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Abstract	The aim of this document is indicate which are the demonstration platforms targeted by the novel DISIRE technologies. Specifically, this deliverable further details the platforms specifications in terms of the physical constraints and clarifies the requirements by introducing measurable performance indexes through which experiments and field trials will be evaluated. A particular focus is put onto the final industrial demonstrations where the integrated implementation of the DISIRE components will be shown and judged according to the described overall system requirements. 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
C2	Ethylene
C3	Propylene
CC4	C4 Crude Fraction – butane, butylene, butadiene, etc.
CCD	Charge-coupled device
CFD	Computational Fluid Dynamics
CSV	Comma Separated Values (file format)
DB	Database
EOR	End of Run
FBG	Fiber Bragg Gratings
GHG	Greenhouse Gases
HC	Hydro-carbons
HVC	High Value Chemicals
IP	Intellectual Property
IPC	Integrated Process Control
LPG	Liquefied petroleum gas
MOC	Management of Change
MOR	Mid of Run
MPC	Model Predictive Control
PAT	Process Analytical Technology
SOR	Start of Run
UV-VIS	Ultraviolet – Visible range

1 Introduction

1.1. Summary

The aim of this document is to indicate which are the demonstration platforms targeted by the novel DISIRE technologies. Specifically, this deliverable will provide further details on the platforms specifications in terms of the physical constraints and will clarify the requirements by introducing measurable performance indexes through which experiments and field trials will be evaluated. A particular focus will be to present the final industrial demonstrations where the integrated implementation of the DISIRE components will be shown and judged according to the described overall system requirements. 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 specifications and requirements of the demonstration scenarios focused within 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 the field trials that will aid the design of a complete and integrated demonstration that will act as the final benchmark of the project.

Furthermore, this document gives indications on the evaluation platforms targeted by the novel DISIRE technologies and provides initial aims with regards to the expected performance improvements and the overall impact of DISIRE's implementation, while the specifications for the further integration of the DISIRE components developed by WP2-4 into the adopted industrial processes are here detailed. The specification documents will be process specific and the efforts will be focused onto further extending the functionalities and the implementation limitations of the pure scientific initial results in the project in the industrial demonstrations of the subcomponents in TRL levels 3-5. All partners will be strongly involved with the definitions of their concern, while the DISIRE mixture of consortium with RTD, SMEs as technology providers and industrial end users will ensure the smooth and accurate specifications for the application of the produced technology in the different industrial processes.

Moreover the specification of operational requirements for the final and integrated DISIRE demonstration benchmark will be established. Being the final benchmark, emphasis will be given to set up a realistic scenario that combines all the developed "primitives" validated in the previous benchmarks, while at the same time will present the overall DISIRE concept in a large extend and most probably in a TRL level of 6.

1.3. Methodology

For each industrial process a short introductory description will be provided stating each problem and giving the general picture. Then the focused evaluation platforms will be described together with their technical specifications and the industrial requirements in terms of desired final performance.

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 (in 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.

Currently, 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 developments is mixed during the transportation.

We refer the reader to deliverable D1.2[3] for a detailed discussion of the processes, the aims established within the DISIRE initiative and the role of the individual partners.

The focus of DISIRE is to enhance these processes through:

1. E-pellet based tracing of the ore: The integration of this component will translate in the ability to determine the quality of the ore at the flotation processes. Information on ore composition will allow controlling the flotation process and optimizing it. Optimized production process will decrease total production costs (e.g. in terms of energy costs incurred by milling). Optimized flotation parameters will in turn lead to reductions in the processing time.

2. Continuous fault-detection in the BC system: The continuous monitoring of the BCs allows for the prediction of machine failures and the introduction of pro-active maintenance strategies aimed at improving the average throughput of the system. Early detection of BC components fault can reduce the cost of the BC maintenance through, e.g., the scheduled planning of BC repairs and downtime. Data acquired by currently used SCADA system allows to analyze the transported ore weight, motor

[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.

current (for each motor) and temperature of the BC systems components. Analysis of relations between these quantities is instrumental to predicting such failures. For instance, slight increase of gearbox temperatures (5-10 degC) for the same load conditions indicates a problem with transmission of energy – possibly an early stage of damage; such increase does not exceed safe operational temperature for the gearbox, but it might predict the failure. Increment of energy consumed by BC per volume of transported ore translates to a reduced efficiency of the BC components (motors, gearboxes, rollers etc.) and might indicate their fault. Due to drilling and blasting technology used in the KGHM copper ore underground mines it is crucial to predict the failure before the nearest break (prediction approx. 12h before failure) or before Saturdays (prediction approx. 5 days before the failure) – therefore the component might be repaired without affecting the production.

As for positioning in the transportation chain, a suitable technological choice is to use passive RFID sensors in which the transponders and other embedded electronics are powered through the magnetic field emitted by the reader's antenna. The sensors are dropped at the origin of the transportation chain to be measured and flow with the transported material. Detection of the transponders is performed by antennas, at various static locations, proximal to the material flow.

The use of RFID in a mining environment presents a number of challenges that include readability issues due to long distances, the unknown radio environment, the uncertain orientation of transponders, the mechanical and electrical interference and the segregation dynamics due to differences in size and density of the e-pellets. RFIDs operating at 13.56 MHz are commonly used in other applications such as smart cards, where a fairly complex signalling scheme is used. To allow for their use in an industrial environment, where limited time slots are available for communication, the most suitable signalling scheme and protocols will need to be investigated and eventually adapted to the specific needs of the DISIRE project. Efforts will be put in the design of the on-tag analogue electronics to achieve maximum efficiency in power transfer as well as in signalling. Similar efforts will be aimed at investigating and optimizing the 13.56 MHz reader technology.

2.2. Overall system requirements

2.2.1. E-pellet based tracking of the ore

The performance indices to evaluate the performance of DISIRE's technologies in this context are:

- Transported ore mass, 26 000 Mg daily, 660 000 Mg monthly
- Transported metal (Cu, Cu equivalent) tonnage, in 0,9% Cu

- Energy consumed by the BC:
  overall 2 800 000 kW/h (concerning Lubin Mining Site)
  specific 4,2 kWh/Mg
- Transportation cost of the BC:
  overall transportation costs in [cash] and specific transportation costs in [cash/mass unit] are company's sensitive data
- Reliability of belt conveyors.
  99,5 % of time when the BC are required to operate (this number includes reliability of charging points, rock breakers etc.)

2.2.2. Continuous fault-detection in the BC system

The requirements imposed to the continuous fault-detection in the BC system concern the time during which the conveyor does not operate due to failure. The proposed performance indices are mainly related to downtime:

- Overall downtime in [h/month] for the entire mine
- Downtime per each conveyor in [h/month]

The fault-detection system should predict the failure before it happens, thus the repair can be scheduled for the break, when operation of the considered conveyor is not required (e.g. Saturday, Sunday).

2.3. Evaluation platforms

The ***FlexSim*** software for simulation of ore flow in the belt conveyor transportation system in the KGHM underground mines will be implemented. FlexSim has specific capabilities allowing the joint simulation of discreet events and the continuous flow. Continuous flow simulation with the capability to tracking ore content (its quality) will be required to simulate ore flow in the conveyor system network equipped with several ore bunkers located along the BC lines. FlexSim has capabilities to model these bunkers and an additional module developed in the Netherlands (FloWorks) was successfully used to simulate the servicing of complex BCs bulk terminals in Amsterdam and Rotterdam harbors as well.

Discreet event simulation will be required to model the flow of pellets in the same conveyor system network as is used to model the flow of ore. In order to find the optimum number of pellet duplicates for their given reliability (recovery rate) as well as to establish their optimum input frequency to estimate ore quality within given confidence and accuracy limits. Special simulation experiments are required to find the best economic answers on how many duplicates should be used in one input and how often pellets should be input into the ore in order to get enough accurate knowledge of quality of ore conveyed to the processing plant in order to improve flotation efficiency and increase metal recovery from the same amount of supplied ore.

FlexSim is a well known system in the mining area in America and Australia. Recently it has been chosen by mining consultancy and development giant Runge Pincock Minarco (RPM) to deliver an exciting and powerful new software product to the mining industry called HAULSIM. It is a haulage simulation package for modelling, analyzing, visualizing, and optimizing a haulage network, providing confidence and accuracy estimates in mine plans. In the DISIRE project such capabilities will also be used to model and simulate the transportation of the ore from excavations to conveyor loading points using short distance haulage transports.

2.3.1. E-pellet based tracking of the ore

Pellets will be put into the ore in the discharging point where LHDs and trucks are unloaded over a screen mounted for stopping and breaking (by hydraulic hammers) oversized lumps. Transfer chutes between consecutive BCs, located every 800 meters (average BC length) give an opportunity to destroy pellets. Each BC line contains approx. 2 ore bunkers (capacity range: from 400 to 5000 Mg), where pellets might be also damaged or lost. Another dangerous spot is a crusher (before the ore is loaded to skips), which can decrease the number of pellets that reach the destination. The information coded in pellets will be read after leaving the skip – on the surface. These final readers will be mounted on the conveyor that connects the mine and the concentration plant.

2.3.2. Continuous fault-detection in the BC system

The continuous fault-detection system can be evaluated using simulations of signals related to faulty BC components. Given real sample signals corresponding to the time during which the analyzed BC system component revealed anomalies (e.g., increment of temperature without increment of load) one can simulate similar signals in a programming environment. Such simulations allow assessing the fault-detection algorithms on specific cases. Design of the simulated signals is known, thus the exact time when the damage started to reveal in diagnostic signals is known, as well. This approach allows assessing the proposed data analysis methods in the context of failure prediction.

2.4. Final industrial demonstration

Three main pellet-loading points have been assigned in the Lubin mine: conveyors L1031, W522 and N465 (see figure below). Additionally, it is suggested to install 8 antenna-readers in the following locations: P8, P4, P1, A 34/1, W1B, T1 and two other in the Concentration Plant on the surface (after hoisting of the ore). These locations are crucial points in the transportation system (ore bunkers, transfer chutes, weights) in terms of possible damage and loss of pellets. The consecutive readers will be used for reading the information from pellets as well as for the identification of loss rate of pellets on their way from the pellet-loading point to their final destination on the surface (after hoisting by skips supplied by the ore from the main ore bunkers).

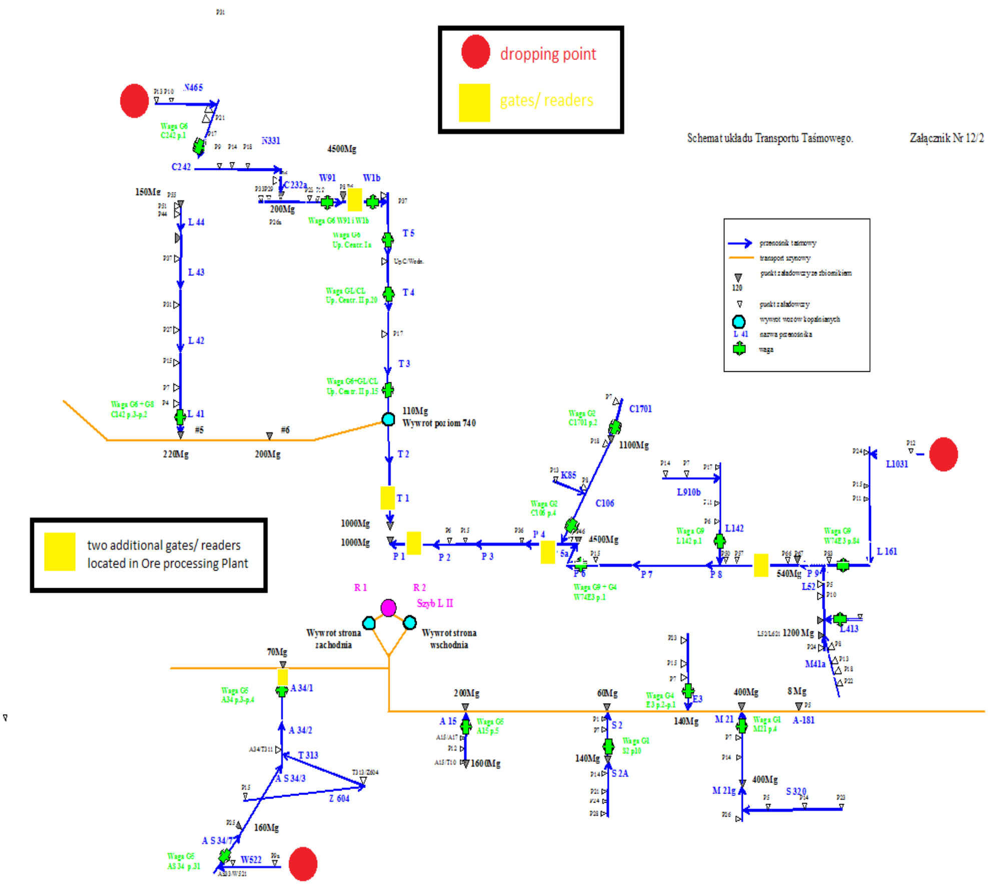

Fig. 1 The underground transportation system in the "Lubin" KGHM copper ore mine with the proposed locations of pellet dropping points (red bullet points) and pellet readers (yellow squares, 2 others are located on the surface on the entrance to the Processing Plant); other symbols on the scheme: blue arrow with an annotation – BC with its marking, blue brown line – underground railroad, empty triangles – discharge points, filled triangles – ore bunkers (numbers represent capacity in tonnes), green poligons – ore weights, blue circles – box cars unloading station, violet circle - shaft

2.4.1. E-pellet based tracking of the ore

During the final demonstration the pellets' endurance will be verified. Three kinds of pellets will be used in the demonstration in order to verify origins of the ore. Eventually: where and when each pellet has been put in to the ore. Hand of pellets are read into the recording system while inputting onto the discharging bulk of ore and then, automatically read from the ore conveyed to the main ore bunkers and eventually after reaching the surface.

2.4.2. Continuous fault-detection in the BC system

Faults in the BC system can affect the way the pellets are transported to the skip. Information on detected faults will help to understand the route of the finally read pellets. The main aim of sensors currently used in BC systems of KGHM underground mines is to quantify the transported ore and the electricity consumed by the motors, although their quality is good enough to analyze them in the context of fault-detection. Demonstration of the algorithms developed for continuous fault-detection system can be performed on the data currently acquired by the existing systems that track the ore weight, current and temperatures of BC system components. Industrial demonstration of the fault-detection system will assess the prediction time, i.e., the time elapsed between the first occurrence of diagnostic symptoms and the failure.

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

3.1. Brief description of 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.

The focus of DISIRE is to enhance this logistic chain through:

1. A novel model of the transportation chain:
   - The traceability capabilities are expected to increase from off-line studies of databases and printouts (a task that is time consuming and in reality not currently performed) to an estimate of when a certain product has been produced and when it has passed certain production steps. A main aim of the coming studies is to determine if the achieved traceability will become sufficiently good for practical use.
   - The transportation chain is an important part of the whole production of the iron ore pellets at LKAB. The transportation chain determines and ensures that the right product is sent to the right customer; It moreover allows for the handling of products with deviating quality parameters, by providing for storage and mixing points. The logistic chain as well as the grate process will generate knowledge useful for off-line 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

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

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. An estimate from LKAB is that with a good traceability system, a reduction of material handling of 20% when products need to be shipped to special customers is possible.

2. E-pellet based tracing of the ore in space and time:
   - The integration of this component will translate in the ability to determine the quality of the ore delivered to customers. For positioning in a transportation chain, the choice of technology is passive RFID. 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. A possible impact of a system with very good traceability is a reduction of the cost related to materials handling, when products need to be directed due to quality issues, specific storage requirements or special customers. The cost reduction is very difficult to estimate since this system has not previously been available and the performance of such a system is therefore not known. However a system with very good traceability will make proactive decisions possible which could make a cost reduction, related to material handling, by up to 20%.

3.1.1. Details on the novel logistic chain model

Backtracking the ore batches is a time consuming task that yields uncertain estimates. It is similarly difficult to determine which batches need to be mixed along the logistic chain in order to achieve prefixed quality requirements for the ore that is eventually shipped to customers. A model describing where a batch is in time and space is therefore necessary. Research and development efforts will be aimed at understanding how the pellets behave during different steps of the transportation chain with a particular focus on how the pellets are mixed and diluted in the storage silos during loading and unloading.

By the introduction of novel modeling solutions and the possibility to validate them through field trials, the process will gain the capability of predicting the time and position of batches with deviating quality along the logistic chain and thus to avoid the shipment of the product with a wrongly paired customer. The aim of the DISIRE project is to reduce the number reported deviations by a factor of 50%.

3.1.2. Details on e-pellet tracing of the ore

Similarly to the non-ferrous mineral processing processes focused in DISIRE, a main research and development target is to enable position measurements in the transportation chain. A suitable technological solution is then provided by the use of passive RFID sensors in which the transponders and other embedded electronics are powered through the magnetic field emitted by the reader's antenna. The sensors are dropped at the origin of the transportation chain to be measured and flow with the transported material. Detection of the transponders is performed by antennas at various static locations proximal to the material flow.

The use of RFID in a mining environment presents a number of challenges. These include readability due to long distances, the unknown radio environment, the uncertain orientation of transponders, the mechanical and electrical interference and the segregation dynamics due to differences in size and density. RFIDs operating at 13.56 MHz are commonly used in other applications such as smart cards, where a fairly complex signalling scheme is used. To allow for their use in an industrial environment, where limited time slots are available for communication, the most suitable signalling scheme and protocols will need to be investigated and eventually adapted to the specific needs of the DISIRE project. Efforts will be aimed at the design of the on-tag analogue electronics to achieve maximum efficiency in power transfer as well as in signalling. Similar efforts will be aimed at investigating and optimizing the 13.56 MHz reader technology.

A second target is positioning in a batch of material inside a large storage area, such as a silo. One solution for accurately determining the position of a sensor within a process can be through measurements of the propagation delay of radio signals between the sensor and a number of fixed reference nodes. Another technology available for localization is the use of low frequency magnetic field ”beacons”. The technique is based on measurement of the strength of the received magnetic field at the transponder. Within the DISIRE project, we plan to use three beacons to transmit ranging pulses. The beacons will transmit, at discrete time slots, and identification string. On the receiving side, the transponder will measure the received signal strength for each beacon, and communicate the trilateration results back to the overlying control system using standardized and consolidated RF technologies operating at 868 MHz or 2.4 GHz.

The availability of this novel DISIRE sensor technology is the stepping-stone towards enabling the development and validation of accurate models for the transportations chain. Consequently, the measurable and expected benefits of introducing this component coincide with the benefits of having a novel accurate model for the logistic chain: The main aim is to reduce the number of deviating batches that have to be handled in separate storages by the proportion of 50%.

3.2. Overall system requirements

Scaled model experiments and full-scale field trials will be implemented as part of DISIRE for both developing and validating the logistic models. It will be central to study and characterize how the RFID tags will perform during the different phases of the transportation. To this aim, we note that earlier research (Kvarnström, Orghazi 2008) shows that the size of the transponder is a most effecting parameter when it comes to the tags' detectability in an iron pellet environment. It is also well known that segregation - that is, the separation or even stratification of the sensors with respect to the ore - can occur during filling of a storage silos due differences in shape and density.

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

The overall impact of a traceability system for LKAB is at this stage difficult to estimate since such a system has not previously been available and the performance of the system is at this stage not known. A plausible impact of a system with good traceability is a reduction of the cost related to materials handling, when products need to be directed due to quality issues, specific storage requirements or special customers, by 20%.

3.3. Evaluation platforms

The current roadmap envisions the following important research and development milestones:

1. Evaluating and characterizing the tag behavior in the silos dependently on the tag's size and shape;
2. Developing prediction models of how the tags propagate within the ore flow during transportation;
3. Devising technological solutions that enable the ore to follow the flow of the bulk material without segregation;
4. Developing prediction models of how the ore propagates with the ore when the silos are loaded and unloaded.

This work will enable the design of decision rules that increase the quality of the ore products delivered to customers according to their quality requirements. We moreover aim at achieving fewer deviations in the quality of different ore batches and thus lesser need to separate batches in different storage areas. The model based analysis will also enable backtracking faulty batches along the logistic chain.

To be able to build a decision model related to material handling in a continues transportation chain, there are questions that need answers such as volumes, type, material behaviour, mixing and flow behaviour in storage and transportation within a specific system.

To answer these questions we create controlled environments and evaluation platforms. These are experimental setups in laboratory scale, large scale experiments within industrial facilities, full scale experiments on parts of a specific transportation chain and finally a verification setup on full scale.

Fig 2 Laboratory granular flow test rig. Shown is a test simulating bottom centre exhaust using peas. Black beads are painted peas used for amplifying flow patterns. (Photography courtesy of: Rickard Garvare and Stefan Englund)

A large scale experiment is planned in cooperation with MEFOS and LKAB in their blast furnace facility in Luleå using one of their storage bins. A possible location of a full scale silo experiment is under evaluation together with LKAB and LTU. The purpose of the experiments is to see if there are a segregation issues related to the use of PATs in iron pellets and to in the end find a robust platform that can be used in an industrial environment.

3.4. Final industrial demonstration

In the final demonstration, a batch of sensors will be dropped in one of LKAB's plants (Kiruna or Malmberget). Readers will be placed at least in the harbour of Luleå and possibly at additional reading stations at the plants (before the pellet is loaded on the trains). When the sensors pass the readers their ID and timestamps will be collected and verified later using the flow models.

4 WP6 Ferrous Mineral Processes: LKAB thermal grate

4.1. Brief description to the process

The last production stage in the refinement of the iron ore pellets involves a thermal process called Grate[5] Kiln[6]. During the passage through the grate, the initially moist pellets are dried, heated and oxidized before being sintered[7] in the kiln. The gas composition and the temperature (which can reach up to 1300°C) inside the grate affecting the oxidizing reaction and thus the final quality of the product.

A natural control objective is the open-loop control of the reaction through the observation of these variables, along the process, and at different times. We refer the reader to deliverable D1.2[8] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

The foreseen enhancements to this process and the expected impacts is mainly in the area of novel sensor technology for sensing high temperature and gas composition:

- 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. We 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 at 100 C as long as possible. Please refer to deliverable D3.1[9] for an in-depth description of the sensor technology.
- The sensor is not expected to control daily the process but rather to act as an input to create optimized control strategies for the process in order to improve product quality and/or induce energy efficiency. Using only the data given by sensors will be insufficient to create an integrated process control.

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

[6] 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.

[7] **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.

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

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

The major technical challenge for the hot side wireless sensors is the extremely high temperatures in the surrounding environment. To keep the internal temperature of the PAT low for as long as possible, a thermal insulation need to be combined with the encapsulation of a material or fluid that will consume energy when heated inside the insulation.

A second challenge is radio transmission in the hot environment. Experiments are being designed for characterizing the attenuation of heated granular materials. The current plan is to enclose miniaturized RF transmitters, transmitting either a modulated tone stepping through the range from 100MHz to 6GHz (according to a predetermined schedule or a square wave with harmonics over the same frequency range. These transmitters will be enclosed in thermal insulation, and measurements will be performed both with the sensor embedded in iron-ore pellets and/or coke at different temperatures.

If the novel sensor is able to measure the temperature and gas composition, LKAB will have the possibility to improve and expand the control strategy of the pelletizing process. A successful implementation can result in a reduction of oil or coal: Saving 0.1l/ton of oil leads to monetary benefit of 1MSEK per year. Additional benefits are moreover envisioned in the area of final quality of the product.

4.2. Overall system requirements

In LKAB's Grate Kiln process there is today no way of measuring the temperature and gas composition in the actual pellet bed. Instead the temperature is measured over and under the bed of pellets while the gas composition is not measured at all.

The data given from the sensors alone is insufficient to create an integrated process control. In order to devise novel control strategies and a novel IPC, it is required that correlations and dependencies with other product and process data be assessed but this analysis is outside of the scope of this project.

The overall requirements are that the sensor can measure various properties of the kiln. Survive in the harsh environment long enough to measure important properties. Surviving and transfer data up to 20 minutes is a great achievement. Assuming that the sensor manage these requirements we expect an overall improvement in increased process knowledge and better quality assurance.

4.3. Evaluation platforms

4.3.1. Chamber furnace and laboratory furnace

To ensure that the developed sensors perform as desired within the necessary temperature range and that they can measure the required gas elements, it is important to carry out tests in a step by step fashion.

The first step will involve running multiple tests in two of MEFOS's furnaces, the chamber furnaces and the laboratory furnaces, depicted in Figure 3. Within these furnaces it will be possible to run experiments in an environment where both temperature and gas composition can be accurately controlled.

Fig. 3 To the left the chamber furnace and to the right the laboratory furnace located at MEFOS

The chamber furnace, with an effective space of 3100x1300x600mm, has a maximal temperature of 1300°C and can be fired with both oil and propane. The furnace is controlled by an ABB system and is fully equipment with different type of sensors for temperature control and gas composition. The furnace can be connected to a gas supply and allows experiments with different (not corrosive) gases. All the acquired data is capture by the embedded system and stored in a database for the offline analysis.

The smaller laboratory furnace is a 25 kW electrical heated furnace with an effective space of 1000x350x 250mm and a maximal temperature of 1280°C. The furnace can be connected to a gas supply and allows experiments with different (not corrosive) gases. The furnace is controlled by a Nabertherm P300 controller. The regulator can store a temperature profile with up to 40 segments allowing for heating curves that can accurately mimic a transit through the thermal grate.

By design, the only way to communicate with the sensors will be through a wireless reader. The reader will access and poll data from the sensor over a distance of 10-50 meters. Achieving the longer reading distances is necessary since when monitoring the actual hot process the reader equipment will not be able to sustain the harsh temperature conditions. The reader will, at periodic intervals, scan for all the sensors in its vicinity and collect their data. For each successful poll, it will store the tag's id-number, the measurement data, the link quality, the battery status and a time-stamp. The reader will locally store all the acquired sensor data until an operator erases it.

During the evaluation period all the data from all readers will be transferred over GPRS to a database that will be made accessible to all partners through a web-interface over the Internet. The sensors will be destroyed and eventually burned up at the end of each test. Since each sensor can be used only once, they will be produced in small volume in a serial manufacturing fashion. The reader’s antenna should survive several test phases but will need to be dismounted between test campaigns.

Notice that, when integrated into the real factory environment, the data will be directly accessible at the reader through IP on Ethernet or WiFi. This could be possible already at the project phase but usually the test site owner does not allow access through their Intranet.

4.4. Evaluation cases

Sensor survival in high temperatures is the most challenging part and will be tested in static ovens at LKAB or MEFOS. The temperature of the electronic components inside the encapsulation cannot rise above 100°C while the surrounding temperature will reach above 1000°C.

The sensors will continuously report both inside and outside temperature to let the end-user monitor the sensors performance. Notice that the radio environment inside the grate oven will have to be examined in parallel to the tests and most likely on the real site.

The hot furnace is a pilot tool were the heat treatment that the pellets experience in a straight grate or a grate kiln process is simulated. The pot furnace consist of one “pot” were the pellet bed is situated, see figure 2, and two burners, one below the bed and one above the bed. The green pellet bed will then go through a heat treatment simulating the different zones of a real pellet plant. This is obtained by having a gas flow going through the bed (either from the top or from the bottom) and controlling the amount of gas, the temperature and the oxygen content. Several different parameters are possible to measure during the heat treatment and the pellets can also be tested in all standard ISO tests after induration.

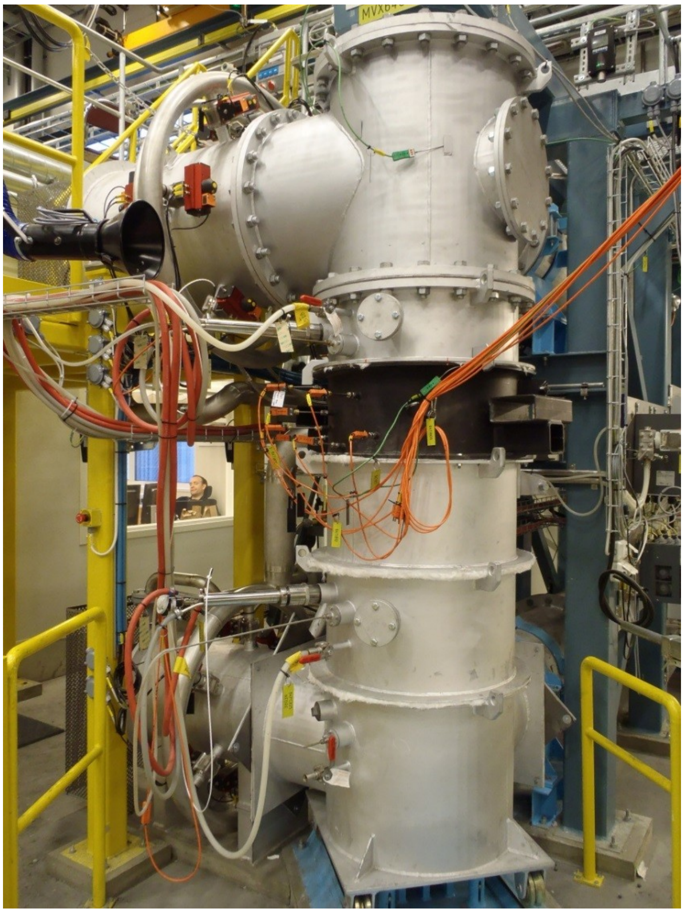

Fig. 4: The pot furnace

All temperature data from the sensor will be compared, offline, to the temperatures of the thermocouples that are in the Pilot Pot Furnace at approximately the same position as the sensor. If the sensor is comparable to the thermocouples the next step is to test it in the final industrial environment.

4.5. Final industrial demonstration

The goal is to test a sensor that can measure the temperature and gas composition. In the process there is currently no corresponding way of measuring the temperature and gas composition. The validation of the DISIRE components developed for the grate kiln will be performed by having the sensor operating throughout the entire grate and by comparing the acquired data to the temperatures measured above and under the pellet bed by the existing temperature sensors.

The sensors should be able to sense temperatures in the range from 0°C to 1200°C (with a relative error of at most 3%) and the proportion of oxygen content in the range from 0% to 100%. Sampling rates of about 1Hz are deemed sufficient for this application.

The sensors will be finally tested/demonstrated in one of LKAB's pellet plants with a Grate/Kiln process. The real data from the process will have to be scrambled due to privacy concerns connected with the use of proprietary IPs.

The sensor data will be provided unscrambled to project partners along with reference data from existing sensors. The available sensor data will be sensor id, timestamps, temperature and oxygen readings. The database will have export functions for .csv formatted files. Finally, the above database will remain accessible throughout the whole project time. No other process data regarding the grate will be disclosed.

5 WP7 Steel Processes: LKAB experimental blast furnace

5.1. Brief description of 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[10];
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[11] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

The foreseen enhancements to this process and the expected impacts are:

- DISIRE based novel sensor technology that is capable of sensing high temperatures and gas compositions. The sensor will measure important properties in the blast furnace and thereby improve the knowledge about the process and enhance the models for blast furnace control. The sensors are not used continuously; they will be used in campaign batches giving the current condition of the furnace. The sensors will work on-line and wirelessly.
- It is foreseen that the novel DISIRE component can result in an energy reduction of 25kWh/tonne of hot metal through: a) improving the gas efficiency by 1% by improving the control of the burden distribution, b) improving the process stability by a better moisture control of the charged burden material and c) improving the overall

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

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

process control by rendering available to the system early information of the furnace conditions (and specifically temperature distribution) in the upper shaft.

As for the grate kiln, the major technical challenge for the hot side wireless sensors is the high temperatures in the surrounding environment. To keep the internal temperature of the sensor within working ranges for as long as possible, a state of the art thermal insulation needs to be designed. A second important challenge is related to the means by which the data will be transmitted through radios in the hot environment.

5.2. Overall system requirements

The measurement system must be robust and provide reliable data on the desired properties. The collected data will be post-processed off-line 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 can potentially be exploited on-line by the furnace' operators to operate the process with an improved performance and safety. This augmented awareness of the process dynamics could influence the principles by which the material is charged at the top of the blast furnace and therefore enable reductions in the use of fossil fuel.

The system requirements are

- That the sensor can measure various properties of the blast furnace.
- Survive in the harsh environment long enough to measure important properties. Surviving and transfer data up to 1 hour is a great achievement.

5.3. Evaluation platforms

The data will both be evaluated with a statistical data analytics software SIMCA. And for the mass and energy balances the MEFOS in house software MASMOD will be used.

5.4. Evaluation cases

The activities in the blast furnace will aim in conducting tests of sensors in appropriate conditions in terms of tracing them and measuring process values, like temperature and gas composition.

5.4.1. Sensor Development: Wireless tests in pellets

In this test the sensors will follow the pellets and coke into the blast furnace and an investigation of the wireless communication between the sensors within pellets will be performed. The sensors will be placed gradually at different depths in the pellet pile. In each mode, the signal quality and transmission rate will be monitored. The aim is to explore the depth at which the sensor is still capable of transmitting a detectable signal. The investigation is conducted at ambient temperature.

The considered performance indices will be:

1. The transfer rate
2. The maximum distance and depth between transmitter and receiver

A successful outcome requires the corresponding successful transfer of data at an adequate bit rate and distance between transmitter and receiver. A positive outcome is crucial since if the data transmission does not work satisfactorily the sensor system cannot support further improvement of the blast process.

5.4.2. Sensor Development: Wireless test in the LKAB experimental blast furnace

This set of tests will be conducted in LKAB’s experimental blast furnace when it is cold. The wireless transfer between the sensor and the antennas will be investigated. A sensor with a transmitter will be placed inside the blast furnace and the receiving antennas inside/outside the blast furnace. This test will investigate the functioning of the antennas, the maximal transfer rate, the maximal distance and best location between transmitter and the receiving antennas. The effects of the ceramic lining and steel shell will be investigated.

The considered performance indices will be:

1. The data transfer rate
2. The maximum distance between transmitter and receiver

A positive outcome is crucial since if the data transmission does not work satisfactorily the sensor system cannot support further improvement of the blast process.

5.5. Final industrial demonstration

The aim is to have sensors that can measure physical properties such as temperature, moisture, gas components and position. The test is planned to performed at the LKAB Experimental blast furnace. Antennas are mounted on the Blast Furnace (BF) and the sensor is moved inside the BF with a vertical probe. If the signal is successfully collected further tests will be conducted. The next effort will target the basket samples with raw materials containing sensors. Pellets or other raw materials with embedded sensors are filled into baskets and charged into the BF before quenching. The signal is collected and the movement of baskets in the upper part of the BF are explored. Furthermore, measurements are also conducted during quenching in order to state the burden movement after stopping the process and contribute with additional information that can improve the understanding of results from evaluation of charged basket samples. The temperature development will be compared to possible endothermic reactions occurring in the materials as e.g. calcination of Ca(OH)2 in cold bonded agglomerates (in-plant material in cold bonded bricks), CaCO3 in limestone, direct reduction in cold bonded agglomerates. The tests are planned to be conducted as the last part of the blast furnace campaign. The sensors is placed in baskets (max diameter 45mm) and dropped into the blast furnace. The signal is measured as the sensor travels through the burden material inside the blast furnace. After the campaign the sensors is excavated and the exact location inside the blast furnace is determined. If the sensor has a logging function, data can be retrieved even if the wireless transfer has failed.

The considered performance indices will be:

1. The ability of the sensor to measure the desired property (position, temperature, moisture, particle size, gas components).
2. The ability of the sensor to transmit data containing important information on the properties of interest.

For a successful evaluation it is required that the sensor can measure the desired properties and transfer the data to the receiver. The accuracy of the measures will be established starting from the available thermodynamic and material information for the considered reaction.

6 WP7 Steel Processes: MEFOS Walking beam furnace

6.1. Brief description of 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.

The foreseen enhancements to this process and the expected impacts are:

1. Novel sensor technology for sensing high temperature and gas composition:
   - A sensor that can operate on-line, in a continuous fashion, to measure measure important variables of the furnace and communicate them to the PAT wirelessly will improve the knowledge about the process and enhance the models used to control the furnace. The sensors are not used continuously, they will be used in campaign batches giving the current condition of the furnace.
   - With improved knowledge about the heating process inside the furnace a better control of the process is feasible. All together a more robust and improved process control will improve the quality of the end product and reduce the energy consumption and cassation. An energy reduction of 0.5% gives 2 kWh per tonne in energy saving.

We refer the reader to deliverable D1.2[12] for a detailed discussion of the process, the aims established within the DISIRE initiative and the role of the individual partners.

6.2. Overall system requirements

With the use of additional sensors, important additional information about the internal state of the process such as position, temperature, pressure, and gas composition is expected. It is expected that an improved understanding of the walking beam furnace dynamics will

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

lead to a reduction of the energy consumption during operation. Moreover, since measuring temperature can aid in reaching a homogeneous temperature within the material at the output, the project expects benefits also in the area of final products' quality.

This specification is needed for product quality and process stability as well as optimization of energy consumption. The proper control of oxide content in the various zones in the furnace can minimize losses caused by excessive oxide scale and degraded surface quality and also control combustion and cost for oxygen.

The system requirements are:

- That the sensor can measure various properties of the walking beam furnace.
- Survive in the harsh environment long enough to measure important properties. Surviving and transfer data up to 4 hour is a great achievement.

6.3. Evaluation Platforms

6.3.1. Experimental Walking beam furnace

On this platform it will be possible to test the developed sensor technologies in an industrial scale equipment. Tests will be aimed at comparing the new technology with conventional sensors in use today.

Two kinds of scenarios are envisioned:

1. The first set of tests will explore if the sensor and its components can sustain the harsh conditions inside the furnace.
2. The second set of tests will investigate the reliability, precision and accuracy of the sensors (the benchmark performance will be provided by the currently deployed sensors).

Furthermore, there will be a number of trials whose exact number depends on the results from the trials. Each trial can last from minutes to hours. With the assumption that the tests are successful, the sensor data are transferred to the main data storing system. How to incorporate the sensor data with the main system will be explored during the project.

6.4. Evaluation Cases

6.4.1. Sensor Development: Protection Shield

Tests will be conducted in an existing furnace at MEFOS that has ceramic lining and steel shell. Initial tests will be conducted in one of the smaller furnaces. The sensor protection shield will be investigated. The purpose of the shield is to protect the sensor electronics from heat and other negative impacts on the sensors. A thermocouple will measure the temperature inside the protection shield chamber.

This test will investigate the temperature rise time inside the protection chamber. From the rise time one can estimate how long the sensor electronics will be able to withstand the temperature inside the reheating furnace (or the blast furnace). An estimated lifetime below a certain threshold will indicate a test failure. It should be also noticed that currently there are no wireless sensors of this kind employed in the furnace.

A successful outcome is crucial: If the protection shield cannot withstand high temperatures, then the sensors might be destroyed before the important quantities are measured.

6.4.2. Sensor Development: Wireless transfer

The aim of the test is to investigate the wireless transfer capabilities of the sensors. A sensor with a radio transmitter will be placed inside the furnace and receiving antennas inside/outside the furnace. This test will investigate

1. the maximal transfer rate
2. the maximal distance
3. the best location between transmitter and receiving antenna
4. the effects of the ceramic lining and steel shell.

A successful test will require the transfer of data with adequate bit rate and distance between transmitter and receiver. Good performance results are crucial since if the radio links cannot function satisfactorily the whole sensor system cannot support further improvements to the process.

6.4.3. Sensor Development: Measured properties

The aim is to test sensors that can measure the physical properties of interest:

1. Temperature (~300-1300°C).
2. Moisture.
3. Gas components (O2, CO, CO2).

4. Position.

The temperature measured by the wireless sensor will be compared with conventional thermocouple sensors. The gaseous composition measured by the new sensor will be compared with an existing conventional gas emission analyser. The position test is done by moving the sensor in a predetermined path inside the furnace. The moisture test in the heated gas is compared with a conventional sensor system.

The considered performance indices will be the error in the measures and the reliability of the sensors. The sensors should be able to measure the desired properties with high accuracy. The uncertainty should be comparable to conventional sensors. If the sensors cannot measure the desired property then the test is regarded as a failure.

Finally, It is important that the new sensors reach satisfactory performance since otherwise the sensor system cannot support further improvements to the process.

6.4.4. Sensor Development: Walking beam furnace test

After successful outcomes from the above initial tests, a full-scale test will be conducted in a walking beam furnace at MEFOS. The objective is to evaluate whether the new sensors can manage the environment in a walking beam furnace during the entire movement through the furnace. First, the furnace runs in normal mode. Thereafter, the sensors are sent into the furnace. The information from the sensors are received with antennas and evaluated.

In general, the performance will be evaluated in terms of successful and reliable transfer of accurate measurement data. A comparison with the data gathered from conventional sensors will be performed.

6.5. Final industrial demonstration

The integration of the sensors is done stepwise. The first tests are done in a cold environment. These tests are mainly to investigate the sensor wireless transmission and robustness. And will be conducted when the sensors or the sensor modules are available. During an Experimental Walking Beam Furnace (WBF) campaign, the developed sensors are tested in the hot environment inside the furnace. The developed MPC system will also be tested during the same campaigns. This final test in the WBF is done during a WBF campaigns preliminary at the end of the project.

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

7.1. Brief description of 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 then it is currently possible.

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

The foreseen enhancements to this process and the expected impacts are:

1. The research, development and field evaluation of an FBG technology that can sense low and medium-high temperatures at the inlets (that is, the input products feeders) and outlets (that is, at the points where the end products are harvested) of the process and along the distillation columns' profiles.
2. The development of novel image diagnosis tools: By means of an extensive experimental campaign based on UV-VIS CCD camera images (with high-speed frame rate) an online algorithm will be developed in order to monitor the quality of combustion process.

13 Application scenarios and demonstration activities specifications, DISIRE deliverable, 2015.

3. The development and validation of improved CFD models of the combustion process aimed at generating information on the processes that is unavailable today and that will support future work on control optimization objectives.

Should these novel measurement technologies perform as required, both installation and maintenance (preventive, predictive and corrective) might significantly be reduced, but at this point in time and at this stage of DISIRE overall implementation it is not possible to do “hard” forecast in terms of monetary benefits.

7.1.1. Details on fiber optic based temperature sensors

Within the DISIRE project the Fiber Bragg Gratings (FBG) technology is used. This technology uses UV-Laser light through an optic fiber to measure temperature at specific hot points (FBG sensors) that are placed along the fiber optics. The temperature around the hot points influences the laser refraction of the FBG sensors allowing a real time observation of the environment or machine where the fiber is installed. The system is mainly composed of:

- A fiber optic with FBG hot points connected to an optical elaboration unit (single side);
- An optical elaboration unit that is able to elaborate the readings of multiple connected sensors and draw the temperature measurements.

D’APPOLONIA, CIRCE and DCI identified several feasible and interesting measurements points (that are not currently monitored / available) and measurement scenarios to test the novel fiber optics measurement devices:

- Temperature across the naphtha header to identify and prevent potential early vaporization phenomena that could affect cracking furnace performance. Worst case temperatures below 110ºC;
- Temperature profile of primary fractionators in the distillation column (C-2001). Temperature range from 108°C to 200 ºC;
- Temperature along the LPG header that feeds the cracking furnaces. This information is useful to troubleshoot and solve problems (insulation issues, insufficient heating capacity and others) that are faced whenever the LPG arrives to the flow-meters coils in the liquid phase leading to inaccurate readings that affect the furnace control and thus the furnace' performance in terms of energy efficiency. Worst case temperatures below 50°C.

Depending on the scenario's requirements, FBG sensors can be implemented using a most suitable technique (embedded, on-surface sticking, etc.) and with the required spatial distribution (a few sensors very close to each other or hundreds of sensors far away covering large distances).

The number of FBG sensors managed by an elaboration unit influences its cost and complexity in future management. Elaboration units handling from one to four fiber optics are available. Moreover the choice of the elaboration unit is based on the measurement rate and specific requirement of data elaboration. At the current stage of the project there is no installation layout available to indicate the exact amount of these system elements.

7.1.2. Details on the novel image diagnosis tools

A novel image diagnosis tool will be developed at laboratory scale (50 kW_{th}) in CIRCE facilities. Once the tool will be completed, it will be tested at full scale in DCI facilities. Some options for the tests have been evaluated in order to use the actual inspection ports to implement the image diagnosis components (spectrometers and cameras).

The image diagnosis is based on a UV-VIS CCD camera of high-speed frame rate with band-pass filters in order to evaluate the generation of radicals during combustion. Probably, a CCD camera sensible to the UV radiation will be used 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 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 and oscillation frequency. Depending on the processing speed of the algorithm the tool will be fully online, or probably data acquisition will be carried out each several seconds.

Previously to the experimental campaign required for the development of the algorithms for flame diagnosis, several spectrometry experiments will be carried out in lab and plant scale. These experiments are necessary to fix the characteristics wavelengths of the system. This info is necessary to setup correctly the CCD cameras, as well all the additional filters.

7.1.3. Improved CFD combustion models

Comprehensive CFD simulations provide additional process information to enhance sensor use and IPC, due to the huge quantity of data generated in this kind of simulations. During the demonstration step, CFD simulations will be validated with plant data in order to improve the use of present sensors and suggest localization for novel ones. Moreover CFD simulations probably will provide additional information about combustion process that nowadays cannot be obtained (i.e. recirculation zones, blind hotspots, etc) and some modifications in operation and/or design should be suggested.

7.2. Overall system requirements

A more accurate understanding of the combustion process, including an improved characterization of how the flame shape affects the combustion properties and a model for the flue gases distribution in the energy intensive cracking furnaces, which will be impacting their energy efficiency and support the design of optimal regulation strategies.

Pending on the implementation of the novel instrumentation and availability of more accurate measurements, we expect an overall energy efficiency improvement in the range 2%-5%. We stress that achieving such figure represents a challenging task with a huge impact for this kind of fired equipment.

As these improvement will be implemented in one of our pilot cracking furnaces to test and verify the developed methodologies, instrumentation, new sensors, controls strategies, etc, in case of success those results can be extended and leveraged to other existing fired equipment units within other premises owned by DOW. Moreover, other energy intensive industrial sectors can be impacted by these findings: Any energy intensive industrial sector operating fired equipment (such as boilers and furnaces) can benefit of the combustion studies and analysis performed within the scope of the DISIRE project. Overall, the envisioned impact is in enabling more competitive and sustainable (in terms of GHG emissions) chemical industries. Finally, we stress that Per 1 Cracking Furnace. 1500 TOE/year (Tonnes of Oil Equivalent), meaning 3200 Tonnes/year CO2 (GHG) emissions reduction.

7.3. Evaluation platforms

The performance and robustness of the DISIRE based solutions will be assessed preliminarily in tailored small-scale simulations and successively in the field by instrumenting operational cracking furnaces within DOW's premises.

For these purpose, the furnaces with reference names F-1001, F-1007 and F-1009 have been selected to carry out the experimentation. Importantly, these are the older and smaller reactors in the plant and thus offer the higher retrofitting potential. Moreover, being a series of identical units, this choice allows the comparison of the acquired results over different units and thus to better understand what are the operational uncertainties and the fundamental limitations of the new components and in particular their robustness.

The instrumentation and field trials will be planned and implemented according to DCI's internal protocols, authorization processes and MOCs.

7.4. Evaluation cases

Developments will be assessed in the following scenarios:

1) Cracking Furnace operated at different feedstock loads (full, medium).
   - Cracking Furnaces can be operated safely and reliably in the range of 50% to 100% of nameplate capacity. Developments/improvements will be tested in different scenarios within this range.
2) Cracking Furnace operated with different types of feedstock (for example, liquid fuel such as naphtha or gaseous fuel such as propane).
   - Cracking Furnaces can be fed either with liquid feedstock (naphtha or condensate) or gaseous feedstock (propane, butane or mix of propane/butane). Developments/improvements will be tested with the different of feedstoacks being fed to cracking furnaces.
3) Cracking Furnace in different lifetime between decokings (SOR / Start of Run, MOR / Mid of Run, EOR / End of Run).
   - Cracking Furnaces run-length between decokings (internal coil combustion cleaning with a mixture of steam and air) is in the range of 40 to 60 days depending on type of feedstock and operating conditions in terms of Severity / Selectivity.
   - SOR (Start of Run) refers to Cracking Furnaces condition just after decoking (run-length initial point).
   - MOR (Mid of Run) refers to Cracking Furnaces status in the middle of operating run-length (in the range of 20 to 30 days since last decoking).
   - EOR (End of Run) refers to Cracking Furnaces status close to the end of operating run-length since last decoking.

- Developments/improvements will be tested along the different Cracking Furnaces status in terms of run-length since last decoking.

7.5. Final industrial demonstration

The proposed improvements to the measurement, data analytics and control systems will be evaluated preliminarily in simulation on DCI proprietary modelling and control infrastructure.

Pending that the proposed changes meet the safety requirements established by DCI's internal protocols and are thus authorized through the opportune MOCs, the same changes will be experimentally evaluated on the field. This applies, in particular, to the more critical control changes where we envision both the possibility of further tuning the parameters of the existing control system and that of testing novel DISIRE based control methodologies.

The considered performance indexes should be:

5. The ability to control the amount of O2 in the exhausted gases.
6. The overall energy efficiency (as measured by the unitary energy intensity).

DCI internally reports an energy consumption / efficiency in terms of ratios; i.e. BTU/lb HVC, BTU/lb C2+C3 (HVC stands for High Value Chemicals, C2 stands for Ethylene, C3 stands for Propylene).

The evaluation should be based on the comparison of before / after performance for the same operating conditions (throughput, feed composition, severity and selectivity parameters). Notice that the current performance of the plant will be assessed by CIRCE as part of WP8.

The main expected impact of a successful demonstration is considered to be an increase in the competitiveness across the European industry (multiple sectors) in terms of energy efficiency and environmental friendliness.

8 Conclusions

In this deliverable, we indicated which are the demonstration platforms targeted by the novel DISIRE technologies, detailing the respective specifications in terms of the physical constraints and clarifying the DISIRE's requirements by introducing measurable performance indexes that will guide the final evaluation of DISIRE through experiments and field trieals.

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.