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Abstract	The aim of this document is to specify the measurable indices and the benchmark performance through which the novel sensing, PAT and IPC components developed within the DISIRE project will be evaluated and the final outcome of the project will be judged. This document thus defines the required and expected capabilities of the DISIRE technologies and relates them to specific industrial settings and evaluation procedures. The detailed specifications are obtained through an iterative process where information from all the involved partners is fused in a coherent technical specification.

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Content

List of Acronyms

ABBREV	Explanation
BC	Belt Conveyor
CC4	C4 Crude Fraction – butane, butane, butylenes, 1,3 butadiene, etc..
CCD	Charged Couple Device
CFD	Computational Fluid Dynamics
GHG	GreenHouse Gases
IPC	Integrated Process Control
MPC	Model Predictive Control
PAT	Process Analytical Technology

1   Introduction

1.1.   Summary

The aim of this document is to specify the measurable indices and the benchmark performance through which the novel sensing, PAT and IPC components developed within the DISIRE project will be evaluated and the final outcome of the project will be judged. This document thus defines the required and expected capabilities of the DISIRE technologies and relates them to specific industrial settings and evaluation procedures. The detailed specifications are obtained through an iterative process where information from all the involved partners is fused in a coherent technical specification.

1.2.   Purpose of document

Building on top of the inputs to deliverable D1.2, the requirements and the objectives of the DISIRE project will be further detailed. A progressive strategy will be followed in order to evaluate the capabilities of each of the DISIRE subcomponents; Identifying the ad-interim experiments and field trials will aid the design of a complete and integrated demonstration that will act as the final benchmark of the project.

Furthermore, this document will give indications on the expected specifications of the DISIRE components with a particular focus on:

1. Specification of advanced inline sensing: This benchmark will specify metrics on the sensing capabilities developed within the DISIRE project. The sensing capabilities should be industrial demonstration specific and will target all the four industrial sectors in the project. The benchmarking will have a general character, including measuring extended properties of the sensors regarding, e.g., the surrounding environment, processing and communicating capabilities, miniaturization, efficiency, accuracy, etc.

2. Specification on PAT analysis: This benchmark will specify metrics regarding the ability to analyse big amount of data near- and real-time timing constraints, while at the same time providing meaningful and useful integrated information that can be utilized by the IPC framework for optimizing the overall process.

3. Specification on PAT based IPC: This benchmark will focus on evaluating the proposed reconfigurable and adaptable PAT when used in the proposed IPC. Specific initial test cases will be drawn from several scientific areas such as, e.g., machine learning, but the focus will be in benchmarking the efficiency of the proposed IPC with respect to the adopted industrial processes.

4. Process Specific Demonstration specification: These benchmarks will produce clear measurable indices for evaluating the impact of the overall DISIRE project into the focused four industrial sectors of ferrous, non-ferrous, combustion and material flow. Particular attention will be given to: a) the extended experimental demonstration of the overall concept in TRL levels at least 3-5 and b) the practical evaluation of the direct impact of the DISIRE platform to the overall SPIRE objectives regarding the sustainable process industry and the direct measurement of the achievable reduction in resources and energy.

1.3. Methodology

For each industrial process a short introductory description will be provided stating each problem and giving the general picture. Then, the novel DISIRE components will be focused and for each of them detailed specifications will be given according to the division introduced in Section 1.2.

1.4. Partners involved

Partners and Contribution	
Short Name	**Contribution**
LTU	Coordinating and integrating inputs from partners
DOW	Description of the WP8: Combustion Processes
MEFOS	Description of the WP7: Steel Processes
ETEC	Description of the WP6: Ferrous Mineral Processes
LKAB	Description of the WP6: Ferrous Mineral Processes
IMTL	Coordinating and integrating control specific discussions
KGHM	Description of the WP5: Non-Ferrous Mineral Processes
ABB	Description of the WP5, 6, 7 and 8

2   WP5 Non-Ferrous Mineral Processes, KGHM: Ore tracing and fault-detection for the belt conveyor system

2.1.   Brief description of the process

The Belt Conveyor (BC) system in KGHM's copper mines transports the raw ore from underground storages[1] to the surface[2] where the flotation process takes place. The BC system is an open-loop process (meaning that there is no automatic control of the flows) characterized by its continuous operation and the high throughput. It comprises complex, redundant ramifications over large underground areas; Main and secondary transportation lines have different capacities and their functioning is overseen by a human according to factors such as the availability of the ore and stop conditions such as the breakdown of individual links.

There is a pressing interest in optimizing/tuning the chemical processes at the processing plant in function of the composition of the utilized ore (which varies with the extraction area). To this aim, it is necessary to develop sensing technologies that are able to trace the flow of different batches of ore and identify how the ore from different underground mining developments is mixed during the transportation.

At this point, we refer the reader to the DISIRE deliverable D1.2[3] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

2.2.   DISIRE technological contribution

The foreseen DISIRE contribution towards the ore transportation system can be summarized as follows (see also Figure 1):

   a) DISIRE based in situ sensors for tracking the ore;
   b) DISIRE based online PAT, with potential extensions in influencing the overall IPC and the fault predictors.

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[1] Underground storages called *bunkers* are employed as an efficient interface between the mining face and the CB system. The feeding points to the CBs, a.k.a. *screens*, are located in correspondence to the bunkers.

[2] More specifically, the output points of the CB system are vertical tunnels known as *shafts* from which the ore is raised to the surface through *hoists*.

[3] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.
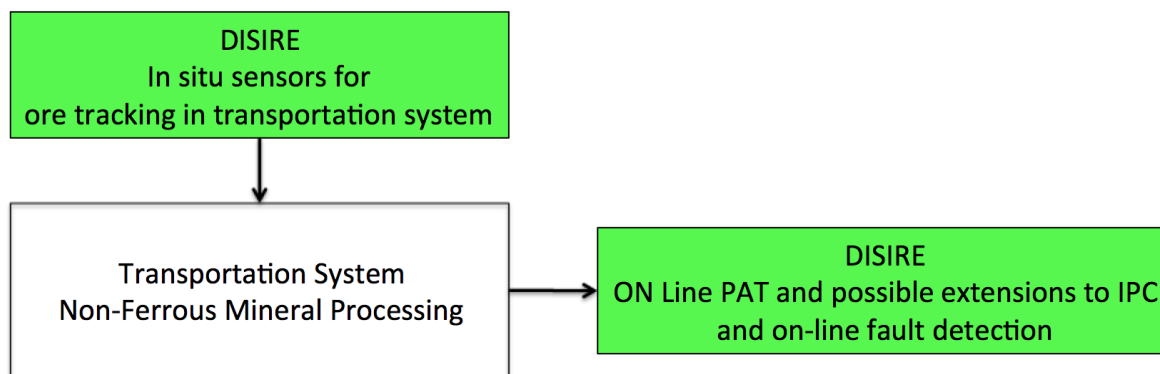
Fig. 1: DISIRE technological impact in the ore Transportation System.

2.3.   Specification of advanced inline sensing

There is a strong requirement that the novel sensor technologies should be able to provide a reliable information in order to be included into the production control process -– e.g., the Quality Assurance-Quality Control (QA/QC) system. An upgrade of the existing QA/QC procedures that would match international standards is a great need of the KGHM domestic operations and investigations of the possible improvements have already been undertaken.

It is worth noting that the considered e-pellet based technology does not guarantee the full recovery of the pellets at the destination point. Nevertheless, the loss of e-pellets will not influence the quality of the data, and thus the corresponding information gathered.

The size and material from which the pellets will be built has to be adapted to the specific mining conditions and to be robust to the potential mechanical damage. Due to the lithological diversity and the employed drilling&blasting technology, the granulation of the ore flow reveals a great diversity.

The information about the lithological composition of the copper ore delivered to the processing plant, its tonnage and the original location where it has been mined, will be utilized in the currently being developed system (ConVis) of automatization and optimization of the process preparation of ore milling and storing. The detailed recognition of transporting of the ore from various fields of the mine will allow the processing plant to manage raw ore bunkers voids which is crucial for the proper blending and managing of ore in the ConVis system.

The following targets are to be achieved with the help of ConVis system:

- Optimisation of supply of the raw ore (monitoring of crushers and screens, monitoring of depots in the crumbling and milling areas and in the crushed ore depot; additional algorithms enabling automatized technological solution finding will be used;
- Stabilisation of ore granulation – monitoring and instant response on any imperfection occurrence (recording of hammers working time, screens in crushers, analysis of vi-

bration and temperature gauges installed on bearings of the main machinery equip-
ment – crushers, screens);

- Automatic safe mode of work over crushed ore bunkers that are switched off due to any maintenance activities.

The optimization is aimed to match the blending and separating criteria for the ore in particular milling bunkers following the information about the lithological composition and granulation of the copper ore being delivered by the BCs to the concentration (processing) plant as well as minimizing the downtime of BCs in order to ensure the optimal ore supply directed to milling.

Such efforts should stabilize and optimize the ore milling and separation equipment work which in turn will benefit the overall transformation process and decrease its specific energy consumption. It also being stressed, that the benefits are difficult to identify exactly and that they can only be verified by an assessment based on industrial trials.

Pellets should carry information about the lithological composition of the copper ore delivered to the concentration (processing) plant. This can be achieved either directly by cod-ing identified lithological composition or indirectly by identifying the origin of ore. Origin of the ore related to the mine geological database (either a existing geological samples database or a novel three-dimensional geological model of the deposit) provides information about litholo-gical composition of the ore.

At this time, based upon the large set of various geological data already stored in databases of samples, digital maps, sections, in the KGHM the geological & mining software DATAMINE is being implemented. The geological, 3D model of the copper ore deposit with the 3D model of mine developments and workings are being built. Once this work will reach a sufficient degree of maturity, the geological model will be regularly updated with the new samples taken from the mined faces. The annotation of mining field embedded into pellets, combined with the information about the geological structure as identified from the 3D model can be then used for recognition of lithological composition of the mined ore.

Due to the nature of the transportation system in the mine, ores from different origins are mixed. Thus, the system should estimate parameters (lithological composition) of the blended ore upon the analysis of the set of pellets read by readers.

2.4.   Specification on PAT analysis

The concentration plant needs about four hours in order to switch processing param-eters, thus the information on lithological composition should be made available in advance. The data read at pellet scanners do not have to be transmitted online, since the ore trans-portation time from the skip to the concentration plant lasts approximately 4 hours. Statistical analysis and post-processing of the acquired data could be performed offline regardless of the mineral processing.

2.5. Specification on PAT based IPC

The aim of the pellet-based technology is to control the mineral processing parameters on the basis of the actual, time-varying lithological composition of the ore.

The improvements could be assessed through the following measurable indices:

- energy consumption of copper ore crushing and milling (energy impact);
- decreased amount of waste/ increased recovery.

2.6. Process Specific Demonstration specification

Knowledge regarding lithology of the transported ore supports the optimization of the crushing and milling processes. The expected improvements are related mainly to the energy consumed during these processes. It is crucial to minimize energy consumption, since it directly and sensibly affects the overall costs of the mineral processing. It is also desired to decrease the amount of waste and increase the recovery indices.

3   WP6 Ferrous Mineral Processes, LKAB: E-pellet based tracking of iron ore in the transportation chain

3.1.   Brief introduction to the process

The logistics of the refined iron ore products involve the management of temporary storages - *silos* - at the production sites and the terrestrial and maritime transportation of the pellets to the end-users.

Each link in the chain is characterized by different physical capacities and can involve the mixing of different batches of the product; this can happen, for example, during loading and unloading operations. On one hand, the composition of the pellet needs to vary depending on the type of transformed goods to which it is intended and the specific needs of different market segments. On the other hand, it would be economically inefficient to fully separate those batches that have different properties. An increased awareness of the flows along the transportation chain is thus instrumental to quantifying and assuring the quality of the delivered pellets.

We refer the reader to deliverable D1.2[4] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

3.2.   DISIRE technological contribution

The foreseen DISIRE contribution towards tracing e-pellets in the logistic chain can be summarized as follows (see also Figure 2):

1) DISIRE based in situ sensors: RFID based transponders are deposited in the material flow at the point of origin for the transportation chain to be measured; Detection of the transponders is made by the use of antennas around or over the process flow.

2) DISIRE based traceability capabilities of the pellets: The traceability capabilities are expected to increase from off-line studies of databases and printouts to an estimate of when a certain product has been produced and when it has passed certain production steps.

3) DISIRE based online PAT module for the Ferrous Mineral Processing with potential extensions in influencing the overall IPC in simulation and hardware in the loop trials; By introducing PAT into the transportation chain the aim is to be able to determine the spatial distribution of a specific batch at specific time and thus how it is mixed with different batches.

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[4] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.
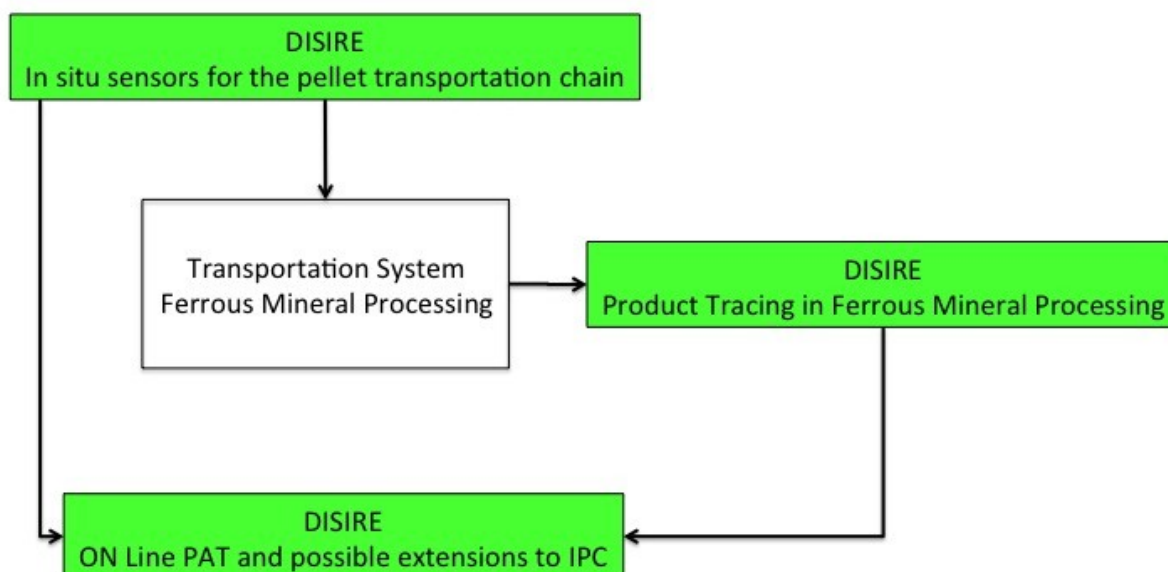
Fig. 2: DISIRE Technological Impact in the Ferrous Mineral Processing Industries.

3.3.   Specification of advanced inline sensing

The industrial process of pellet production is naturally split – in both time and space - into hot and cold sides. We stress that throughout the DISIRE project a greater emphasis will be put on the hot side since this is where the most affecting and novel solutions can be re-searched and applied. Consequently, the research and development of novel sensing devices to be applied to the so called cold side has been concentrated on the acquisition of positioning information as further elaborated below.

Specifically, the target for a localization technology in the ferrous mineral processing plants is that of endowing the transportation chain of the finished product with batch tracing capabilities. By being able to follow product batches, from the manufacturing site onwards to the harbours, where it will be loaded on the maritime transports, it becomes possible to steer the material to different customers according to the incoming material's properties and the end-user's requirements.

In addition, such positioning technology allows the measurement of the pellets at the initial storage locations. This therefore enables not only the estimation of the properties of

the product at the harbours but allows predicting these properties throughout space and time along the logistic chain. Positioning information is moreover instrumental to the future utilization of in-situ sensors where the location can be exploited as meta-data attached to measurements of a different kind and can be further exploited to estimate distribution densities of the sensed properties.

Towards the above measurement and estimation aims, a model-based approach will be considered and specifically a novel model of the pellet transportation process will be researched and developed.

No new positioning sensors will be developed within the scope of this project. Instead, a novel miniature RFID-tag technology will be adapted to these processes and operationally tuned in order to be employed to spread markers within the pellet batches. The segregation effects of the tags will be studied and evaluated according to their size in order to enable future designs of RFID-tags that integrate additional kinds of sensors. Indeed, for positioning in a transportation chain, the most promising choice of technology is the passive RFID approach. In this technology, passive transponders use energy supplied by a reader antenna to power the internal electronics. The transponders are deposited in the material flow at the point of origin for the transportation chain to be measured. Detection of the transponders is made by the use of antennas around or over the process flow. The segregation effects of the tags will be studied and evaluated according to their size in order to enable future designs of RFID-tags that integrate additional kinds of sensors. Major technical challenges include detectability in the harsh environment and miniaturization to reach pellets sized transponders.

The described methodology is based on off-line models for the prediction of the product, separated into virtual batches. In the sequel, the position of these virtual batches is calculated based on statistical models obtained by use of RFID pellets or e-pellets throughput times from different process sections. The transit times are measured as the RFID pellets pass readers along the transportation chain. The detectability of the RFID pellets thus need to be high enough to be useful for model validations and the same RFID pellets needs to pass several readers. Currently, the detectability of each sensor depends on its size. Earlier experiments have shown that tags of the same size as the iron ore pellet (Ø 10,0-12,5 mm) have a detection rate around 20% at some installations, which is too low for model calibration and validation purposes. New RFID transponders are developed and off the shelf products can be aso utilized in this case, where the detection rate in these cases will be also evaluated. Additionally, in DISIRE it will also continue to study if larger sized pellets with higher detection rates can be used. The risk with such larger transponders and enclosures is that they segregate and therefore generate wrong throughput estimates. Early experiments

in the DISIRE project have not indicated grave tendencies of segregation, but more work is needed in this area, thus the results will have to be verified in full-scale testing.

A measurable goal of the DISIRE project will be the increment of the reading rate for the small tags by at least 50%. A second goal will be to investigate and demonstrate how larger tags can be included without segregation from the real pellets.

DISIRE will also study possibilities for position triangulation using larger, active transponders using multiple antennas. One important variable here will be the penetration depth and attenuation of the radio signal in the iron ore pellets. Laboratory tests of 20kg samples have not shown large attenuations, but these results may differ when performed in full-scale ore silos where the distance between transponder and the antennas may exceed 50m.

3.4. Specification on PAT analysis

The PAT analysis will focus on correlating the positioning measurements in time and thus providing aggregate statistical descriptions of the state of the transportation chain at specific points in space and time. The passive RFID measurements will allow the analysis of the distribution of the tags along the iron ore pellet transportation chain and thus also that of the pellet mixing rates at specific points and the overall mixing behaviors.

An important role in the statistical state reconstruction problem is played by the actual detectability properties of RFID pellets that will have to be studied and characterized through field trials. These trials will provide the ground truth to identify and compare simulation models of the transportation chain. A difficulty here is that the detectability of the RFID transponders induces different technological and development decisions: On one hand, too few detected RFID pellets will lead to large modeling uncertainties; On the other hand, larger RFID-pellets increase detectability (through the larger antenna size), but the larger casings have already exhibited strong tendencies to segregate, which introduce bias in the models. It will be then interesting to dedicate part of the work in the field trials to the study of the means (for example, using different shapes and materials) by which one can let larger RFID-pellets flow within the batch like actual pellets. In the future, exploiting larger casings will allow the integration of sensors such as accelerometers and moreover batteries and memory storage. Active tags that are able to detect acceleration, pressure or temperature will also facilitate analysis of, for example, the transportation induced stresses (the latter in turn could aid the redesign of the most stressful stages in the transportation chain).

Preliminary case studies will be performed to evaluate existing and readily available / off-the shelf RFID sensor platforms. This will result in a selection of those platforms that, once refitted with ad-hoc casings, can potentially withstand the harsh interaction along the transportation chain, while providing the desired performance. These platforms will then be evaluated, if possible, in field trials.

Finally, the acquired data will be processed offline by comparing the estimation capabilities of the novel model with the actual field measurements

The objective of using the new PAT in the transportation chain is to give information related to a specific batch such as the batch's location at a specific time and how it is mixed up with other batches. Moreover, assuming knowledge of the specific properties of a batch at the origin the newly available information will enable to perform steering decisions in connection with the customer requirements, the state of storage facilities and other quality issues.

3.5.   Specification on PAT based IPC

As discussed above and in Deliverable D1.2[5], the main objective is to allow the discrimination of batches of pellets with differing material properties. A second objective is to predict and control, through a mixture model, the spread and amplitude at shipment that results from process disturbances. In other terms, an objective is to facilitate product management in the presence of disturbances.

The logistic chain as well as the grate process will generate knowledge useful for offline or open loop control purposes. The LKAB processes are not expected to be controlled in closed loop during the development of the DISIRE project. The existing control systems for the LKAB processes are open-loop. Human operators perform control decisions based on the simulation of the position of virtual product batches in the transportation chain. Control strategies will therefore be developed to utilize the information obtained by the traceability models, in the sense that operators will be able to guide the flow of products with certain properties to selected customers where these properties are not harmful or even beneficial.

3.6. Process Specific Demonstration specification

With new possibilities to track and trace iron ore pellets in the logistics transportation chain in combination with a novel model, the iron ore producer, LKAB, will improve the ways of controlling how different types of products can be handled in the logistic flow. For example

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[5] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.

a product batch with a deviating quality parameter that requires to be stored separately can be handled more efficiently reducing the amount of pellets with different properties that have to be stored at each time.

A measurable performance index is therefore the amount of material that has to be separately stored to be later made available for mixing with another production batch. Reducing this amount and the possibility of predicting how the product batch with deviating quality is distributed along the logistic chain are improvements in this area.

4   WP6 Ferrous Mineral Processes: LKAB thermal grate

4.1.   Brief introduction to the process

The last production stage in the refinement of the iron ore pellets involves a thermal process called Grate[6] Kiln[7]. During the passage through the grate, the initially moist pellets are dried, heated and oxidized before being sintered[8] in the kiln. The gas composition and the temperature (which can reach up to 1300°C) inside the grate affect the oxidizing reaction and thus the final quality of the product.

A natural control objective is the tuning of the reaction through the observation of these variables, along the process, and at different times.

We refer the reader to deliverable D1.2[9] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

4.2.   DISIRE technological contribution

The foreseen DISIRE contribution towards the grate process can be summarized as follows (see also Figure 3):

a) DISIRE based in-situ sensors for temperature and gas composition measurements;
b) DISIRE based online PAT, with potential extensions in influencing the overall IPC in simulation and hardware in the loop trials.

The novel in-situ sensor technology will be able to report data while the sensing devices are transported through the Grate (online PAT). By giving each sample a time-stamp and by knowing the transport conveyor speed, this will make it possible to estimate the temperature and oxygen content at various positions inside the oven.

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[6] A **grate** is where a stationary bed of pellets, approximately 20cm high, is transported and exposed to the process of drying and heating.

[7] A **kiln** is a thermally insulated chamber (a type of oven) that produces temperatures sufficient to complete processes, such as hardening, drying, or chemical changes.

[8] **Sintering** is the process of compacting and forming a solid mass of material by heat and/or pressure without melting it to the point of liquefaction.

[9] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.
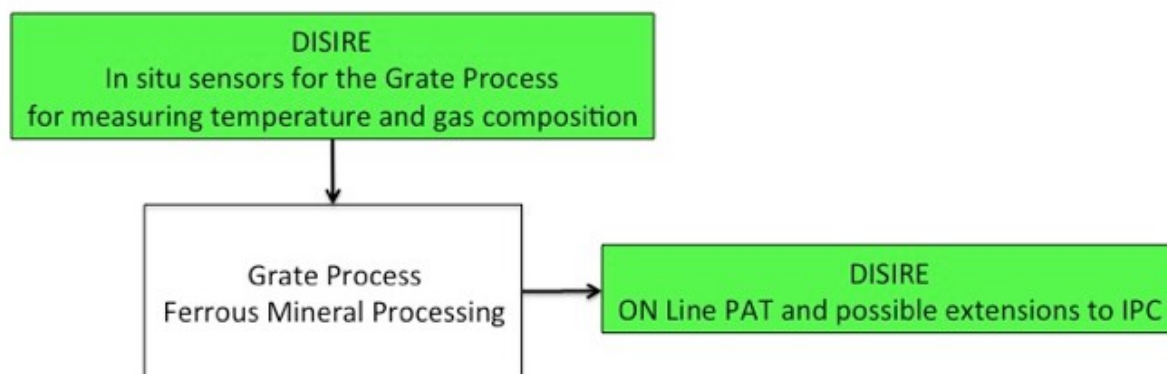
Fig. 3: DISIRE technological impact in the Grate Process.

4.3.   Specification of advanced in-line sensing

The variables of primary interest in the thermal grate process are the temperature of the grate and the oxygen content of the gaseous flows. Within the scope of the DISIRE project a novel wireless and heat-resistant sensor capable of sensing these quantities will be researched and developed. The sensor will travel through the grate on the pellet bed and perform measurements in a continuous fashion.

An important technological challenge is found in the high temperatures that need to be sustained during the transit time (which can vary from 8 to 20 minutes with temperatures in the final stages of up to 1200°C and temperature gradients of up to 400°C; as it has been indicated in the Deliverable D1.2[10]). Moreover, since the instrumentation of the process through the novel sensors should leave the flow of gasses along the bed unimpaired, a target sensor diameter of 10cm has been set.

DISIRE foresee thermoelectric sensors for the temperature measurement, and zirconium dioxide or titanium dioxide-based sensors for the measurement of the oxygen content. The sensors will be protected by an insulating outer shell wherein the sensors and associated electronics are immersed in water that is evaporated to keep the internal temperature below 100°C for as long as possible. Please refer to deliverable D3.1[11] for an in-depth description of the sensor technology.

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[10] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.

[11] Sensor technology selection report, DISIRE deliverable, 2015.

4.4.   Specification on PAT analysis

Readings from the sensors will be acquired on-line and continuously as they travel along the bed before the process destroys the devices. The corresponding data will be collected online and sequentially processed off-line through the PAT.

The measurements and sensor systems of the grate process include temperature and oxygen content gauges such as thermocouples and lambda sensors. The sensors allow to better study the chemical environment and the heat distribution within the process.

4.5.   Specification on PAT based IPC

The sensor will not be used on-line as a feedback source to optimally control the process but rather data from field trials will be exploited to improve the physical understanding of the reactions happening in the grate. This enhanced understanding, and in particular a more accurate model of the oxidative reactions, will be instrumental to devising optimal control strategies that target both an improved product quality and higher energy efficiencies.

The design of a novel IPC that is based on the sensing technologies developed in DISIRE requires the study of correlations and dependencies with other products and processes data, which is outside of the scope of this project.

4.6. Process Specific Demonstration specification

A sensor technology that is capable of sustaining the harsh environmental conditions of the thermal grate process will be assessed in field trials via comparisons with the existing statically positioned temperature sensors above and below the pellet bed. An improved accuracy of the temperature measurements (low bias and variance) and the ability of following the pellets on-line as they travel throughout the process are considered as significant improvements to the overall process.

5   WP7 Steel Processes: LKAB blast furnace

5.1.   Brief introduction to the process

The blast furnace is a continuous process that transforms (*smelts*) the ore, coke and slag formers charged at the furnace's top into slag (a by-product waste) and hot metal that are retrieved at the furnace's bottom. Heat is maintained through the injection of pulverised coal and the blowing of blast from the bottom of the furnace.

The steady state operation of the furnace is subject to the following main disturbances:

1. Differences in the chemical composition of coke and ore and in particular the content of alkali metals and zinc and fines[12];
2. Changes in the permeability of the unstable solid layers leading to changes in the distribution of the gases inside the furnace;
3. The moisture content in the blast air.

To counteract the disturbances several variables such as temperatures at different heights and the gas composition of the exhaust gases are monitored and used by an operator to control the process (there is no automatic closed-loop controller). A relevant objective is therefore to develop a novel sensor technology that can follow the pellets and coke into the blast furnace and provide an increased awareness of the considered physical and chemical process.

We refer the reader to deliverable D1.2[13] for a detailed discussion of the process, the overall aims established within the DISIRE initiative and the role of the individual partners.

5.2.   DISIRE technological contribution

The foreseen DISIRE contribution towards the blast furnace process can be summarized as follows (see also Figure 4):

1) DISIRE based in-situ sensors for temperature, gas composition and position measurements.

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[12] The term **fines** indicates iron ore dust.

[13] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.
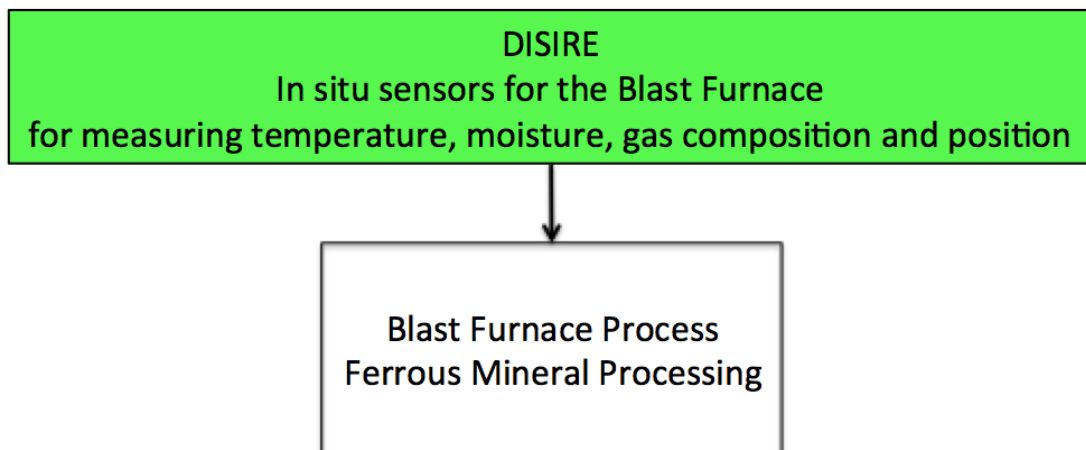
Fig. 4: DISIRE technological impact in the Grate Process.

5.3. Specification of advanced inline sensing

The sensing technologies developed within DISIRE, in synergy with all the other work packages, are expected to be re-targeted and evaluated also on the blast furnace. For a successful field trial the sensors shall be able to measure temperatures and communicate wirelessly from the positions they will reach inside the blast furnace after being dropped from the furnace's top together with the fuelling materials.

5.4. Specification on PAT analysis

The collected data will be post-processed offline through especially designed software algorithms based on multivariate analysis tools such as SIMCA. The in-situ sensors are in principle going to contribute to the current knowledge on the operation of the process with more accurate and reliable measurements of variables that either cannot be measured by the existing system or are difficult to estimate with sufficient precision. Recommendations from the PAT analysis could potentially be exploited on-line by the furnace's operators to control the process with an overall improved performance and safety.

5.5. Specification on PAT based IPC

Broadly speaking, the control objectives are more stable temperature, silicon and carbon contents of the tapped liquid iron. However, a study of the control strategies that are the most effective towards these goals is postponed to after a quality control test has established the desired safety and performance requirements of the sensors.

5.6. Process Specific Demonstration specification

The performance of the system can be assessed through the following points:

1) A fundamental objective is that the sensor can measure the desired properties of the blast furnace;

2) How long the sensors can provide measurements before they disappear (burn up);

3) The robustness of the data transfer;

4) The precision and accuracy of the measures.

Being able to measure the blast furnace brings new knowledge to the blast furnace process. This will potentially improve the control of the blast furnace process since today there are no sensors which meet the objectives set for DISIRE.

The capabilities of measuring the temperature of the molten metal and the gas composition inside the furnace in a continuous fashion are considered improvements. The more accurate the measurements and the longer the sensors' survival times, the more precise knowledge will be acquired on the process dynamics.

Additional performance indices are the stability of the temperature, the silicon and carbon contents of the tapped liquid iron.

6   WP7 Steel Processes: MEFOS Walking beam furnace

6.1.   Brief introduction to the process

The walking beam furnace is used to re-heat *slabs* (large steel beams) to a specific temperature before their refinement. The slabs are "walked" from the feed to the output of the furnace by the cyclic movement of so-called walking beams. During this passage, the items are directly exposed to the heat produced by burners located inside the furnace. Since the heat distribution affects the quality of the finished product, a natural optimal control problem in this context is to regulate pre-assigned temperatures at specific points of the furnace, while minimizing the energy expenditure for the heat generation.

The main objective is thus to reduce the operating costs through the reduction of the energy consumption. In this respect, a small decrease in energy consumption such as 0.5% translates into a saving of 2kWh per tonne of heated product. In addition, optimal control strategies could lead to quality improvements as well. To achieve these goals there is a need to gather more information about the process on-line through an improved understanding of the reheating process and the deployment of novel sensors than can measure both the temperature and the gas composition within the furnace.

We refer the reader to deliverable D1.2[14] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

6.2.   DISIRE technological contribution

The foreseen DISIRE contribution towards the walking beam furnace can be summarized as follows (see also Figure 5):

1) DISIRE based in-situ sensors: Wireless sensors measuring temperature and optionally gas composition will be developed. Thermocouple will be employed for sensing temperatures while there is an open investigation on the most promising technology for sensing the gas composition

2) DISIRE improvements to the online PAT and IPC mechanisms: the PAT aims to deliver data to the control module that are robust in regards to infrequent updates, varying measurement intervals, missing data, erroneous data, etc.

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[14] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.
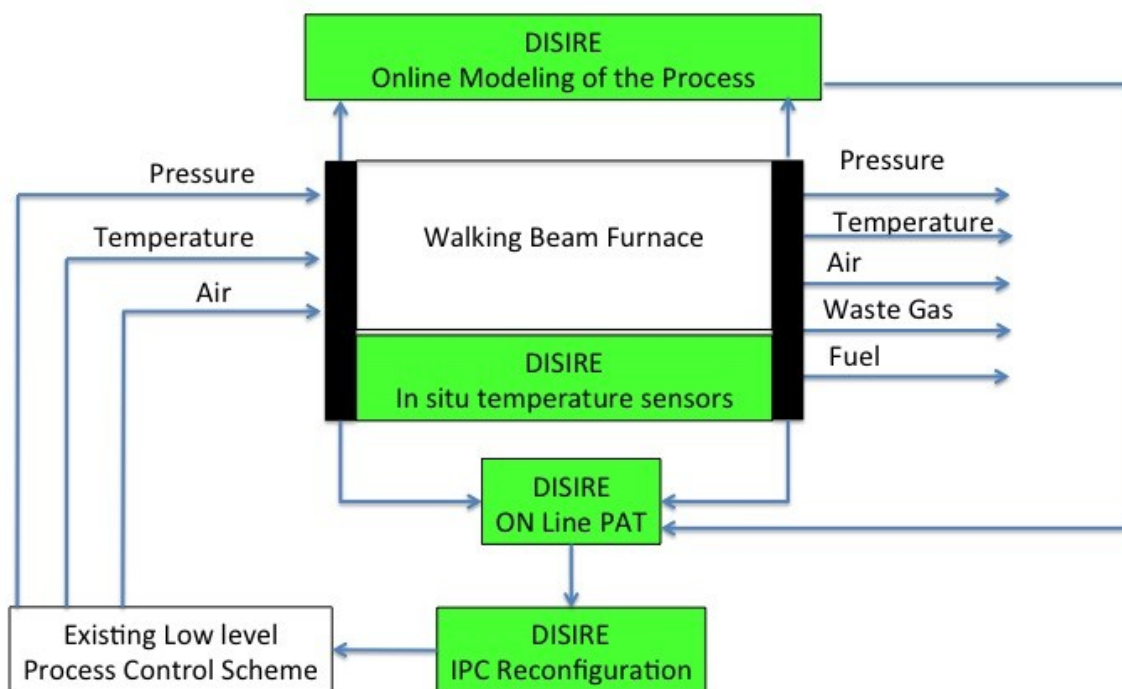
Fig. 5: DISIRE technological impact in the Walking Beam Process.

6.3.   Specification of advanced inline sensing

It is required that the developed sensors can sustain the harsh environment inside the furnace for long periods of time. With the novel sensors new opportunities for measuring the funace's inside will increase the available knowledge on the process and this will allow the refinement of existing mathematical models of the process.

The novel sensors are not expected to be used in a continuous fashion but rather periodically in campaign batches in order to acquire the current state of several important variables inside the furnace.

To have a system that measure and transfer the data in a robust manner is challenging because the sensor is exposed to an extremely harsh environment. Temperatures reach up to about 1150°C and the thick walls of the furnace represents by themselves a challenge for a wireless data transfer system. The objectives set for the sensor are to measure the temperature with an error of less than 5 °C and that of being capable to transfer the data wirelessly in a robust manner with a minimum of data drop .

6.4. Specification on PAT analysis

An on-line PAT system will be able to process the acquired data and render it available to the IPC component. Among the tasks performed by the PAT will be the cleaning/filtering of the measured data through the deletion of unnecessary or unreliable data points (such as outliers).

The PAT objective will be to deliver data to the control module that are robust with respect to infrequent updates, varying measurement intervals, missing data, erroneous data etc.

6.5. Specification on PAT based IPC

The most affecting variables in this process are the temperatures and the gas composition inside the furnace. Indeed, as a preliminary step to the manufacturing of steel sheets, the steel slabs must be reheated and their temperature at the output affects the quality of the end products. Moreover, monitoring the composition of the gas insider the furnace is instrumental to both operating the furnace in a safe manner and to complying with environmental emission regulations.

Given the above, a relevant control objective is to reduce the variance in the temperature of the slabs at the output of the furnace. A special case that could be considered is the one where the production is halted due to process problems in the rolling phase but the slabs already within the furnace have to be kept at the desired temperature while minimizing energy expenditure.

6.6. Process Specific Demonstration specification

A reduction of the variance in the slab temperatures at the output whilst minimizing scaling phenomena is considered an improvement. An additional objective is to improve the operational efficiency of the process: To this aim, it has been noticed that an overall energy reduction of 0.5% gives 2KWh per tonne of end-product in energy savings.

7　WP8 Combustion Processes: Cracking Furnace at Dow Chemical Co.

7.1.　Brief introduction to the process

The *cracking furnace* at DCI produces ethylene, propylene and CC4s (butane, butane, butylenes and butadiene). In brief, a *hydrocarbon feedstock* (naphtha or Liquefied Petroleum Gases) is diluted with steam and cracked (i.e., the long hydrocarbon chains are split into shorter ones) by an endothermic reaction. The heat required to reach the cracking temperature is provided by the combustion of *fuel gas* inside a firebox at the lower section of the furnace. The cracking reaction occurs within the firebox (where a mixture of hydrocarbon feedstock and steam is conducted through coils) at a specified temperature and steam/oil ratio that depend on the properties of the feedstock and the desired *severity* and *selectivity* of the reaction (i.e., varying the cracking temperature and the steam/oil ratio respectively): Changes in these variables affect the ratio of the refined products in the output.

Within DISIRE, the main objective is to reduce the operating costs and reduce the environmental footprint (GHG) of the plant by optimizing the fuel consumption, i.e., decreasing it for a given operational set-point. Optimal control strategies for the whole cracking furnace, as well as a comprehensive analysis and knowledge of the burner's frame shape and combustion and of the flue gases distribution in both the firebox and convection sections, would lead to an improved use of the combustion products, maximizing heat transfer through the convection section and improving operational safety and reliability. The strategies should build on top of novel sensor technologies that can measure the by-products O2 / CO / NOx in a more reliable and accurate way then it is currently possible.

We refer the reader to Deliverable D1.2[15] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

7.2.　DISIRE technological contribution

The foreseen DISIRE contribution towards the cracking furnace process can be summarized as follows (see also Figure 6):

1) DISIRE based in-situ sensors: optical-fibre sensors (for measuring temperatures) and camera-based sensors (for flame diagnosis).
2) Online PAT and the overall IPC reconfiguration based on the online PAT.
3) Analysis and better knowledge of flue gases distribution in the cracking furnaces firebox (radiant & convection sections) for an improved energy efficiency (maximize energy recovery from flue gases residual heat) by means of CFD simulations.

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[15] Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.
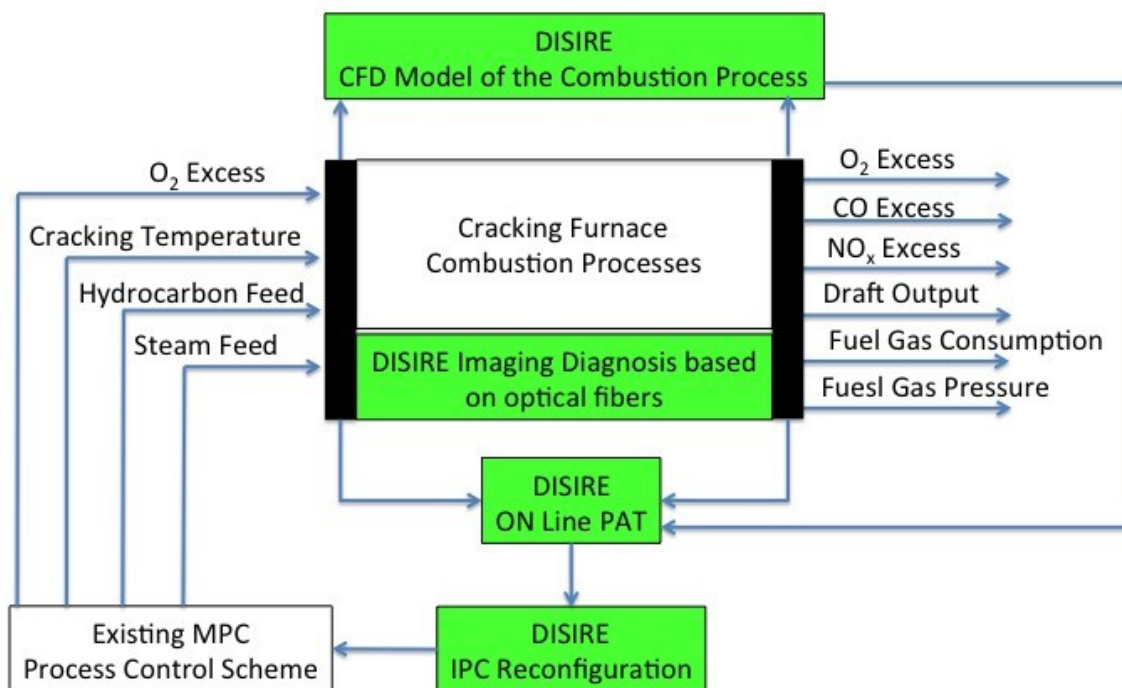
Fig. 6: DISIRE technological impact in the Cracking Furnace Process.

7.3.   Specification of advanced inline sensing

It would be desirable to avail of a novel sensor technology capable of measuring the concentration of NOx in the exhaust gasses with higher accuracy and reliability then the existing conventional sensors in the market.

Research and development activities will be focused on:

1. Development of optics fibre based sensor to monitor temperature in the low range (100ºC) in crucial zones of the furnace that are related with the quality of the hydrocarbons feed (in the fuel or process side);

2. Development of a novel combustion diagnosis tool based on CCD cameras to control the combustion process at very high temperatures (up to 1000ºC).

To this aim we noticed that, on the one hand, optical fibre based temperature measurements are partially implemented in industry and thus the novelty in this project is their in-

troduction in processes associated to the chemical industry where their usage is still scanty. On the other hand, the imaging diagnosis will be fully developed at a laboratory scale by CIRCE and tested for the first time in an industrial environment. The novelties of this tool will be disseminated as the projects progresses. They will include filters for participate gases, hydrogen natural gas spectrum in flat flames and wall radiation filters.

The image diagnosis is based on a UV-VIS CCD camera with high-speed frame rate and band-pass filters in order to evaluate the generation of radicals during combustion. In the cracking furnace, fuel is formed by methane and hydrogen, and the combustion spectrum of these flames is oriented to the UV range. At this point in time, CCD cameras that are sensible to the UV radiation appear very suitable in this application. Although depending on the radiation intensity, other options as Intensified-CCD (ICCD) o even Electron Multiplying CCD (EM-CCD) are required to be used in the case of very low intensities. Moreover, the effect of radiative walls and the contribution of participate gases must be subtracted to the global emission spectrum, in order to evaluate the quality of combustion. Processing stage comprises the digital analysis in the spatial and spectral domain of recorded videos. The parameters that may be evaluated additionally to emission spectrum are flame brightness, fluctuation amplitude, distribution symmetry (Kurtosis and Skewness) and oscillation frequency (Flicker). Depending on the processing speed of the algorithm the tool will be fully online, or quasi-online with the data acquisition and processing phases being carried out in a periodic way.

7.4. Specification on PAT analysis

DCI's plant is fully monitored and controlled on-line with proprietary technologies. Within DISIRE several actions will be carried out in order to improve the existing PAT of the plant:

- A review of combustion flue gases sensor techniques (manly based in oxygen measurement) will be carried out. This will allow to perform better informed decisions as to how and where the novel sensors will be used.
- By means of CFD, new practical information will be obtained to improve the IPC:
  - Simulations will help to optimize the use of actual sensors, providing new positions in the furnaces;
  - Additional information about the process will be generated (e.g., recirculation zones, blind hotspots, etc.) and some modifications in operation and/or design will be suggested;

○ Increased knowledge of the process will support further studies on the optimal placement of the new sensors throughout the plant.

• Imaging diagnosis and fiber-optics sensors will be developed and tested in industrial conditions to improve the IPC.

7.5. Specification on PAT based IPC

By means of the CFD simulations and the field trials of the novel sensors (temperature and flame stability) a vast quantity of information will be generated. The most interesting aspect is that all this information is at this point unknown and difficult to estimate. Thus all this information could be implemented as input in the current IPC or in a model predictive control.

Improvements in the control strategy will allow a more stable operation of the cracking furnaces leading to:

• Minimizing upsets and disturbances;
• Being able to quickly react and recover stable conditions after the unexpected disturbances acted on the system.

The energy conversion (Btu/lb HV Product) will be the indicator / measurement used to check and validate the impact of the control strategy improvement in terms of energy efficiency.

7.6. Process Specific Demonstration specification

A better control of the combustion process in the cracking furnaces will lead to an improved energy efficiency and intensity of the whole process yielding a reduction of the operation costs as well as a lower impact of the environmental footprint through a reduction of GHG (CO_2) and other environmental harmful emissions (CO and NOx).

Performance improvements will be assessed through a detailed energy and mass balance statistical study of the process (old set-up vs. improved set-up) by comparing the so-called conversion energy of the process (Btu/lb HVC) over a sufficiently long interval of time.

More details about the demo specification can be found in the Deliverable D1.3[16].

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[16] Demonstration platforms specifications and overall system requirements, DISIRE deliverable, 2015.

8   Conclusions

In this deliverable, the DISIRE related industrial processes have been put in relation to measurable performance indices and performance benchmarks that will guide the final evaluation of the developed DISIRE technologies. More specifically this document focused attention on four principal aspects of the specifications: a) the specifications of advanced in-line sensing, b) the specification on the PAT analysis, c) the specification on the PAT based IPC and finally d) the specification of the process specific final industrial demonstrations.

At this point it should be highlighted that this document is considered as a live one, and as the project evolves and matures, the descriptions of the evaluation procedures for the specific processes will become even more specific and detailed. However, at the M12 stage of the project, we believe that the current document provides a good detailed overview of what DISIRE will aim for and specific directions on the impact that we envision for the project.