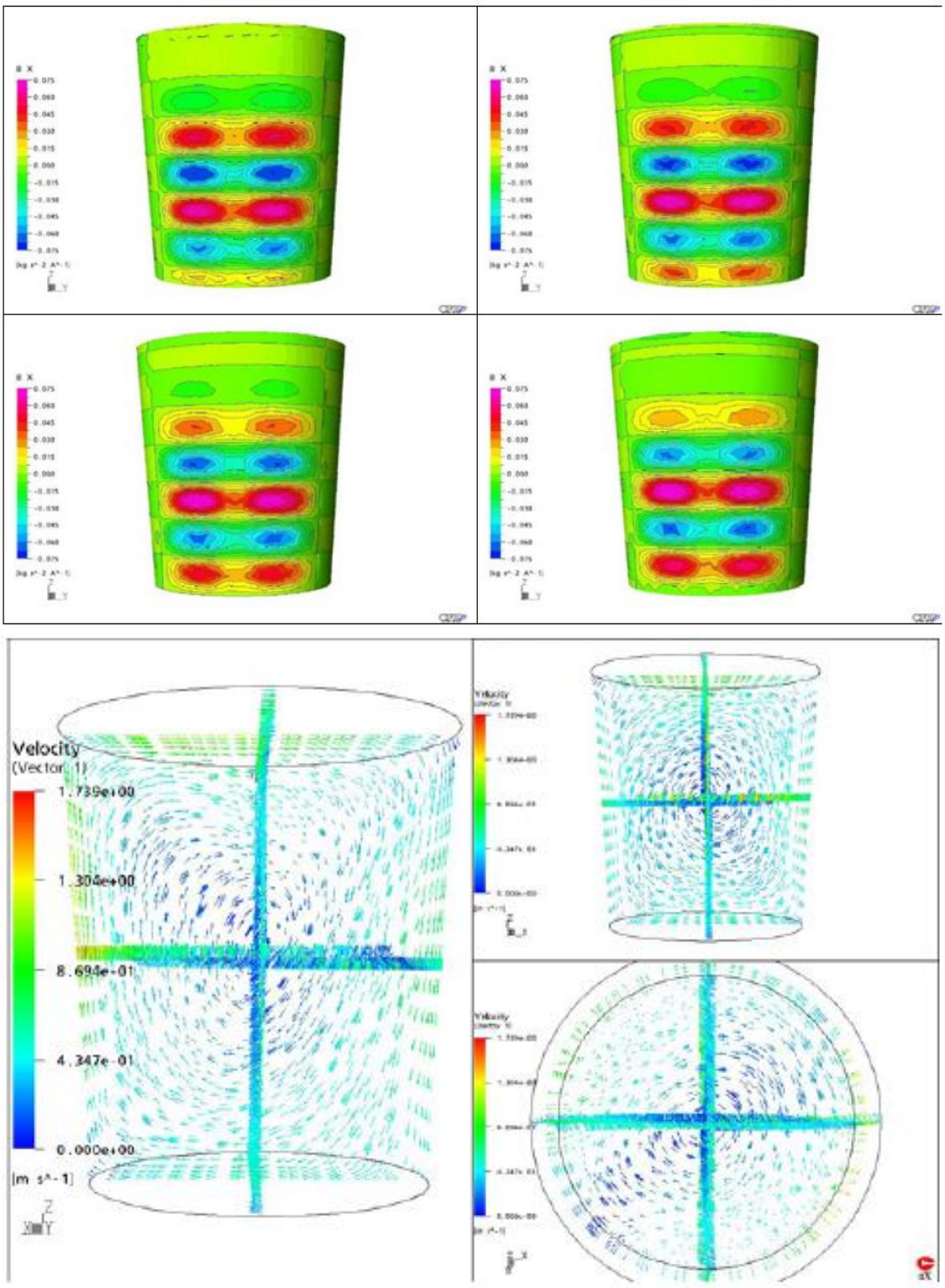


Figure 10: Magnetic field (top) and velocity field (bottom) in steel in a ladle with electromagnetic stirring.

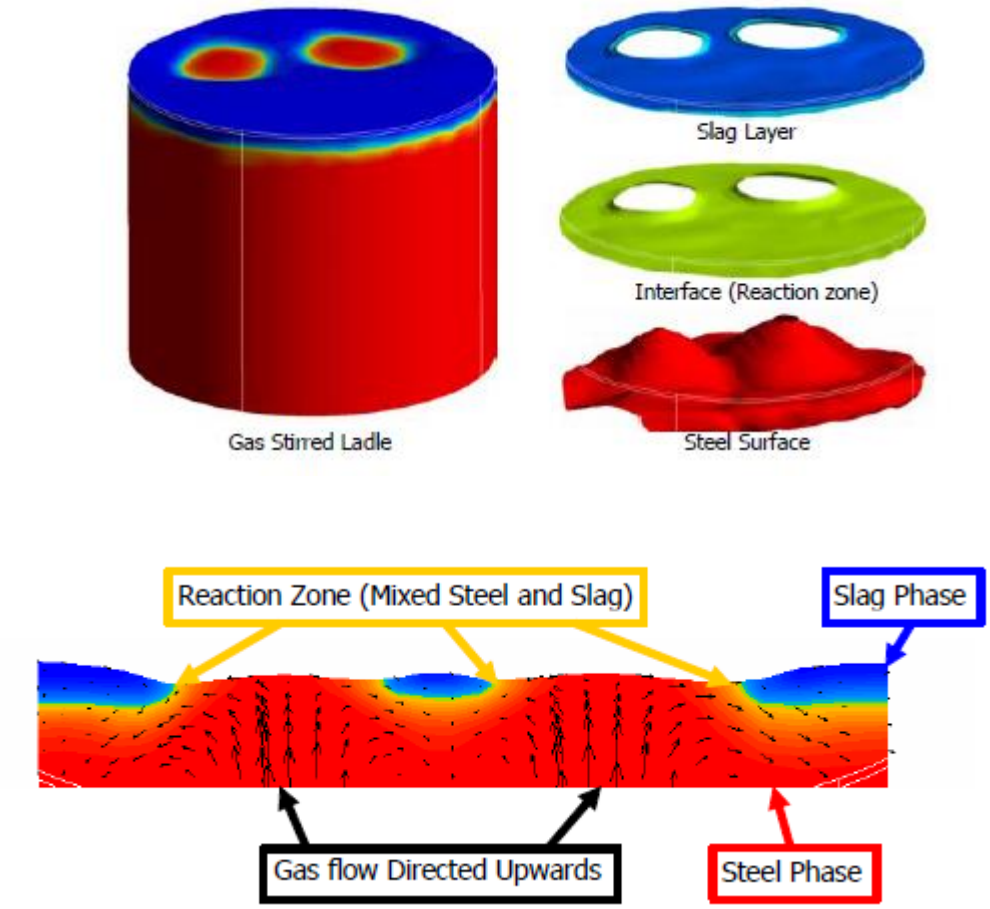


Figure 11: Predicted slag/metal interface in a ladle with gas stirring.

The reaction zone at the slag metal interface has a significant importance regarding steel cleanness. The modelling of this interface has previously been performed using a volume of fluid approach (VOF). The figure in the bottom is a magnification of the interaction zone.
The model allows to evaluate the amount of slag interacting with steel as a function of stirring practices and slag properties.

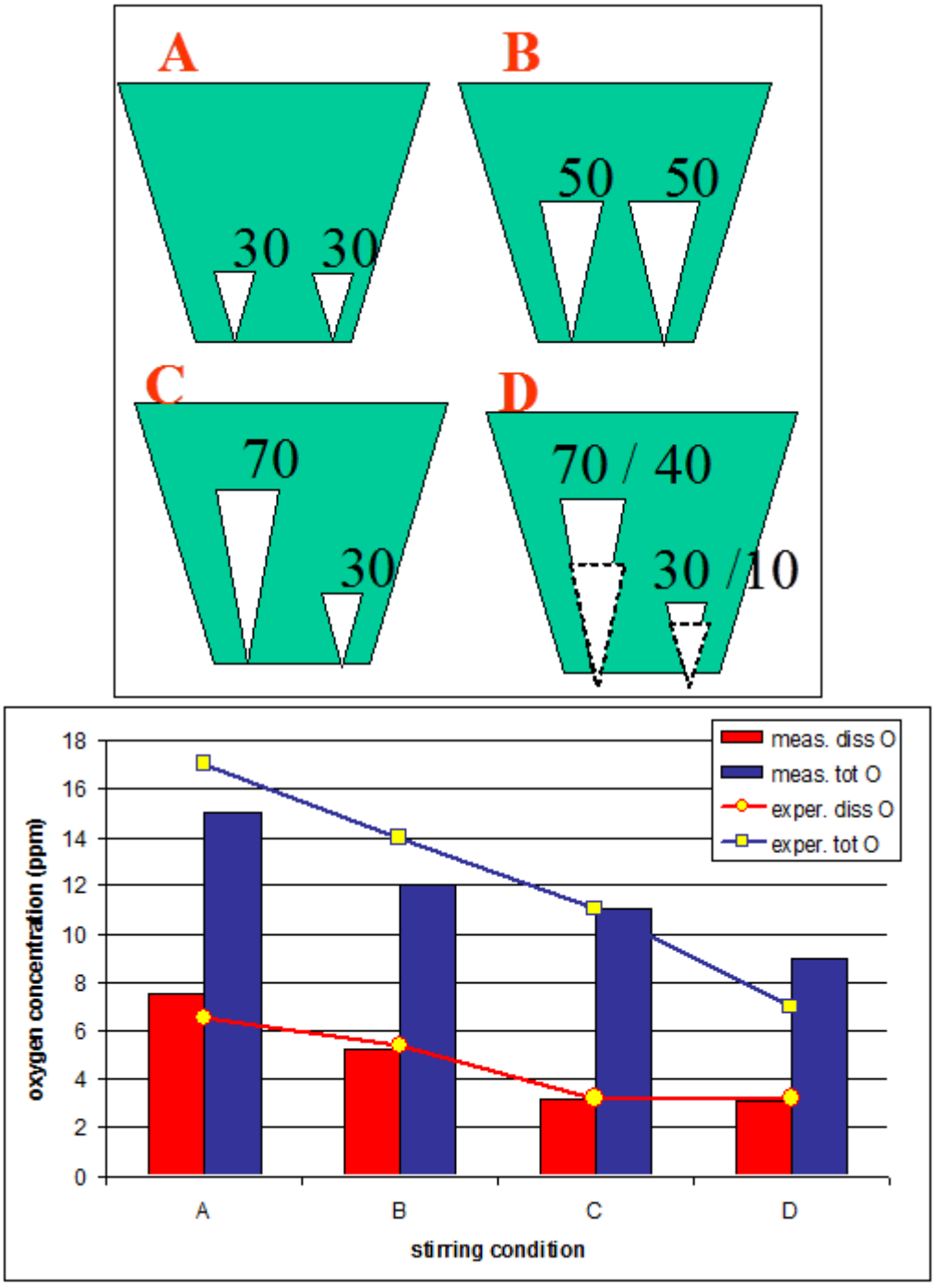


Figure 12: Impact of gas stirring practices on steel cleanliness

Top - Schematisation of different stirring practices for ladle with two porous plugs: A (low stirring), B (high stirring), C (high stirring – asymmetric) and D (high stirring – asymmetric – variable in time). For each porous plug, the gas flow rate in l(STP)/min is indicated.

Bottom - Comparison between calculated and measured values of total and dissolved oxygen after the application of stirring conditions A (low stirring), B (high stirring), C (high stirring – asymmetric) and D (high stirring – asymmetric – variable in time)

Material 4 - RFSR-CT-2010-00003 (Project No. 53)

Multi-criteria through-process optimisation of liquid steelmaking - TOTOPTLIS

The objective of the project was the development of a model-based through-process optimization system to be applied at the liquid steelmaking routes of three different oxygen and electric steelmaking plants. The focus of this development was laid on the specific operational requirements regarding liquid steel temperature and quality control in the respective steel plants, which were individually identified by the different industrial partners. Analytical and data-based process models were developed respectively adapted, and combined for through-process monitoring and prediction of liquid steel temperature and composition for selected relevant elements. The prediction models were combined with optimization tools to derive corrective actions for through-process control, to achieve the target values for temperature and composition of liquid steel under minimum costs with maximal productivity. For each steel plant, finally a case- study was performed to investigate on the applicability and transferability of the new control concept, and to estimate the expectable industrial benefits.

The project is based on the integration of models of steelmaking operations and modern techniques for the optimization of complex systems. The developed optimization tools can be considered as basic instruments for an integrated management of the liquid steelmaking area which are able to support the improvement of steel products quality at lower costs. Actually the project was carried out on three different industrial cases, with three different production cycles. New models of the operations performed in the ladle during the secondary steelmaking cycle have been developed.

Figure 13 shows a schematic representation of the three process routes present in the project.

Figures 14, 15 and 16 show examples of models describing the evolution of steel temperature and carbon concentration during the secondary metallurgy process route. The models have been implemented in real time software and are available for the operator for online process monitoring and control. The integration of the models with optimization tools allows to improve the global performance of the process route.

Figures 17 shows an example of through-process integration of process models.

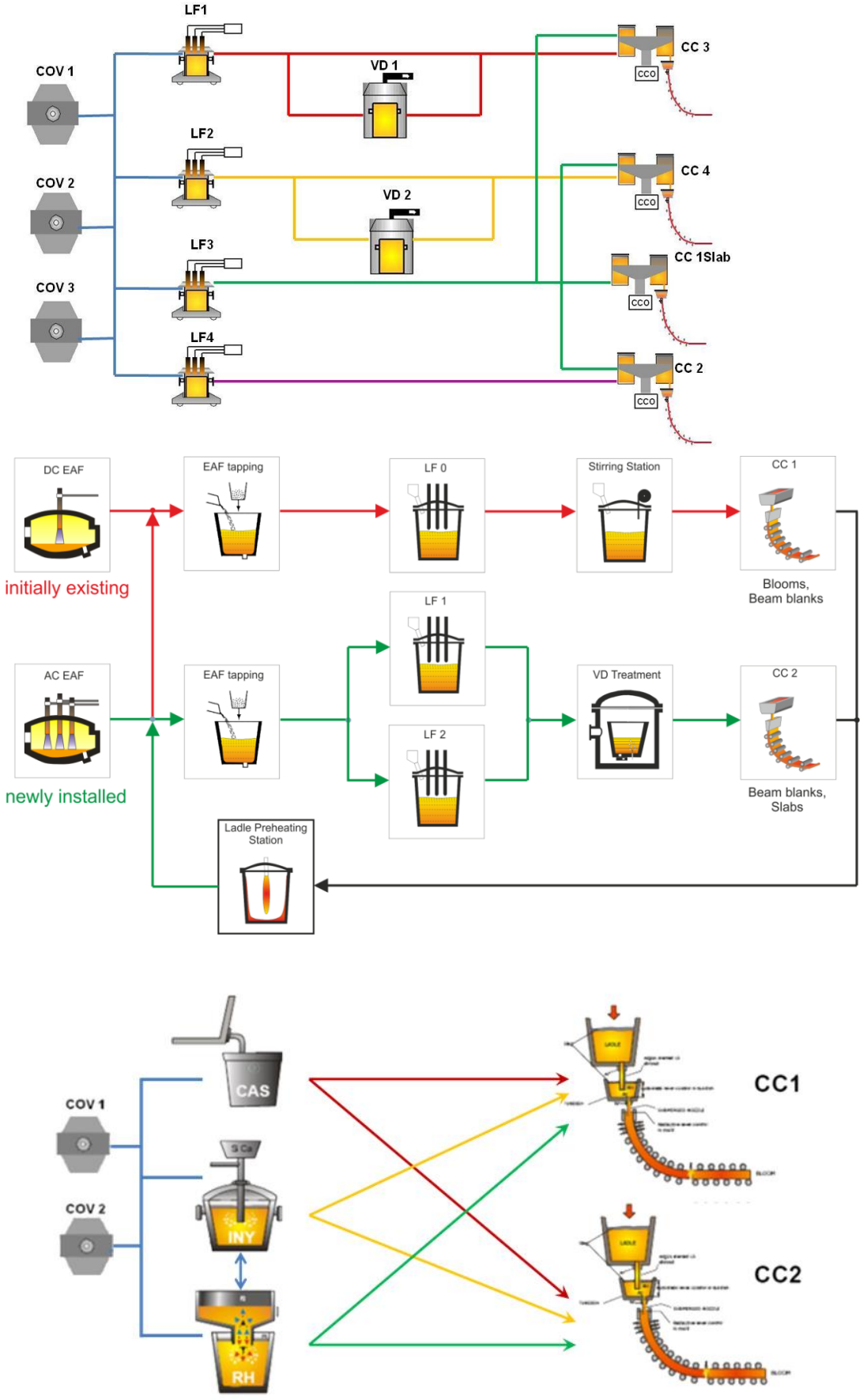


Figure 13: Process routes involved in the project

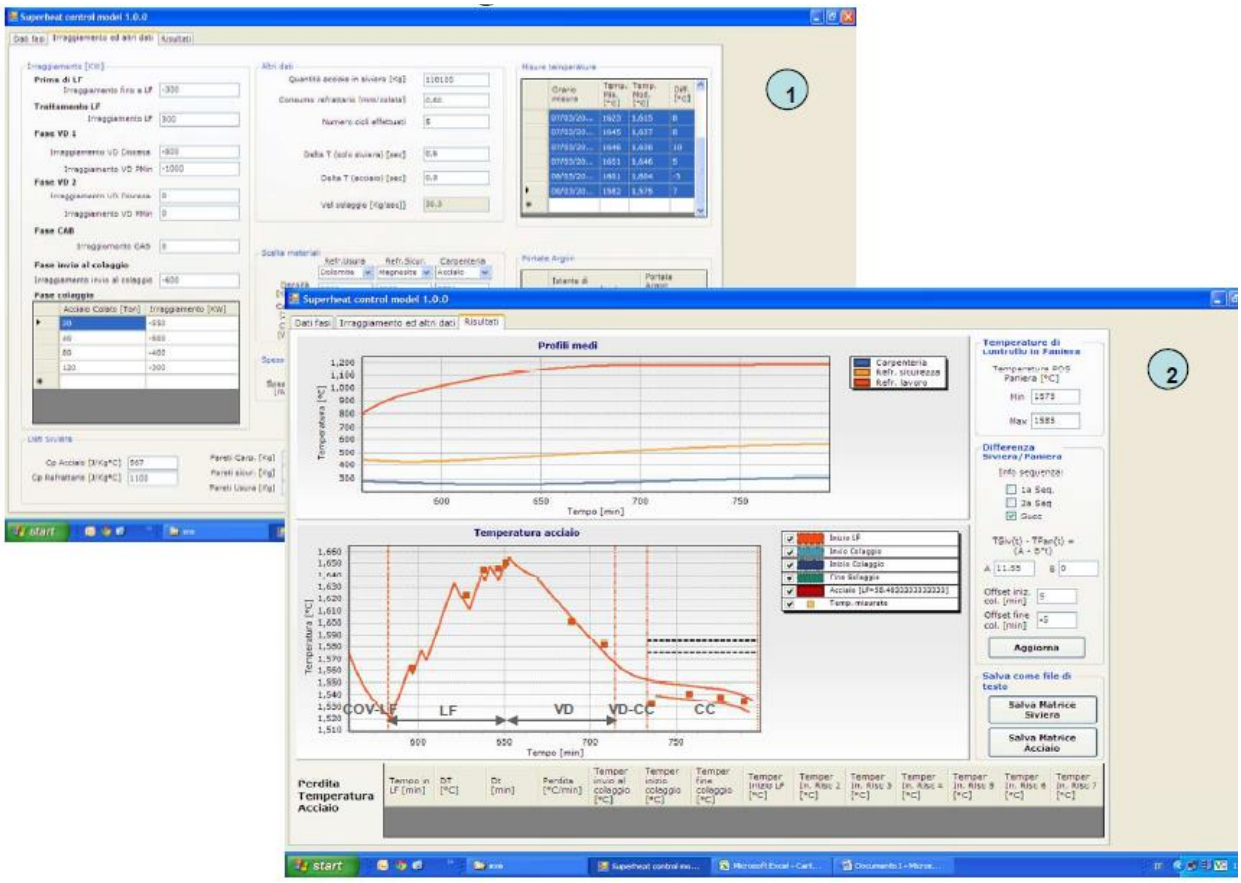


Figure 14: Model of thermal evolution of the steel and ladle during the secondary steelmaking cycle.

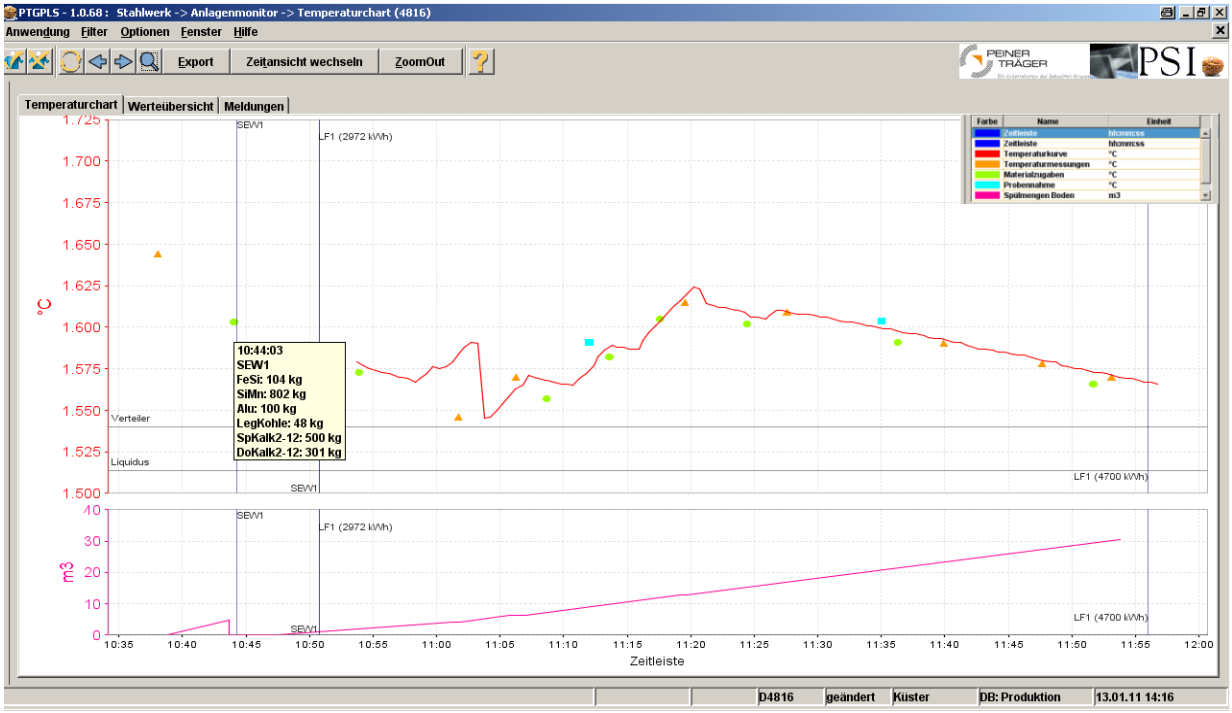


Figure 15: Evolution of steel temperature throughout secondary metallurgy treatment within the online monitoring and control system

Figure 16: Operator interface where the model for C estimation is integrated

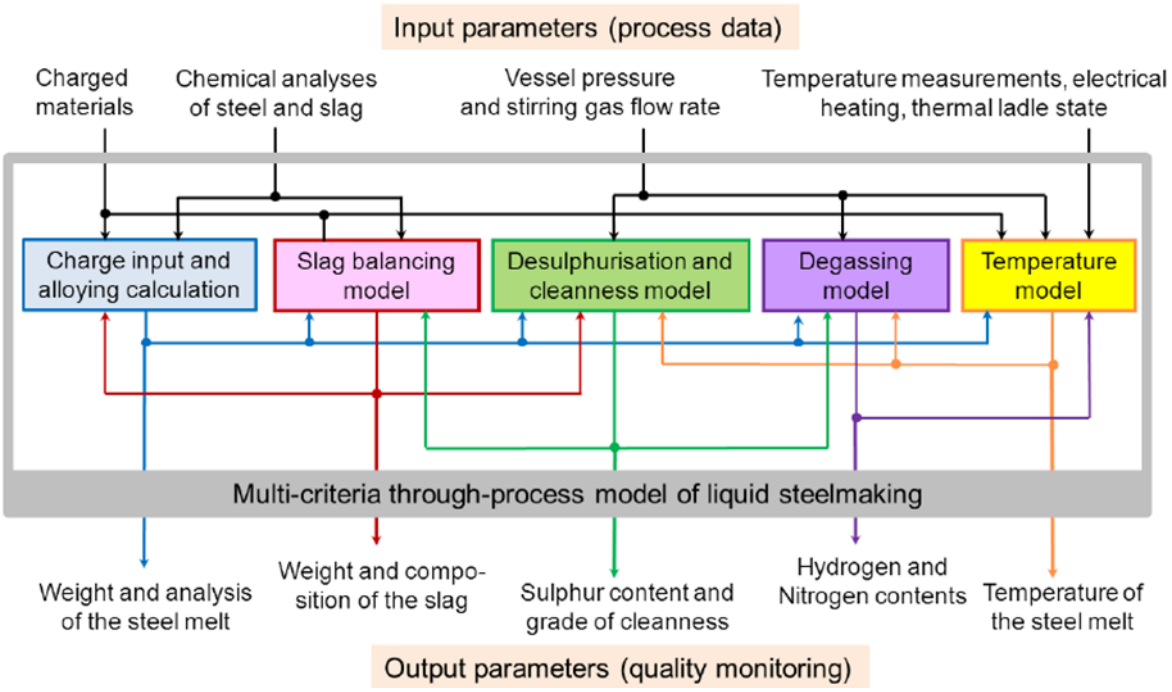


Figure 17: Structure of through-process model predictions with input data from operating instructions

1.2.5 Work package 4: Performance of seminars, webinars and workshops

The main objectives of Work Package 4 were the:

- Planning and preparation of dissemination events (seminars, webinars and workshops)
- Holding of seminars on selected topics at different locations across Europe
- Performance of webinars with on-line access via the internet
- Holding of a workshop for road map preparation

a) Task 4.1 Planning and promotion of dissemination events (All partners)

As events for dissemination, seminars, webinars and a workshop were scheduled. The seminars and the workshop were as far as possible scheduled in conjunction with scientific and technical conferences, in order to allow the participation for a larger number of attendees from the steel industry. The events were performed at different locations across Europe. All project partners were involved in organising and hosting the events. The participation in all dissemination events was free of charge.

Seminars

It was scheduled to hold in total five seminars with dedicated topics of secondary metallurgy technology. Each seminar should focus on one technological field. The topics were selected according to the classification of relevance identified during the evaluation procedure of the ECSC and RFCS projects, see under Task 2.2. As it was found that the topic "resource efficiency and environmental aspects", which was originally planned as a topic for one seminar, was tackled in only very few projects as the main topic, it was decided that this topic is not suitable to be treated in a dedicated seminar. Instead the following list of topics was set up for the seminars:

- Measurement technologies for the quality relevant parameters of liquid steel
- Process models
- On-line control approaches
- Connected auxiliary materials
- Optimisation of secondary metallurgy practices with focus on clean steel production

Each seminar consisted of a number of oral presentations on the selected topic. The presentations were mainly prepared by the project partners, but also external speakers were invited depending on the topic (e.g. steel plant engineers or specialists in measurement technologies).

It was envisaged that some seminars will have a more scientific character, to be addressed to Research Institutes and Universities, to disseminate fundamental knowledge on measurement and modelling techniques. Other seminars were intended to have a more industrial character, to present practical tools, prototypes and process control practices to the engineers of the steelworks and the engineering companies. Of course a certain overlapping was desirable, to establish the contact among the different actors in the technological field.

Webinars

In total two webinars were scheduled to demonstrate successful applications in the field of measurement and automation technologies for secondary metallurgy processes. These webinars should allow the participation of interested engineers from the steel plants without a requirement for travel. The contents of the webinars will be prepared in cooperation with companies for measurement technologies and process automation systems which were involved in the practical application of the respective technology in the context of the research projects.

Workshop

The scheduled workshop was dedicated to the definition of a road map for future developments and research activities in secondary metallurgy. This workshop shall provide the possibility for information exchange and open discussion among the experts in the field of secondary metallurgy. For this purpose it is necessary to receive feedback from the industrial world. Some feedback can immediately be obtained from the steelmaking companies that were involved as industrial partners of the considered research projects. Further feedback is required from industrial realities, like plant engineering companies and suppliers of measurement and process automation systems. All the partners of the dissemination project have long-term and good relations with several of those companies. Hence, it was expected to be not difficult to invite the relevant experts to participate in the workshop.

The workshop will be organised by BFI, and was planned to be held at the premises of the Steel Institute VDEh in Düsseldorf, Germany, in connection with the event Stahl 2017, which was scheduled for the 10th of November 2017.

Preliminary event schedule

For the different dissemination events, a preliminary time schedule (see **Table 6**) with dates, locations, organisation responsibilities and topics has already been set up at an early stage of the project. Some dates and locations were already fixed at the time of first publication of the event schedule, other dates and locations of the events were defined throughout the project duration. An update of the time schedule was published on the project web site after fixing date and place of each further event.

Advertising for the events was also done on the project web site and by flyers distributed by the project partners via E-mail or as handouts. It was also supported by the organisers of the connected conferences.

In addition, advertising of the project and the dissemination events was made by flyer distribution and short introductory presentations in correspondence of other events as

- ‘Made of Steel’ (8th Conference & Exhibition in Southern Europe dedicated to the steel industry), held in Milan, 17-19th of May 2017
- Technical expert group meetings of the VDEh for Electric Steelmaking (21st of February 2017) and for Oxygen Steelmaking (8th of March 2017)

Table 6: Preliminary schedule of the DissTec dissemination events

Event	When	Who	Where	Context	Topic
Seminar 1	14. / 15. Nov. 2017	BFI	Duisburg, Germany FEhS Institute	VDEh expert group meeting "Electric Steelmaking"	On-line process control of Secondary Metallurgy plants (focus on EAF steelmaking)
Seminar 2	June 2017	BFI & CRM	Vienna, Austria	ESTAD 2017	Measurement technologies
Seminar 3	April or Sept. 2017	CSM	Milan, Italy AIM Premises	EuroSteelMaster, AIM yearly conference	Models for Secondary Metallurgy processes
Seminar 4	May / June 2017	MPI	N.N., UK	IOM Seminar	Optimisation of Secondary Metallurgy practices wrt. models, measurement and control technologies (focus on clean steel)
Seminar 5	22. / 23. May 2017	MEFOS	Stockholm, Sweden	KIMAB	Connected auxiliary materials, gas stirring
Webinar 1	September 2017	CSM & BFI			Measurement technologies
Webinar 2	October 2017	MPI & BFI			Level 2/3 Control Systems
Workshop	10. Nov. 2017	BFI	Düsseldorf, Germany	Steel 2017, Annual conference	Road map for future Secondary Metallurgy technology

b) Task 4.2 Preparation and holding of seminars (All partners)

One type of events for dissemination in the DissTec project are seminars. As far as possible, the seminars were scheduled in conjunction with scientific and technical conferences, in order to allow the participation for a larger number of attendees from the steel industry. The seminars took place at different locations across Europe. All project partners were involved in organising and hosting the seminars, and inviting the participants.

As already described under Task 4.1, it was scheduled to hold in total five seminars on dedicated topics of secondary metallurgy technology. Each seminar should focus on one technological field. The following list of topics was set up for the seminars:

- Measurement technologies for the quality relevant parameters of liquid steel (temperature, composition of steel and ladle slag, concentration and composition of non-metallic inclusions)
- Process models (analytical, thermodynamic, statistical, CFD-based, off-line simulation, on-line dynamic for monitoring and control, …)
- On-line control approaches (manufacturing execution systems, set-point and alloy calculations, regulation and control, through-process control for the whole chain of secondary steelmaking, ….)
- Connected auxiliary materials (refractories, stirring plugs, …)
- Optimisation of secondary metallurgy practices with focus on clean steel production (with respect to models, measurement and control technologies)

Each seminar consisted of a number of oral presentations on the selected topic. The presentations were mainly prepared by the project partners, but also external speakers from the steel industry and corresponding research institutes were invited, depending on the topic (e.g. steel plant engineers or specialists in measurement technologies).

Table 7 shows the final schedule of the different seminars with dates, places, context, topic and partner's responsibility for organisation. The first four seminars were held according to this schedule. The fifth seminar with the topic "Process control" had to be cancelled on short notice, so that it was not possible to hold it within the project duration. However the topic "Process control" was handled within one of the webinars (see Task 4.3) and also by a detailed presentation in the workshop (see Task 4.4). In addition the sub-topic "Model-based process control" was also tackled in the Seminar 1 "Models for Secondary Metallurgy processes".

The presentations of each seminar were uploaded to the DissTec web site as PDF files, so that they were downloadable directly after holding the seminars.

Table 7: Schedule of DissTec seminars

Event	When	Who	Where	Context	Topic
Seminar 1	27. April 2017	CSM	Brescia, Italy		Models for Secondary Metallurgy processes
Seminar 2	22. / 23. May 2017	MEFOS	Stockholm, Sweden		Connected auxiliary materials, gas stirring
Seminar 3	29. June 2017	BFI & CRM	Vienna, Austria	ESTAD 2017	Measurement technologies
Seminar 4	27. September 2017	MPI	London, UK IOM3 premises	IOM Seminar	Optimisation of Secondary Metallurgy practices with focus on clean steel)
Seminar 5	15. November 2017	BFI	Duisburg, Germany FEhS Institute	VDEh expert group meeting "Electric Steelmaking"	On-line process control of Secondary Metallurgy plants (focus on EAF steelmaking)

1) Seminar on Process models (CSM)

A seminar entitled 'Process models for Secondary Metallurgy' was held in Brescia on April 27th 2017 with the support of AIM (Associazione Italiana di Metallurgia). The event flyer and the registration form (as for all DissTec seminars, the event was free of charge) is shown in **Fig. 18**. The focus of the mentioned event was on the relevant issues on process modelling

activities and outcomes in the field. The seminar was intended for stakeholders (steel industry, research institutes) in Italy and Europe.

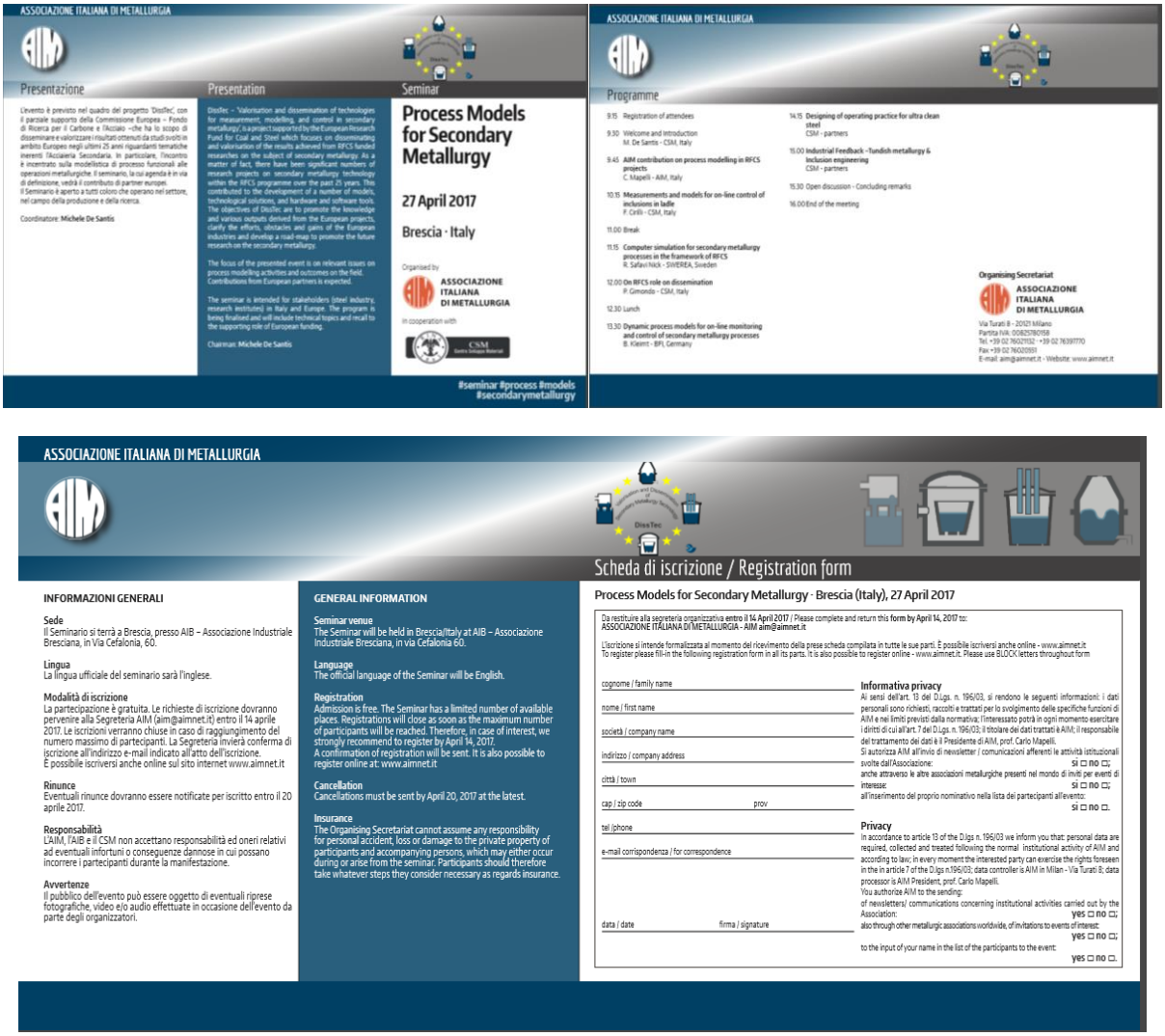


Figure 18: Flyer and registration form of the DissTec seminar on Process models

About 30 participants attended the meeting, among which 50% were technology suppliers, 35% from steel plants and the remaining 15% from research centres & Universities.

The following contributions were presented:

- 'AIM contribution on process modelling in RFCS' (Mr. Mombelli, AIM) with fundamentals of the modelling activity carried out at Politecnico – Milano on inclusion removal features during the secondary steelmaking route;
- 'Measurements and models for on-line control of inclusions in ladle' (Filippo Cirilli, CSM) showing relevant results achieved in European projects focused on inclusion scenario control in ladle steelmaking, describing integrated measure-thermochemical and thermo-fluid-dynamics modelling strategies;

- ‘Computer simulation for secondary metallurgy’, (Reza Safavi Nick from SWEREA), with a state-of-the-art on simulation modelling in the field of concern, especially ladle stirring;
- ‘On RFCS role on dissemination’ (Michele De Santis, CSM), with focus on the RFCS opportunities to support research and dissemination projects. The presentation was kindly sent directly by a EU Project Officer (Dr. Konstantinos Serderidis);
- ‘Dynamic process models for on-line monitoring and control of secondary metallurgy processes’ (Bernd Kleimt, BFI) with a broad overview on relevant results achieved after application of dynamic process models in different steelmaking routes (AOD, VOD, LF,…) ;
- ‘Designing of operating practice for ultra clean steel’ (Filippo Cirilli, CSM) showed some results in the field of defining suitable steelmaking operations aimed at producing steel with a reduced inclusion content;
- finally, in ‘Industrial Feedback –Tundish metallurgy & Inclusion engineering’ (Michele De Santis, CSM) successful results were shown when facing in a RFCS project the problem of performing inclusion engineering to keep them in the steel as needed for giving well defined properties to the metal improved workability steels). This facing in turn two technical problems, one consisting of achieving homogeneous steel composition in a continuous reactor (tundish) instead of in a batch ladle, another consisting of avoiding that the inclusion formed were removed as normally occurs in tundish after proper layout design.

A common discussion followed each contribution.

2) Seminar on Connected Auxiliary Materials (MEFOS)

Swerea MEFOS was responsible for the seminar in the topic of auxiliary materials. The seminar was held in Stockholm as a lunch-to-lunch event with the title of “European Research of Secondary Metallurgy: with Emphasize on Connected Auxiliary Materials” during 22-23 of May 2017. The total of 35 persons from a wide range of steel industries in Sweden has participated in the seminar. Nine presentations were given in which four were held by project partners, four were given by industrial attendees and one with the title of “Development of Applied Process Metallurgy with respect to secondary refining” given by Professor Pär Jönsson from Royal Institute of Technology. **Fig. 19** shows the program for the event. Moreover, it should be mentioned that Uvån Hagfors Teknologi AB (UHT), which is active in the field of control systems for secondary metallurgy processes and thus was also involved in one of the webinars, invited the attendees for a free demonstration at the end of the day one.

It should be mentioned that the seminar in Stockholm not only attracted the engineers of the steel industry in Sweden, but also guests from Finland, Norway and France attended the seminar. It can be said that the seminar was a full success, as the attendees were asking for the presentation and access to the DissTec webpage, where they were distributed to all the participants.

European Research of Secondary Metallurgy:
with Emphasize on Connected Auxiliary Materials

22-23 MAY 2017, Nordic Forum, Kista

DURING THIS LUNCH-TO-LUNCH workshop the past and present researches on the topic of secondary steelmaking will be presented. Presentations will be given by European experts including researchers from Swerea MEFOS.

DissTec - Valorisation and dissemination of technologies for measurement, modelling, and control in secondary metallurgy, is a continuation of the previous RFCS project VALEAF (Valorisation and dissemination of EAF technology) which focuses on disseminating the projects funded by RFCS on the subject of secondary metallurgy. Within the current project, results obtained in previous RFCS projects will be valorized and disseminated.

There have been significant numbers of research projects on secondary metallurgy technology within the RFCS programme over the past 25 years. This contributed to the development of a number of models, technological solutions and hardware/ software tools. The objectives of DissTec are to promote the knowledge and various outputs derived from the European projects, clarify the efforts, obstacles and gains of the European industries and develop a road-map to promote the future research on the secondary metallurgy.

The seminar is intended for Swedish and European steel industry and research institutes.

Welcome!
Reza Safavi Nick, project leader DissTec

Phone: +46 (0)920 -20 19 39
E-mail: reza.safavinick@swerea.se

LOCATION
Nordic Forum, Torshamnsgatan 35, Kista

REGISTRATION
Registration should be made by 17 May 2017.
The participation is free of charge.
Register on: www.swerea.se/disstec

PROGRAMME

Monday 22 May
13.00-13.30 Introduction *Swerea MEFOS*

13.30-14.00 Development of applied process metallurgy with respect to secondary refining *Pär Jönsson and Andrey Karasev, KTH*

14.00-14.30 Improved purging plugs performances and monitoring to improve availability and performance of the gas stirring *Birgit Palm, BFI*

14.30-15.00 Break

15.00-15.30 Development of steel grade related slag systems with low reoxidation potential in ladle and optimised ladle glaze technique for improving steel cleanness *Mselly Nzotta, Uddeholms*

15.30-16.00 Resource-saving operation and control of stainless steel refining in VOD and AOD process *Mikael Ersson, KTH*

16.00-16.30 Grain size control in steel by means of dispersed non-metallic inclusions *Jesper Janis, Outokumpu Stainless*

Visit at UHT – Demonstration of UTCAS®

19.00 Dinner (FnB Market, Kista Galleria)

Tuesday 23 May
09.00-09.30 Increased yield and enhanced steel quality by improved deslagging and slag conditioning *Lars-Erik From, Swerea MEFOS*

09.30-10.00 Enhanced steel ladle life and thermal state ladle monitoring by temperature measurements and numerical simulation of temperature and stresses *Birgit Palm, BFI*

10.00-10.30 Break

10.30-11.00 Refractories in secondary metallurgical processes *Johan Björkvall, Swerea MEFOS*

11.00-11.30 Characterisation and optimisation of ladle stirring systems for the steelmaking industry *Jonas Alexis, Swerea MEFOS*

11.30-12.00 Concluding remarks *Swerea MEFOS*

12.00-13.00 Lunch

DissTec BFI CRM GROUP CSM MPI Materials Processing Institute swerea MEFOS

Figure 19: Seminar on connected auxiliary materials at Stockholm, Sweden

3) Seminar on Measurement technologies (BFI, CRM)

The seminar entitled "Measurement technologies in Secondary Metallurgy" was held in the framework of the ESTAD conference 2017 held from June 26th – 29th in Vienna, Austria. A separate session for this DissTec seminar was integrated within the ESTAD programme at the 29th of June from 2 to 4 pm, see **Fig. 20**. It was implemented in the conference time frame and held at the conference venue at the Austria Centre Vienna. Access was granted with the normal conference fees, no additional fees were charged. Therefore it was accessible by all of the about 1.000 visitors of the ESTAD conference.

Figure 20: Agenda of the DissTec seminar on measurement technologies at the ESTAD conference

During the two hours seminar six presentations were given. The following topics were addressed:

- "Overview on the DissTec project and introduction into the topic 'Measurement technologies in Secondary Metallurgy' ", Dr. B. Kleimt (BFI)
- "SecMet Measurement technologies in ECSC and RFCS research projects – an overview", Dr. T. Kordel (BFI)
- "Measuring of liquid steel temperature in secondary metallurgy", Dr. T. Lamp (Minkon)
- "Online measuring of dissolved gasses in secondary metallurgy", B. Wisniewski (Minkon)

- "Fast analysis of slag chemistry during secondary metallurgy", J.-C. Pierret (CRM)
- "Online measurement of steel cleanness using rapid inclusion characterisation techniques", S. Millman (MPI)

Despite the large number of potential participants, only about 20 participants were attracted by the session. The reason for the low number of participants in the seminar was probably because it was held in the afternoon of the last of four conference days, when many attendees were already leaving the conference. Nevertheless, a lively discussion of the different presentations took place duirng and also after the seminar.

4) Seminar on Clean steel production (MPI)

The Materials Processing Institute was responsible for the seminar on the topic of Clean Steel. The seminar was held at the offices of IOM3, 297 Euston Road, London on Wednesday 27th September 2017. A total of 18 people participated in the seminar of which around half were from industry and academia.

During the five hour seminar (including time for lunch and refreshments), nine presentations were made. Six were from project partners, while two were by industrial attendees and one by a delegate from Swansea University.

The following presentations were given:

'Welcome and Overview of DissTec project' – Stuart Millman, *Materials Processing Institute*

- '10th International Clean Steel Conference – Budapest, 18th-20th September, 2018' - Pál Tardy, *Association of the Hungarian Steel Industry (MVAE)*
- 'Cleanness assessment of high quality steels produced by RH treatment' - Jean-Christophe Pierret, *Centre for Research in Metallurgy (CRM)*
- 'Impact of inclusions formed in steelmaking operations on flow control in continuous casting and defects formation' - Filippo Cirilli, *RINA CONSULTING - Centro Sviluppo Materiali*
- 'Inclusion control through secondary steelmaking and tundish', Marc Jemson, *Materials Processing Institute*
- 'Development of cleaner steel utilising mathematical modelling' – Reza Safavi Nick, *Swerea MEFOS*
- 'The European Pilot Plant Network'- Alan Scholes, *Materials Processing Institute*
- 'European funded projects: a tool to support steelmaking customers in problem solving'- Filippo Cirilli, *RINA CONSULTING - Centro Sviluppo Materiali*
- 'RFCS impact on steel making performance over the last 20 years' – Andrew Dunsmore, *Swansea University*

It should be noted that at the selected time of this seminar there were no suitable conferences being held in London that it could have been successfully linked to and therefore, the seminar was organised as a free-of-charge, stand-alone event.

Fig. 21 shows the publicity poster and program for the seminar.

Optimisation of Secondary Metallurgy Practices with Focus on Clean Steel
Dissemination of results from European research projects

The results of past and present European research projects on the topic: 'Optimisation of secondary metallurgy practices with a focus on clean steel', will be presented at this seminar by European experts.

The RFCS project DissTec – 'Dissemination of technologies in Secondary Metallurgy', is a continuation of the previous RFCS dissemination project VALEAF (Valorisation and dissemination of EAF technology) and focuses on disseminating the results of secondary metallurgy projects funded within the European Commission-managed ECSC and RFCS funding programs.

There have been a significant number of research projects on secondary metallurgy technology within the course of these ECSC and RFCS programs over the past 25 years that have contributed to the development of measurement systems, process models, control tools and other technological solutions. The objectives of DissTec are to review and assess this work; disseminate the research results and knowledge derived from these projects; identify the obstacles and benefits for the steel industry; and develop a road map to stimulate future research and development of secondary metallurgy technologies.

This seminar is free of charge and is intended for representatives from the European steel industry and related research institutes.

Those wishing to participate should contact:

stuart.millman@mpiuk.com

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Web: www.bfi.de/en/projects/disstec

SEMINAR PROGRAMME
Wednesday 27th September, 2017
IOM3, 297 Euston Road, London

10.00-10.20 'Welcome and Overview of DissTec project' – Stuart Millman, *Materials Processing Institute*

10.20-10.30 '10th International Clean Steel Conference – Budapest, 18th-20th September, 2018' - Pál Tardy, *Association of the Hungarian Steel Industry (MVAE)*

10.30-11.00 'Cleanness assessment of high quality steels produced by RH treatment' - Jean-Christophe Pierret, *Centre for Research in Metallurgy (CRM)*

11.00-11.30 'Impact of inclusions formed in steelmaking operations on flow control in continuous casting and defects formation' - Filippo Cirilli, *RINA CONSULTING - Centro Sviluppo Materiali*

11.30-11.45 Coffee

11.45-12.15 'Inclusion control through secondary steelmaking and tundish', Marc Jemson, *Materials Processing Institute*

12.15-12.45 'Development of cleaner steel utilising mathematical modelling' – Reza Safavi Nick, *Swerea MEFOS*

12.45-13.30 Lunch

13.30-13.40 'The European Pilot Plant Network'- Alan Scholes, *Materials Processing Institute*

13.40-14.10 'European funded projects: a tool to support steelmaking customers in problem solving'- Filippo Cirilli, *RINA CONSULTING - Centro Sviluppo Materiali*

14.10-14.40 'RFCS impact on steel making performance over the last 20 years' – Andrew Dunsmore, *Swansea University*

Figure 21: Seminar on Clean Steel held in London, UK

5) Seminar on On-line control approaches (BFI)

The seminar on on-line control approaches was originally planned to be held on the 15th of November 2017 in connection with the VDEh expert group meeting "Electric Steelmaking" at the FEhS Institute in Duisburg, Germany. By this it was expected to attract many professionals from the steel shops in Germany and the neighborhood countries, allowing to minimise the travelling effort. However, since many frequent participants from the main steel shops had already cancelled their participation on short term notice, only little participation was expected such that the entire meeting was cancelled by the VDEh committee. Therefore no platform for the DissTec seminar was available anymore, and thus also the seminar had to be cancelled. Unfortutanetly the expert meeting could not be rescheduled, since a new date was not planned within the DissTec project period, i.e. within the year 2017.

However the topic "Process control" was covered within the webinar on "Online Process Control in Secondary Metallurgy" which was held on the 18th of October 2017 (see Task 4.3), and also by a detailed presentation in the workshop (see Task 4.4). In addition, the sub-topic "Model-based process control" was also tackled in the Seminar "Models for Secondary Metallurgy processes", see above. Thus it can be stated that the cancelling of the seminar on on-line control approaches was sufficiently substituted by other dissemination events.

c) Task 4.3 Preparation and holding of webinars (BFI, CSM, MPI, MEFOS)

One type of events for dissemination in the DissTec project are webinars. They were used to demonstrate successful applications in the field of measurement and automation technologies for secondary metallurgy processes, and allowed the participation with no travelling effort.

Two webinars on the following topics were scheduled:

- Online control approaches
- Measurement technologies

Each webinar consisted of oral presentations (including animations and videos) by the project partners and by invited speakers dedicated to the subject of the seminar. The webinar was performed using a WebEx platform which is a commercial provider for online meetings and video conferences. So no physical presence of the participants of the webinar was necessary, which avoids travelling and limits the time effort of the attendance. Therefore, the participation of a higher number of engineers from the steel plants was achieved. During the presentation the screen was shared to display the presentation to all participants of the webinar. The sound of the voice of the lecturer was also transmitted. The attendees were only able to listen so that the presentations were not interrupted. Questions could be asked by a chat function with the lecturer.

The participation in the webinars was free of charge.

The presentations of each webinar were uploaded to the DissTec web site as PDF files, so that they were downloadable directly after holding the webinars.

Webinar on "Online Process Control in Secondary Metallurgy"

The Webinar on "Online process control in Secondary Metallurgy" was performed on the 18th of October 2017 from 10 to 12 am. The following presentations were held during the webinar:

- "Level 2/3 control system PSImetals of PSI", I. Vollenberg (PSI Metals, Germany)
- "On-line process models for Secondary Metallurgy Processes (LF, VD, RH, VOD) of BFI", Dr. M. Schlautmann (BFI)
- "Level 2 control systems for stainless steelmaking processes of UHT", Dr. K. Beskow, UHT Uvån Hagfors Teknologi AB, Sweden

The invitation to the webinar is shown in **Fig. 22**. The webinar was followed by about 30 attendees.

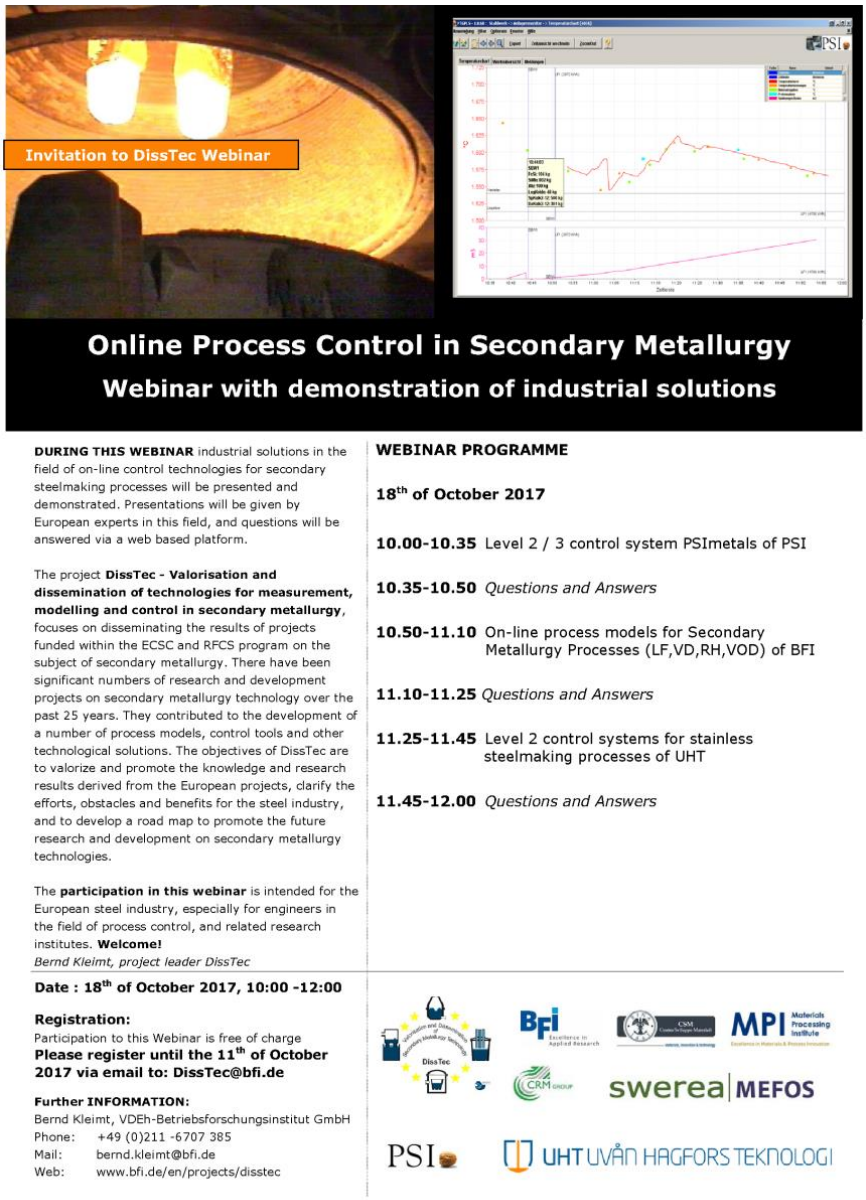


Figure 22: Invitation to the DissTec webinar „Online Process Control in Secondary Metallurgy"

Webinar on "Measurement Technologies in Secondary Metallurgy"

The Webinar "Measurement Technologies in Secondary Metallurgy" was held on the 11th December 2017 from 2 to 4 pm. The following presentations were given during the two hour lasting webinar:

- "Measurement techniques for secondary metallurgy", Dr. T. Kordel (BFI)
- "Measuring the liquid steel temperature in secondary metallurgy", Dr. T. Lamp (Minkon)
- "Electromagnetic slag detection solutions from the furnace to the caster", M. Persson (Agellis Group AB)

The invitation to the webinar is shown in **Fig. 23**. The webinar was followed by about 25 attendees.

Figure 23: Invitation to the DissTec webinar „Measurement Technologies in Secondary Metallurgy"

d) Task 4.4 Organisation and holding of a workshop for road map definition (All partners)

As final dissemination event in the DissTec project, a workshop on "Road map for Secondary Metallurgy technology" was held which was dedicated to the definition of a road map for future developments and research activities in secondary metallurgy. During this workshop, the state of the art regarding research and development results on five selected topics of secondary steelmaking technologies was shortly presented, to initiate a discussion on future needs of research and development in these technological fields. After each presentation an open discussion among experts in the field of secondary metallurgy was performed, to exchange information and to receive feedback from the industry.

The participation in this workshop was intended for the European steel industry, especially for process engineers in secondary metallurgy, as well as related plant suppliers and research institutes.

Originally it was planned to hold the workshop at the premises of the Steel Institute VDEh in Düsseldorf, Germany, in connection with the annual event Stahl 2017, which was planned to take place on 10th of November 2017. This should ensure the participation of a larger number of engineers from the steel plants and from plant suppliers, which are normally coming to Düsseldorf for this event. However, in 2017 unfortunately the event was cancelled on short notice, so that it made no sense to hold the workshop in Düsseldorf.

Thus the workshop, organised by BFI and MEFOS, was finally held at the premises of the Jernkontoret in Stockholm, Sweden. It took place during the afternoon and evening of the 16th of November, 2017, on the day before an expert meeting of Scandinavian metallurgists on ladle metallurgy at the Jernkontoret. The invitation to this workshop is shown in **Fig. 24**.

After an introduction to the DissTec project in general, presentations of the DissTec partners were given with respect to the following topics:

- Process models, P. Miceli (CSM)
- Auxiliary materials, Dr. J. Björkvall (Swerea MEFOS)
- Measurement systems, Dr. T. Kordel (BFI)
- Clean steel production, Dr. S. Millman, (MPI)
- On-line process control, Dr. B. Kleimt (BFI)

The presentations of the workshop were uploaded to the DissTec web site as PDF files, so that they were downloadable directly after holding the workshop.

After each presentation, about 20 min time for discussion of the different topics was allocated. Industrial needs and requirements with respect to future research activities were discussed with the participating production engineers and researchers from the steel plants. In total about 30 people attended the meeting. The discussions were pursued informally during the common dinner after the meeting in smaller groups.

The topics raised in the discussion were collected by the DissTec partners and transferred into a questionnaire. With the help of this questionnaire, which was sent out to the participants of all DissTec dissemination events and further potentially interested stakeholders in the field of Secondary Metallurgy, the industrial relevance of the different identified topics was assessed. The evaluation of the feedback of this questionnaire was finally be used as a basis to set up a road map for future developments and research activities in Secondary Metallurgy technologies.

Figure 24: Invitation to DissTec workshop, held on 16th of November 2017 at Jernkontoret, Stockholm

e) Task 4.5 Evaluation of dissemination events (All partners)

At the end of the seminars a feedback questionnaire **(Fig. 25)** was distributed among the participants.

The feedback was in general positive. From the questionnaires collected , 73% of them indicated the technical information achieved from the seminar was 'significantly' useful, and this achieves more relevance when considering that about 2/3 of the participants (64%) belong to companies not having at all experience in RFCS projects or having taken part into very few (less than 5) of them. This represented a success in the dissemination 'goal' of the event, as a contribution to knowledge sharing and raising of the technical level of steel stakeholders.

This questionnaire is intended to have feedback on the topics of the workshop and the related features concerning Research Fund for Coal and Steel projects outcomes.

Please fill the relevant parts or tick one of the answers when suggested.

Your information will be of relevant importance to allow having a look on the existing scenario and to address action aimed at improving R&D targeting and approach.

Thanks for your contribution.

RFCS Project 'DissTec'

Seminar

PROCESS MODELS FOR SECONDARY METALLURGY -

Brescia - Italy, April 27th 2017

Questionnaire

Valorisation and Dissemination of Secondary Metallurgy Technology

DissTec

1. How were you informed about this workshop?
2. Which steelmaking sector is of your major interest?
3. Have you or your company ever taken part in some RFCS projects? No Yes, less than 5 Yes, more than 5
4. Have you or your company ever taken part in some RFCS projects about EAF items? No Yes, less than 5 Yes, more than 5
5. If yes have you increased your knowledge concerning EAF processes by participating to RFCS projects? No poorly significantly
6. At what extent you feedback from your participation in the projects was positive? Not at all poorly significantly
7. Do you think it is possible to optimize EAF efficiency by the result coming from RFCS Projects?

8. What are in your opinion the main problems for implementation or development of R&D issues?
9. As feedback of this workshop, have you received additional and useful information ? Not at all poorly significantly If yes, please specify the topic(s).
10. Do you want to give us any other feedback regarding the workshop ?
11. Do you think there are ideas that need additional development and implementation? In which sector (automation, environment, energy recovery,….)

Figure 25: Feedback questionnaire distributed at the DissTec seminar on Process models

1.2.6 Work package 5: Preparation of road map

The main objectives of Work Package 5 were the:

- Identification of industrial needs for future technological developments
- Preparation of a road map for future research and development directions

a) Task 5.1 Identification of industrial needs and trends (All partners)

The industrial requirements and trends regarding SecMet technology were mainly assessed on the basis of the critical analysis of the past research projects carried out in WP 2, as well as the discussion and feedback from the seminars, webinars and the workshop held within WP 4.

For this purpose, a questionnaire was designed, setting up for each of the relevant topics which were handled within the dissemination events, i.e.

- Measurement technologies
- Process models
- On-line control approaches
- Connected auxiliary materials
- Clean steel production

a list of sub topics regarding future development trends and potential research topics. This questionnaire was installed as a web-based survey. The access data to the survey was distributed by the DissTec partners and via the DissTec web site among all stakeholders of SecMet technology, i.e. mainly

- researchers
- steel plant managers and engineers
- plant suppliers
- suppliers of measurement technologies
- suppliers of auxiliary materials (refractories etc.),

to ask for a feedback regarding scoring of the relevance and importance of the different sub-topics. The scoring was defined as follows:

1 = not relevant

2 = fairly relevant

3 = relevant

4 = extremely relevant

In total more than 40 fully filled questionnaires from different stakeholders were received. The distribution of stakeholders with respect to profession, region and steelmaking route (where applicable) is shown in the **Figures 26-27**.

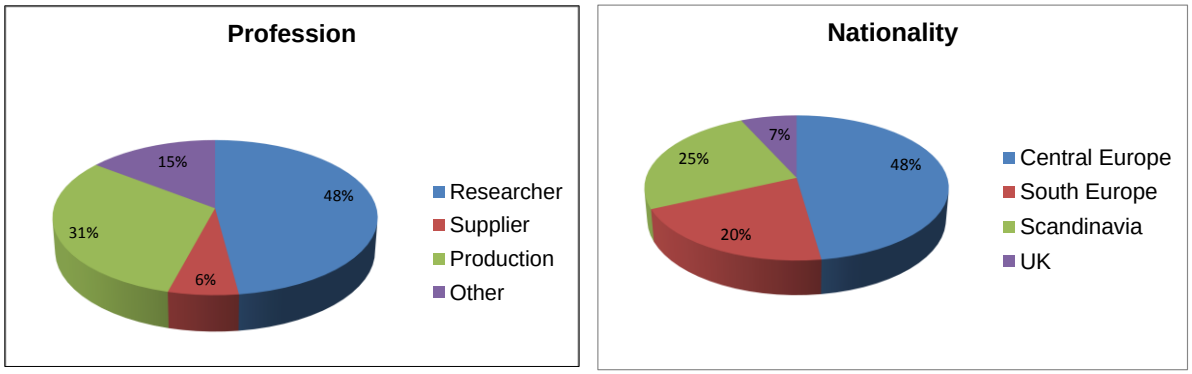


Figure 26: Survey participants grouped by profession (left) and by region (right)

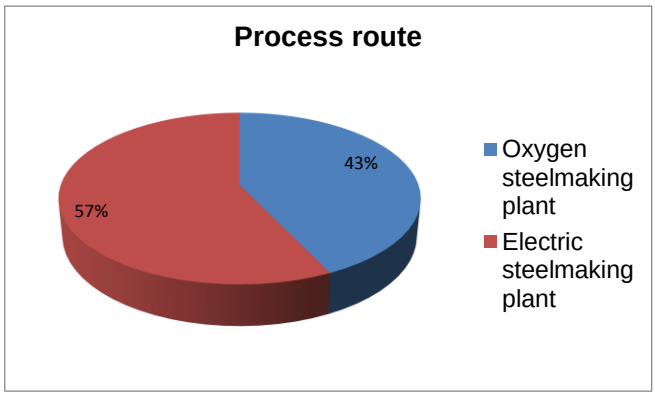


Figure 27: Survey participants from production grouped by steelmaking route

This feedback was evaluated and used, among others, as indicative information for definition of a road map for future research and development directions in Secondary Metallurgy, as described in detail under the following tasks 5.2 – 5.4.

b) Task 5.2 Evaluation of technological challenges (All partners)

The results regarding the average score of the topics and the number of subtopics are presented in **Table 8**.

Table 8: Average score per topic (order according to the list above) as resulted from the stakeholders questionnaire.

Topic	No. of subtopics	Average score
Measurement technologies	10	3.02
Process models	10	2.58
On-line control approaches	9	2.89
Connected auxiliary materials	8	2.81
Clean steel production	6	2.87

Table 9 highlights the subtopics receiving a scoring of 65% or more as either ‘relevant’ or even ‘extremely relevant’, or an average score higher than 2.8.

Table 9: Results from the Stakeholders' questionnaires: subtopics with scoring of 65% or more as either relevant or extremely relevant, or an average score higher than 2.8

Topic & Subtopics	% score 3 or 4	∅ score
Measurement technologies		
Smart sensors based on combination of measurements and models	86 %	3.27
Inline analysis of concentration and composition of NMIs	81 %	3.17
Inline measurement of slag carry-over amount	80 %	3.16
Inline analysis of slag composition	75 %	3.16
Inline measurement of actual stirring intensity	73 %	3.09
Inline analysis of steel composition regarding C and O content	80 %	3.05
Inline continuous steel temperature measurement	75 %	3.00
Inline measurement of slag depth / total ladle slag amount	66 %	2.84
Process models		
Combined modelling of inclusion removal and engineering	66 %	2.91
Extension of dynamic process models by utilisation of thermodynamic data bases	64 %	2.80
Coupling of thermo-chemistry and fluid dynamics calculations	66 %	2.75
On-line control approaches		
Automatic ladle tracking with continuous assessment of stirring plug operation (stirring efficiency, lifetime)	80 %	3.07
Through process control of the complete process chain of SecMet	84 %	3.05
Utilisation of further sensor information for extended on-line process monitoring and closed loop control	79 %	3.02
Closed loop control of stirring intensity, depending on metallurgical operation (degassing, desulphurisation, inclusion removal)	73 %	2.98
Self-adaptive / self-learning process models and control functions	66 %	2.93
Horizontal and vertical integration of automation systems (Industry 4.0)	65 %	2.86
Accurate through-process control for each steel quality using statistical / Artificial Intelligence / Big data analysis techniques	65 %	2.84
Connected auxiliary materials		
Fundamental investigations on refractories effect on steel quality	75 %	3.02
Determination of slag amount to allow well-aimed slag conditioning	77 %	2.95
Optimisation of maintenance procedures for stirring plugs	75 %	2.95
Inline monitoring of refractory state/erosion for predictive maintenance	74 %	2.86
Innovative tundish refractory materials to avoid reoxidation and hydrogen pick-up during casting	62 %	2.83
Antioxidant additions to refractories for inclusion control	66 %	2.70
Optimisation of ladle preheating methods (flameless burners, microwave technology	66 %	2.68
Clean steel production		
Clean steel issues for new steel with higher mechanical performance (e.g. dedicated practices, limitations…)	75 %	3.09
Inline / fast analysis of non-metallic inclusions (density, size distribution, chemical analysis)	74 %	3.02
Inclusion design / modification by injection of alternative materials so that inclusions become liquid at rolling temperature	65 %	2.81
Fundamental research on extremely low total oxygen content	66 %	2.75

Figure 28 additionally highlights individual results of the questionnaires. For each topic the three sub-topics with the highest overall score are shown, with their distribution of scoring results.

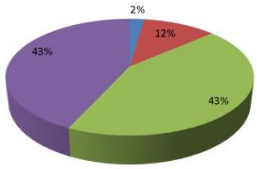
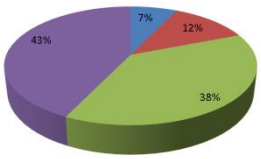
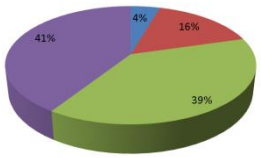
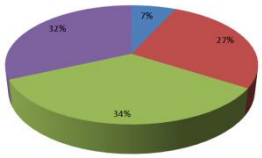
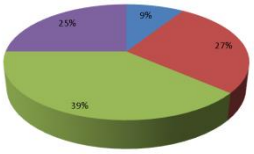
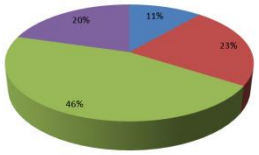
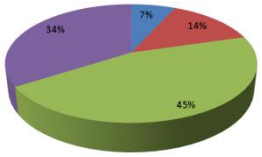
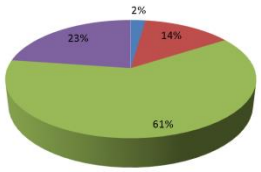
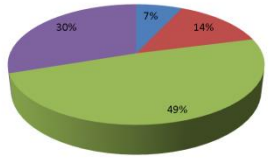
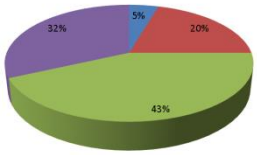
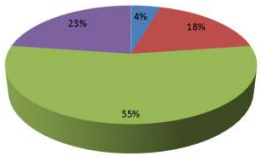
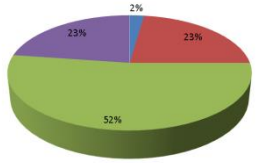
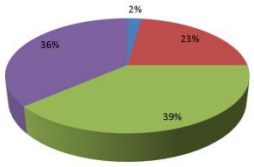
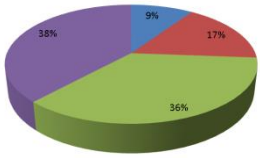
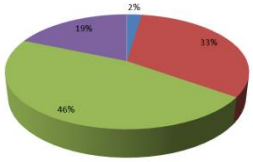
Topic	Three sub-topics with the highest scores and score distribution (1 2 3 4)		
Measure-ment technologies	Smart sensors based on combination of measurements and models 	Inline analysis of concentration and composition of NMIs 	Inline measurement of slag carry-over amount 
Process models	Combined modeling of inclusion removal and engineering 	Extension of dynamic process models by utilisation of thermodynamic data bases 	Coupling of thermo-chemistry and thermo-fluiddynamics calculations 
On-line control approaches	Automatic ladle tracking with continuous assesment of stirring plug operation 	Through process control of the complete process chain of SecMet 	Sensor information for on-line process monitoring and closed loop control 
Connected auxiliary materials	Fundamental investigations on effect of refractories on steel quality 	Determination of ladle slag amount to allow well-aimed slag conditioning 	Optimisation of maintenance procedures for stirring plugs 
Clean steel production	Clean steel issues for new steel with higher mechanical performance 	Inline / fast analysis of NMIs (density, size distribution, chemical analysis) 	Inclusion modification by injection so that they become liquid at rolling temperature 

Figure 28: Topics with three subtopics of highest scoring from the stakeholders questionnaires

The topic **'Process Modelling'** had the lowest stakeholder feedback score with only 3 out of its 10 subtopics scoring 65% or more as either 'relevant' or 'extremely relevant' or having an average score higher than 2.8. These were: 'Combined modelling of inclusion removal and

engineering', 'Extension of dynamic process models by utilisation of thermodynamic data bases' and 'Coupling of thermo-chemistry and thermo-fluid dynamics calculations'. The low overall score for this topic may result from concerns that process modelling in general is more aimed at gaining theoretical understanding of processes rather than developing practical applications for industrial control. This might also be the reason that the two most relevant subtopics also have a strong relation to other, overall more relevant topics as 'Clean steel production' and 'On-line control approaches'.

Higher stakeholder feedback scores were received for the other topics: 'Measurement Technologies', 'On-line Control Approaches', 'Connected Auxiliary Materials' and 'Clean Steel Production'. For these, the scores were quite similar and the subtopics that were most prominent related particularly to inline measurement and analysis - probably highlighting the most urgent needs in secondary metallurgy technology.

The topic **'Measurement Technologies'** had the highest stakeholder feedback scores with 8 out of the 10 subtopics scoring 65% or more as either 'relevant' or 'extremely relevant'. The most important subtopics were: 'Smart sensors based on combination of measurements and model information', 'Inline analysis of concentration and composition of non-metallic inclusions', 'Inline measurement of slag carry-over amount', 'Inline analysis of slag composition', and 'Inline measurement of actual stirring intensity'. Also here some of these prominent sub-topics have a strong relation to the topic "Clean steel production".

The topic **'On-line Control Approaches'** had 7 out of the 9 subtopics scoring 65% or more as either 'relevant' or 'extremely relevant'. The most important subtopics were: 'Automatic ladle tracking with continuous assessment of stirring plug operation', 'Through process control of the complete process chain of secondary steelmaking', 'Utilisation of further sensor information for extended on-line process monitoring and closed loop control', and 'Closed loop control of stirring intensity, depending on metallurgical operation (degassing, desulphurisation, inclusion removal)'. Here a strong relation of some subtopics to the topics of "Measurement technologies" and "Process models" can be found. Also obvious is the tendency of growing relevance towards Industry 4.0 topics as through process control, smart sensors, self-adaptive models as well as horizontal and vertical integration of automation systems.

The topic **'Clean Steel Production'** had 4 out of the 6 subtopics scoring 65% or more as either 'relevant' or 'extremely relevant'. The most important subtopics were: 'Clean steel issues for new steel with higher mechanical performance', 'Inline / fast analysis of non-metallic inclusions (density, size distribution, chemical analysis)' and 'Inclusion design / modification by injection of alternative materials so that inclusions become liquid at rolling temperature'. The second of these subtopics has a strong overlapping to a similar one in the topic "Measurement technologies".

Finally, the topic **'Connected Auxiliary materials'** had 7 out of the 8 subtopics scoring 65% or more as either 'relevant' or 'extremely relevant' or having an average score higher than 2.8. The most important subtopics were: 'Fundamental investigations on effect of refractories on steel quality', 'Determination of ladle slag amount to allow well-aimed slag conditioning',

‘Optimisation of maintenance procedures for stirring plugs’ and ‘Inline monitoring of refractory state/erosion for predictive maintenance’. Here the subtopics with relevance to steel quality were dominant, and also some overlapping to the topic “Measurement technologies” can be found.

The feedback of the stakeholders in secondary metallurgy, acquired in the DissTec project during seminars, webinars, workshops and by the evaluation of the questionnaire comments, can be summarised to six main lines of technological challenges, which are tackled by one or more topics and subtopics:

- In-line determination of steel melt chemistry and temperature
- In-line analysis and control of ladle slag amount and chemistry
- Improved control of inclusion mass, chemistry and size distribution
- Through process control based on self-adaptive models and smart sensors
- Industry 4.0 approaches for intelligent manufacturing
- Increased refractory life with less impact on steel quality

These main technological challenges have been addressed in more detail in the identification of research needs and the set-up of a road map for secondary steelmaking technologies, which is described in the following chapter.

c) Task 5.3 “Identification of research needs” and Task 5.4 “Preparation of a road map” (All)

Trends and Drivers

The introduction and growth of secondary steelmaking technologies in steelmaking operations started in the 1960s on a broad basis and eventually led to the successful production of consistently high-quality steel grades throughout the industry. The steel industry has evolved as a complex mix of secondary metallurgy production units, with each steel plant having unique operating practices and constraints that may be categorised to include:

- Available treatment facilities and capacity constraints
- Number, size and capability of the casters
- Degree of manufacturing difficulty and range / variability of products
- Arrangements for scheduling these products through the various process routes

The product mix affects the scheduling criteria, processing procedures and the way in which various processing plants are coupled. Large variations in product mix and processing equipment (type, design, capability, age, layout and capacity) requires especially, a suitable plant operating philosophy such as:

- Matching equipment capacities
- Simplifying logistics
- Minimising bottlenecks
- Understanding and applying scientific principles

In general, there is no serious ambition for developing new secondary steelmaking processes or significant changes in procedure. Instead, developments for **improving existing processes** have sought to optimise resource expenditure and improve liquid steel quality. The main issues in improving and optimising ladle metallurgy processes are thus related to:

- energy efficiency
- productivity
- yield
- melt temperature and chemistry control
- inclusion morphology, chemistry and size distribution
- refractory life

Over the last 20 years, the European research projects within the framework of the ECSC and RFCS steel research programmes that have targeted developments to improve secondary steelmaking processes have produced 56 completed projects with a further 4 projects currently ongoing. These projects were evaluated within the DissTec project, project outlines were given in Deliverable D 2.1. The projects have made significant contributions towards the present high level of technical achievement demonstrated by secondary metallurgy processing. Largely, this has been through the development of measurement technologies, process models and online control approaches for the production processes, with the aim of achieving the required tight tolerances for casting temperature, chemical composition and cleanness, to meet the properties of the final steel products, with high reliability and minimum energy consumption.

Drivers for technological improvements, which were also identified within the feedback of the stakeholders in secondary metallurgy, acquired in the DissTec project during seminars, webinars, workshops and by the questionnaire comments, were

- the demands of innovative steel grades with extraordinary physical and chemical properties such as low carbon levels, low sulphur levels
- tight temperature control to decrease energy consumption and improve material properties
- demands on high steel cleanness with low concentration of non-metallic inclusions
- decreasing quality of raw materials (lower quality of ores, tramp elements in scrap)
- need for lower production costs due to low price margins
- need for higher energy and material efficiency to decrease energy and material costs

The following main lines of technological challenges, which were already mentioned above, will be discussed in detail to define the road map for secondary metallurgy technology and to identify future research needs:

- Inline determination of steel melt chemistry and temperature
- In-line analysis and control of ladle slag amount and chemistry
- Improved control of inclusion mass, chemistry and size distribution
- Through process control based on self-adaptive models and smart sensors
- Increased refractory life with less impact on steel quality
- Industry 4.0 approaches for intelligent manufacturing

While some technological challenges of liquid steelmaking arising from such demands have been frequently addressed, some challenges have not been solved satisfactorily (e.g. inline analysis of concentration and composition of non-metallic inclusions). Some challenges have been tackled, but the solution does not solve the entire challenge thoroughly, so some decent research need still exists.

To meet the **high demands of innovative steel grades**, the most important control parameters for liquid steelmaking are melt temperature and melt composition. The current state of the art is that the ladle refining stations are equipped with in-process sampling and temperature measurement capabilities. The sample is sent to a laboratory where it is analysed for selected metallic elements using x-ray fluorescence, optical emission spectroscopy or evaporative techniques for gaseous elements. However up to now no accurate technique for **online chemical analysis** is available. Expendable immersion thermocouples are the most commonly used method of measuring temperatures, producing spot readings accurate to ±2.5°C within seconds. Immersion samplers have been developed for most common grades. However no **continuous melt temperature measurement** technique with high accuracy and low thermal inertial is commercially available at present.

Currently all steel ladle processes are limited to **lowest levels of solute elements** (like H, N, S) and oxide inclusion contents in the ppm regime. For highly inclusion-sensitive steel grades, levels of solute and inclusion contents can be even lower than ppm levels and the necessary applied analytical techniques and processing steps will require some development to effectively accommodate such extreme values.

Unwanted residual elements are often established within liquid steel because of recycling. Future advances could involve improved control of reactive residual elements such as calcium, aluminium, magnesium and zirconium and developing better control practices for partially reactive residuals such as chromium, sulphur, phosphorus, manganese, nitrogen and hydrogen and non-reactive residuals such as copper, nickel, tin, cobalt, antimony, arsenic, tungsten and molybdenum. This could include an improved focus on limiting the ways in which these elements enter the process chain or by reducing their concentration and impact once they have entered.

Product properties such as fatigue life and mechanical performance issues such as die life are related not only to the mass of inclusions but also to the chemistry and size distribution of inclusions. For example, most fatigue problems in bearing steel result from hard and brittle oxides, especially large alumina particles over 30µm. In addition, initiation of **solidification** in the mould and solid-state phase transformations are related to the chemistry and distribution of inclusions formed in the liquid steel. Therefore, a future focus of ladle metallurgy will be even stricter **control of chemistry and deoxidant additions**. To accommodate this, metallurgical control in the ladle should include the development of rapid response sensors for steel and slag chemistry and fast determination of inclusion chemistry, mass and size distribution. Smart-Sensors, based on a combination of measurements and modelling information might meet such a challenge. Such applications will minimise processing time and increase the potential for highly accurate composition control.

Ladle stirring is a key requirement for **inclusion level control**. Continuous assessment of stirring plug operation and stirring intensity will provide assurance of optimised operation.

A consistent steelmaking practice also demands **precise slag control** which necessitates the development of rapid or inline methods to quantify slag carry-over from primary production, together with a good estimate of total slag mass and chemistry.

Developments in **slag usage** involve slag recycling and reuse within the steel plant in order to minimise waste. Manipulation of slag viscosity and solidification characteristics could lead to slags that are not easily emulsified with steel while being easily removed from the ladle.

Techniques for **temperature prediction** and control are necessary. Trials using an optical fibre fed into a melt to provide direct in-line continuous temperature measurement have been carried out within several RFCS and Horizon 2020 projects. Expectations are that a commercial system will soon be available, after current developments are completed.

A further challenge regarding process control is to consider the interactions and interdependencies of the different ladle processes in the secondary metallurgy chain. **Through process control** approaches for a horizontal integration are needed, using predictive and self-adaptive dynamic process models as well as smart sensors for seamless monitoring and control of the entire chain of secondary metallurgy processes from tapping to casting. This horizontal integration follows the new paradigm of Industry 4.0, with a 100% traceability of intermediate and final products, establishing an intelligent product with knowledge of its own quality and production history. This Industry 4.0 philosophy should in the future also be applicable in digitalisation of the liquid steel production within secondary metallurgy processes.

The above mentioned drivers have also increased the demands on the refractory lining, to increase the duration, to reduce maintenance effort and to increase steel cleanness. **Refractory developments** such as innovations in high alumina and basic refractories have made it possible to tap heats at high temperatures and hold heats for extended periods of time. Refractories are readily available that resist damage from the electric arc and wear from the stirred bath, while resisting the corrosiveness of refining slags and remaining chemically stable with respect to the chemistry of the steel. For example, magnesia, magnesia-spinel and magnesia-chrome materials can include carbon and metallic additions for slag resistance and added strength.

Ladle refining vessels demand low cost **refractory lining** systems that are environmentally sound, chemically inert and operationally safe. Steel and slag interaction with container refractories remains a limitation of ladle processing, thus further development is required of inert and long-life refractories that can be easily and quickly installed. Legislation will ensure that landfilling of spent refractories is not affordable or permitted.

Removal of technological barriers to process improvement requires a **research environment for system development** that offers a prospective for practical and affordable solutions even though they are not yet proven. Such solutions could be focussed on concurrent processing or

the reduction or **elimination of unproductive time**. Advances in ladle metallurgy include the development of **rapid or continuously operating sensors** for steel and slag chemistry and temperature, as well as for inclusion chemistry, mass and size distribution. Such sensors would help to **reduce operating time** and increase capability for highly accurate chemistry and temperature control.

Future research activities

Many of the technological challenges which have been listed above can be addressed on a medium and long-term basis by future R&D or Pilot & Demonstration projects on secondary metallurgy technologies.

In-line measurement technologies

For **inline analysis of metallic elements in steel and slag** Laser Induced Breakdown Spectroscopy (LIBS) technique has been applied to provide in-line information on steel, slag and inclusion chemistry. This technology has already been tested successfully on a lab basis, while it is still struggling with difficulties especially with respect to accuracy in industrial environments and irregular surfaces of real samples. This or similar technologies for inline chemical analysis should be further developed to be applicable in the harsh industrial environment of secondary steelmaking since the measurement helps to control the chemistry of steel, slag and non-metallic inclusions.

The melt temperature is usually measured by lances with thermocouple probes for spot measurements. The fibre optical system DynTemp has proven its potential for **continuous melt temperature measurements** with high accuracy even in inhomogeneous melts. New techniques for melt access should be developed to apply the great opportunities of continuous measurements for melt temperature control in other aggregates throughout secondary metallurgy.

Smart sensors should be developed based on continuous measurements of different process parameters in combination with process models to deduce further information which would be not easily or continuously accessible by standard sensors. One example would be a smart sensor for the C concentration based on an oxygen activity measurement, supplemented by an appropriate model.

Inline measurement of **slag carry over** should be addressed to improve the slag metallurgy. If the amount of slag carry over from primary steelmaking can be monitored, it can even be reduced without excessive steel losses, the slag former and slag conditioner additions can be reduced leading to increased material and energy efficiency while increasing productivity.

Measurement of the **actual stirring efficiency** is important for successful and efficient ladle metallurgy. Gas stirring helps to bring the steel slag system closer to the thermodynamic equilibrium, which improves and speeds up processes like degassing of H and N and refining like dephosphorisation as well as desulphurisation. This topic has been addressed by application of camera technique and vibration sensors showing its high importance for the process.

Process models and on-line process control

Coupled heat and mass transfer models are necessary to predict the effect of ladle processing on chemistry and inclusion control. Several recent RFCS research and demonstration projects have already been designed to develop on-line predictive models for ladle treatment that include heat transfer with the container and the slag, reaction between the steel and the slag, reheating, degassing, and refining. These models, combined with smart sensors for on-line monitoring and equipped with self-adaptive functions, will have to be integrated within **through process on-line control concepts**, fulfilling future guidelines of automation according to the **Industry 4.0** paradigm.

Yield

New ladle design and other methods to prevent the onset of metal vortexing during ladle drain are necessary to increase yield from the ladle and preserve quality. Vortex prevention, development of repeatable free opening performance and design are key components.

Productivity

Future developments in steel plant design include better matching of logistics in steelmaking, casting and rolling mill activities, and this will demand a significant reduction in ladle refining times. Thus, rapid refining methods, rapid chemical sensors and new linings at the ladle metallurgy station must be developed to meet these new ladle refining productivity requirements. New technology and automated processes are being applied to analysis and reporting methods to further minimise cost and time.

New steel qualities

Work continues on the development of steel grades with fewer harmful inclusions, desired inclusion composition and morphology, ultra-low residual element content and also high alloy element content like manganese and aluminum. For many of these approaches, key steps are already known for the process (e.g. desulphurisation, dephosphorisation and degassing). For other steps, new process models based on fundamentals of thermodynamics in combination with fluid dynamics are required. Also new fluxing agents and inclusion modifiers could be developed to flux undesirable residual elements in order to moderate their impact during processing or to tie them up as engineered inclusions that impart beneficial mechanical properties to the product.

Conclusions

The above described road map for future technological developments and research activities has tackled the main lines of technological challenges which have to be faced by the steelmakers in improving the performance of the secondary metallurgy processes. The work of valorisation and dissemination of results of European research projects on secondary metallurgy performed in the DissTec project will surely promote the industrial exploitation of achieved knowledge and technological solutions in European steel plants.

This has to be considered in conjunction with the economic scenario in the field of steelmaking. Following the suggested road map may allow the European steel producers to cope with the ever increasing demands of the customers on the quality of steel products, and also with the stricter regulations concerning environmental impacts. In addition, regarding some applications of measurement and control technologies, a direct involvement of manpower in plant operation can be avoided, which will increase health and safety in the workplace.

Summarising it is highly recommended to continue the fruitful European partnership and knowledge sharing between research institutes and steel producers, thus ensuring a reinforced market position especially against Asian and American Competitors.

2. Exploitation and dissemination of results

Due to the nature of the DissTec project, the dissemination of the project results was to a large extent already performed via the dissemination events as seminars, webinars and the workshop. Also the project web site was actively used for dissemination of the results from the very beginning of the project, by offering information and the presentations of all events to interested stakeholders in the field of secondary metallurgy.

In addition, after the finalisation of the project, the DissTec consortium intends to present the project results at the following conferences to be held within the next two years:

- Clean Steel 2018
- 8th European Oxygen Steelmaking Conference (EOSC) 2018
- 4th European Steel Technology & Application Days (ESTAD) 2019
- 12th European Electric Steelmaking Conference (EEC) 2020

Furthermore the results are intended to be published in the following technical journals:

- Stahl & Eisen
- Steel research
- La Metallurgia Italiana
- Steel Times International
- Ironmaking & Steelmaking

3. Follow-up of recommendations and comments from previous review(s)

The recommendation to involve besides research institutes also other stakeholders in secondary metallurgy in the evaluation of the industrial implementation of the project results was followed within the further evaluation procedure. Besides direct bilateral contacts, the meetings at the dissemination events and the feedback from the questionnaire were used.

Following a further recommendation, the dissemination of the results of the project will not be limited to Europe. The project results shall be presented within overview papers and papers on selected topics at several large international conferences in Europe, with participants from all over the world. Thus the exchange of ideas on a wider scale may contribute in defining future developments.

4. Deviations from Annex 1 and Annex 2 (if applicable)

4.1 Tasks

As already described under Task 4.2, it was originally scheduled to hold in total five seminars on dedicated topics of secondary metallurgy technology. The first four seminars were held according to this schedule. The fifth seminar with the topic “Process control” had to be cancelled on short notice, so that it was not possible to hold it within the project duration. However, the topic “Process control” was handled within one of the webinars (see Task 4.3) and also by a detailed presentation in the workshop (see Task 4.4). In addition the sub-topic “Model-based process control” was also tackled in the Seminar 1 “Models for Secondary Metallurgy processes”.

4.2 Use of resources

Only minor deviations between actual and planned use of resources occurred. It should be mentioned that the manpower needed for planning and holding the dissemination events in Work Package 4 was significantly higher than expected in Annex 1 and 2. The transfer of costs categories was only required on a minor level.

5. List of Figures

6. List of Tables

7. List of symbols, indices, acronyms and abbreviations

Acronyms and abbreviations are explained directly in the text.

8. List of References

ECSC and RFCS projects dealing with Secondary Metallurgy technology

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[3] ECSC project 7210-CC/104: "Development of a model for the vacuum circulating process", (8/1990-1/1994), EUR 16186 DE

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[8] ECSC project 7210-CC/109,110,701: "Process Modelling, Process Measurements and Control to Optimise Secondary Steelmaking in the Production of Super Clean Steels", (07/1993 – 12/1996)

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[16] ECSC project 7210-PR/009: "Control of inclusions in RH degassing processes", (07/1997 – 12/2000), EUR 20179

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[19] ECSC project 7210-PR/207: “Operation and control of vacuum circulation (RH) process with lance oxygen input”, (07/1997 – 12/2000), EUR 21435

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[22] ECSC project 7210-PR/135: “Production of EAF steels with low contents in N2 and S through vacuum treatment”, (07/1999 – 06/2002), EUR 20945 EN

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