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Dissemination level

PU	public	☐
PP	restricted to other programme participants (incl. the Commission Services)	☐
RE	restricted to a group specified by the consortium (incl. the Commission Services)	☐
CO	Confidential, only for members of the consortium (incl. the Commission Services)	☒

Content

1 Introduction

This “Dissemination & Exploitation Plan” consists of three main parts: A chapter on expected impact, one on dissemination and a business plan. The first version of this document was embedded in the project application and is then a part of the Grant Agreement.

In the second release of the Updated Dissemination & Exploitation Plan, the main modifications can be summarized as follows:

1. The impact section is updated based on input from partners.
2. The dissemination part is updated to reflect current status.
3. The business plan is further developed, and the exploitation plan is updated based on information from project partners.

2 Expected impact of RECOBA

2.1 Expected impact on society, environment and European industry

RECOBA will address the Grand Societal Challenges defined within the EUROPE 2020 Agenda to help transform the EU into a **smart, sustainable and inclusive economy** by 2030.

The project contributes to four flagships initiatives of the EUROPE 2020 Agenda: **Innovation Union**, **Resource Efficient Europe**, **New Skills for New Jobs** and **Industrial Policy for the Globalisation Era**. Figure 2-1 provides an overview over RECOBA’s overall impacts and shows the links to the four flagship initiatives.

Figure 2-1: RECOBA impact on EUROPE 2020 objectives

Across industries, advanced online control concepts are an enabling technology to run process at its economic and ecological optimum. The opportunity to constantly observe and control product quality opens the door to the production of new tailor made products that require tight processing windows. For the production of existing products advanced sensing and control technologies make it possible to deal with uncertainties in quality of raw material, thus stabilising processes per se and make it possible to use bio-based or recycled material whose quality is less well controlled than feedstock originating from a conventional sources (e.g. from a petrochemical route, virgin ore). A real-time controlled process has substantial advantages compared to an uncontrolled or not optimally controlled one, because:

- Products have higher and more consistent quality.
- Less energy is needed for heating and cooling due to the more precise control.
- Less product has to be discarded due to low quality. Production losses will be reduced.
- Production, raw material and energy costs can be decreased due to increased yield, reduced batch times, increased uptime, fewer unplanned stops, and more stable process conditions.
- Robust real-time control enables for the use of bio-feedstock and a higher ratio of secondary raw materials.
- High-end production plants will stay in the European Union, thereby jobs will be secured and new highly skilled jobs created.
- The production of new materials, requiring tight and complex process routes becomes feasible, thereby the use of significantly less raw material to achieve the same product performance is possible.

- Creation of business models in sensor and control technology is enabled to ensure subsequent market implementation and breaking potential barriers for cross-sectorial technology exploitation (cf. exploitation plan).

RECOBA will significantly improve energy-, resource- and cost-efficiency of batch processes in various industries. This enhances the competitiveness of the energy-intensive European process industry in the short to medium term. In the medium to long term some of the new control and sensor technologies will also be transferred to continuous processes, can be implemented in modularised production concepts and facilitate the development and implementation for advanced & improved processes.

RECOBA will contribute to fight against the loss of traditionally dominant positions for the European process industry in global production. The process industries outside Europe have experienced very high growth in the last years whereas Europe is stagnant. RECOBA's cross-sectorial approach for the process industry can help to keep and bring the European production capacities at the frontier of the current technological limit.

Energy efficiency is one of the key factors in achieving Europe's long-term energy and climate goals. The cross-sectorial implementation of real-time control concepts in the here selected process industries lead to **huge energy and raw material savings**: totalling **1.554 GWh/a = 932,500 t/a CO_2.** The **raw material savings** depend on the industrial sector and may vary between **1% and 5%.** For new products whose manufacturing is enabled by advanced sensing and control, raw material savings of **25%** and more are achievable. Better controlled processes enable the higher use of bio-feedstock, a higher ratio of recycled material, and an increase in product quality, which may save additional 3% of material input.

These generated savings will bring cost reductions, reduced energy consumption as well as increased productivity, while at the same time **disconnecting growth from its environmental footprint**.

The challenge will be to exploit **new business opportunities** resulting from the transition to a more sustainable, resource efficient and low carbon economy as stated in the Europe 2020 Flagship Initiative. For RECOBA these business opportunities are to be found along the various product value chains (new and better products with new features) and along the implementation of real-time concepts in the process industry (new highly skilled jobs for better automation and control services, for sensor developments, maintenance and training provision etc.).

RECOBA will deliver **growth in the short to medium term**. In addition to early effects on the labour market through additional investments in R&D capacities, the project will contribute to **maintaining and creating jobs in the European process and manufacturing industry**. As such it contributes to improve the international competiveness of the European process industry and indirectly also the European manufacturing industry.

The benefits for European citizens, consumers and workers are improved and customised products with enhanced product quality and smaller ecological footprints. Enabling the process industry to improve yield and increase process efficiency, the international competitiveness will be strengthened and thus many jobs are secured and new highly-skilled jobs as a result of the innovation process are created. This leads to healthy and comfortable lives in Europe, providing the opportunity to engage in sustainable lifestyles.

New technologies will lead to the need of information material for decision makers, **new training tools** for workers as well as teaching material for the use at higher educational institutions. RECOBA will develop such toolkits.

RECOBA's relaton to the SPIRE objectives for the European process industry is illustrated in Figure 2-2. The RECOBA objectives and impacts are embedded in the overall SPIRE concept – the cross-sectorial target-driven resource efficiency and competitiveness programme for the process industry.

RECOBA develops, demonstrates and validates real-time control systems for three of the six SPIRE sectors: steel, non-ferrous metals and chemical industries. The research results are of interest to the other three SPIRE sectors: minerals, ceramics and cement, and preliminary contact is established. The results are tranferable to many other sectors using batch processes such as food, consumer products (beauty care), detergent, copper, aluminium and glass industry. Large industrial players like DSM, Nestlé, P&G, Unilever have shown interest in the project results to evaluate a transfer to their batch processes.

Beside the transferability to other batch processes, the new sensors and the control technology can be adapted to continuous processes and modularised production concepts.

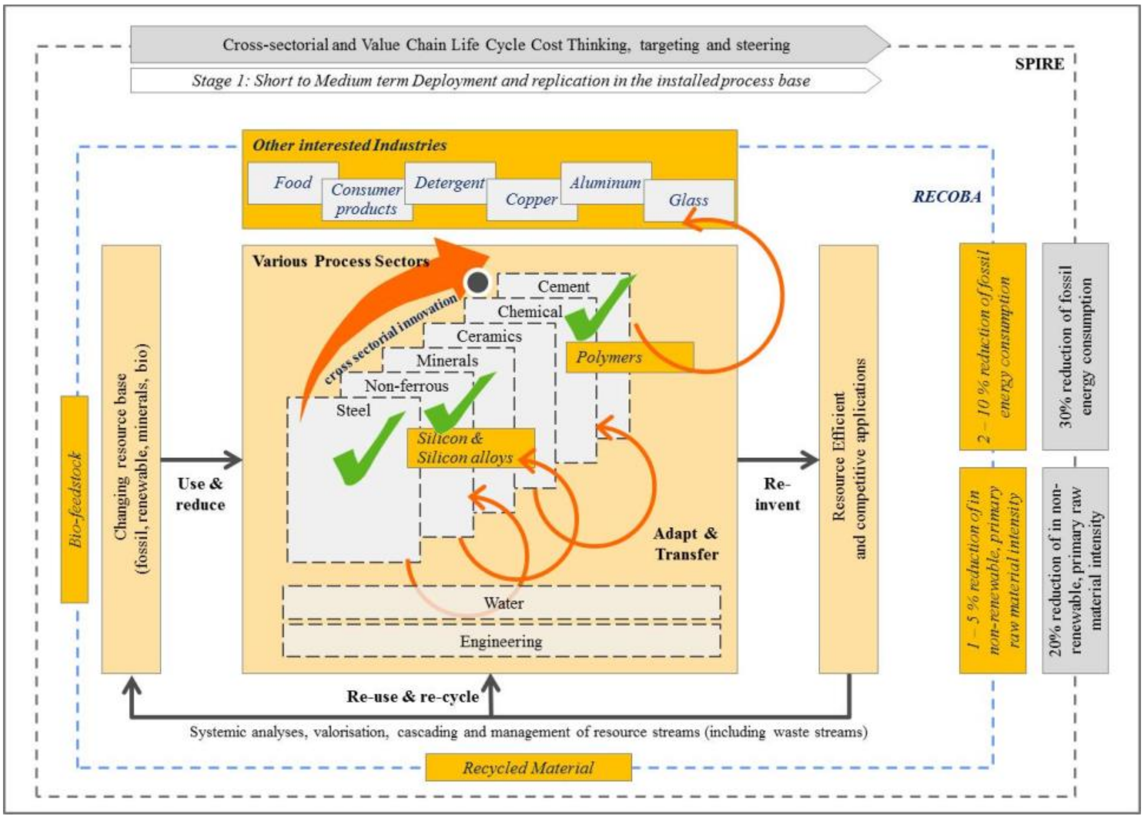

Figure 2-3: RECOBA importance in the context of SPIRE objectives

2.2 Expected impact in the polymers, steel and silicon industries

The three batch-producing industry sectors represented in Recoba constitute important branches of the European process industry. Although the developed methods will be also applicable for other large industrial sectors, these three sectors will be in the scope of a first estimation of the ecological and economic impact of the project.

The following impact generated in the three industrial validation cases are based on conservative assumptions:

Polymers

Dispersions deriving from emulsion polymerisation are mainly used in architectural coatings and construction. The annual production in Europe is around 2-2.5 million t/a with an overall market value of €3,000 million. The world market for dispersion including other applications (adhesives, paper, …) is around 15 million t/a, thereof Europe 5-6 million t/a. The overall CO_2 consumption for the production of 1kg lattices is around 1,5kg/kg along the whole production chain (including monomer production etc.). Using the developed methods, savings in the order of a few percent will be possible, for instance a 5% saving in energy and raw materials and decrease the waste material by 2%. This would result for the evaluated dispersion polymerisation in a reduction in CO_2 emissions by 2.2 million t/a * 1,5 t CO_2/t * 0.07 = 230 kt/a. For dispersions in general in Europe this would be 5 million t/a * 1,5 t CO_2/t * 0.07 = **525 kt/a savings in CO_2 emissions**.

The polymer industry in Europe produces overall more than 57 million t/a. Since emulsion polymerisation is only an ambitious example system among the existing polymerisation processes, it can be expected that with the transfer to other polymerisation processes the figures will increase dramatically.

Steel

The European annual steel production is around 180 million t. With an improved process control for steelmaking, the temperature losses during the chain of batch processes can be reduced by about 10K. At liquid steel temperatures of about 1600 °C, around 3 kWh/t of electrical energy input in a ladle furnace are needed to compensate such a temperature loss of 10K. For oxygen steelmaking plants where the temperature loss has to be compensated by a higher tapping temperature of the BOF converter, the required primary energy input is around 4.5 kWh/t. For the whole steel production in Europe this sums up to estimated **energy savings of around 600 GWh/a**. Converted into specific CO_2 emissions (around 600 kg/MWh depending on the energy mix) this means **savings in CO_2 emissions of about 360 kt/a**. In addition to this **10%** energy savings, an increase of the metallic yield of about **1%** and a reduced consumption of refractory materials by **5%** can be expected.

Silicon metal

For the production of silicon metal the primary savings would result from increased yield. Assuming that a typical furnace producing 25 kt/a, but 500 t are lost in the refining step due to poor process control. Then the specific energy consumption (MWh/t Si produced) is reduced by 2%. The actual energy consumption depends on several parameters, but a typical value is 12 MWh/t Si produced. As such, a reduction from 12 to 11.76 MWh/t is anticipated assuming that the entire potential can be taken out. For Elkem alone with its production of about 100 kt/a, the total reduction of energy is 24 GWh. This means savings in CO_2 emissions of about 14.4 kt/a (around 600 kg/MWh depending on the energy mix). For the whole silicon metal production in Europe with 330 kt/a this leads to estimated **energy savings of around 79.2 GWh/a** respectively **CO_2 emission savings** of about **47.5 kt/a.**

This illustrates the huge potential impact that the new developed techniques will have for the current European industry processes in saving energy, raw materials and waste. Apart from that the new process control will also drive forward new innovative processes and products. Higher product quality delivered from the process industries will also result in less consumption in the manufacturing industry and so helping to reach the goals of Europe 2020. Aside from the direct savings of energy and raw material, a precise real-time process control will also help strongly for making alternative feedstock, like bio-feedstock or recycled materials, e.g. steel scrap for the steelmaking process, usable for established processes.

In addition to the monetary advantages, the implied use of automation will add an addition layer of safety to the process. Manual operations that carry some element of risk due to exposure/proximity to molten metal will be eliminated compared to todays`s practice.

2.3 Obstacles to the realization of impact

The strongest limitations that prohibited implementation of real-time process control until now were the insufficient computer power for complex models and inadequate sensors. The rapid growth in computer capability could enable today the implementation of advanced process control concepts. In addition, commercial sensor technologies improved considerably in the last years, especially with regard to robustness and size, thus making them more adequate today for industrial implementation than 10 years ago.

Today, the potential of applying mathematical optimisation and model-based predictive control of batch processes is not commonly known in the process industry, therefore not widely used. The expected impact of the improved measurements and control is strongly depending on the acceptance of the new measurement, control and decision support solutions by the process managers. Therefore supporting actions to prove advantages and reliability of new control technologies are essential to introduce new systems to production personnel. Even more challenging, when a direct transfer from lab to production is the only way to implement new systems.

3 Dissemination Strategy

The dissemination activities within the project are dedicated to three main objectives:

1. Creating awareness about the RECOBA results among the European energy-intensive batch-producing process industries and related stakeholders;
2. Promoting the importance and opportunities for energy and resource savings as well as product quality improvements in the European process industry;
3. Stimulating the market uptake by showing the positive impacts on the European manufacturing industry.

The dissemination of the project is conducted on multiple levels and is carried out by all partners.

This dissemination plan will be continuously updated and adapted during the project, depending on the project results and achievements. Dissemination achievements are monitored and reported in annual reports. Dissemination activities may be intensified, modified or restructured in order to obtain maximum effect in the respective markets and policy domains. Once the project comes to an end, continuity of the project impacts will be ensured by establishment of a durable stakeholder network.

The current status of dissemination is outlined below and in the attached publication list.

The following dissemination actions are included in the work plan.

3.1 Project web-site

Recoba will have its own web-site and actively update it in partial fulfilment of the above strategy.

Status:
The Recoba web-site is installed (http://www.spire2030.eu/recoba/).

An initial press release was published 25 March 2015, see
(http://www.spire2030.eu/recoba/uploads/Modules/Publications/p172e_recoba.pdf).

3.2 Organisation of workshops

The *industrial validation partners* plan to organise two open dissemination events demonstrating and promoting the technology within the European batch producing industry. These events will take part in the frame of large events at the premises of the industrial partners or at collaborating organisations.

Four exploitation workshops are planned in Recoba. **Status:**

- Exploitation Workshop 1: Kick-off exploitation workshop to agree on exploitation actions. This internal workshop was held in San Sebastian 2015-06-22 in conjunction with the 6 months technical project meeting. A summary of this meeting is reported in deliverable D10.3.
- Exploitation Workshop 2: BASF will co-organize a KoMSO-workshop (Committee for Mathematical Modelling, Simulation and Optimisation). KoMSO serves as network within the “Mathematics for Innovations in Industry and Services” program established by the Federal Ministry of Education and Research (BMBF) and its office is located in Universsity of Heidelberg. Mathematicians working on modelling, simulation, and optimisation meet with researchers and practitioners from manufacturing industry to develop a holistic mathematical view on digital manufacturing. The workshop is scheduled for 9-10 February 2017 in Heidelberg. (external)
- Exploitation Workshop 3: Project presentation at ELKEM in Kristiansand on application of state-of-the-art sensor techniques and process control methodology to industrial batch processes. (external)
- Innovation workshop on instrumentation: *UCAM and MINK*, the experts in sensing technology, will invite possible sensor manufacturers to a workshop to share knowledge and discuss opportunities for future (joint) developments.

3.3 Publications

The consortium partners are committed to publishing project results in journals which allow green or gold open access. There is budget for the associated costs. Publications in the following journals are expected: Chemical Engineering Science, Polymer, Macromolecules, Chemical Engineering Journal, Langmuir, Macromolecular Reaction Engineering, Computers & Chemical Engineering, Industrial & Engineering Chemistry Research, Journal of Process Control, Steel Research, Metallurgical Plant and Technology, Stahl & Eisen, Automatisierungstechnik, Technisches Messen, IFAC Control Engineering Practice, IFAC Automatica.

Status:
Three journal publications are accepted (cf. the attached publication list). More publications are planned in the near future.

3.4 Development and Realisation of Teaching and Training actions

Research results will be delivered in lectures and seminars for both, industry and academia. Training material development and training provision to the industrial validation partners are part of the work plan. BFI and MINK are planning to set up two workshops:

- a **Training Workshop** on high temperature sensor technology;
- an **Innovation Workshop** on the generic application of high temperature sensor technology in the process industry will be organised to explore the inputs from specific

industrial applications of sensors into generic development of sensor technology within the project.

BASF organises each year a Summer School for 100 international and interdisciplinary PhD students, including those that work on EU funded projects. During two weeks the students get an insight in the production and research facilities of BASF and will be informed about RECOBA via poster sessions. The students will also present their own research projects and exchange ideas.

Status:
MINKON held a training and introductory workshop in Poland for Polish steelmakers over the weekend of 3rd to 5th June 2016, which resulted in many positive and useful feedbacks. Within the guidance of Bernd Kleimt, there is also planed to prepeare a presentation to the Steel Industry in the beginning of 2017.

Two project internal training events are held:

- VŠCHT organized a polymerization modelling workshop in Trondheim on 2-3 November, 2015.
- Cybernetica organized a Cybernetica CENIT hands-on training in Trondheim on November on 4-5 November 2015. The purpose of the event was to introduce and hand over the tools provided by Cybernetica through D5.5, and offer training in the tools for the project partners. The following tools were covered:
    - Cybernetica CENIT NMPC: Complete software for on-line state and parameter estimation, optimisation and control.
    - Cybernetica ModelFit: Engineering tool in model development work to perform off-line optimisation using logged process data and off-line parameter estimation.
    - Cybernetica RealSim: Fully functional test bench for an on-line application, used for controller tuning etc.

Cybernetica hosted both these training events. Present at these events were representatives from CYBERNETICA, POLYMAT, RWTH, VSCHT, UCAM and BASF.

In addition, Elkem has organized two internal seminars for its employees:

- Internal training/demonstration session of the dynamic refining model at the Elkem University, 21-23 September, 2015, Kristiansand, Norway.
- Status updates of Recoba-project at quarterly seminars in the operative divisions of Elkem to ensure knowledge sharing and project results awareness.

3.5 Participation at Conferences, Symposia and Seminars

RECOBA members presents the research results and business opportunities at conferences and events, where a cross section of stakeholders is present to achieve effective visibility.

Status:

- European Symposium on Chemical Reaction Engineering 27.-30.10.2015
- ESTAD 2016 (TKSE, BFI) – 3rd European Steel Technology Application Days
- IFAC Conference, date to be defined (BFI)

Dr. Peter Singstad represented Recoba in the “SPIRE Impact Workshop” in Brussels 21-22 April 2015.

Dr. Libor Šeda introduced the Recoba project in the workshop “Introduction of SPIRE projects 2014” in Brussels 29 June 2015.

Dr. Libor Šeda presented the achievements on the polymrisation field in the frame of an international CHISA 2016 (International Congress of Chemical and Process Engineering) and PRES 2016 (Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction) in Prague.

Elkem did not participate as planned at INFACON 2015 (International Ferro-Alloys Congress) due to imposed travel restrictions to Ukraine. Furthermore, the program at “Silicon for the Chemical Industry and Solar Industry 2016” were not sufficiently coherent with the work Elkem has carried out in Recoba. A different venue was chosen, see the updated publication list.

Dr. Peter Singstad represented Recoba in the “SPIRE Impact Workshop” in Brussels 21-22 April 2016.

Prof. Dr. Juraj Kosek, Dr. Peter Singstad and Prof. Dr. Klaus-Dieter Hungelberg partisipated at Workshop on Polymer Reaction Engineering 2016 in Hamburg, Germany.

AC.CES 2015 (RWTH) – International conference on computational engineering science

AIChE 2015 (RWTH) – International conference for chemical engineers

ESCAPE 2016 (RWTH) – European conference on process systems engineering

FOCAPO/CPC 2017 (RWTH) – International conference about process control

3.6 Cooperation with standardisation bodies

The industrial validation partners are trendsetters in their respective industry and used to cooperate with standardisation bodies. RECOBA results will be discussed in the following bodies:

- Chemical sector: Namur and ProcessNet
- Steel: Steel Institute VDEh - Technical Committee for Process Automation
- Silicon alloys: FFF - Norwegian Ferroalloy Producers Association

4 Business Plan

The business plan presented here is continuously refined and updated by the Exploitation Board.

The Consortium Agreement settles IPR matters as well as exploitation interests by the partners.

4.1 Exploitable results

The knowledge developed in RECOBA will lead to the development of new products and services. The process industry partners will test the results and serve as pilot users. The results will also be used in scientific teaching and training.

The expected exploitable results fall into these categories:

1. New and updated real-time process control concepts for batch processes, including Nonlinear Model Predictive Control (NMPC) technology, Dynamic Real-Time Optimization (DRTO) and plant level scheduling algorithms.
2. New and better exploitable sensors that can be commercialised together with the control concepts and as stand-alone products.
3. New knowledge on modelling techniques for batch and semi-batch processes – in particular related to steel, emulsion polymerization and silicon production.
4. New algorthms for signal processing and calibration of spectral sensor signals.

The modelling results will directly be used in the development of the control concepts. In the current level of planning, these results will therefore be exploited together with the control concepts. Similarly the signal processing algorithms will be included in the exploitation plan for sensors.

4.2 Market potential in steel, emulsion polymerization and silicon

4.2.1 Market potential in steel production

Global growth of the crude steel production

The industry directly employs more than two million people worldwide, with a further two million contractors and four million people in supporting industries. Considering steel's position as the key product supplier to industries such as automotive, construction, transport, power and machine goods, and using a multiplier of 25:1, the steel industry is at the source of employment for more than 50 million people. World crude steel production has increased from 851 megatonnes (Mt) in 2001 to 1,607 Mt for the year 2013. World average steel use per capita has steadily increased from 150kg in 2001 to 217kg in 2012. India, Brazil, South Korea and Turkey have all entered the top ten steel producers list in the past 40 years[1].

The steel industry in the EU

Figure 4-1: Steel industry production sites in the EU28 (Source: EUROFER)

The European steel industry employs 350,000 highly skilled people at over 500 production and processing sites located in 24 EU member states. Several million more jobs are directly and indirectly dependent on steel in the value chain and service sectors. The industry produces on average 170 million tonnes (Mt) of crude steel per year. In 2009, the steel sector generated a turnover of approximately €170bn, 1.4% of the EU's GDP. The European steel industry is known for being among the most energy and resource efficient worldwide. Figure 4 3 shows the steel industry production sites in EU28. The largest primary steelmaking companies are located in Germany, Italy, France and Spain.

[1] https://www.worldsteel.org/media-centre/key-facts.html

Table 4-1provides some more facts about the steel market and the target customers for the stage 2 phase.

Table 4-1: Steel market facts (Source : EUROMER- The European Steel Association)

Products	Application sectors	European Steel Manufacturers
Iron Steel & ferro-alloys Tubes Other iron, steel & ferro-alloys	Construction Automotive Appliances and household goods Energy Packaging	ArcelorMittal, Tata Steel, Gerdau, RIVA Group, Saarstahl, Evraz Group, NLMK, Techint Group, voestalpine, ThyssenKrupp, CELSA Group, Lech Stahlwerke, Outokumpu, Deutsche Edelstahlwerke, SSAB, AG der Dillinger Huette, Ascometal, Salzgitter AG, Acerinox, Huettenwerke Krupp Mannesmann, Aperam and others.

4.2.2 Market potential in emulsion polymer production

Global growth of the emulsion polymer production

According to a market study from the Freedonia Group[2], global demand for emulsion polymers is forecasted to rise over 5% per year to 13.3 million metric tonne in 2016. Advances will be fuelled by increased production of water-based coatings and adhesives, which are displacing solvent borne formulations in virtually all parts of the world. Acrylics will remain the largest and fastest-growing emulsion polymer product type through 2016, accounting for nearly 40% of the global market. The most rapid gains through 2016 will be for emulsion polymers in coatings, where water-based formulations are steadily increasing their market share. Even in industrialised regions - North America and Western Europe, there are ample opportunities for emulsion polymers in the industrial and specialty coatings markets, reported the study. More moderate gains in demand are expected in the adhesives market, where emulsion polymers are facing competition from other low-VOC technologies such as hot melts. Below-average advances in emulsion polymer demand are forecast for the highly mature and slow-growing paper and paperboard coatings market.

The basic chemicals industry in the EU

The manufacture of plastics in primary forms (NACE 24.16) was the principal activity of about 2.700 enterprises across the EU-27 in 2006. These enterprises employed an estimated 189.300 people in 2006. The sector generated a turnover of €106.9 billion in 2006, about one fifth (€20.2 billion) of which was left as value added.[3,4] The basic chemicals manufacturing sector in Germany was by far the largest among the Member States, alone generating 29.0% of the value added generated by this sector across the EU-27, followed by United Kingdom, Ireland, the Netherlands and France. These countries will be the target countries for the Stage 2 phase. Some of the leading emulsion polymer manufacturers that are interesting to be approached during Stage 2 are displayed in Table 4-2.The demand for emulsion polymer is mainly triggered by growing demand from paint and coatings industry and adhesives market.

[2] ‘World Emulsion Polymers,’ a market study from The Freedonia Group.
[3] Eurostat: European business — Facts and figures 2009
[4] Verband der Chemischen Industrie e.V. (VCI)

Table 4-2: Emulsion polymer market facts (Source: Transparency market research)

Products	Applications	Emulsion Polymer Manufacturers
Acrylics, Styrene-Butadiene Latex, Vinyl Acetate Polymers, others	Paint & Coatings Paper & Paperboard Coatings, Adhesives, others	BASF SE, Celanese, Dow Chemical, Styron, Synthomer, Wacker Chemie, Clariant International, DIC Corporation, Nuplex Industry and Omnova Solution

4.2.3 Market potential in silicon metal production

World-wide growth of the silicon industry

In 2013, the world production of silicon metal amounted to about 2.056 million tonnes[5]. China, Brazil, **Norway**, the USA and **France** are countries with major silicon production. Aluminium and chemical industries define the demand for silicon metal. World output of the compound increased by 1.4% in 2013. China dominates the market with 65.7% share. Norway is second with 8% contributed to the world output[6].

The silicon industry in the EU

The major European silicon alloys producers are located in Norway and France. ELKEM is the largest producer in Norway providing silicon alloys to the chemical industry. From the world consumption of silicon metal the chemical industry has with 35% a large share behind aluminium alloys with 45%. Altogether, the below producers represent nearly 100% of Western Europe's capacity of 335,000 tonnes/year in 2013.

Table 4-3: Silicon metal market facts (Source : European Silicon Center)

Products	Application sectors	European Silicon Metal Producers
Silanes, silicones and silica “Hardener” or alloying element to produce aluminium alloys	Chemical industry: Paints and coatings, sealants and adhesives Construction & Interior, Kitchen & Household, Personal Care, Medical & Health, Transportation, Other Uses	B.S.I. d.o.o (Bosnia Herzegovina), Elkem (Norway), Ferroatlantica (Spain) Fesil (Norway), Ferropem (France), RW Silicium (Germany) and Jugohrom (Macedonia)

Due to the fact that RECOBA has a TRL 3-5, it is difficult to provide a complete exploitation plan with figures over the three exploitation stages. Below figures for stage 1 are presented. During the project the consortium will develop comprehensive exploitation figures for stages 2 and 3. Nevertheless, the European replication potential of the three industries has already been estimated in Table 4-4 with forecasting market shares of 20% in the polymer, 25% in the steel and 50% in the silicon alloys industry up to ten years after project end. The total turnover amounts up to €32.5 million.

[5] CRU Group

[6] http://mcgroup.co.uk/researches/silicon

Table 4-4: RECOBA replication potential in the three concerned industries

Target groups	Emulsion Polymer industry	Steel industry	Silicon alloys
Units in Europe	350 - 400	300	15
Production volume in Europe	4-5 Million t/a	180 Million t/a	335,000 t/a
Replication potential in Europe (first 5 years)	20%	25%	50%
Production volume with new concept	1 Million t/a	45 Million t/a	167,500 t/a
Costs for control concept / unit	100.000 €	100.000 €	100.000 €
Turnover for control concept	8.000.000 €	7.500.000 €	750.000 €
Costs for sensors or manipulator/unit	75.000 €	75.000 €	75.000 €
Turnover for sensors concept	6.000.000 €	5.625.000 €	562.500 €
Costs for maintenance, support and training	25.000 €	25.000 €	25.000 €
Turnover for maintenance, support and training	2.000.000 €	1.875.000 €	187.500 €
Sum	**16.000.000 €**	**15.000.000 €**	**1.500.000 €**

4.3 Exploitation strategy – a three phase approach

The intention of the cross-sectorial market implementation is gradually planned in three stages as depicted in Figure 4-2.

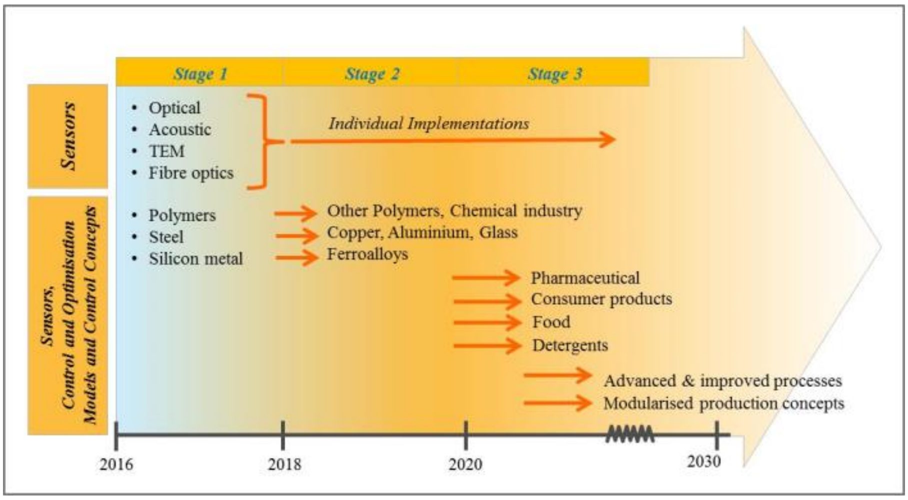

Figure 4-2: Timing of cross-sectorial implementation of the real-time control concepts and sensors in various sectors and processes

The exploitation strategy is to start the commercialisation in already experienced and known markets in stage 1, continue with similar markets in stage 2 and then enter different markets in stage 3.

Considering the timeline of the exploitation actions, the stage 1 exploitation route will lasts for a period of five years from 2016-19. Stage 2 will start with some overlap in 2018 and ends in 2022. Stage 3 may start in 2020 and is forecast to end in 2030.

Stage 1: The project results will be employed in the same process industries as addressed within RECOBA: polymer, steel and silicon metal production. If RECOBA is a success, the participating three industrial players BASF, TKSE and ELKEM will implement the real-time control concept and new sensor technology in their production plants in Europe.

Stage 2: Stage 2 will include replications in the same sectors as addressed in stage 1, but outside BASF, TKSE and ELKEM. Additionally, the implementation in sectors with similar process conditions is envisaged such as copper or aluminium production that are closely related to steel and silicon alloy production. The transfer to continuous processes such as Glass production is also envisaged.

Stage 3: At Stage 3 the process industry with higher demands on documentation and reliability issues will be addressed such as food and pharmaceutical industry. By 2020 it is assumed that modularised production plants deriving from the F3 Factory project will emerge. The research results will be transferred to new as well as advanced and improved production methods, when they become available.

In parallel and over all three stages, the new sensing technology will also be deployed as stand-alone solutions for the use in individual applications.

Figure 4-3 shows the various exploitation routes, targeted markets and business opportunities of RECOBA over a timeline from 2016 till 2025 and beyond.

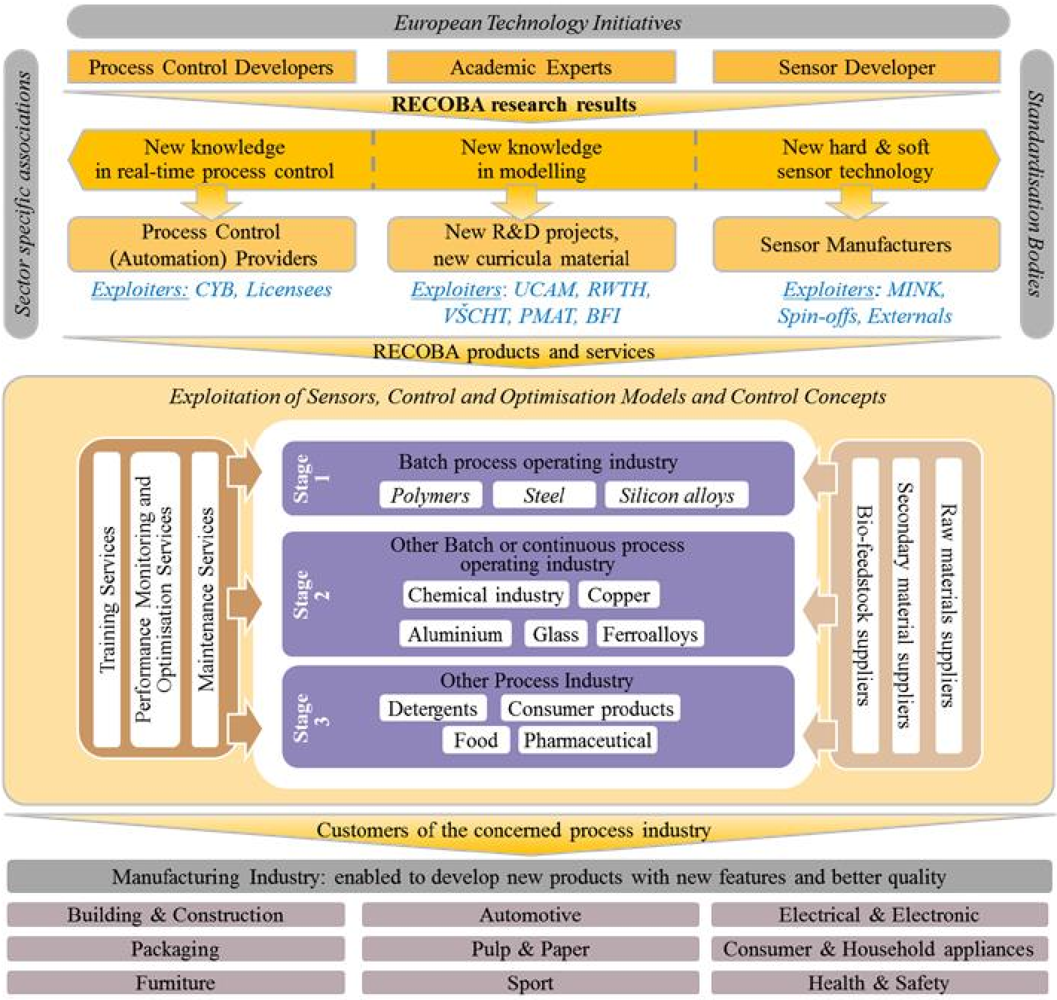

Figure 4-3: RECOBA exploitation matrix

4.4 Exploitation plan

The three industrial validation cases of RECOBA will serve as sector-specific reference cases. Other process industry in the same sector will be invited to site visits to evaluate the technology. First, the technology will be replicated in other own plants of the validation partners in Europe. Later on other companies as presented above will follow to replicate the technology.

4.4.1 Exploitation of new temperature and coverage sensing tools by Minkon.

Minkon has for over 50 years a world-leading position in the development, manufacturing and implementation of sensors for high-temperature processes like liquid steelmaking. MINK will be responsible for the exploitation of the new developed sensors for their markets, starting with the sectors of ferrous and non-ferrous metallurgy, but potentially extending to glass and other high-temperature processes at stage 2. Table 4-5 shows estimated sales figures for the new temperature sensor applied in the steel industry.

At each batch-process-line in the steel industry around 3 to 5 measurement station could be installed. If the new sensor-technique would penetrate 100% of the EU28 steel industry, around. 6.000.0000 yearly measurements must be carried out. In that scenario the expected consumable fibre costs are €120 million/year. In the first five years after finalising the RECOBA project and building a prototype instrument the main focus would be on the, from the project well known two treatment-stations, Ladle-stirring-station and RH-Degasser. The estimated number of this treatment station in Europe is between 300-350 units. The total fibre consumption costs for all of these applications are €~60 million. The exploitation target for the new sensor system is to reach a market share in EU28 of approx. 25-30%, five years after starting the official sales activities.

Table 4-5: Sales figures for temperature measurement and coverage efficiency sensors

Temperature Measurement Sensor - stage 1					
Exploiter: MINK	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Number of new installed measurement units	4	10	15	22	32
New measurement equipment	200.000 €	500.000 €	750.000 €	1.100.000 €	1.600.000 €
Running measurement stations	4	14	29	51	83
Fiber consumption	640.000 €	2.240.000 €	4.640.000 €	8.160.000 €	13.280.000 €
Sum	**840.000 €**	**2.740.000 €**	**5.390.000 €**	**9.260.000 €**	**14.880.000 €**
Accumulated turnover		3.580.000 €	8.970.000 €	18.230.000 €	33.110.000 €

Coverage efficiency sensor - stage 1					
Exploiter: MINK	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Number of new installed units	2	4	8	16	20
New measurement equipment	60.000 €	120.000 €	240.000 €	480.000 €	600.000 €
Accumulated turnover	60.000 €	180.000 €	420.000 €	900.000 €	1.500.000 €

An early installation of the Dyntemp system is now at site is TKSE. Trials are expected to run then for up to 2 months at this and then a second location within TKSE. Upon completion of these trials, the intension is to move on to Elkem where an installation will be made in a development furnace. Upon success there, one may then move directly to the main production facility.

The proposed system MINKON/BFI Dyntemp systems would potentially realise the following additional annual benefits:

- 18,720 tonnes of paperboard would be saved and associated environmental transport costs.
- Health and Safety would be improved as operators would no longer need to make manual measurements for temperature monitoring
- Temperature modelling would be possible for individual process stations allowing continuous improvement based on “real time/location” data
- Cost of implementation for end users would be minimal as customers would not be expected to buy the systems, but rather pay a rental, usage and maintenance fee thus removing need for capital investment
- Ultimately Dyntemp will be fully integrated into customers own control systems
- Potential number of Dyntemp systems across Europe is estimated at around 100.
- Potential European annual sales value is estimated to be €10,000,000

4.4.2 Exploitation of the model based control concept by Cybernetica.

In Recoba, Cybernetica have developed and implemented new applications in existing products for model identification and model based predictive control. These new and updated real-time process control concepts, based on Nonlinear Model Predictive Control (NMPC) technology, will bed demonstrated for the emulsion polymerization case and the silocon case as part of the project.

Cybernetica's exploitation of Recoba results will preimarily be done by offering own products to the market. Cybernetica has more than sixteen years of experience in the development, implementation and maintenance of specialised solutions for model based process control and optimisation. It will use the new developed concept as part of industry specific applications that they bring to the market.

Implementation of model predictive control applications is Cybernetica's core business. Any new developments will be included in the portfolio. Services include long-term maintenance of the installed applications, training and performance monitoring.

The estimated sales figures for the control concept in stage 1 are based on replications in the polymer, steel and silicon industry.

In estimation of sales figures, the size of the market is not a limiting factor. As pinpointed above, the market is large and the potential impact is significant. Model predictive control technology is today, however, to a very limited degree adopted in the targeted industries. The market needs to be developed, which takes time and limits the rate of market penetration. There are however clear indications that the demand for advanced process control solutions is increasing.

Table 4-6: Estimated sales figures for new batch control system in all three industries

New batch control system - stage 1					
Exploiter: CYB	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Number of new batch control systems	3	5	7	9	11
Batch control systems in operation	3	8	15	24	35
Revenue from new installations	350.000 €	550.000 €	800.000 €	1.050.000 €	1.300.000 €
Maintenance, support and training	70.000 €	180.000 €	340.000 €	550.000 €	810.000 €
Sum	**420.000 €**	**730.000 €**	**1.140.000 €**	**1.600.000 €**	**2.110.000 €**
Accumulated turnover (Stage I)	420.000 €	1.150.000 €	2.290.000 €	3.890.000 €	6.000.000 €

4.4.3 Exploitation of new sensors, signal processing technology and sensor calibration.

For the **exploitation of the various sensors** the consortium will first identify the need to improve instrumentation beyond what is currently on the market and develop the corresponding relationship during the project. It is foreseen to invite a sensor/instrumentation contractor at a later stage for close co-development of instrumentation. This could be in either of the areas (acoustics, optics, temperature, optical imaging or electron microscopy), where most important intervention would be required to ensure that the most promising sensor technique for commercial demonstration within the project will have the necessary technical development. Table 4-7 shows the sensor developments of RECOBA and its **wide applicability across the process industry**.

Table 4-7: Branches for which the new developed sensors will be applicable

Branch \ Sensors	Optical Spectroscopy	Acoustic Sensors/ ultrasound	In-line flow-TEM	Temperature Measurements	Coverage efficiency sensor
Polymer	■	■	■	■	
Steel		■		■	■
Silicone	■	■		■	■
Copper		■		■	
Aluminium		■		■	
Food	■		■	■	
Consumer Products	■	■	■	■	
Detergents	■	■		■	
Glass				■	
Cement	■	■		■	
Minerals	■	■		■	
Ceramics	■	■		■	
Chemicals	■	■	■	■	

The exploitation routes of the individual sensors vary depending on their commercial availability:
RECOBA will develop IP on signal processing and calibration, which could be licensed to existing commercial suppliers of Raman equipment and methods. However, there are very few commercial developers and suppliers of acoustic sensors and almost none in processing industries sector. Therefore, there is a **significant potential for developing a useful IP portfolio and spin-outs** to commercialise RECOBA developments. The University of Cambridge is actively exploring the possibility of spinning out a company which would fabricate film bulk acoustic resonator devices using an external foundry. This would be based on background IP, but would provide a route to manufacturing new devices tailored to the needs of the particulate sensing requirements of the RECOBA end users. This would be a valuable extra product line and would be executed in collaboration with the RECOBA project partners.

The in-line flow TEM is a very new method with yet un-determined full potential. This work is likely to remain at TRL level 3 within the lifetime of RECOBA project. UCAM explored options for manufacture of TEM chips via external foundry and found it to be not cost effective. UCAM will therefore retain IP and know how on the manufacture of these devices and will offer expertise for specific commercial collaborations or specific contracts to manufacture small batches of chips. The new imaging cell is expected to be of commercial interests to suppliers of standard TEM equipment, as well as developers of low-cost compact TEM instrumentation. The most feasible route to exploitation would be through **licensing of IP, development of new partnerships** with established industrial developers of electron microscopy equipment, and direct contract research using proprietary expertise and know how.

4.4.4 Use of Recoba results in BASF

BASF Expects the the following types of benefits from using the Recoba results:

- Optimal energy consumption (heating, cooling)
- Less waste
- Better reaction control (possible to work closer to safety limits)
- Consistent quality of product properties (operation in narrow process window)
- Shortening of batch time (increase space-time yield)

BASF produces 2 mill. tonnes per year of dispersion polymers. With that volume, they estimate the following gains by using the results:

- Resource efficiency (due to better product properties): 5 %
- Energy efficiency during polymerization: 5 %
- Decrease of waste, thus increase of ressource efficiency: 2 %
- Batch time reduction: 5–10%

After having tested the technology on emusion polymerization production plants, BASF plans to transfer the enhanced control technology to other polymerization processes. Implementtation of the real-time control concept and new sensor technology in BASF’s emulsion polymerization production plants is planned for the period 2017-2022. Spreading the MPC technology into other polymerization plants and similar production sites will take plase in 2020-2030.

BASF consider the following factors crucial for their success:

- Having an optimized workflow for implementation of online MPC, with reliable and experienced partners for development projects (sensors, models, data management and interpretation), and a clear workflow for MPC introduction into single processes (device needs, interfaces, build up of in house expertise)
- Fast implementation of RECOBA results into production, so as to become between the first emulsion polymer producing companies who utilizes MPC on a big scale

4.4.5 Use of Recoba results in ThyssenKrupp Steel Europe

TKSE plans to use Recoba results to reduce energy consumption and material input. That will be achieved through optimisation of melt temperature control throughout the process chain of liquid steelmaking, with focus on the following two batch processes:

- RH vacuum treatment for decarburisation and degassing of the steel melt
- Gas stirred ladle treatment for homogenisation, alloying and refining

This requires:

- Application of a new continuous melt temperature measurement based on optical fibres at the main aggregates of the liquid steelmaking process chain (RH plant and ladle stirring station),

- Enhancement of dynamic on-line process models for monitoring and prediction of melt temperature evolution, including the thermal state of the refractory-lined reactors (RH and ladle)
- Development of tools for auto-calibration of process models, to maintain high model accuracy
- Application of innovative control and optimisation methods for energy and resource efficient process control.

Direct and measurable expected benefits include:

- The new developed sensors and models will provide important process parameters like melt temperature, accessible in a real-time and continuous manner
- Reduced energy consumption, by avoiding unnecessary heating and cooling during the process chain
- Reduction of waste and saveed resources through reduction in the number of unsuccessful batch runs
- Increased metallic yield and a reduced consumption of refractory materials

In summary, the costs of production, raw material and energy can be decreased due to increased yield, reduced batch times, increased uptime, fewer unplanned stops, and more stable process conditions.

Indirect benefits:

- Based on extensive usage of in-line information on the process state, the batch processes of liquid steelmaking can be run closer to the optimal trajectory, leading to higher reliability and more consistent product quality
- The new process control will enable operators to detect serious deviations from expected process runs in real-time and make the process safer and more sustainable, and the product quality more reliable.
- Less product has to be discarded due to low quality. Production losses will be reduced.
- The production of new complex steel qualities, requiring tight process control along the process route of liquid steelmaking becomes feasible.

4.4.6 Use of Recoba results in Elkem

Elkem's vision for the future silicon production, which Recoba project results may serve to bring about, is summarized in three points:

1. Remove personell from processes involving hot metal and slag. That requires new
   - Increased degree of automation
   - New sensor technology
   - Computer based control system based on automatic measurements, without human interactionsactions.
2. Increase yield of tapped Si through better process control, which also implies maximum utilization of raw materials and energy.
3. Improve quality of Si product, which leads to repeatability of casting process

Elkem plans to use Cybernetica CENIT products in the Recoba activities. A pre-existing Silicon refining simulator, called RaffSim, has been re-implemented as a Cybernetica CENIT Model and Application Component (cf. illustration in Figure 4-4).

The off-line model Raffsim developed during the first 18 months of the project is now used at a production site to test the effect of various process modifications, such as change of gas flow and gas composition, increased recycling of materials to utilize superheat of the melt and optimize timing for the addition of slag formers. During the remainder of the project, the off-line model will be used for process support and eventually the gain of modified procedures can be calculated.

In parallell, the online-model developed by Cybernetica is now being implemented as a "in-silicon" demonstration module at Elkem Thamshavn. The goal of this demonstration is to demonstrate the benefits of the new model-approach for Si-production. The model will also be used at analysing old data to calculate the economic model for the new, model-based approach to process control.

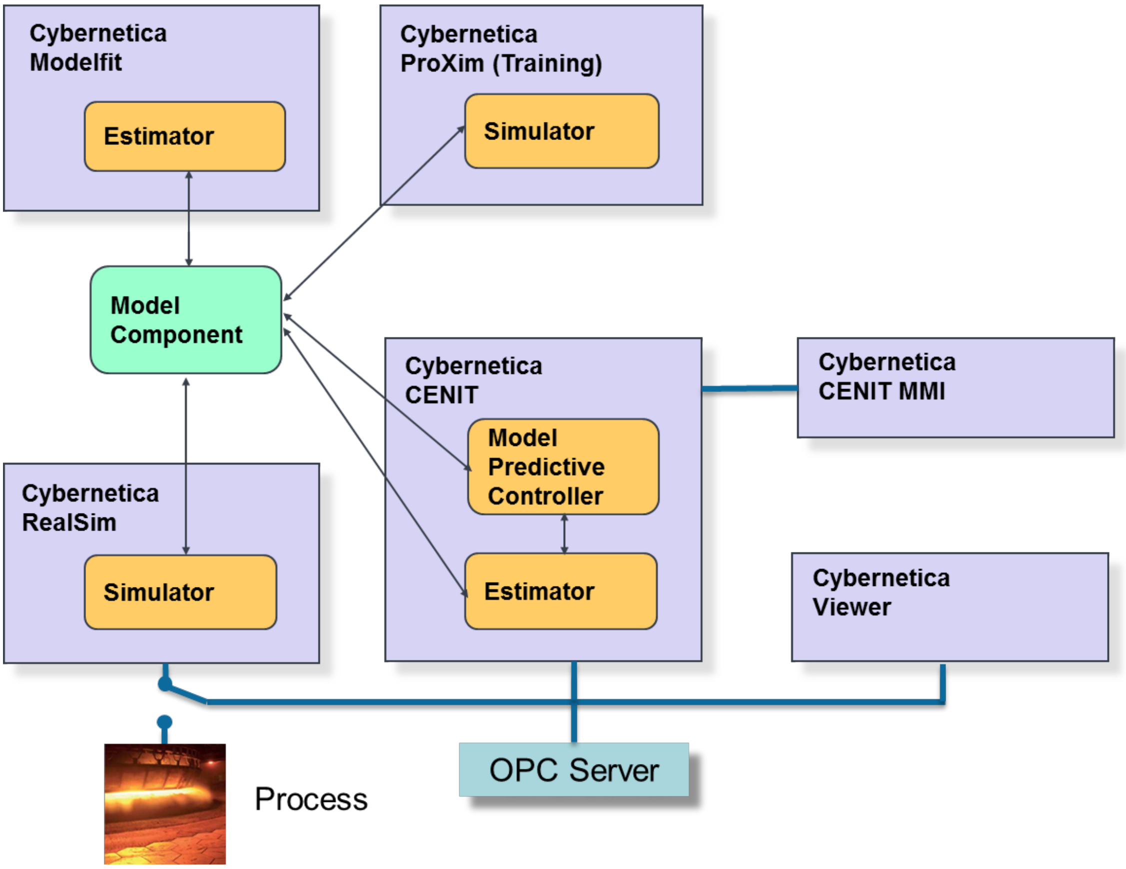

Figure 4-5: Cybernetica's products, using the same Cybernetica CENIT Model and Application Component.

Regarding sensors, the test programme scheduled in the initial project description has been continuously updated and modified as new insight is gained. As of today, the following new sensor packages has been tested in industrial or pilot scale:

- Radar combined with load cells for accurate determination of tapping rate and metal level in ladle.
- The Dyntemp system, developed by Minkon, has been tested in silicon production at an industrial scale with success. Further exploitation demands that system can be modified to fit refining ladles, where the gas enters the system through a bottom plug as opposed to the test setup where then gas entered by a submerged lance.
- Coverage efficiency sensor developed by BFI has been tested in pilot scale in order to measure the slag coverage fraction. The experiment was successful, but modifications are necessary to achieve measurements during industrial scale operation.

Further exploitation and use of these sensors is subject to a cost analysis, looking at both investment cost and cost during operation. The installation and operation in a heavy-duty industrial environment is also a challenge, as the robustness of the sensor will be tested. It will be a requirement that new sensors installed adhere to restrictions on accuracy, cost, durability, robustness, ease of operation and integration with exisiting infrastructure and process control systems.

Appendix A: Publications, presentations and exhibitions

Journal Articles:

G. Rughoobur, M. DeMiguel-Ramos, T. Mirea, M. Clement, J. Olivares, B. Díaz-Dúran, J. Sangrador, W. I. Milne, E. Iborra and A. J. Flewitt: *Room temperature sputtering of inclined c-axis ZnO for shear mode solidly mounted resonators.* Sumbitted to the Applied Physics Letters.

M. Kroupa, M. Vonka, M. Soos and J. Kosek: *Utilizing the Discrete Element Method for the Modeling of Viscosity in Concentrated Suspensions.* Langmuir 32, 8451 (2016).

Shaghayegh Hamzehlou, Jose R. Leiza, José M. Asua. A new approach for mathematical modeling of the dynamic development of particle morphology. Chemical Engineering Journal 304 (2016) 655–666.

Conference contributions:

Johannes M.M. Faust, Jun Fu, Benoit Chachuat and Alexander Mitsos*: Local Optimization of Dynamic Systems with Guaranteed Feasibility of Path Constraints.* Oral presentation at the AIChE Annual Meeting 2015, Salt Lake City, UT, USA.

Martin Kroupa, Michal Vonka, Juraj Kosek: *Shear-induced Coagulation in Stabilized Dispersions: Modeling by Discrete Element Method*. Poster presentation at IACIS 2015, Mainz, Germany.

A. Zubov, R. Pokorny, P. MAtuska, Juraj Kosek: *On-line control and optimization for intensification of emulsion copolymerization reactors*. Oral Presentation at the 3th International Conference on Chemicl Technology (ICCT 2015), Mikulov, Czech Republic.

Johannes M.M. Faust, Jun Fu, Benoit Chachuat, Alexander Mitsos: *Optimization with Dynamic Systems embedded with Guaranteed Satisifaction of Path Constraints*. Poster presentation in the 3th Aachen Conference on Computational Engineering Science (AC.CES 2015), Aachen. Germany.

Martin Kroupa, Michal Vonka, M. Soos, Juraj Kosek: *Coagulation and Fouling in Stabilizied Colloidal Dispersions: Building a Predective Model Based on First Principles*. Oral Presentation at the 4th International Conference on Chemicl Technology (ICCT 2016), Mikulov, Czech Republic.

Martin Kroupa, Michal Vonka, M. Soos, Juraj Kosek: *Viscosity and Stability of Consentrated Colloidal Disepersions: Building a Predective Model Based on First Prinsiples*. Oral presentation at the 12th International Workshop on Polymer Reaction Engineering (PRE 2016), Hamburg, Germany.

T. Chaloupka, A. Zubov, Juraj Kosek: *Real-Time hybrid Monte Carlo method for modelling of 4-monomer semi-batch emulsion copolymerization*. Poster presentation at the 12th International Workshop on Polymer Reaction Engineering (PRE 2016), Hamburg, Germany.

S. Hamzehlou, J.R. Leiza, J.M Asua: A new approach for mathematical modelling of the dynamic development of particle morphology. Poster presentation at the 12th International Workshop on Polymer Reaction Engineering (PRE 2016), Hamburg, Germany.

Johannes M.M. Faust, Jun Fu, Benoit Chachuat, Alexander Mitsos: *Optimization of dynamic systems with rigorous path constraint satisifaction*. Poster presentation in the European Symposium on Computer Aided Process Engineering 2016 (ESCAPE26), Portoroz, Slovenia.

Noushin Rajabalinia, Shaghayegh Hamzehlou, Jose R Leiza, Jose M Asua: *Study the effect of reaction condition on the morphology of structured polymer particles in latexes*. Oral presentation at XIV Meeting of the Group of Polymers of the Spanish Royal Chemistry and Royal Physics Societies(GEP-2016), Burgos, Spain.

L. Šeda, E. Jahns, A. Mhamdi, A. Mitsos, P. Joy, S. Hamzehlou, J. R. Leiza, J. M. Asua, N. Rajabalinia, J. Kosek, T. Chaloupka, M. Kroupa, M. DeMiguel-Ramos, A. J. Flewitt, A. Lapkin, J. Suberu, F. Gjertsen, P. Singstad: EU project RECOBA: *Expected impact and an overview about progress in advanced process control of emulsion copolymerization*. Oral presentation at the CHISA/PRES 2016 conference, Praha, Czech Republic.

T. Chaloupka, A. Zubov, Juraj Kosek: *Real-time hybrid Monte Carlo method for modelling of 4 monomer semi-batch emulsion copolymerization*. Oral presentation at CHISA 2016, Prague, Czech Republic.

M. Kroupa, M. Vonka, M. Soos and J. Kosek: Viscosity of Concentrated Dispersions: *Modeling by Discrete Element Method*. Oral presentation at CHISA 2016, Prague, Czech Republic.

E.Nordgaard-Hansen, K.Hildal: *Skull formation in dynamic modelling of silicon refining*. Oral presentation/paper at 17th IFAC Symposium on Control, Optimization and Automation in Mining, Mineral and Metal Processing, Vienna, August 31-September 2, 2016.

Exhibitions:

Mark Potter (Minkon). Exhibition of the developed fibre optical temperature sensor. METEC 2015, Düsseldorf, Germany