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|  | EUROPEAN COMMISSIONRTD – EnergyENER - Renewables, R&I, Energy EfficiencyJRC – Institute for Energy and Transport**SET Plan Secretariat** |  |

**SET-Plan ACTION n°6 - Implementation Plan - DRAFT**

**"Continue efforts to make EU industry less energy intensive and more competitive"**

# Introduction and policy context

The Energy Union Strategy[[1]](#footnote-1), launched in early 2015 and being one of the 10 big priorities of the European Commission (EC), includes research, innovation and competitiveness at the same level of importance with its 4 other dimensions, for accelerating the decarbonisation of the European energy system cost-effectively. The SET Plan has been recognised as one of the major tools to deliver this goal by contributing to the cost reduction and improve of performance of low carbon energy technologies through impactful synergetic innovation actions.

As part of the deliverables of the Energy Union strategy, the European Commission adopted a Communication for an Integrated Strategic Energy Technology Plan[[2]](#footnote-2). The Communication identifies ten priority actions to accelerate the energy system transformation through coordinated or joint investments between European countries, private stakeholders (including research and industry) and the European Commission. These actions have been defined building on the proposals of the Integrated Roadmap (that was developed with stakeholders and Member States) and in line with the new political priorities defined in the research, innovation and competitiveness dimension of the Energy Union strategy. Out of the ten priorities, Action 6 aims at the continuation of our efforts to make EU industry less energy intensive and more competitive.

The issue of energy consumption and costs and their impact on industrial competitiveness has become central for EU policy making in the context of the EU ambitious energy and climate objectives and against the challenge of growing competitive pressures from emerging economies. At the EU level, the energy efficiency of the industrial companies is mainly driven by four pieces of EU legislation: 1) the Energy Efficiency Directive (EED) (2012/27/EU) which requires energy distributors or retail energy sales companies to achieve 1.5% energy savings per year through the implementation of energy efficiency measures, and which require large companies to make energy audits and also MS to support and foster voluntary energy audits in SMEs; 2) the EU Emission Trading System (ETS) Directive 2003/87/EC; 3) the Industrial Emissions Directive (IED) (2010/75/EU) which provides that the BAT (Best Available Techniques to reduce emissions and environment impact, including the reduction of energy consumption) conclusions shall be the reference for setting the permit conditions of the installations covered by the IED. 4) the Eco-design (2009/125/EC) and Energy-labelling (2010/30/EU) directives, setting minimum energy efficiency standards and energy labels to support the development and market uptake of energy efficient products;

In the context of this Implementation Plan for Action 6, it is important to underline that the European Commission in November 2016 has proposed to review two highly relevant pieces of legislation:

* A proposal to review the EU emissions trading system (COM(2015)0337), in the framework of the summer energy package, on 15 July 2015. The proposal envisages achieving at the very least a 43 % reduction in greenhouse gases by 2030 in comparison with 2005 levels, in the sectors covered by the ETS. To this end, it proposes: a new annual emissions reduction rate (1.74% currently); to allocate 52% of emission allowances to auctioning and distribute the rest free of charge; to address the problem of the relocation of production outside the EU – carbon leakage – by introducing two categories of energy-intensive industries most exposed to that risk; sectors or sub-sectors fulfilling specific criteria of carbon leakage exposure will receive free allowances corresponding to all or part of their emissions; a mandatory earmarking of revenues from the sale of 450 million allowances for an Innovation Fund in order to further extend support for low-carbon innovative technologies; a creation of a Modernisation Fund, which will be worth 2% of ETS allowances; it will promote the renewal of the energy infrastructure and support the reduction of GHG emissions in Member States with low GDP per capita.
* A proposal to review the Energy Efficiency Directive (COM(2016) 761 final), as part of the Energy Union Strategy of 25 February 2015, and under its Clean Energy For All Europeans package (COM(2016) 860 final) of 30 November 2016. The revision is one of the key strategic energy efficiency policy initiatives to contribute to moderation of demand. The proposal includes, amongst other points, a 30% binding target at EU level for reduced energy consumption by 2030 (compared with 2007) to be achieved by national energy efficiency contributions and the notification by MS to the Commission of their contributions by means of 10-year integrated national energy and climate plans proposed as part of the Energy Union Governance.

R&I in energy efficiency in industry is needed to ensure that industry contributes to climate change targets and to further increase the European export competitiveness in a situation where manufacturing companies from across the globe have more and more access to the same energy saving technologies. R&I investments is therefore necessary to further improve our technological leadership and innovation know-how. As a result, it should help European industry companies tap into their existing technical energy saving potential and support the development and commercialisation of future disruptive technologies.

**This document is structured as follows**:

1. Recall of the priorities and targets (Declaration of Intent)
2. Overview of the proposed R&I activities (Note: detailed Activity Fiches in Annex3)
3. Other actions proposed to foster cooperation between SET plan Countries

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# Priorities and targets (recall from declaration of intent)

Starting with the *Issues Paper* drafted by the European Commission in January 2016, stakeholders (list in Annex 1) and SET Plan Countries representatives were consulted to jointly agree on priorities and targets to make the EU industry more energy efficient, which were published in the *Declaration of Intent[[3]](#footnote-3)*, endorsed by the SET Plan Steering Group in April 2016.

To maximise impact of R&I, there is a need to prioritise sector-specific technologies with the highest potential. For that purpose, eight industrial sector groups have been analysed which account for 98% of the industrial final energy consumption in EU28.

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| Sector metrics – only for the purpose of prioritising (sources: [[4]](#footnote-4) [[5]](#footnote-5)) | Final energy consumption  | Economic[[6]](#footnote-6) potential savings by 2030 (payback <=2 year) | Technical[[7]](#footnote-7) potential savings by 2030 | Energy[[8]](#footnote-8) cost/ Value Added | No. of employed | Value added, gross |
| Sector | Mtoe/y | Mtoe/y | Mtoe/y |   | Million | € billion |
| Pulp and paper | 34.3 | 1.1 | 7.2 | 16% | 1.43 | 79.0 |
| Iron and steel | 50.8 | 2.9 | 16.3 | 36% | 0.63 | 39.7 |
| Non-metallic mineral | 34.2 | 1.2 | 7.1 | 23% | 1.29 | 63.9 |
| Chemical and pharma. | 51.5 | 2.6 | 16.5 | 12% | 1.72 | 229.8 |
| Non-ferrous metal | 9.4 | 0.5 | 1.9 | 23% | 0.46 | 23.7 |
| Petroleum refineries | 44.7 | 1.7 | 10.6 | 44% | 0.12 | 24.3 |
| Food and beverage | 28.4 | 1.4 | 6.8 | 10% | 4.53 | 251.4 |
| Machinery | 19.3 | 1.0 | 5.3 | 3% | 9.03 | 579.8 |
| **Total** | **272.5** | **12.4** | **71.7** |  |  |  |

Iron & Steel, Chemical & Pharmaceutical and Petroleum & refineries account for 54% of the final energy consumption and 61% of the technical saving potential. For Iron & Steel and Petroleum & refineries, the cost of energy is a high share of the value added and therefore significantly affects their competitiveness. The sectors with the highest employment and value added are Chemical & Pharmaceutical, Food & Beverage and Machinery, but the last two sectors are not energy intensive.

Based on these criteria, it was proposed to focus the EU's sector-specific R&I efforts on cooperating on three sectors, which have the greatest potential for energy savings and enhanced competitiveness: Iron & Steel, Chemicals & Pharmaceuticals and Petroleum refineries. However, after consultation of the relevant stakeholders, it appeared that the Petroleum Refineries sector would mostly benefit from the cross-cutting technologies and that R&I on sector specific technologies for Petroleum Refineries should not be prioritised at this stage. Therefore, it was decided to focus on two sectors: Iron & Steel and Chemicals & Pharmaceuticals.

The aim of the prioritisation is to be more focussed and so identify and implement concrete and coordinated actions. Activities in other sectors are not excluded and, if a number of stakeholders and/or Member States want to cooperate on specific actions, they are invited to make proposals for concrete actions. The other sectors will also benefit from actions addressing the cross-cutting technologies.

For the two identified sectors, we have classified their sector specific technologies according to their maturity and economic viability:

1. the existing technologies which have been demonstrated but are not (yet) economically viable, i.e. with payback period longer than 3 years[[9]](#footnote-9)
2. the emerging technologies, which still need to be validated in pilot or demonstration plants

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| **Priorities[[10]](#footnote-10) 1 and 2** | **R&I Targets** | **Indicators** |
| 1. Sector specific R&I: Increasing the energy efficiency of our most energy consuming industries by **increasing the cost effectiveness of not yet economically viable technologies** (TRL>=7) through technological development, while striving to reduce GHG emissions proportionally | By 2030, at least 1/3 of the technical potential energy savings related to sector-specific technologies, identified for Iron & Steel and Chemical & Pharmaceutical, become economically viable (Payback <= 3 years) | Progress of the cost effectiveness of the identified technologies; cumulated energy saving potential of technologies reaching economic viability.Two sets of Assumptions:* Fixed energy prices & production volume
* Actual energy prices & production volume
 |
| 2. Sector specific R&I: Increasing the energy efficiency of our most energy consuming industries by **progressing emerging technologies** (TRL 4 to 6), while striving to reduce GHG emissions proportionally | By 2030, 1/3 of the currently promising emerging technologies are successfully demonstrated at large scale (TRL>=8) | R&I Maturity progress (lab, pilot, large scale demonstration) |

Target1: Considering the breadth and the specificities of possible actions and technologies in the chemical sector, it is unlikely that the set target can be met through the limited number of actions under the SET Plan only, or even that the baseline could be exhaustively defined. The target could be redefined as: number of actions aiming at reducing the cost effectiveness of existing technologies.

Target2: Similarly to target1, target2 could be redefined as: number of actions aiming at progressing technologies from TRL 4-5 to 8.

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| **Priorities 3 to 5** | **R&I Targets (baseline 2015)** | **Indicators** |
| 3.Cross-cutting R&I: maximising the **recovery of industrial excess heat/cold** in a cost efficient manner | By 2025, develop and demonstrate (to TRL 8) cost effective excess heat/cold recovery solutions (e.g. heat exchangers, upgrade to higher temperature, storage, distribution, heat-to-power, heat-to-cold, power-to-heat) | Evolution of solutions maturity (TRL), of their cost effectiveness and energy efficiency performance with reference to Best Available Techniques (BAT) (Industrial Emissions Directive) |
| 4. Cross-cutting R&I: maximisingthe energy efficiency of cross-sector **industrial components** in a cost efficient manner | By 2025, develop and demonstrate (to TRL 8) industrial components whose losses are reduced by 15% (e.g. boilers, dryers, pumps, compressors, fans, conveyors … all of which systems typically contain motors and drives) | Evolution of solutions maturity (TRL), of their cost effectiveness and energy efficiency performance with reference to BAT /Progress of minimum energy performance standards |
| 5.Cross-cutting R&I: Improving **system integration, optimal design, intelligent and flexible operation, including industrial symbiosis,** to increase energy and resource efficiency while striving to reduce GHG emissions  | By 2025, develop and demonstrate solutions enabling small and large, industries to reduce their energy consumption by 20% while striving to reduce GHG emissions proportionally | % of specific energy savings (J/unit of product or J/goods produced in industrial park) achieved by at least 10 projects in at least 5 industrial sectors |

# Overview of the proposed activities

Following the endorsement of the Declaration of Intent, the Temporary Working Group for Action 6 (WG6) was setup. Twenty Countries have joined the WG6, Finland taking up the chairmanship. Stakeholders are represented by the European Associations of the relevant industry sectors, research association and education; the A.SPIRE association is co-chair of WG6. The composition of the WG6 can be found in Annex 1.

Both Countries and stakeholders were asked to propose activities contributing to the priorities of the Declaration of Intent. Countries also shared their R&I programmes related to the priorities. A first “long list” of activities was selected. The “activity leader” (or sponsor) of each activity then developed the activity fiche. The WG6 reviewed the activity fiches and down-selected the final “short list” of activities.

The table below presents the final list of activities and, for each one, the Countries that expressed support to it (some Countries have not yet expressed their support and are invited to do so). It is clear that the support by a Country does not mean a commitment to finance the activities. Each Country has its own R&I projects selection procedure, in most cases based on bottom-up R&I approach, where calls for proposals are open and not limited to specific technologies or sectors.

Steel and Chemical activities address both priorities 1 and 2, as future projects in these areas will tackle both the cost effectiveness of existing technologies (1) and the demonstration of emerging technologies (2). For sake of simplicity, the activities are labelled 1A.x for steel, 1B.x for the chemical sector.

Four out of five priorities are covered by activities. Only the 4th priority “Components” is not covered. The European association Orgalime priority is more on fostering the deployment of already optimised components, rather than their further improvement. Neverthless, it is partly covered by the development of some components in the 3rd priority on Heat/Cold recovery.

The TRL ranges of the activities are quite diverse. Generally starting from medium TRL (4-6), they target high (5-7) or very high (8-9) TRL at completion. As an example of very high TRL, the Activity 1A.1b: “HYBRIT - HYdrogen BReakthrough Ironmaking Technology”: first-of–a-kind full-scale demonstration of steel making plant, using H2 instead of Coal to reduce iron ore.

Some activities are very concrete and partnership well defined (e.g. 1A.1b HYBRIT). Other activities are concrete but the partnership is not defined (e.g. Heat recovery/upgrade fiche 3.2). Other fiches are more generic and partnership is not defined (e.g. Chemical fiche 1B.2 on separation technologies, with several options).

In Action6, covering a very wide range of sectors and products, it is not surprising to see a great variety of Activity proposals: concrete for sectors (e.g. steel) where there are a few big companies; more open for sectors with a lot of small companies (e.g. chemical).

It makes sense that European associations of industrial sectors are not mandated by their members to make the selection which specific project/partner is to be put forward in SET Plan Fiche. It seems reasonable not to push these associations further at this stage.

Nevertheless, even these more generic Fiches are valuable in describing what is needed to contribute to the priorities identified in the Declaration of Intent. And so: stir the R&I strategy in the Countries, foster cooperation and identify projects in later stages of implementation.

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| Priority | Activity | **Selection Status** | **Tot** | AT | BE | CH | CY | CZ | DE | ES | FI | FR | IE | IT | LV | NL | NO | PL | PT | SE | SK | TR | UK |
| 1A-STEEL | 1a-H2-Reduction | Y | **6** | Y |   |   |   |   | Y |   | Y | Y |   |   |   | Y |   |   |   | Y |   |   |   |
| 1A-STEEL | 1b-H2-HYBRIT | annex of 1a |  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1A-STEEL | 1c-H2-SALCOS | annex of 1a |  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1A-STEEL | 2-HISARNA smelting reduction | Y | **4** | Y |   |   |   |   |   |   | Y | Y |   |   |   | Y |   |   |   |   |   |   |   |
| 1A-STEEL | 3-TGR-BF2-Plasma torch | Y | **5** | Y | Y |   |   |   |   |   | Y | Y |   |   |   |   |   |   |   | Y |   |   |   |
| 1B-CHEM | 1b Process (re)design and optim. – intensification | Y | **8** | Y |   | Y |   |   | Y | Y | Y | Y |   |   |   |   |   |   |   | Y |   | Y |   |
| 1B-CHEM | 2 Separation technologies | Y | **7** | Y | Y | Y |   |   | Y | Y |   | Y |   |   |   | Y |   |   |   |   |   |   |   |
| 1B-CHEM | 3 Power to chemicals -Electrification | Y | **9** | Y | Y | Y |   |   | Y | Y | Y |   |   |   |   | Y |   |   |   | Y |   | Y |   |
| 3-HEAT | 3.1 New techs waste heat recov. | Y | **14** | Y | Y | Y |   |   | Y | Y | Y | Y |   | Y |   | Y | Y |   | Y | Y | Y | Y |   |
| 3-HEAT | 3.2 Heat upgrade  | Y | **12** | Y | Y | Y |   |   | Y | Y | Y | Y |   | Y |   | Y | Y |   | Y |   |   | Y |   |
| 3-HEAT | 3.3 Heat-to-Power | Y | **11** | Y | Y |   |   |   | Y | Y | Y | Y |   | Y |   |   | Y |   | Y |   | Y | Y |   |
| 3-HEAT | 3.4 Polygeneration-hybrid plants  | Y | **12** | Y | Y | Y |   |   | Y | Y | Y | Y |   | Y |   | Y | Y |   | Y |   |   | Y |   |
| 4-COMPO | 4.1 Flow driving - None | None | **0** |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 4-COMPO | 4.2 Materials - None | None | **0** |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 5-SYST | 5.1a-Industrial Symbiosis | Y | **13** | Y | Y | Y |   |   | Y | Y | Y | Y |   |   |   | Y | Y | Y | Y | Y | Y |   |   |
| 5-SYST | 5.1b-Non conventional energy sources | Y | **11** | Y | Y | Y |   |   | Y | Y | Y |   |   |   |   | Y | Y | Y | Y |   | Y |   |   |
| 5-SYST | 5.1c-Steel mill gas fermentation | moved to Action9-CCSU | **1** |   | Y |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 5-SYST | 5.2-Integration IT systems | Y | **13** | Y |   |  Y |   |   | Y | Y | Y | Y |   | Y |   | Y |   | Y | Y | Y | Y | Y |   |
| 5-SYST | 5.3-Improving energy culture- disseminate Business Models | Y | **10** | Y | Y | Y |   |   | Y | Y |   |   |   | Y |   | Y | Y | Y |   | Y |   |   |   |

Table 2.a: List of activities and Countries’ support

## Steel and Iron sector

There are two main routes for producing steel depending on the raw material: the integrated route reduces the iron ore into steel using coal as reductant in blast furnaces (BF); whereas the recycling route, based on the electric arc furnace (EAF) recycles and melts the scrap steel. Both routes are based on processes that are already well optimised thermodynamically and second one is already highly electrified.

Therefore, the focus of the three activities proposed is on the integrated route, with the aim of increasing energy efficiency, but also of reducing CO2 emissions and maintaining competitiveness in the frame of ETS reform that will reduce the amount of free CO2 emission allowances in the future.

* *1A.1 CO2 emission avoidance through direct reduction of iron ore using hydrogen*

CO2 emissions can be avoided by replacing carbon (coal and coke) by hydrogen to reduce the iron ore. The hydrogen would be produced by electrolysis, allowing the use of electricity from renewable sources.

The activity consists of three parts. Fiche 1A.1a describes all ongoing projects that contribute to the hydrogen reduction, including electrolyser projects and feasibility studies (HYBRIT-PFS and MACOR) for future projects of full scale integration in steel plants (HYBRIT and SALCOS respectively). Fiches 1A.1b (HYBRIT) and 1A.1c (SALCOS) address the potential future full scale integration projects.

Altogether, the three parts have a potential for cooperation between several projects in several Countries, to tackle the environmental, regulatory, economic and social challenges of the steel industry at European level. The full scale demonstration (~€1bn) will require a financing mix, possibly including private/public equity/loans/grants, specific to these first-of-a-kind demonstrations.

* *1A.2 Hisarna smelting reduction process for lowering energy consumption and CO2 emissions of steel production*

HIsarna is a Smelting Reduction process concept, in which the main savings come from handling raw materials directly without the need for agglomeration or coking. This concept incorporates a cyclone for heating and melting iron ore and a bath smelter. It is being tested with higher steel scrap additions that results in lower specific energy consumption and lower CO2 emissions. It is also designed to produce CO2-rich off-gas, by using pure oxygen rather than enriched air, making end-of-pipe carbon capture easier.

As a continuation of ongoing EU and national projects, the proposed R&I Activity will on the one hand further progress the pilot-plant research following completion of this fifth campaign and, on the other hand, focus on design, impact and financial aspects of a scaled-up demonstration plant. The Activity is an essential step in the development chain to bring the technology toward TRL>=8.

Budget: €35m; financing: mix of private/public funding

* *1A.3 Top Gas Recycling – Blast Furnace (TGR-BF) using plasma torch*

This TGR-BF technique will recover all CO + H2 in the top gas of the blast furnace, for re-injection in the furnace. This will increase the Carbon-efficiency in the furnace by 80%, reduce specific energy consumption and CO2 emissions.

The TGR-BF project consists of several phases including the design of a plasma torch for steel mill gas conversion, the design of a novel tuyere allowing to inject coal, oxygen and steel mill gas into the blast furnace, the engineering and construction of all this equipment on one European blast furnace.

Budget: € 16m + 79m + 400m; financing: mix of private/public national/European equity/loans/grants

The detailed description of the activities is given in the Activity Fiches in Annex 3.

## Chemical and Pharmaceutical sector

Three main areas of R&I activities have been identified, as necessary to be pursued in order to achieve the targets set for the chemical/pharma sector. They address both priorities 1 and 2 (labelled 1B, 2B for the chemical/pharma sector), as future projects in these areas will tackle both the cost effectiveness of existing technologies (1B) and the demonstration of emerging technologies (2B). For sake of simplicity, the activities are labelled 1B.x:

* *1B.1 Process (re-)design, and optimisation: intensification and modular approach*

Achieving more flexible modular and standardised chemical production capacity within Europe will enable accelerated innovation towards a wider portfolio of end products due to its flexible and multipurpose operational modes.

More robust and tolerant production systems are also required to adapt to potential feedstock specification variations in a more circular economy approach.

New catalyst development can provide major opportunities for resource and energy efficiency as chemical reactions can be achieved at optimal conditions with significantly less side reactions creating fewer by-products, and using less auxiliary materials

* *1B.2 Separation technologies*

Separation technologies are essential in chemical processes for the purification of the products, recycling of solvents or catalysts, further valorisation of by-products or gaseous effluents, removal of harmful substances etc. Most mature separation technologies are energy intensive, and separation operations can represent up to 50% of energy consumption in chemical plants. Therefore intensified separation technologies and their control technologies have to complement higher selectivity of the reactions

* *1B.3 Power to-X & unconventional energy sources*

Energy supply in the chemical industry is mostly based on fossil resources. Access to cost competitive renewable electricity can be an opportunity for the chemical industry to reduce its carbon footprint. The development of advanced electricity based process technologies have to be developed for optimal utilization of low carbon electricity in the chemical industry;

The direct utilisation of electricity for electrochemistry and use of unconventional energy sources (e.g. microwaves, ultrasound, plasma) in particular, will bring significant efficiency gains in existing chemical processes and can also be used for the production of functional products which are difficult to obtain using conventional processes.

Activities under those 3 areas are expected to start at TRL 4-5 and to reach TRL 8 within 3 to 5 years. Concrete projects, financing sources, and partnerships are not defined at this stage and this makes sense for the Chemical/Pharmaceutical sector. Indeed, there is a large variety of products and companies in most Countries and it is not the role of European Industry Associations, neither of the WG6 representatives, to make the selection of specific projects.

In low/medium TRL development phases, the projects can be co-financed via public grants (national and/or European) and private funds. In the high TRL range, private/public loans, state aids and European funds can come in complement (more details on financing in Annex 2). As those areas are also addressed under the Horizon 2020 SPIRE cPPP work programme 2018-20, as the result of cooperation between Action 6 and the Horizon 2020 Industrial Leadership's NMPB programme , additional actions to be decided by the WG should be complementary to those undertaken under SPIRE.

The detailed description of the activities is given in the Activity Fiches in Annex 3.

## Heat/cold recovery

Heat and cold recovery technologies are instrumental for intra-plant optimisation and inter-plant integration to enable cascade use of heat (or cold) between cross-sectoral plants in industrial parks, and with district heating/cooling networks. A mapping of the industrial excess/surplus heat and cold while considering the proximity to users such as other industrial sites, district heating and cooling networks in EU would contribute to better prioritise R&I programme.

* *3.1 New technologies for utilization of high temperature waste heat in industrial systems, from the heat production to the delivery and end use*

Design, build and test more sustainable processes/components (these should be different to the ones covered by Activities 3.2, 3.3 and 3.4) by developing the necessary knowledge and technology to propose new techniques and integrating energy recovery, storage and utilisation.

Demonstrate new processes on pilot industrial scale for validation of solutions to improve the environment impact using the new waste heat recovery approach

Map the waste heat sources (inventory) in energy-intensive industrial sectors, understand the quality and quantity of the waste heat available and perform technical / financial feasibility studies of the different possibilities for heat usage

* *3.2 Heat pumps and refrigeration converting low grade heat or cool into higher grade heat or cool*

Heat pumps converting low grade heat (typically 50°C-120°C) into higher grade heat (up to 200/250°C) and refrigeration cycles converting low grade cooling into higher grade cooling. Development of pilot and demonstrate innovative heat pump or refrigeration concepts to make cost effective use of waste heat or cool at highest efficiencies by using advanced thermal cycles or unique concepts. Demonstrator (1MWt) of the heat extraction system coupled to an existing plant.

The activity will progress the TRL from 4 up to TRL8. Budget €4m, private/public funding

* *3.3 Heat-to-Power (electrical) recovery (low and high temperature)*

*3.3a: Low temperature waste heat recovery as usable power using advanced heat cycles.* Screening of concepts using Organic Rankine Cycle (ORC), thermo electric, magneto caloric, Stirling… Down-selection and development of two concepts and demonstration (1MWe) of one heat extraction system coupled to an existing plant. TRL: from 1-4 up to 9. Budget: €16m, mix of private/public funding.

*3.3.b: High temperature waste heat recovery using the supercritical-CO2 cycle to generate electrical power*: The use of s-CO2 technology (largely studied for nuclear and solar applications) for waste heat recovery requires development of turbomachinery, heat exchangers and bottoming cycle components. The budget for the project (including engineering, construction and commissioning, from TRL4 up to 9) amounts to €40m; mix of private/public funding.

* *3.4 Polygeneration (heat, cold, electrical power) and hybrid plants*

*3.4a: Hybrid plants for waste heat recovery integrating renewable energy into industrial plants and processes.* Development of hybrid plant integrating renewable energy into industrial plants and processes reducing the reliance from external energy. Demonstration of the technology in a relevant environment increasing the TRL level from 4 towards more effective applications (TRL 9). Budget €20m, mix of private and public funding.

*3.4b: Advanced compact CHP plants of industry scale.* Further development of advanced compact CHP- plants of industry scale for generation of electricity, steam and heat (i.e. polygeneration) for industrial application with fuel conversion ratios > 90%. Special requirements are operational and fuel flexibilities including low calorific gases. TRL starting at 3-5 and finishing at 5-7. Budget €10m, mix of private and public funding.

The detailed description of the activities is given in the Activity Fiches in Annex 3.

## Components

No activity on components (other than heat recovery components) was identified by the WG.

## System Integration

Four main areas of cross-cutting R&I activities have been identified as having large potential for energy saving due to their applicability in several sectors.

* *5.1a Industrial symbiosis between industries to valorise energy losses streams and better manage energy globally*

Industrial symbiosis initiatives which involve the exchange of material and/ or energy flows between two or more production sites or sectors can help saving energy and material, hence improve carbon, energy and resource efficiencies. Building real industrial symbiosis is however a complex topic, not only from the technological standpoint, but also from the operational standpoint: in order to be materially possible, safe, and cost effective for all partners, and for society as a whole, the energy and material transfer between different industrial units will require a very good coordination regarding, e.g. production cycles, management of unexpected stoppages, etc.

Actions, which should build on a number of existing SPIRE EU Research Projects and National initiatives, should target: (i) identification of an appropriate quantification methodology for industry symbiosis, to enable price setting of interchanged commodities; (ii) identifying, assessing and testing possibilities of symbiosis between different industries or plants inside large industrial units, and the development of enabling tools to these aims. Cross-borders industrial clusters would benefit particularly from the European added-value of Action 6. A two-stage approach is recommended, with a first stage targeting TRL 4 to 6 within a timeframe of about 5 years, followed - for successful actions - by a second stage targeting scale-up, validation and demonstration (TRL 7-8, 5 years). Demo scale activities are essential for showcasing as a reference for a large number of industrial locations across the EU.

* *5.1b Non-conventional energy sources in the process industry*

Energy coming from renewable sources challenges the process industries as there is a paradigm shift from the requirements on the demand side governing the energy usage to the coming necessary flexibility of the production processes to adapt to the available supply. In more general terms, the challenge for the production processes is to react to highly fluctuating energy supply.

The development of prediction tools for the demand side, combined with matching and optimising algorithms, as a tool for intelligent support for decision processes, together with the establishment of platforms for data collection and processing, would support the balancing of energy flows in industrial plants and the collaborative management of energy intensive plants in an industrial symbiosis concept.

Actions may also cover research on changes/improvements in processes, equipment, and unit operations that can be driven completely or in a major part by sustainable electricity. Processes powered by non-conventional energy sources may be particularly suitable in this respect but further research and upscaling work is necessary to demonstrate their potential and to be deployed on an industrial scale.

A number of actions may be envisaged, addressing different TRL level, depending on the technologies and the targeted sectors.

* *5.2 Digitisation: Further integration in process and plant management including plant/process design phase and processing plant retrofit*

Significant steps toward higher energy efficiency will be driven by digital technologies and process automation, providing new ways to improve flexibility in plants, optimise consumption and reduce GHG emissions.

Enriched process understanding and evaluation of the impact of each decision from early process/plant design phase to production management is essential. In particular, bringing appropriate sustainability assessment at lower TRLs (starting ~TRL 4) of the process/product development where it can make a larger impact woud be very beneficial. A major breakthrough would be the availability of a software platform(s) for sustainable digital engineering with simulation capabilities along the whole life-cycle of a plant specifically in early design phases of processes and plants. Such a platform integrating sustainability assessment along the whole life cycle of a plant, would support optimal product and process design, plant engineering, procurement, plant construction, commissioning, possible operation modifications, as well as plant flexibility, extensions and reuse for next generation and new products. Such platform(s) could be the target of specific action and could be built on recently closed projects such as SAMT and STYLE. (to mention in the fiche)

The development of cognitive equipment and plants retrieving information from sensors for continuous and batch-processes (on-line monitoring and big data analytics) are key to optimize production operations. Advanced data analytics would allow companies to convert various type of data (from R&I, engineering, production, asset management, marketing, sales, other production site, etc.) into knowledge in real-time, and effectively contribute to more sustainable manufacturing processes with more resource and energy efficiency on production sites and potentially between industrial sites.

A number of actions targeting TRL 4 to 8 could be considered, within a timeframe of 5 years.

Activities under these 3 areas are expected to start at TRL 4-5 and to reach TRL 8 within 5 to 10 years. Concrete projects, financing sources, and partnerships are not defined at this stage. The target agreed in the DoI is industrial demonstration achieved in at least 10 projects, in at least 5 industrial sectors.

Those areas are also addressed under the Horizon 2020 SPIRE cPPP work programme 2018-20, as the result of cooperation between Action 6 and the Horizon 2020 Industrial Leadership's NMPB programme, which can already be considered as an achievement of the SET Plan Action6 Working Group. Therefore, additional actions to be proposed decided by the WG should be complementary to those undertaken under SPIRE.

* *5.3 Improving exchange of technological, economic, behavioural and social knowledge; training, capacity building and dissemination*

This activity aims at increasing cooperation between academia, industry, authorities, research institutions, communities in order to adopt an industrial symbiosis approach opened also outside industrial plant perimeters (e.g. buildings, district heating/cooling networks, etc), along the following two strands:

* 1. Mapping the methodological approaches and tools (covering diagnosis, evaluation and optimisation of energy efficiency of systems and processes) available in academia, research organisations, as well as best practices and business models experienced in pilot plants from industry. The objectives are: to reinforce technology networks in order to utilise resources and transform them to useful products and energy services; to contribute to the development of innovative business models along the value chain; and to disseminate these tools/models and so facilitate the implementation of energy and resource optimisation and industrial symbiosis.
	2. Improve the level of awareness and overall ‘energy culture’ of industrial companies and SMEs. This includes: providing exchange of knowledge between universities, research organisations and industry, including training to industry on how to best use methodological approaches and tools; providing training and capacity building programmes to industry staff at all levels.

TRL at start: 5 (Methods, technologies and pilot plants are already available); TRL at the end: 7 (The tools, methods are utilised in industry). Concerning training and capacity building activities, the TRL at the end would be level 9. Total budget required: between EUR 1 and 2 million per project/deliverable

The detailed description of the activities is given in the Activity Fiches in Annex 3.

# Other actions proposed to foster cooperation between Countries

All Countries have national research programmes that are open to international cooperation. In most cases, the Berlin model applies whereby each Country funds its own national partners (without European top-up funding). In a few Countries and under specific conditions, even the foreign partners of national projects can receive national programme funding.

A database of national and European projects in the field of energy efficiency in industry was setup. It is based on the SETIS database and complemented with the inputs received from the Countries within WG6, with filtering possibilities on WG6-priorities/areas, on Countries, on start/end dates. The SETIS database has nevertheless not been updated recently (the most recent projects in the DB started on 01/01/2014) and its content is limited to projects subject (at best abstract).

Therefore, the idea of more interpersonal exchange in the form of Workshops on Cooperation, where Ministries or Funding Agencies would meet, present their projects portfolios and discuss together opportunities and forms of cooperation (bilateral or multi-lateral, ex-post cooperation of running projects, new projects with European added-value, etc). The workshop could be organised in the frame of existing conference or back-to-back. Several sessions would focus on the priorities of the Action6. Concrete cooperation experiences could also be shared.

This idea of Workshops on Cooperation received a support from the following Countries: AT, BE, CH, DE, ES, FI, IT, NO, PT, SE, SK, TR. With these 12 positive responses, a critical mass is already reached and justifies organising “Cooperation Workshops between Countries”, subject to WG6 approval. The countries which have not yet responded are kindly invited to do so (no negative response was received so far).

# Annexe 1: Stakeholders and Countries involved in the process

## Stakeholders consulted for defining the Declaration of intent

The Declaration of Intent agreement follows consultations with:

* BUSINESSEUROPE (European National Business Federations) [[11]](#footnote-11)
* CEFIC (European Chemical Industry Council)
* CEMEP (European Committee of Manufacturers of Electrical Machines and Power Electronics)
* COGEN Europe (European Association for the Promotion of Cogeneration)
* CONCAWE (European Petroleum Refiners Association)[[12]](#footnote-12)
* EEIP (Energy Efficiency in Industrial Processes)
* EERA (European Energy Research Alliance)
* EUA – European University Association
* Eurofer (European Confederation of Iron and Steel Industries)
* Euroheat & Power (District Heating & Cooling and Combined Heat & Power Association)
* Orgalime (Mechanical, Electrical & Electronic, Metalworking & Metal articles industries) [[13]](#footnote-13)
* SPIRE (Sustainable Process Industry through Resource and Energy Efficiency)

## Composition of the Temporary Working Group 6

SET Plan Countries

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| --- | --- | --- | --- |
| AT | DE | IT | PT |
| BE | ES | LV | SE |
| CH | **FI Chair** | NL | SK |
| CY | FR | NO | TR |
| CZ | IE | PL | UK |

Stakeholders

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| --- | --- |
| A.SPIRE / Co-Chair | Association - Sustainable Process Industry through Resource and Energy Efficiency |
| CEFIC | European Chemical Industry Council |
| Eurofer | European Confederation of Iron and Steel Industries |
| COGEN Europe | European Association for the Promotion of Cogeneration |
| DHC+ / Euroheat & Power | The Technology Platform and Network for district energy, promoting sustainable heating and cooling in Europe and beyond |
| EGEC | EU Geothermal Energy Council |
| ETN - EU Turbines | European associations representing the turbine sector in Europe |
| FCH | Fuel Cell Hydrogen PPP |
| EERA | European Energy Research Alliance |
| EUA | European University Association |

# Annexe 2: Financing/Funding sources

**Funding controlled by Member States**

Most Countries have R&I programmes, usually limited to TRL level 7.

Higher TRL financial support provided by Member States need to comply with the EU's State aid rules. Relevant documents are two Commission Communications: 1. Framework for State aid for research and development and innovation[[14]](#footnote-14), which limits aid intensity for applied research undertaken by large enterprises to 60% (or 70% in case of cross-border cooperation or cooperation with an SME or a research organisation); 2. Guidelines on State aid for environmental protection and energy 2014-2020[[15]](#footnote-15) which in the case of CCS, energy infrastructure, district heating infrastructure and aid in the form of tradable permits allows for a higher aid intensity (up to 100%).

Important Projects of Common European Interest (IPCEI) are transnational projects of strategic significance for the EU. In 2014 the European Commission adopted specific State aid guidelines for IPCEIs[[16]](#footnote-16) allowing Member States to provide financial support to such projects undertaken by industry beyond what is usually possible for R&D and innovation projects. For example, public funding may also support the first industrial deployment of the results of an R&D project and may cover a higher percentage of the funding gap. An example is the IPCEI on High Performance Computing (HPC) and Big Data Enabled Applications launched in January 2016 by Luxembourg, France, Italy and Spain[[17]](#footnote-17).

Within European Structural and Investment Funds (ESIF), the relevant fund is the European Regional Development Fund (ERDF). However, the ERDF Regulation stipulates prohibits supporting investments to achieve greenhouse gas reductions from activities covered by the ETS. R&I activities can nevertheless be supported if they are included in the Smart Specialisation Strategy of the respective Member States or region[[18]](#footnote-18). This is a bottom-up process, hence the initiative would need to come from the Member State.

**Funding by European Investment Bank (EIB)**

The European Fund for Strategic Investment[[19]](#footnote-19) (EFSI) ("Juncker Plan") can be relevant in case projects expect to have a business case / achieve a Return on Investment (possible with complementary funding by grants) and the main hurdle is the reluctance of banks to provide loans to inherently risky innovation projects.

A key objective of EFSI is to leverage additional private funding, hence EFSI may be most appropriate for R&I activities rather close to the market.

**EU grant programmes**

Currently available EU grants are limited to Horizon 2020 and the Research Fund for Coal and Steel (RFCS[[20]](#footnote-20)), which, however, are not aimed at TRL higher than level 7.

The Innovation Fund (IF) was proposed by the Commission as part of a reformed Emission Trading System (ETS). Current planning is to adopt a Delegated Regulation setting the Fund's detailed rules in the first half of 2018 with the Fund being operational in 2020. Before 2021 (and conditional to the new ETS Directive being adopted) available funding are the proceeds from 50 million ETS allowances from the Market Stability Reserve and the leftovers from NER300 (up to EUR 1 billion). For the period from 2021 to 2030, proceeds from an additional 400 million (Commission proposal) or 600 million (European Parliament amendment) ETS allowances would be available.

The Commission proposal for a new ETS Directive defines the scope of the Innovation Fund rather broadly: demonstration projects in the areas CCS, innovative renewable energy technologies and low-carbon technologies and processes in industrial sectors covered by the ETS. The Innovation Fund could cover a maximum of 60% of the costs of projects.

# Annexe 3: Activity Fiches

## Steel Activity Fiches 1A.x

Activity 1A.1a-Iron ore reduction using Hydrogen

Activity 1A.1b-Iron ore reduction using Hydrogen – HYBRIT

Activity 1A.1c-Iron ore reduction using Hydrogen – SALCOS

Activity 1A.2 HIsarna smelting reduction process for lowering energy consumption and CO2 emissions of steel production

Activity 1A.3 Top Gas Recycling – Blast Furnace (TGR-BF) using plasma torch

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 "Make EU industry less energy intensive and more competitive"

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 1A-2A Steel sector |

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| **Activity number**: 1A.1a H2 Direct Reduction |
| **Title:** CO2 avoidance through hydrogen direct reduced Iron (CDA...Carbon Direct Avoidance) |
| **Targets:** Technology Roll-Out of Iron Ore Reduction with essentially hydrogen | **Monitoring mechanism**: CO2-Mitigation monitoring in ETS |
| **Description:** The classical way of iron ore reduction in Europe as part of the steel production is carbon based because of the use of coke and coal in the blast furnaces. The new technology of iron ore reduction with essentially hydrogen thus can minimize CO2 emissions significantly. Today the technology of iron ore reduction by hydrogen is economically hardly feasible in Europe (OPEX). The main challenge in this context is the economic production of renewable hydrogen via renewable electricity. All future activities in this direction would additionally cause considerable investments (CAPEX) to the steel industry.  |
| **Impact:** **- Primary energy saving potential in percentage and in ktoe/a:** energy consumption to be discussed**- GHG emission saving potential in percentage and in ktCO2eq/a:** up to 80 % / up to 150 m t CO2 / a |
| **TRL:** Technical Readiness Level for Europe: 6-7, Technical Readiness Level target: 8 |
| **Total budget required:** appr. 50 m € for R&D activities |
| **Expected deliverables** | **Timeline** |
|  | *2025+* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| **HYBRIT** - HYdrogen Breakthrough Ironmaking Technologies, SE**H2Future** – big scale electrolyser for H2 production to be used in direct reduction of iron ore –demonstrator in AT***SuSteel*****GrInHy** – Green Industrial Hydrogen via Reversible High-Temp Electrolysis (HTE) – running FCH project in Salzgitter, DE**MACOR** –Feasibility study of **SALCOS** (Salzgitter low CO2 steelmaking), Salzgitter, DE | Technology Roadmap for Iron Ore reduction with HydrogenDemonstration of iron or reduction by Hydrogen from one big scale ElectrolyserHydrogen plasma based Iron ore reduction Implementation of a reversible HTE Electrolyser in an integrated steel millFeasibility study of the SALCOS project (the incorporation of a direct reduction plant in an existing operating integrated steel plant) | Start 20162017-2020?2016-20192017-2019 | SwedenEUAustriaEUGermany | 8 m €€12 m €*2.6 m€*4.5 m €~2 m € |
| **Gaps**: The stabile operation of direct reduction technology with increased, fluctuating renewable hydrogen feed is yet to be developed as well as the incorporation of such a technology in an existing operating integrated steel plant. Today the technology of iron ore reduction by hydrogen is economically hardly feasible in Europe (OPEX). The main challenge in this context is the economic production of renewable hydrogen via renewable electricity. All future activities in this direction would additionally cause considerable investments (CAPEX) to the steel industry.. |

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 1A-2A Steel sector |

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| **Activity number**: 1A.1b HYBRIT  |
| **Title:** HYBRIT – Hydrogen Breakthrough Ironmaking Technology |
| **Targets:** The aim is to drastically reduce carbon dioxide emissions from ironmaking by eliminating the need to use fossil fuel for iron ore reduction. The idea is to replace the blast furnace with an alternative process, using hydrogen produced from “clean” electricity. This means that the by-product from iron ore reduction would be **water** instead of carbon dioxide. | **Monitoring mechanism**: the project is currently at the prefeasibility study phase, which is planned to be followed by a feasibility study on pilot plant scale and later on converting one of SSAB’s blast furnace based sites to the HYBRIT-set up on a demonstration scale. |
| **Description:** The HYBRIT project focuses on the feasibility of converting the blast furnace based production sites under Swedish conditions to a CO2-free ironmaking process using hydrogen for iron ore reduction. Hydrogen is produced from clean electricity. The project explores the overall feasibility as well as specific technology areas such as electricity system analysis, mass scale production-, handling and storage of hydrogen, tailor-made DRI-pellets for hydrogen based reduction as well as usage of such DRI in electric arc furnace based steelmaking process for production of advanced high strength steel products. Transitional pathways as well as the role of policies and communication aspects are key areas to be addressed in the project. |
| **Impact:** **-** By eliminating the root cause of CO2-emission in steelmaking process, i.e. by replacing carbon used for iron ore reduction by hydrogen produced from clean electricity, if proven feasible, can solve the steel industry’s emission problem. For a country like Sweden this would eliminate about 10% of its total CO2 emissions- Sweden has a unique condition with already close to emission free electricity system with surplus capacity already today, with huge potential of further growth in renewable energy- The outcome of this project can be a good example and catalyse the transition of the iron and steel industry in co-evolution with the energy system in other countries |
| **TRL:** 4-7 |
| **Total budget required:** €1-2 billion |
| **Expected deliverables** | **Timeline** |
| Pre-feasibility study (ongoing)Feasibility study – pilot plant trialsDemonstration plant trials | Project Month: 18 (Jul 2016 – Dec 2017)Project Month: 72 (2018-2024)Project Month: 132 (2025-2035) |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| The HYBRIT project is a joint initiative by SSAB, LKAB and Vattenfall. Universities and research institutions as well as other relevant industrial partners with expertise in specific areas are engaged in the project:* Feasibility study – pilot plant trials
* Demonstration plant trials
 |  | 1-2 bn € |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| HYBRIT PFS: The pre-feasibility study project | The HYBRIT project is a joint initiative by SSAB, LKAB and Vattenfall. Universities and research institutions as well as other relevant industrial partners with expertise in specific areas are engaged in the project.  | Jul 2016-Dec 2017 | Sweden: SSAB/LKAB/VattenfallSwedish Energy Agency support accounts for 50% of the total budget | 1.5 M€ |
| **Gaps**: * Policies securing the steel industries capability of survival and possibility to invest in this breakthrough technology
* Financial support in the form of grants and low interest loans to enable the development of this breakthrough technology as well as the transition from current technology
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| Implementation Plan – Activity Fiche  |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 1A-2A Steel sector |

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| **Activity number**: 1A.1c SALCOS (CDA) |
| **Title:** CO2 direct avoidance (CDA) through hydrogen enhanced, natural gas based direct reduction combined with electric steelmaking in integrated steelworks |
| **Targets:** Technology Roll-Out “Incremental electrification of primary steelmaking” | **Monitoring mechanism**: CO2-Mitigation monitoring in ETS |
| **Description:** Salzgitter AG and Fraunhofer Gesellschaft have embarked on project SALCOS (Salzgitter Low CO2 Steelmaking) in 2015, aimed at stepwise transformation of carbon based into hydrogen and electric power based steelmaking, with all measures planned to be realized at the location and in the framework of our existing integrated steelworks facility in Salzgitter, Germany.If feasible especially in terms of economical aspects and political framework, the steps could be tailor-made to the respective future EU CO2 emission reduction targets. The first step on this pioneering path would be the implementation of natural gas based direct reduction (DR) technology as a substitute for respective blast furnace capacity, additionally offering the potential of integrating significant, variable shares of (renewable) power via hydrogen produced by water electrolysis. Long-term steps might include the successive change to electrical steelmaking, flanked by the built-up of further hydrogen optimized direct reduction capacity, until the contemporary blast furnace/basic oxygen route could finally be completely shut down. In principle our concept thus aims at an incremental electrification of steelmaking.As we focus on progressive development of established, proven technology and the challenges of new operational modes - rather than process development from the scratch - we are highly confident in the technical feasibility of our concept. The realization of the first step could start on relatively short notice and on a large, industrial scale – as soon as the relevant political and economic framework will be set.To clearly distinguish concepts based on the direct use of hydrogen in reduction processes - combined with electrical steelmaking - from other CO2 reduction concepts like CCU and CCS we introduced the term CDA (Carbon Direct Avoidance). CDA generally has a lower specific energy demand per ton of CO2 reduction, compared to CCU approaches.However, creating a stable framework to facilitate the economical feasibility of the project will be of paramount importance – but this holds for all CO2 reduction projects: Beside the necessity of public support for the considerable investments, the crucial challenge is to ensure a continuous, internationally competitive supply with “green” electrical power.In the context of the described larger frame, we have already launched the project GrInHy (largest high temperature (HT) electrolyzer industrial installation worldwide) and have been granted public funding for a SALCOS study by the Federal German government. |
| **Impact:** **- Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28):As currently integrated steelmaking is already energetically optimised and operating close to boundaries set by natural laws, the implementation of any CO2 reduction technology will - in this context­ - not lead to a decrease in total energy demand per ton of steel produced, but to an overall increase. What can anyhow be achieved is a decrease in the use of fossil energy, combined with a respective increase in the implementation of renewable energy sources. SALCOS is planned to reduce the needed fossil energy input by maximum 11.05 GJ/t of crude steel (corresponding to 0.263 toe/t of crude steel, assuming that one ton of oil equivalent equals 42 GJ). With 100 Mt/a of steel produced via the integrated route (2015), implementation of SALCOS to the maximum possible scale would result in a fossil energy saving of 26 300 ktoe/a within EU28.**- GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28):SALCOS is planned to reduce CO2 emissions up to ~80 % of the emissions of a typical integrated steelworks; this reduction equals roughly 1.5 tCO2eq/t of steel produced**.**With 100 Mt/a of steel produced via the integrated route, implementation of SALCOS to the maximum possible scale would result in an emission reduction of 150 000 ktCO2eq/a within EU28. |
| **TRL:** Technical Readiness Level for Europe: 6-8, Technical Readiness Level target: 9 |
| **Total budget required for step 1+2:** 1,200 mio. € |
| **Expected deliverables** | **Timeline** |
| SALCOS industrial scale DR and electrolysis implementation (step 1+2); could avoid more than 2 mio. t of CO2 for Salzgitter | *2021 -2030* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| **GrInHy** – Green Industrial Hydrogen via Reversible High-Temp Electrolysis (HTE) – running FCH project in Salzgitter, DE**MACOR** –Feasibility study of **SALCOS** (Salzgitter low CO2 steelmaking), Salzgitter, DE | Implementation of a reversible HTE Electrolyser in an integrated steel millFeasibility study for the SALCOS project | 2016-20192017-2020 | EUGermany | 4.5 mio. €~2 mio. € |
| **Gaps**: The stable operation of natural gas based direct reduction technology with increased, fluctuating (renewable) hydrogen feed is yet to be developed as well as the incorporation of such a technology - optionally to be combined with electric arc furnace steelmaking - in an existing operating integrated steel plant. Today the technology of iron ore reduction by natural gas/ hydrogen is economically hardly feasible in Europe (OPEX). The main challenge in this context is the economic production of hydrogen via (renewable) electrical power. All future activities in this direction would additionally cause considerable investments (CAPEX) to the steel industry. |

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 1A-2A Steel sector |

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| **Activity number**: 1A.2  |
| **Title:** HIsarna smelting reduction process for lowering energy consumption and CO2 emissions of steel production |
| **Targets:** the targets of the Declaration of Intent that the R&I Activity will help to achieve. This activity will help to achieve that by 2030, 1/3 of the currently promising emerging technologies are successfully demonstrated at large scale (TRL>=8) | **Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS The achieved energy savings and CO2 reduction will be assessed by a process model with the possibility to run on real-time plant data or to run with specific historical data sets. All outputs and inputs to the process, such as coal and other fuels and hot metal and slag produced, are measured and the data is stored. Two complete offgas analysis systems (redundancy) are installed on the plant. This data is essential for determination of the energy efficiency and CO2 emissions. Other models are available to make the translation from results obtained at pilot scale to results applicable to commercial scale installations. Reporting of the progress on each target will be done by regular progress meetings. Periodic reports to be provided to SETIS. |
| **Description:** a summary of the R&I Activity including the goals and a justification of why the Activity is keyAchievement of the Target is directly related to a successful scale-up of the HIsarna technology. Up till now, four successful campaigns (period 2011-2014) in the pilot-plant (65 kton/a hot metal capacity) at Tata Steel (NL) have brought the technology to TRL 6. Early 2017, a fifth campaign will commence in which long-term operating stability as well as several aspects of energy saving will be tested. The proposed R&I Activity will on the one hand further progress the pilot-plant research following completion of this fifth campaign and on the other hand focus on design, impact and financial aspects of a scaled-up demonstration plant. The Activity is an essential step in the development chain to bring the technology toward TRL>=8. In the R&I Activity, the following tasks are foreseen:1. Scrap additions: initial tests in 2014 have demonstrated that feeding scrap (in addition to iron ore) is feasible in the HIsarna process. Contrary to iron ore, scrap only needs to be melted and no coal/energy is needed to reduce iron oxides to metallic iron. Scrap additions thus result in significantly lower specific CO2 emissions and specific energy consumption of the produced metal. In the upcoming fifth campaign (H2020-SILC-2), tests will be performed in which scrap rates will be increased, but test duration will still be limited. In the proposed R&I Activity, long-duration pilot-plant tests with scrap will be performed in which scrap dosing will be maximised. In the future, zinc will be increasingly present in the scrap. For the steel industry to successfully recycle this type of scrap, it is important to resolve the zinc issue. Therefore, the effect of zinc in scrap will be a major topic of investigation as well.
2. CO2 capture: HIsarna is an oxygen-based process and the top-gas is very rich in CO2. Up to sofar, concentrations of ~ 75 % CO2 have been achieved on pilot-plant scale. The remaining gas being N2 from raw material injection (coal is injected with N2). Having such concentrated CO2 opens up possibilities for more energy efficient capture technologies as compared to standard amine technology, for example cryogenic separation. In the proposed R&I Activity, a study regarding the most suitable emerging/existing CO2 capture technology for the HIsarna top gas will be performed. In addition, a pilot capture facility taking (part of the) HIsarna pilot-plant off-gas will be designed, constructed and tested at the pilot-plant.
3. Preparations for a demonstration scale plant: in an earlier project, a conceptual design for a demonstration scale plant (1 mton/a hot metal capacity) has been made. Several tasks need to be employed to prepare for an investment decision of such a plant. An important aspect of the HIsarna process is the fact that the hot metal produced can be processed to steel in the BOS plant and therefore requires no changes in the configuration downstream of the ironmaking facilities.
	1. Basic engineering study, regarding the integration of HIsarna in a typical EU brown-field production site. Aspects that will be studied are amongst others: design of the core plant, its facilities, embedding of the plant in the existing site energy infrastructure (gas, electricity, etcetera) and compatibility with the existing downstream configuration of an typical European steel production site. .
	2. Economic study, with specific attention for a brown-field site energy balance. Aspects that will be studied are amongst others: capital investment, operational costs, etcetera.
	3. Study regarding the use of sustainable biomass. Aspects that will be studied are amongst others: potential for treatment of large quantities of biomass to make it suitable for use/injection in HIsarna as a coal replacement, potential use of generated biogas (during biomass treatment step) for optimizing a brown-field production site gas/energy balance.
 |
| **Impact:** **- Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28): HIsarna reduces specific CO2 emissions with 20 % (without CCS), corresponding to a maximum energy saving of 3.75 GJ/t of steel. In the next calculations, a toe (tonne of oil equivalent) is taken to be 42 GJ. In other words, a saving of 0.089 toe/t of steel. Assuming that 100 Mton/a of steel is produced via the blast furnace route, full substitution with HIsarna technology would result in an energy saving of 8928 ktoe/a. **- GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28). HIsarna reduces specific CO2 emissions with 20 % (without CCS) which is ~ 360 ktCO2eq per Mton of hot metal produced, compared to blast furnace practice. If all blast furnace capacity (~ 100 Mton of hot metal in EU) would be substituted with HIsarna, then emissions would be reduced with 36 000 ktCO2eq/a.  |
| **TRL:** Advanced research /Industrial research & demonstration / Innovation & market uptake. Also mention TRL at start and envisaged at the end. The TRL of this Activity would be “Industrial research & demonstration”. The current TRL is 6 (“technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)”). This Activity furthers several aspects that are needed in preparation for TRL7 (system prototype demonstration in operational environment) and beyond.  |
| **Total budget required 35 M EUR**  |
| **Expected deliverables** | **Timeline** |
| 1. *Long duration tests with scrap additions*
2. *Test of several scrap qualities*
3. *Determine and test most suitable CCS technology*
4. *Basic engineering study for demonstration scale plant*
5. *Economic study demonstration scale plant*
 | *Month 18 Project Month (start = project Month 0)**Month 18**Month 36**Month 24*Month 24 |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| 1. Selection, design and construction of energy efficient CO2 capture technology for HIsarna. (Tata Steel + suitable industrial partners)
2. Engineering for demonstration scale plant (Tata Steel + suitable industrial partners)
3. Long-duration scrap tests (Tata Steel + suitable industrial partners)
 | Foreseen is Private + Public fundingForeseen is Private + Public fundingForeseen is Private + Public funding | 15 M EUR8 M EUR12 M EUR |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| Fill in one line per ongoing R&I Activity | explanation on how its contributes to the target(s) and, if it is the case, why it is considered as Flagship activities | start and end dates | (countries / stakeholders / EU) |  |
| H2020-SILC-2 (“LoCO2Fe”) – EU grantDemonstratie Energie Efficiency (DEI) – NL grant\* Note: this is the total budget, of which 50 % subsidised in the SILC-2 grant, and 25 % in DEI grant. | Targeting 35 % reduction in CO2 emission intensity vs. BAT by utilising scrap and biomass. Involves tests of limited duration with these materials.Long-duration testing (mainly using iron ore; limited/no scrap usage)  | 1-7-2015 to 1-7-20181/10/2016 to 1-10-2018 | NL: Tata SteelDE: ThyssenKruppFR: ArcelorMittalLUX: PaulWurthAT: Voest alpine StahlNL: Tata Steel | M€ 14.9 \*M€ 6.4 \* |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goalNone |

**Strategic Energy Technology Plan**Action 6
 "Make EU industry less energy intensive and more competitive"

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 1A-2A Steel sector |

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| **Activity number**: 1A.3  |
| **Title: Top Gas Recycling – Blast Furnace (TGR-BF) using plasma torch.** The steel industry can lower its carbon consumption (and thus GHG emissions) by the dry reforming of steel mill CO2 in a plasma torch with renewable electricity. For this reaction, methane from coke oven gas or natural gas can be used. The CO2 is in the BF or BOF gas that will be recycled and heated for injection into the blast furnace. |
| **Targets:** this project is a first step on the way to develop a new generation of Top Gas Recycling Blast Furnace.This TGR-BF project will recover all CO + H2 in the top gas of the blast furnace, for re-injection in the furnace. This will increase the C-efficiency in the furnace by 80%.The dry reforming of steel mill CO2 with CH4 will help to develop all necessary technologies for the design of a new generation TGR-BF i.e. the refractory for heating gases, the design of the furnace, the tuyere for top gas injection, the operation practices... | **Monitoring mechanism**: * one (or more) plasma torches will be installed on the tuyeres of a blast furnace
* the gas flows, analysis and energy consumptions (coke, oxygen, electricity) will be measured
* the CO2 emission will be calculated through LCA calculations
 |
| **Description:** the TGR-BF project consists of several phases including the design of a plasma torch for steel mill gas conversion , the design of a novel tuyere allowing to inject coal, oxygen and hot reformed steel mill gas into the blast furnace, the engineering and construction of all this equipment on one European blast furnace (BF 2 in Dunkirk), the testing of this equipment and once these parameters are determined, these values and designs can be used to start the study of a full Top Gas Recycling Blast Furnace. This study may well take another 4 years.Construction may take another 2 to 3 years.Goal is to have the industrial furnace ready for operation before 2030. |
| **Impact:** **- Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)* The impact of the plasma torch project is estimated at 325 MJ per ton of crude steel. Assuming a yearly EU conventional steelmaking capacity of 116 Mt, this amounts to 37,7 million GJ/y or 900 ktoe/a
* The impact of the TRG-BF without CCS is estimated at 1.993 MJ per ton of crude steel. Assuming a yearly EU conventional steelmaking capacity of 116 Mt, this amounts to 231 million GJ/y or 5.500 ktoe/aImportant remark : these energy savings of the two stages of the project are not cumulative !!! They cannot be added.

**- GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)* The impact of the plasma torch project is estimated at 89 kg of CO2 per ton of crude steel. Assuming a yearly EU conventional steelmaking capacity of 116 Mt, this amounts to 10,3 Mt/a of CO2
* The impact of the TRG-BF without CCS is estimated at 306 kg of CO2 per ton of crude steel. Assuming a yearly EU conventional steelmaking capacity of 116 Mt, this amounts to 35,5 Mt/a of CO2if the TGR-BF is combined with a storage project of the CO2 then the potential raises to 1.052 kg of CO2 per ton of crude steel. Assuming a yearly EU conventional steelmaking capacity of 116 Mt, this amounts to 122 Mt/a of CO2

Important remark : these CO2 savings of the two stages of the project are not cumulative !!! They cannot be added. |
| **TRL:** Industrial research & demonstration TRL at start : 6 for Plasma torch, 7 for conventional TGR-BF; at end : 8 |
| **Total budget required :** * 16 M€ for testing of 1 tuyere on a blast furnace
* 79 M€ for the plasma torch dry reforming project
* Over 400 M€ to construct the Top Gas Recycling Blast Furnace (this is a rough estimate based on the former ULCOS project that applied for NER 300 funding).
 |
| **Expected deliverables** | **Timeline** |
| * Development of adequate refractory materials and metals and coating, Mastering of the metal dusting and carbon deposit problem.
* Development of a novel tuyere (combination of O2, pulverised coal and hot syn gas).
* Development of a plasma torch, easily switchable, to add the electrical energy to the gas.
* Design of a gas mixing chamber to quench the hot syn gas from the plasma torch,
 | * Tuyere design, test and trial program = years 2017 – 2023). Roll out of the plasma technology on blast furnaces after 2025.
* Design of the Top Gas Recycling Blast Furnace using the elements of the plasma trials years 2023 – 2025
* Engineering, design of the TGR-BF = years 2023 – 2025. Construction of the TGR-BF, commissioning and trial programs = years 2026 – 2030. Full production after 2030
 |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| * plasma torch suppliers (Europlasma (Fr), Scanarc(Swe), Tetronics (UK), Westinghouse (USA)
* electrical control equipment (Siemens, ABB, (Germ/Fra))
* development of heat resistant metals (Sumitomo (Jap), Sandvik (Swe), Manoir (Fr),..)
* development of heat resistant refractory (companies = Steuler – Refracast,Fr/Germ), (universities : CEMTI (Fr))
* design and casting of tuyeres (Paul Wurth (Lux), KME (Ger),...)
* integration engineering (Jacobs, Arcadis, Foster Wheeler, Technip, (It, Fra, Germ)
* industrial gas suppliers for gas separation and treatment (Dow (Neth), MHPSE, Linde (Ger),Air Liquide (Fra)
* Steel companies from EU 28 and all over the world
 | *National funding organisations (ADEME (Fr), BMBF (Ger), ISPT+ RVO (Neth).., Agentschap ondernemen (Bel))**European funding : H2020 SILC and LCE, SPIRE, Circular Economy,...* | *…* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| LIS program (Low Impact Steel Making) in France | In this program several universities (IJL – LRGP- CEMTHI ..) and companies (ICAR, CORIA) have done studies about the problem to produce an use a hot syn gas for re-injection in the blast furnace | Start = 2013, end = Q2 2017 | FranceAcademic partners =Companies = CNRS – CORIA, CNRS ICSM, CNRS LRGP, CNRS PACTE, CNRS-CEMHTI, ICCF, IDEEL-IEED, IJL,TAP-UCBL Air Liquide, ArcelorMittal, ICAR | 32,2 M€ |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goal |

## Chemical/Pharmaceutical Activity Fches 1B.x

Activity 1B.1. Chemical reactor, process and plant (re)design and optimisation – Process intensification

Activity 1B.2. Separation technologies

Activity 1B.3. Power-to-X & Unconventional energy sources

**Strategic Energy Technology Plan**Action 6
 "Make EU industry less energy intensive and more competitive"

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name** 1B-2B-Chemical sector |

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| **Activity number**: 1B. **1.** Chemical reactor, process and plant (re)design and optimisation – Process intensification |
| **Title:** Process intensification & modular approach |
| **R&I Targets:** 1B2B | **Monitoring mechanism**: Level of development of deliverablesKPIs and benchmark to be defined  |
| **Description:** Process intensification, including new catalyst development can provide major opportunities for resource and energy efficiency as chemical reactions can be achieved at optimal conditions with significantly less side reactions creating fewer by-products, and using less auxiliary materials.More robust and tolerant production systems are also required to adapt to potential feedstock specification variations in a more circular economy approach.The introduction and further penetration of process intensification technologies will also achieve more flexible modular and standardised chemical production capacity within Europe. It will enable accelerated innovation towards a wider portfolio of end products due to its flexible and multipurpose operational modes. Modular continuous plants for small and medium scale chemical processes today typically performed in relatively inefficient batch processes. A priority is therefore design and realisation of “plug-and-produce” modules (including reaction, separation/workup, pumps and other utilities) equipped with advanced process control and automation (see 1.a) to enable different plant set-ups and flexible adaptation of scale. The integration of downstream process units should be a key element of the projects.Advanced process design and retrofit of existing assets will be supported by advanced sustainability assessment tools, modelling and digitisation technologies, and new technologies such as 3D printing of reactors.  |
| **Potential Impact:** Process intensification is essential to achieve further energy efficiency improvement in the European chemical industry. Reduction in energy intensity estimated up to 30% (based on past projects) for production of high added value chemicals which have a key role in the competitiveness of the European chemical industry.  |
| **TRL:** Advanced research and Industrial research & demonstration; start: TRL 4-5 end TRL8 |
| **Total budget required:** >20M € |
| **Expected deliverables** | **Timeline** |
| * Development of new advanced catalytic systems including reactor design optimisation for improved heat and mass transfer
* Process design and optimisation of continuous multi-purpose chemical plants
* Definition and standardisation of modules, fluid, electric and data interfaces
* Demonstration of intelligent modules for different unit operations with integration of downstream process units
 | 3 to 5 years |

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| **Gaps**: to be addressed in 5.2:* Advanced sustainability assessment tool and integration in chemical process modelling/design tools for decision making starting at TRL 4 of process design
* Advanced online monitoring technologies
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| **Parties / Partners** | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Chemical and engineering companies | European and Member States support with coordination at EU level. | *To be developed at a later stage* |

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| **Activity number**: 1B **2.** Separation technologies |
| **Title:** Separation technologies  |
| **R&I Targets:** 1B-2B | **Monitoring mechanism:** Level of development of deliverables KPIs and benchmark to be defined |
| **Description:** Separation technologies are essential in chemical processes for the purification of the products, recycling of solvents or catalysts, further valorisation of by-products or gaseous effluents, removal of harmful substances etc. Most mature separation technologies are energy intensive, and separation operations can represent up to 50% of energy consumption in chemical plants. Therefore intensified separation technologies and their control technologies have to complement, higher selectivity of the reactions. Different technology options can be considered for more efficient separation operations, including:* Flexible distillation columns designed for plants with load changes
* New distillation concepts such as dividing wall columns, Heat Integrated Distillation, cyclic distillation
* Integrated reactive and hybrid separations technologies that can significantly reduce energy consumption by integration into one unit of (multi) reaction separation steps, or several separation processes.
* Alternatives to distillation such as adsorption, membrane, nanofiltration

Particular applications of alternative separation technologies would include:* recovery of catalysts,
* development of more cost-competitive separation units for energy-efficient treatment of industrial gaseous effluents, including for further chemical valorisation CO2.

Optimization of the design and engineering of separation operations would also include the development of specific materials, such as: * highly selective membranes: for hybrid separation systems, to make pervaporation economically viable for other industrial applications than current dehydration of alcohols)
* new organic solvent nanofiltration membranes
* zeolites, MOFs for advanced adsorption technologies at lower cost.
 |
| **Expected Impact:** up to 30% reduction of energy required for separation operations |
| **TRL:** start: TRL4-5, end TRL8 |
| **Total budget required:** above 10M€ |
| **Expected R&I deliverables** | **Timeline** |
| * Development of alternative separation technologies with significant lower energy consumption (compared to technologies currently implemented) demonstrated at pilot level
* Demonstration of new cost-competitive separation units for treatment of industrial gaseous effluents, including for further chemical valorisation of CO2.
 |  3-5 years |

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| **Gaps**:  |

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| **Parties / Partners** | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Chemical and engineering companies | European and Member States support with coordination at EU level. | *To be developed at a later stage* |

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| **Activity number**: 1B **3**. Power-to-X & Unconventional energy sources |
| **Title:** Power-to-X & Unconventional energy sources |
| **R&I Targets:** 1B-2B | **Monitoring mechanism**: Level of development of deliverables Key performance indicators and benchmark to be defined |
| **Description:** Energy supply in the chemical industry is mostly based on fossil resources. Access to cost competitive renewable electricity can be an opportunity for the chemical industry to reduce its carbon footprint. The development of advanced electricity based process technologies have to be developed for optimal utilization of low carbon electricity in the chemical industry. Electricity can be introduced directly or indirectly in chemical processes:* Indirect use of electricity can be considered for heat/steam/vapour generation or upgrade:
* Electricity based steam generation could allow significant reduction of CO2 emissions (depending on the carbon footprint of electricity)
* Development of mechanical vapor recompression system to upgrade low temperature vapor into medium pressure.
* Direct utilisation of electricity for electrochemistry and use of unconventional energy sources:
* Further utilisation of electrochemical processes would require the development of new catalysts, electrodes and compact electrolysis cells.
* Development of sustainable, intensified chemical processes using unconventional forms and sources of energy, such as microwaves, ultrasound, plasma can boost the efficiency of existing chemical processes carried out in a conventional way, and can also be used for the production of functional products which are difficult to obtain using conventional processes. Such technologies can also contribute to the production of low carbon Hydrogen, and can be at the root of low carbon production routes for various chemicals including large volume production such as methanol and ammonia.
 |
| **Expected Impact:** GHG emission saving potential for the chemical industry will depend on penetration rate of the technology and carbon footprint of the electricity. As an illustration: initial figures –to be validated- for electricity based steam production: CO2 avoided emissions estimated to vary from 2.7Mt in 2030 to maximum 20Mt in 2050 for an electricity demand around 16TWh in 2030 to 130 TWh in 2050 |
| **TRL:** start TRL 4-5; end TRL8 |
| **Total budget required:** >30M € |
| **Expected deliverables** | **Timeline** |
| * Optimisation of electricity based steam generation technologies
* Development of mechanical vapour recompression systems for the chemical industry
* Intensified processes using unconventional forms and sources of energy (e.g. microwaves, ultrasound, plasma) for chemical production demonstrated at pilot level
* Cost competitive low carbon Hydrogen production for integration in the chemical sector's processes demonstrated at pilot scale

*Depending on the development of SET Plan action 9 , some activities related to the chemical valorisation of CO2 and other gaseous effluents and renewable electricity to produce methanol, Fischer-Tropsch hydrocarbons, and other chemicals could be added in this activity fiche* | 3-5 years |

**Gaps** :

Integration into the power grid to be addressed in 5.1b

Competitive access to low carbon electricity

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| **Parties / Partners** | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Chemical and engineering companies | European and Member States support with coordination at EU level. | *To be developed at a later stage* |

## Heat/Cold recovery Activity Fiches 3.x

Activity 3.1 New technologies for utilization of high temperature waste heat in industrial systems, from the heat production to the delivery and end use.

Activity 3.2 Heat or cool upgrade from low to high grade (heat pump / refrigeration)

Activity 3.3 Heat-to-Power (electrical) recovery (low and high temperature)

Activity 3.4 Polygeneration (heat, cold, electrical power) and hybrid plants

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**Strategic Energy Technology Plan**Action 6
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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 3-Heat/cold recovery |

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| **Activity number**: 3.1 (formerly 3.1b) |
| **Title:** **New technologies for utilization of high temperature waste heat in industrial systems, considering the whole energy cycle from the heat production to the delivery and end use, including environmental impact.** |
| **Targets:** R&I Targets: By 2025, develop and demonstrate cost effective excess heat recovery solutions | **Monitoring mechanism**:Key performance Indicators will be developed which will allow comparison to a given bench mark; such as:* Specific energy consumption per ton produced product, base line 2015
 |
| **Description:** Energy and fuels represent between 20 % and 40 % of the production costs in several Resource and Energy Intensive Industries (REII) (Iron & Steel, Aluminium, non-ferrous metals, Chemicals, Cement, Ceramics and Glass). This proportion is expected to increase in medium & long terms because of the increasing cost of energy, as well as the increase of (environmental) taxes. Since 30 years, many technological progresses were already done in REII to reduce the energy consumption of the main industrial processes. In some high temperature processes (>800°C) significant parts of the input-energy are still lost in the form of waste heat, because high temperature recovery in these cases is technically challenging, for example the off-gas contains high concentration of dust and impurities or waste heat is lost as high temperature liquid (slag). In addition, with existing processes getting closer to their optima, the future technologies for energy recovery from waste heat will require a more global and systematic approach, including relevant downstream industries. New scientific and technical knowledge thus are to be developed to implement new cost-effective solutions necessary for cutting of present energy recovery costs. Projects should address the following areas:* Design, build and test more sustainable processes/components (these should be different to the ones covered by Activities 3.2, 33.3 and 3.4) by developing the necessary knowledge and technology to propose new techniques and integrating energy recovery, storage and utilisation. This will maintain the competitiveness of European industrial sites in medium & long terms.
* Sharing competence and costs between companies to develop new processes in collaborative projects would permit many industries, including large numbers of SMEs, to:
* Develop new processes that they would not be able to develop on their own because of a lack of resources;
* Encourage uptake of the technologies as well as transfer from different industrial sectors
* Coordinate a platform along value chains.
* Integrate the development of these enabling technologies with demonstration units to prove their integration capability in the whole product network.
 |
| * Increase adoption by improved economics and solutions which are already developed in line with the needs of the affected value chains. The latter will have the additional and important effect to drastically reduce time-to-market, which is a unique feature of Process Industry and a significant advantage for European industry in global competition in the development of energy recovery technologies.
* Improve the energy efficiency of large industrial systems, on the condition of designing new strong and economic industrial solutions based on new technologies for recovery of waste heat, considering the whole energy cycle from the heat production to the delivery and end use, including environmental impacts
* Improve understanding of internal energy flows in a given system (e.g. Sankey Diagram) and integration with irreversible thermodynamics to enable new heat integration and recovery strategies.
* Developing low-cost wireless sensors that can communicate with one another to achieve robust and redundant global measurement networks providing a real time view of wide and complex energy networks
* Adapt high temperature storage (>400°C) to smooth the intermittent character of the recoverable energy flows (such as low cost materials with high thermal inertia, Phase Change Materials, fluidized beds, etc.)
* Achieving safe, controlled and efficient recovery of heat from media, which are very difficult to handle and control (high temperature, high volumes, highly aggressive- fouling/deposits/corrosion, compact hot solids or granulated particles).
* Transfer of energy flows from one process line to the other one, investigating the potential use of recovered energy in other processes with various heat transfer media (water/steam, oil, salts, gases, solids ….), or investigating the possibility of sharing energy between different companies (by creating a network of energy streams).
* Work on systems that do not decrease the quality of recovered heat (e.g. dry cooling instead of wet cooling)
* Demonstrate new processes on pilot industrial scale for validation of solutions to improve the environment impact using the new waste heat recovery approach
 |
| **Impact:** An ambitious but realistic objective is a recovery of at least 60% of the sensible heat contained in each waste heat carrier addressed by a project. The improvement of the energy efficiency and the reduction of energy costs will lead to an advancement in competitiveness. This will expand the available portfolio of energy resources and technologies, which can be integrated within sites, across sectors and along value chains. The corresponding reduction of the energy environmental footprint of the process industries (especially from a value chain perspective) will contribute to an improved environmental net balance, when building the future infrastructures necessary for the transformation of Europe towards a CO2-lean economy. Any single technology in the integration of novel combustion and gasification technologies and advanced energy systems will not deliver the targeted 30% improvement of fossil energy intensity for Process Industries. However, each of these technology gaps will deliver an important contribution. A profound work on integration of these individual technologies will be needed; where the quality of the energy is determining the efficiency.**- Primary energy saving potential in percentage and in ktoe/a (assuming full deployment in the EU28)****- GHG emission saving potential in percentage and in ktCO2eq/a (assuming full deployment in the EU28)**To be provided at a later stage as it needs to be assessed further by the sectors. |
| **TRL:** 5-7 |
| **Total budget required** Recommended budget per project would be 12 M euros |
| **Expected deliverables** | **Timeline** |
| Possible deliverables could include:* Inventory of Waste Heat sources in energy-intensive industrial sectors
* Specific design and engineering of the high temperature Waste Heat Recovery technologies

Understand the quality and quantity of the waste heat available Technical / financial feasibility studies of the different possibilities for heat usage;Identification of process requirements (new equipment) and constraints associated (corrosion studies);* Design of a system for max efficiency / cost minimization.
 | Projects of 36 to 48 months are recommended. |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| *Stakeholders: academia, industry, authorities, research institutions, financial institutions, communities.**Examples of concerned companies: LAFARGE, Terreal, Voestalpine, Arcelormittal, CEA, CSM* | * Funds at EU level should be guaranteed in order to achieve true cross-sectorial EU dimension of technologies development and demonstration (e.g. H2020, FP9 et al.)
* Other complementary funds or tools could cover specific territorial interests (e.g. national or regional funds) or support deployment (e.g. Investment and financial instruments from EIB, ETS Innovation Fund et al.)
 | *…to be developed at a later stage* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal**National initiatives from Norway:* **HighEff - Energy efficient and Competitive Industry for the future**: Targets:
	+ 20% to 30% reduction in energy consumption
	+ 10% reduction of greenhouse gas emissions
	+ Energy efficient processes and components

<http://www.sintef.no/projectweb/higheff/>* **Centre for Research-based Innovation on Metal production:  Resource efficient metal production from a clean industry**

Goal:  reduction of emissions (NOT only CO2) and increased energy efficiency<https://www.ntnu.edu/web/metpro/cri-metal-production> |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| *I-ThERM Project* <http://www.itherm-project.eu/>  | The project focuses on two-phase innovative heat transfer technologies (heat pipes-HP) for the recovery of heat from medium and low temperature sources and the use of this heat.  | 2015 - 2018 | <http://www.itherm-project.eu/partners/>  |  |
| *SusPIRE project* <http://suspire-h2020.eu/>  | The project works in the area of energy recovery from residual heat streams. | 2015 - 2018 | <http://suspire-h2020.eu/consortium/>  |  |
| *Smartrec project* | The project identified Secondary aluminium recycling and ceramic processing as key examples with economically recoverable waste heat.  | 2016 \_ 2019 | http://cordis.europa.eu/project/rcn/205693\_es.html |  |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goal |

TECHNOLOGICAL BARRIERS:

Several obstacles should be considered: the non-existence of nearby heat sinks or end-use applications, time discrepancy generation-demand and severe operation conditions. Besides, conditions like chemical composition of the Waste Heat sources may vary among sectors and companies and could put in danger the smooth operation of technical solutions proposed. Thus, those elements should be at the core of the projects / actions in the spirit of covering the whole range of production conditions. Other technological barriers:

* Contaminants in high temperature gases to be used, which may cause corrosion
* Lack of cleaning mechanisms that would allow maintenance costs reduction (for example, self-cleaning innovative equipment could be an outcome of the actions/projects)
* No existing practical way to recover wasted heat from equipment. For example, the cement kiln or moving conveyors constitute a topic to address. Another critical topic is the heat recovery from hot solids (i.e. coke, granulated slag and chemical products, solid steel slabs, steel coils …)
* Very often, existing heat recovery technologies decrease the quality of the recovered streams (i.e. decrease in temperature or chemical energy). Energy storage systems also degrade the stored energy for long periods (several hours or days) and are not enough flexible (too long response times) and hardly transportable. These points are very challenging because today there is no inexpensive and efficient system avoiding these disadvantages and which can be disseminated on a large scale. Some compact and efficient techniques already used in other domains need to be adapted for heat recovery use (i.e. high temperature fluidized beds, supercritical water …).

PRODUCTION PROCESS BARRIERS:

They are expected to be tackled by the analysis of Waste Heat sources in different sectors. Furthermore, among other solutions, there is some potential in non-invasive technologies, which should not disturb the operation of the plant or the production reliability. Nevertheless, requirements and constraints differ between industries and obstacles such as inaccessibility to the heat source or variation of the control process as well as problems related to the scale-up could appear.

FINANCIAL AND ADMINISTRATIVE BARRIERS

They are mainly related to the economic feasibility of the solutions to be implemented. Furthermore, other obstacles such as availability of investment funds, priority of the core business and uncertainty of the economic future or administrative efforts could hamper the implementation of Waste Heat Recovery solutions in the industry.

Most companies lack of business knowledge or have not overviewed which opportunities for waste heat recovery even exist in the market. There is also lack of special staff for efficiency technologies in general and WHR technologies in particular.

In the integration and installation of waste heat recovery technologies in process industry the risk is commonly assumed by the final user, i.e. factory that wants to implement a waste heat recovery solution on site. Therefore, business model feasibility is based on the industrial processes and the key factor to succeed is the Return on Investment (ROI) or Payback time of the solution. In this sense, energy related measures in process industry are nowadays treated as a main driver for future competitiveness but strict conditions are applied. ROI under 3-4 years is a general rule to be found in energy intensive industries, and even more limited periods. Projects/actions should seek into technologies that are able to fulfil that periods in the short-medium term after the project ends, to ensure successful market uptake of the results.

Moreover, alternative business models should be defined, as the existing ones are rather conservative and there is a need to innovate also in business models for process industry. If a technology provider is confident on the technology, alternatives for sharing risks will be also explored, in order to increase market uptake. In this sense, possibilities such as guaranteed performance of a solution or shared savings should be analysed and proposed for the business plans for each result.

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 3-Heat/cold recovery |

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| **Activity number**: 3.2. Heat or cool upgrade from low to high grade (heat pump / refrigeration) |
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| **Title: Heat pumps and refrigeration converting low grade heat or cool into higher grade heat or cool** |
| **Targets:** 3. Cross-cutting R&I: maximising the recovery of industrial excess heat/cold in a cost efficient mannerBy 2025, develop and demonstrate (to TRL 8) solutions enabling small and large, industries to cost effectively reduce their energy consumption by 5% by cost effectively upgrading excess heat / cold for more valuable application elsewhere in the process. | **Monitoring mechanism**: the deployment of heat pumps and refrigeration cycles will be monitored using the installed capacity (MWt) as well as energy saved (MWht). The efficiency of this will be assessed using the level of coefficient of performance (COP). Finally, the CO2 avoided can be reported. |
| **Description:** Heat pumps converting low grade heat (typically 50°C-120°C) into higher grade heat (up to 200/250°C) and refrigeration cycles converting low grade cooling into higher grade cooling. Development of pilot and demonstrate innovative heat pump or refrigeration concepts to make cost effective use of waste heat or cool at highest efficiencies by using advanced thermal cycles or unique concepts. Demonstrator (1MWt) of the heat extraction system coupled to an existing plant:* Demonstrate operability of heat pump or refrigeration concepts
* Verify performance of components
* Demonstrate potential to produce process energy savings
* Demonstrate potential for heat pump or refrigeration cycle efficiency
* Configuration for different operating modes
 |
| **Impact:** Reduction in process energy demand by 5%**Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)At least 3.5% (1750ktoe/a) only relative to the steel industry sector. Higher primary energy saving assuming the deployment of the technology in other industry sectors.**GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)At least 1.2% (4575 ktCO2/a) of the steel industry sector (the data consider the deployment of the technology only to the steel industry sector). |
| **TRL:** starting TRL4 moving to TRL8 |
| **Total budget required** €4 mio. |
| **Expected deliverables** | **Timeline** |
| * optimised cycles for different low grade heat opportunities,
* design tools including media properties,
* cycle optimisation in terms of efficiency and capex,
* engineering, construction and commissioning of pilot plant

***on component level:*** * component and module concepts and enhanced design tools,
* innovative heat pump or refrigeration heat exchanger
* (3) Balance of plant as required by concept
 | 36 months |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Energy-intensive industry, turbine industry, universities  | *…* | *…* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| *Indus3Es (Horizon2020 project EE-18-2015)* | Development of a new Absorption Heat Transformer | 2016-2020- |  | 3.8 M€ |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goal |

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 3-Heat / cold recovery |

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| **Activity number**: 3.3. Heat-to-Power (electrical) recovery (low and high temperature) |
|  |
| **Title: 3.3.a Use of low temperature waste heat to generate electrical power at highest efficiencies** |
| **Targets:** 5. Cross-cutting R&I: maximizing the recovery of industrial excess heat/cold in a cost-effective manner By 2025, develop and demonstrate (to TRL 8) solutions enabling small and large, industries to cost effectively (€/kW) reduce their energy consumption (MWH) by 10% by using low temperature waste heat (100-300˚C) while striving to reduce GHG emissions proportionally (tons CO2 avoided). | **Monitoring mechanism**: Monitoring of the waste heat / cold recovery potential (MWh) and GHG emissions (tons CO2) with the proposed technology compared to the conventional one. The efficiency of this will be assessed using the cycle efficiency (%) and waste source utilization (%). Finally, the specific capital cost will be tracked (€/kW) |
| **Description:** Low temperature heat extraction from harsh environments to recover low temperature waste heat as usable power using advance heat cycles. Development of pilot and demonstrate innovative power generation concepts to make cost effective use of low temperature waste heat at highest efficiencies by the use of Organic Rankine Cycle (ORC), thermo electric, magneto caloric, Stirling, etc. Demonstrator (1MWe) of the heat extraction system coupled to an existing plant* Demonstrate operability of waste heat cycle
* Verify performance of components
* Demonstrate potential to produce a low LCOE
* Demonstrate potential for cycle efficiency
* Configuration for different operating modes
* Reconfigurable / open architecture

The target is to identify the winning technology, as so far no approach proved to be economically viable |
| **Impact:** Recovery of up to 10% low temperature waste heat as usable power**Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)At least 6.9% (3500ktoe/a) only relative to the steel industry sector. Higher primary energy saving assuming the deployment of the technology in other industry sectors.**GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)At least 2.4% (9150 ktCO2/a) of the whole industry sector (the data consider the deployment of the technology only to the steel industry sector). |
| **TRL:** From current level TRL 1-4 to TRL 9. (Current depends on technology)  |
| **Total budget required** TRL1: 0.5 M€ (screen x4 low TRL options to create a short-list based on performance and cost. Screening could include new ORC, thermo electric, magneto caloric, Stirling or other concepts) TRL2: 1.5 M€ (develop promising concepts (x2) to select the best option)TRL 3 to 9: 14 M€ (demonstrate the best technology from the previous two steps, estimated based on 5MW demonstrator at $1500/kW for production cost and doubled to included development costs) |
| **Expected deliverables** | **Timeline** |
| ***on system level:*** * optimised cycles for different exhaust temperature levels,
* design tools including media properties,
* cycle optimisation in terms of efficiency and capex,
* engineering, construction and commissioning of pilot plant

***on component level:*** * component and module concepts and enhanced design tools,
* waste heat recover heat exchange
* (3) Balance of plant as required by concept
 | 60 months |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Energy-intensive industry, turbine industry, universities  | *…* | *…* |

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| **Title 3.3.b: High temperature waste heat recovery using the sCO2 cycle to generate electrical power** |
| **Targets:** By 2025, develop and demonstrate (to TRL 8) solutions enabling small and large, industries to cost effectively (€/kW) reduce their energy consumption (MWh) by 20% by using high temperature waste heat (>300˚C) while striving to reduce GHG emissions proportionally (tons CO2 avoided). | **Monitoring mechanism**: Monitoring of the waste heat / cold recovery potential (MWh) and GHG emissions (tons CO2) with the proposed technology compared to the conventional one. The efficiency of this will be assessed using the cycle efficiency (%) and waste source utilization (%). Finally, the specific capital cost will be tracked (€/kW) |
| **Description:** Supercritical CO2 cycles have been largely studied for nuclear and solar applications where they are expected to achieve high cycle efficiencies combined with smaller turbomachinery leading to a reduced environmental footprint. However, supercritical CO2 cycles for waste heat recovery have virtually no deployment. The use of sCO2 technology for waste heat recovery requires development of turbomachinery, heat exchangers and bottoming cycle components. For the given temperature level and heat quantity of the industrial process waste heat, an initial comparison with conventional technology will provide the potential in thermodynamic efficiency and economic benefit. Turbine concepts, enhanced design tools, new sealing technologies, high pressure low cost heat exchangers, advanced blade technology and bottoming cycle components need to be developed. Another critical element is the waste heat recovery unit that transfer the waste heat into the sCO2 working fluid. The waste heat is usually in an unfriendly form: limited space, limited pressure drop, harsh fluids and gases, and multi streams. All these need to be overcome in an affordable and reliable heat exchanger. Material properties considering sCO2 specific issues (corrosion, life-time, creep, fatigue) need to be assessed.The detailed plant layout needs to be optimised followed by engineering, construction and commissioning. |
| **Impact:** Transformation of high temperature waste into usable power **at an efficiency level of about 20%.****Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)At least 13.8% (7000ktoe/a) only relative to the steel industry sector. Higher primary energy saving assuming the deployment of the technology in other industry sectors.**GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)At least 4.8% (18300 ktCO2/a) of the whole industry sector (the data consider the deployment of the technology only to the steel industry sector). |
| **TRL:** Translate from TRL4 to TRL 9 is expected |
| **Total budget required** 40M€ (costs determined by size of demonstrator) |
| **Expected deliverables** | **Timeline** |
| **Demonstrator (10MWe)** of the CO2 Waste Heat Recovery cycle***1) System level deliverables:**** *evaluate optimised cycle for given exhaust temperature levels,*
* *design tools including media properties,*
* *cycle optimisation in terms of efficiency and capex,*
* *engineering, construction and commissioning of pilot plant*
* *demonstrate operability of SCO2 cycle*
* *verify performance of components*
* *demonstrate potential to produce a low LCOE*
* *demonstrate potential for cycle efficiency*
* *configuration for different operating modes*
* *reconfigurable / open architecture*

***2) Component level deliverables:**** *Development of turbine concepts (definition of casings, arrangement, fix points, blade path, speed, etc).*
* *Enhance turbine design tools*
* *Development of new sealing technologies for sCO2 requirements,*
* *advanced blade technology profiles based on changed fluid properties such as viscosity, speed of sound, etc.*
* *Develop robust last stage blades matching cycle specific requirements,*
* *Considering the fluid specific requirements with respect to corrosion/erosion, adapt/develop appropriate and cost-effective materials for sCO2 applications incl. material tests (corrosion, life time, creep, fatigue)*

***3) Development of optimized design for heat recovery system/condenser/heat exchanger*** | 36 months |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Energy-intensive industry, turbine industry, universities  | *…* | *…* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| *Fill in one line per ongoing R&I Activity* | explanation on how its contributes to the target(s) and, if it is the case, why it is considered as Flagship activities | start and end dates | (countries / stakeholders / EU) | M€ |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goal |

For impact:

* **Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)
	+ 7000 ktoe/a
	+ Total Consumption of Energy in Industry 2015 EU28 = 272.5 Mtoe/a
	+ Iron and steel energy consumption = 50.8 Mtoe/a
	+ Reduction related to the steel industry sector = - 13.8%\*
* **GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)
	+ 18.3 MtCO2/year
	+ Total Production EU28 = 4400 MtCO2/year
	+ Reduction = -0.4%
	+ 8.5 % related to Industrial processes.

Reduction related to the industry sector = -4.8%\*

<http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics>

\*Assuming energy conversion efficiency not lower than the average generating efficiency of the thermal power plants in the EU28.

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 3-Heat/cold recovery |

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| **Activity number**: 3.4. Polygeneration (heat, cold, electrical power) and hybrid plants |
|  |
| **Title: 3.4a Hybrid plants for waste heat upgrade integrating renewable energy into industrial plants and processes**  |
| **Targets:** 3.Cross-cutting R&I: maximising the recovery of industrial excess heat/cold in a cost efficient manner at high levels of fuel and operational flexibility at reduced GHG emissions - By 2025, develop and demonstrate (to TRL 8) cost effective excess heat/cold recovery solutions | **Monitoring mechanism:**Monitoring of the waste heat recovery potential and GHG emissions with the proposed technology compared to the conventional one. |
| **Description:** Development of hybrid plant integrating renewable energy into industrial plants and processes reducing the reliance from external energy. Demonstration of the technology in a relevant environment increasing the TRL level towards more effective applications |
| **Impact:** **- Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)13.8% (7000ktoe/a) only relative to the steel industry sector. Higher primary energy saving assuming the deployment of the technology in other industry sectors.**- GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)4.8% (18300 ktCO2/a) of the whole industry sector (the data consider the deployment of the technology only to the steel industry sector). |
| **TRL:** From current TRL 4 to TRL 9. |
| **Total budget required:** 20 M€* 3 M€ TRL 5 – development and design
* 17 M€ TRL > 5
 |
| **Expected deliverables** | **Timeline** |
| * Improved thermodynamic cycles
* Full integration of renewable energy generation in a combined heat and power system for the industrial environment;
* High electrical efficiency of more than 65% and total thermal efficiencies of more than 90%.
* Wide operating range of ambient conditions
* Very low emission levels with single digit ppm NOx (at 15% vol. residual oxygen);
 | 36 months |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Energy-intensive industry, turbine industry, universities  | *…* | *…* |
| **Title: 3.4b Advanced compact CHP- plants of industry scale** |
| **Targets:** 3.Cross-cutting R&I: maximising the recovery of industrial excess heat/cold in a cost efficient manner at high levels of fuel and operational flexibility at reduced GHG emissions -By 2025, develop and demonstrate (to TRL 8) cost effective excess heat/cold recovery solutions  | **Monitoring mechanism**: - Monitoring of the fuel conversion rate in industrial processes, electrical efficiency and emission (GHG and NOx) with both gaseous and liquid fuels |
| **Description:** Further development of advanced compact CHP- plants of industry scale for generation of electricity, steam and heat (i.e. polygeneration) for industrial application with fuel conversion ratios > 90%.Compact CHP plants are usually driven by industrial gas turbines and a combination of steam turbines and recovery steam generators which need to further developed for enhancing the fuel conversion rate of compact CHP-plants up to 85-90%. Special requirements are operational and fuel flexibilities including low calorific gases. Fuel flexibility must also cover liquid fuels applications. The project should build on an on-going projects at component level and extend the results to plant level, lifting the TRL from 3-5 to 5-7.  |
| **Impact:** **- Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)Industrial CHP-Plants can be widely used for all energy intensive industries as steel, pharma, chemical and automotive industries with a saving potential of > 25% (~12000ktoe/a) in all industry sectors.**- GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)Extensive GHG-emissions reduction potential estimate > 8% (> 32000 ktCO2/s) after full deployment of the technology in all relevant industry sectors |
| **TRL:** From component level 3-5 (running projects) to plant level 5-7 |
| **Total budget required:** 10 M€* 3 M€ TRL 5 (further development)
* 7 M€ TRL > 6
 |
| **Expected deliverables** | **Timeline** |
| * Improved thermodynamic cycles with respect to generation of process steam, heat and cold
* Improved plant components optimized for compact CHP cycles
* Wide operational flexibility ranging from 25% to 100% electric power;
* High ramp rates
* Very low emission levels for gaseous fuels at wide range of Wobbe numbers with single digit ppm NOx (at 15% vol. residual oxygen);
* Low emission levels for liquid fuels near single digit ppm NOx
* Validation of component improvements in real plant environment
 | 36 months |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| Energy-intensive industry, turbine industry, universities  |  | *…* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| *CHP components for industrial application* | Development/improvement of components for an advanced compact CHP- plants of industry scale for generation of electricity, steam and heat for industrial application | 2016 | DE (COORETEC) |  |
| **Gaps**: The focus is on components only. A pilot demonstration is needed to gather all improvements achieved, as proposed above. |

## System integration Activity Fiches 5.x

Activity 5.1a Industrial symbiosis between energy intensive industries to valorise energy losses streams and better manage energy globally.

Activity 5.1b Non-conventional energy sources in process industry

Activity 5.2 Digitisation: Further integration in process and plant management including plant/process design phase and processing plant retrofit

Activity 5.3 Improving exchange of technological, economic, behavioural and social knowledge; training, capacity building and dissemination

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 5-System Integration |

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| **Activity number**: 5.1a |
| **Title:** **Industrial Symbiosis**. Symbiosis between energy intensive industries to valorise energy losses streams and better manage energy globally |
| **Targets:**  Understanding of the industrial systems, covering energy/heat/cold/materials/by-products cross-sectorial flows, including valorisation of output. Development and demonstration of solutions enabling small and large industries to reduce their energy consumption by 10 to 20% while striving to reduce GHG emissions proportionally | **Monitoring mechanism**: Input neededKey performance Indicators will be developed which will allow comparison to a given bench mark; such as:* Specific energy consumption per ton produced product, base line 2015
 |
| **Description:** Process industries are in general consuming significant amounts of energy and material in order to trigger or accelerate chemical reactions, synthetize or break molecules, melt materials together or, on the contrary, to separate components of a given material, etc... All those processes generate by-products (process gases or condensed material) as well energy losses, showing global energy efficiency well below 100%. Typically, the amount of energy losses can reach 40 to 50% in Cement production, 50% in Steel, 55% in Glass, 20% in Refining, 65% in Wood products.Industrial symbiosis initiatives which involve the exchange of material and/ or energy flows between two or more production sites or sectors can help saving energy and material, hence improve carbon, energy and resource efficiencies.Building real industrial symbiosis is however a complex topic, not only from the standpoint of the fundamental physics and chemistry involved, but also from the operational standpoint: in order to be materially possible, safe, and cost effective for all partners, and for society as a whole, the energy and material transfer between different industrial units will require a very good coordination regarding, e.g.: production cycles, management of unexpected stoppages, etc. |
| **Recommended action: Identification of an appropriate quantification methodology for industry symbiosis**There is a need for a metric that can further quantify the work potential of the energy losses and the capacity of by-products and enable an analysis of both heat and mass integration of industries. To enable the analysis and establish key performance indices, the potential must be taken into account in addition to the energy. An exergy based metric (instead of energy based one) is capable of this, but there are challenges in quantifying the integration of the work potential or loss associated with mass streams crossing production battery limits, especially where chemical reactions are involved and when the end product is not stable from a thermodynamic point of view.A methodology based on proper adjustments of thermodynamic reference states can enable the analysis from an equilibrium perspective that can be used by the industries and which will be sufficiently simple - without the need for revealing process sensitive information and based on information from only the major process substrate and product streams. This analysis will aid the cross sector and cross battery limit analysis of energy (exergy) losses valorisation and quantify potentials for new integrations. Recommendations for the basis and methodology for this equilibrium analysis with adjusted references must be established if comparisons are to be made on the same scale.Exergy Analysis can be used in many ways to improve efficiencies;* Process design and improvement
* Process optimization
* On-line Thermo economic Diagnosis: Detection of inefficiencies and calculation of their economic effects in operating plants
* Rational cost assessment of plant products based on physical criteria
* Evaluation of alternatives among various designs or operation decisions and profitability maximization. Energy (Exergy) audits
* Setting rational legislation about commercially efficient solutions

All the above will result in price setting of interchanged commodities, which will lay the foundation of Industrial Symbiosis scenarios. Expected Actions and R&I projects should aim at identifying, assessing and testing possibilities of symbiosis between different industries or plants inside large industrial units, with the energy and materials wastes of the ones being the inputs of the others. Actions and projects should cover:* Analysis, characterisation and assessment of the sources of energy and material losses in the spirit of reusing them in other plants or industries, e.g. amount, composition, temperature, impurity and fluctuation have to be taken into account, improving the global environmental impact. To identify these parameters new measurements and models are needed. In particular, systemic models of dynamic systems must be developed to easily simulate time dependent technical constraints but also environmental, social, legal and economic aspects. This needs new global approach of modelling and new tools to allow the users to keep all these aspects without increasing the complexity of models.
* Determining the flexibility to coordinate the sources and demands to optimise yearly the energy fluxes between the different plants and industries.
 |
| * Determining storage technologies and strategies to harmonize energy use for fluctuating inputs (e.g. wind, converter gas) and variable (batch) process demands. These energy storage systems must not degrade the stored energy for long periods (several hours or days) while remaining very flexible (very short response times) and easily transportable. Some compact and efficient techniques already used in other domains need to be adapted for heat recovery use (ie high temperature fluidized beds, supercritical water and CO2 …).
* Determining conversion technologies and strategies to improve the accordance of demands and sources of energy.
* Definition of the most suitable energy carriers to be implemented in a laboratory scale at the proper scale in the environment representative of industrial application laboratory scale
* New management systems for the energy loss fluxes have to be developed basing on the parameters and models described above
* Expanding the flexibility of existing energy management systems to enable what-if calculations for strategic planning of process changes in the connected plants
* Fusing and combination of existing energy management systems for electricity and gas with the new management systems for the energy loss fluxes. To connect individually existing management systems to enable a plant and industry crossing optimisation
* Harmonising energy use by exploitation of existing flexibilities in production to prevent peaks in the energy demands and sources. To achieve this, existing production planning tools have to be extended and connected to energy management systems
 |
| **Impact:** 1. ***Impact of the identification of an appropriate quantification methodology for industry symbiosis***
* The general ambitions to reduce the fossil fuels used by up to 20%
* It is expected to perform cost-saving optimizations of energy and resources supply and demand in selected areas on the basis of new energy and heat measurements, data processing, energy and exergy balances, pinch analysis, Sankey diagrams, prediction of energy demand, diagnostic and optimisation, including heat recovery, by taking into consideration both economical and sustainability constraints

To lay the foundation of the forthcoming real and large deployment of the sustainable cross-sectional energy networks focusing on streams of energy losses.**- Primary energy saving potential in percentage and in ktoe/a** (assuming full deployment in the EU28)**- GHG emission saving potential in percentage and in ktCO2eq/a** (assuming full deployment in the EU28)To be provided at a later stage as it needs to be assessed further by the sectors. Current analysis is not yet consolidatedIndustrial Symbiosis requires a long path to become a reality: a first stage of development and a second of demonstration, which is proposed in the present Fiche. The success of the first step would have a significant impact in the second stage. |
| **TRL:** 4-5 at first stage to be up scaled to 7-8 TRL  |
| **Total budget required:** 4-5 M€ for low TRL and 10-15 for high TRL |
| **Expected deliverables (preliminary list of some of the deliverables)** | **Timeline** |
| * Database of archetypes for typical facilities across SPIRE industrial (sub)sectors, identifying the waste heat rejection streams and heat demands, the type of facility, and capacity
* Database of technical characteristics and specific costs (investment and operational) for heat recovery, storage, conversion and upgrade technologies
* Report on Clustering and Many-to-many matching of Heat Sources with WHVTs for Industrial Symbiosis
* Design of Demonstration Energy Management Networks
* Validation and Assessment of Simulated Energy Network Performance
* Enhancement of Innovative Energy Storage, conversion, transport, transformation Technologies and Solutions
* Report on the mathematical modelling approach and result framework for the demo Networks
* Business Models
 | Projects of 36 to 48 months are recommended.First stage would need a timeline of 5-6 years.If first stage successful, a subsequent second stage should need 4-5 years of development(This is to be considered an estimation while timeline could vary depending on achievements) |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| * *It might be beneficial to all EU countries.*
* *In all cases, industrial sites and clusters are at the core of those initiatives as they are the most promising locations in which IS could be applicable.*
 | * Funds at EU level should be guaranteed in order to achieve true cross-sectorial EU dimension of technologies development and demonstration (e.g. H2020, FP9 et al.)
* Other complementary funds or tools could cover specific territorial interests (e.g. national or regional funds) or support deployment (e.g. Investment and financial instruments from EIB, ETS Innovation Fund et al.)
 | *To be completed at a later stage* |

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| **On-going R&I Activities (Flagship activities or not): relevant to this new activity proposal**Besides the projects specified, please see further examples of regional initiatives in the Gaps section below |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| Holistic energy and resource management systems to be implemented in the energy-intensive industries | Analysis and optimisation tools (for flexible energy use and material flow integration), new approaches (for cost-saving optimisation of energy and resources supply and demand), both integrated into a holistic system will facilitate significant gains in sustainable processing and will enable industrial symbiosisHorizon2020 Projects: EPOS, MAESTRI, SHAREBOX, SYMBIOPTIMA | 2015 - 2018 | EU grant: Universities, RTOs, Industry in 13 EU countries | ~24M€ |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goal |

Industrial symbiosis initiatives involve the exchange of material and/ or energy flows between two or more production sites. The realisation of this concept usually faces a series of technological **and non-technological challenges**. Besides, to make technical solutions marketable, demo scale activities are mandatory to make them more visible and use them to showcase them as a reference for a large number of industrial locations across the EU. As a result, the IS concept should start by TRL 4-5 to end up at TRL 7-8 as a second stage. The latter implies a larger amount of funding to manage the investments required to make those solutions happen.

The following information briefly describes the challenges that the promoters of four different IS initiatives encountered. These initiatives are very different from one another in terms of geographical location (2 in Europe, 1 in the US), scope, number of organizations involved, approach (top-down versus bottom-up), funding schemes, etc. However, the experiences and lessons that can be drawn from them are applicable to all IS initiatives.

1. NISP (National Industrial Symbiosis Programme) – UK: The National Industrial Symbiosis Programme facilitates synergies within the UK encouraging companies to look for business opportunities capable of saving resources. This programme started as a regional initiative that was extended to all the country and has supported more than 13,000 companies in the country. NISP´s role varies from company to company but often involves identifying new and novel input stream for industrial processes.
2. Kalundborg Symbiosis – Denmark: Kalundborg is and industrial town in Denmark. In Kalundborg, energy, water and material flows are exchanged and shared between public and private enterprises, providing environmental and economic benefits. It is the first case discovered of spontaneous industrial symbiosis. The exchanges started through self-organization among the companies and later a Symbiosis Institute was created.
3. Sustainable Chemistry 2030 – Sweden: Stenungsund is the home of the largest chemical cluster in Sweden. These companies share the common aim to become leaders in sustainable chemistry. In 2011, they adopted the compromise to transform Stenungsund into a sustainable chemical process cluster in which all the activities will be based on renewable feedstock and fuels.
4. Gulf-Coast By-Product Synergy Project – USA: The Business Council for Sustainable Development created a methodology to facilitate industrial symbiosis approaches called By-Product Synergy. This initiative was carried out between six major Dow manufacturing sites along the Gulf Coast.

To reach this high TRL as a second stage of the actions or combination of projects, it is requested to provide a commercial framework, which fully puts the operating facility in the setting of commercial markets for XX and YY (resources to be decided depending on the final clusters and case studies). And then, to extend the rule based system for maximising operational profitability within the context of external markets and the practical deployment of industrial symbiosis principles. This technical and commercial optimisation need to be set within the boundary conditions determined by the legislative frameworks. Furthermore, the project/s would deliver proper scenarios at short and long term. The exchange flows identified as triggers of IS solutions would reply upon the best economic, environmental and effective conditions. The operation guidelines to meet the appropriate production will include and be related and reflected on a DDSS.

Specific objectives to be fulfilled at the end of TRL 8 are:

* To provide with some competitive production settings in order to maximize the deployment of the technical solutions identified through the Best Practices
* To characterise the market opportunities for XX and YY supply to the local, regional and national energy markets through the development of a series of operating scenarios. These will include the potential opportunities for the manufacturing units to provide services to the operation of XX and YY networks beyond the fence-line.
* To provide a techno-economic model of the manufacturing units that defines the operating freedoms to maximise revenues in these external markets. This market intervention may take the form of demand side management or the increased power generation for the stability of the external networks. This could be as a long-term strategy or as an instantaneous response to network conditions.
* To extend the internal rule based system for decision making within the manufacturing units to include the interaction with external markets
* To assess the potential use of any resource that might be considered as an added value in any way; recovered, recycled, exchanged, stored and valorised.
* To largely deploy the most adapted solutions or combination of technical solutions in a poll that will be replicated and used under different production conditions, involving a large number of industrial sectors.
* To identify further opportunities which deliver aspects of the circular economy
* To use, apply and develop KRI and KPI that will facilitate the transition towards industrial symbiosis principles

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 5-System Integration |

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| **Activity number**: 5.1.b |
| **Title: Non-conventional energy sources in process industry** |
| **Targets:** Develop and demonstrate solutions enabling small and large industries to reduce their energy consumption by 20% while striving to reduce GHG emissions proportionally. | **Monitoring mechanism**: * Way of electrification of a process
* Increase of energy efficiency
* Increase of energy productivity
 |
| **Description:** Energy coming from renewable sources challenges the process industries as there is a paradigm shift from the requirements on the demand side governing the energy usage to the coming necessary flexibility of the production processes to adapt to the available supply. In more general terms, the challenge for the production processes is to react to highly fluctuating energy supply. This could be done by: * balancing of energy flows in the plant including energy source flexible utilities
* collaborative management of energy intensive plants in an industrial symbiosis concept
* design of processes with very wide operating windows and/or quick start-up/shut-down capabilities
* storage of energy via intermediate products/steam/energy-rich process chemicals (including H2)

The first two points could be covered by developing prediction tools for the demand side combined with matching and optimising algorithms as a tool for intelligent support for decision processes. The platforms where the relevant information is collected and processed also have to be established. To achieve the aforementioned general aims, as power and energy markets form an integral part of electrical and thermal intervention activities, a specific focus should be set on energy and power market integration. Furthermore, it is necessary to do research on different approaches for equipment like reactors, furnaces and processing/separation steps to create a pool of options for further development. The proposals should cover research on changes/improvements in processes and unit operations that can be driven completely or in a major part by sustainable electricity.Specific models that consider the long-term behaviour of the main equipment should be defined. Actions or projects should focus on: * The prime movers of the generators (e.g. turbines, reciprocating engines, renewable sources, energy-source flexible utilities),
* The equipment that control the reactive power flow inside the plant (e.g. on-load-tap-changers, capacitor banks, SVC),
 |
| * The economic issues deriving from the contract with the Distributor for energy exchange,
* Possible storage systems based on electrical solutions (e.g. batteries), or physical systems (e.g. compressed air) or buffering solutions.

One other hand, Europe is rapidly increasing the contribution of renewable energy. The challenge for the energy intensive process industries is to prepare for this transition and develop processes and unit operations that can be operated using renewable energy as utility. Many industrial processes still have their major energy input (in form of heat) from conventional fuels. Changing this to renewable sources, mainly sustainable electricity has several large challenges, 1.) the electricity demand will increase very significantly 2.) the costs of these (often basic) products will increase if current electric prices levels are used by several folds (e.g. a building could cost 2x the price of today 3.) todays processes run usually 24/7 for 10-12 month per year and are not made for large energy input fluctuations as needed when renewable electrical energy sources are used. Analogue to electrical driving it would be interesting whether the process industry could make a transition to processes with increased usage of sustainable electricity. It would be interesting to look for opportunities where decentralized production could be linked with decentralized production of sustainable electricity.~~Non-conventional energy sources, such as microwave, plasma, photons, ultrasound and laser, have already been applied in process intensification, mainly at lab scale, showing in several cases significant improvements in the main process parameters (e.g. reaction selectivity, crystal nucleation, reaction speed) and in the overall energy efficiency.~~ The processes powered by non-conventional energy sources are suitable for connection to the electricity grid and can significantly improve the productivity of industrial processes. They provide a higher flexibility, allowing variable throughputs to better follow market demand and enabling leaner production paradigms (e.g. decreased stock, production on demand). ~~Furthermore, such technologies are suitable for downscaling, which can be an advantage in some cases (e.g. in-situ biomass processing).~~ They are well suited to continuous processing and can be conveniently coupled with real time monitoring and control systems. From a sustainability point of view they are able to bring the right amount of energy on the right place in the reaction and increase in that way efficiency and energetic productivity. However, further research and upscaling work is needed before the full potential of non-conventional energy powered processes can be widely deployed on an industrial scale. Cross-sectorial aspects can be provided by converting waste heat into new non-conventional energy sources to be used by other industrial sectors. Types of actions / projects needed include:* Set up of pilot plants for process industry making use of non—conventional energy sources
* Linking of these energy sources to renewable electricity
* Comparison between innovative use and conventional use in the process
* System that pays attention to energy losses or efficiency (e.g. by converting non-conventional energy from processes or reactions into energy)

The system described could be combined with New energy sources, meaning not only non-conventional energy but also distributed renewable generation.Finally, further solutions for value chain optimisation through addressing energy efficiency considerations in the design phase of manufacturing equipment and processes, collective demand side strategies, and potential integration of the nearby renewable energy sources should be also considered. |
| **Impact:** The proposals should start on low to medium TRL levels mainly targeting research and demonstration of the proof of principle at small scale or start at lower medium TRL and go to the demonstration of in an industrial relevant environment. The proposals should pay attention to the scale up principles that can be applied when the concepts would go to the innovation phase. Furthermore, the developments should clearly indicate how the use of sustainable electricity could contribute to industrial symbiosis between the decentralized production of energy and materials (e.g. chemicals, metals, cement, minerals), with a significant impact on the sustainability profile of the process and or the products made in the process. It should clearly address as well the challenges a fluctuating energy input has. This should be supported by a quantitative LCA analysis.- Show potential for integration of the technology with renewable energy sources such as wind and photovoltaic. - Improvement in energy efficiency of 40% compared to the current state of the art process (or similar one).- Decrease in CO2 emissions by 50% (without considering the electricity generation and at steady state) compared to the current state of the art process (or similar one). - Decreased OPEX and CAPEX by 20% compared to the current state of the art process. **- Primary energy saving potential in percentage and in** 10.000 to 50.000 ktoe/a(assuming full deployment in the EU28)**- GHG emission saving potential in percentage and in** 40.000 to 100.000 ktCO2eq/a(assuming full deployment in the EU28)Provided data to be considered as an initial estimation. |
| **TRL:** 4-9 |
| **Total budget required:** 20 – 30 million euro per project (TRL 4-6) and 10-20 (TRL 6-9), recommended.Due to the diversity of the different scenarios depending on the sectors, we encourage to cover from a low TRL as 4 while reaching up to TRL 9 in other sectors. |
| **Expected deliverables** | **Timeline** |
| *Fill in one line per deliverable** *Preparation of several processes based on non-conventional energy use*
* *Pilot plants operational at TRL 7-8*
* *Demonstrations at TRL 8-9*
* *Calculations on energy efficiency and productivity including other savings*
 | *36 – 48 Months / project recommended* |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| * *Electrification of chemical processes*
* *Application in the steel and minerals industry*
 | * Funds at EU level should be guaranteed in order to achieve true cross-sectorial EU dimension of technologies development and demonstration (e.g. H2020, FP9 et al.)
* Other complementary funds or tools could cover specific territorial interests (e.g. national or regional funds) or support deployment (e.g. Investment and financial instruments from EIB, ETS Innovation Fund et al.)
 | *To be provided at a later stage* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| Development of new processes using renewable energy  | Developing a high temperature (800-1000°C) 24h/day solar process suitable for particle treatment in non-metallic minerals’ industries, developing new concepts in electro-geochemistry and geological engineering (combined heat, power and metal extraction) for a new generation of geothermal energy will contribute to an optimised feedstock mix for the energy-intensive industries.Horizon2020 projects: SOLPART, CHPM2030 | 2016 - 2020 | EU grant: Universities, RTOs, Industry  | NA |
| The use of non-conventional fossil natural resources | Exploring the possibilities of using CO2/CO containing process gases as new feedstock for producing high-value chemicalsHorizon2020 projects: CarbonNext | 2016 - NA | EU grant: Universities, RTOs, Industry | NA |
| Adapting industrial processes to use of renewables (biomass, residue and waste gas conversion) | The adapted processes need to be able to cope with the seasonal or even daily fluctuations of the renewable source. The unit should also be able to process feedstock from different sources in order to guarantee the level of supply.Horizon2020 projects: SteamBIO, MefCO2, MOBILE FLIP | 2015 - 2018 | EU grant: Universities, RTOs, Industry in 12 EU countries | ~28M€ |
| **Gaps**: * Pilot scale facilities need to be built. At the moment, most of the results are obtained in rather small to lab scale installations
* Processes need to be converted from batch into continuous and this needs a new way of monitoring as well
* These processes cannot be up scaled on existing plants and need new installations, meaning a high CAPEX-cost
* Efficient conversion of renewable energy into the new energy sources is still an issue
* A good LCA study will be necessary to show the additional savings (on top of the energy savings)
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**Strategic Energy Technology Plan**Action 6
"Make EU industry less energy intensive and more competitive"

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 5-System Integration |

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| **Activity number**: 5.2 (the numbering remains 5.2, it integrates Fiche 1B-1a) |
| **Title: Digitisation: Further integration in process and plant management including plant/process design phase and processing plant retrofit** |
| **Targets:** Process control and process automation solutions to enable small and large industries efficient plant design and operation leading to reduced energy consumption and GHG emissions. | **Monitoring mechanism**: Level of development of deliverables |
| **Description:** All areas of process industries are highly dependent on efficient plants and process chains. To reach a **significant step forward on energy efficiency** compared to today’s industrial reality, new ways to improve flexibility in plants, optimise consumption and reduce GHG emissions are necessarily driven by digital technologies and process automation.In order to drive continuous sustainable progress and innovation in the process industry, to effectively enable improved resource and energy efficiency, enriched process understanding and evaluation of the impact of each decision from early process/plant design phase to production management is essential. Hence, process design, engineering methodologies and systems engineering methods and tools, such as process modelling, simulation and control strategies, are essential to support decision making as regard to all aspects including feedstock, energy management, production pathways, extrapolate and catalyse the dissemination of advanced process technologies, into all kinds of production units and optimize asset management and also explore industrial symbiosis between process industries sectors. Linking process modelling capabilities with eco-efficiency and economic models is also a requirement for qualified, knowledge- based decision making for sustainable chemical production.**Sustainability evaluations** require lots of data, expertise and effort. Consequently, these detailed analyses can often only be done at higher Technology Readiness Levels, by which point they are less able to influence the design decisions being made in the chemical industry. Bringing appropriate sustainability assessmentat lower TRLs (starting ~TRL 4) of the process/product development where it can make a larger impact is therefore essential and would require the development of an appropriate software platform integrating sustainability advanced assessment tools, process and plant design tools, and databases.A major breakthrough would be the availability of a **software platform(s) for sustainable digital engineering** with simulation capabilities along the whole life-cycle of a plant specifically in early design phases of processes and plants. Such a platform integrating sustainability assessment along the whole life cycle of a plant, would support optimal product and process design, plant engineering, procurement, plant construction, commissioning, possible operation modifications, as well as plant flexibility, extensions and reuse for next generation and new products.During plant operation, **cognitive equipment and plants** retrieving information from sensors for continuous and batch-processes are essential to optimize production operations. This is linked with simulation capabilities including combined multi-scale and multi-physics first principle models and data analytics in high performance computing environment to enable cyber-physical systems for the online plant control and management. In this context, attention is focused on recognition of unusual situations, proposal of optimized recovery measures, condition monitoring and processing of environmental targets, energy consumptions, emissions, including retrofit of process industries ‘brownfield’ assets.  |
| Furthermore, advanced data analytics would allow companies to convert various type of data (from R&I, engineering, production, asset management, marketing, sales, other production site, etc.) into knowledge in real-time, and effectively contribute to more sustainable manufacturing processes with more resource and energy efficiency on production sites and potentially between industrial sitesImplementation of concepts across sectors to introduce energy and resource efficiency indicators with operator friendly dashboard concepts, increase operator’s awareness and influence on plant condition and efficiency. In many process industries sites, indicators that are in use are very aggregated, for example the energy used per ton of a product for a whole plant, or site. Such highly aggregated indicators do not provide enough information on the performance of subunits and the possible root causes of deviations of the performance from its ideal/usual value. The target of projects should be to visualize sector-relevant REI on energy and resources, including the challenging goal to utilize them in real-time optimization in combination with advanced process control systems.**Specific developments (actions or projects) should therefore include:**1. New reliable hard and soft sensors to enable advanced inline process and product measurement systems as inputs model based control of process and process chains
2. Development of an appropriate software platform integrating sustainability advanced assessment tools, process and plant design tools
3. Integration of energy and resource efficiency indicators in process automation systems
4. Develop advanced simulation capabilities including combined multi-scale and multi-physics first principle models and data analytics in high performance computing environment to enable cyber-physical systems for the online plant control and management
5. Simulation capabilities along the whole life-cycle of a plant specifically in early design phases of processes and plants, use ‘digital twins’ as simulation tool
6. Overcoming the modelling bottleneck, reduce the effort for modelling, improve model re-use, and develop strategies for model maintenance and adaptation, “living” models
7. Combined use of rigorous models and data analytics for the recognition of unusual situations in complex plants and the proposal of adequate measures
8. Integration of control, scheduling, planning and demand-side management
9. Humans in the loop - what is the role of humans in the operation of plants in the process industries, how can their role and their knowledge and experience be optimally combined with advanced control algorithms and optimization, how can humans supervise complex computer-based solutions; this includes but is not restricted to human-machine interfaces Strategies to efficiently retrofit process automation in brownfield plant/side environments
10. More resilience against cyber-attacks including identification and real-time counteracting
11. Explore the possibilities of having a micro grid between industries, which includes distribution, consumption and storage of energy (conventional, alternative, renewable), as well as advanced monitoring, control and automation systems though IT systems.

**Such integrated systems would enable:*** Optimized (re-)design of processes and plants including for structures, equipment, piping etc.
* Predictive assets management leading to maximum asset utilization, less downtime and less energy consumption
* Optimized production
* Demand forecasting and supply chain optimisation
 |
| **Impact:** Advanced online monitoring is expected to play a key role to achieve **significant energy efficiency improvement** in the European process industry. Recent projects report energy efficiency improvement between 5- 15%, but specific impact will actually depend on current level of energy efficiency of each site. Advanced **sustainability assessment tool and integration in process modelling/design tools** supporting early decision making and digital engineering would enable improved design of new plants and optimized valorisation of **existing assets (brownfield) to be re-designed** with expected high GHG saving potential.Improved capabilities for valid, reliable and real-time control logics of the properties and quality of process streams and final products for existing and for more flexible process operation concepts:* Strengthening of the competiveness of the European industry both in the domain of measurement technologies and control solutions and with respect to economically sustainable industrial processes
* Retention and creation of jobs for the European measurement and automation and process industries

- Primary energy saving potential in percentage and in ktoe/a (assuming full deployment in the EU28)- GHG emission saving potential in percentage and in ktCO2eq/a (assuming full deployment in the EU28)To be provided at a later stage as it needs to be assessed further by the process industry sectors. Current analysis is not yet consolidated |
| **TRL:** Advanced research and Industrial research & demonstration ; TRL 4-5 to TRL 8 |
| **Total budget required**  20 M euros per project recommended |
| **Expected deliverables** | **Timeline** |
| * Advanced sustainability assessment tool and integration in process modelling/design tools for decision making starting at TRL 4 (of process/product development phase) including connection to data platforms
* Advanced energy and resource management control strategies integrated into process automation systems and plant operator’s tasks
* Software platforms for optimized digital engineering and plant design, re-design/upgrade and plant management
* Cognitive equipment and plants systems including advanced process control and monitoring technologies and model based control for optimized production automation.
* Specification of electrical network of the companies involved
* Conceptual Design/ Software Prototype of the network (Wireless-Transmission-System, system performance report, etc.)
* System Integration and Validation Test Plan/ Report
* Pilot preliminary evaluation
 | Projects of 36 to 48 months are recommended |
| **Parties / Partners**(countries / stakeholders / EU) | **Implementation financing / funding instruments** | **Indicative financing contribution** |
| * It might be beneficial to all EU countries.
* In all cases, industrial sites and clusters are at the core of those initiatives as integration of IT systems could transform the way they operate thoroughly.
* Industries with waste heat could be interested (for example, cement, glass ceramics, etc.)
 | * Funds at EU level should be guaranteed in order to achieve true cross-sectorial EU dimension of technologies development and demonstration (e.g. H2020, FP9 et al.)
* Other complementary funds or tools could cover specific territorial interests (e.g. national or regional funds) or support deployment (e.g. Investment and financial instruments from EIB, ETS Innovation Fund et al.)
 | *To be developed at a later stage* |

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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal** |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| Integrated control of industrial processes | Sensor technologies, data mining and management, integration methodologies within different production conditions and their application across sectors will make the process operations more energy efficient, more sustainable and more flexible.Horizon2020 Projects: RECOBA, ProPAT, DISIRE, CONSENS, iCspec  | 2015 - 2019 | EU grant: Universities, RTOs, Industry in 15 EU countries | ~25M€ |
| Integration of unit control systems into whole-plant operations monitoring | The development of dynamic overall plant models, robust scheduling system and real-time optimisation of the plant's operations, accounting for geographic and logistic constraints, potential malfunctions and providing the necessary interfaces for real-time communication between systems.Horizon2020 Projects: CoPro, MONSOON, FUDIPO, COCOP | 2016 - 2020 | EU grant: Universities, RTOs, Industry in 16 EU countries | ~24M€ |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goal include:* Lack of workforce educated to use digital technologies as central sources for process optimization, control, smart data applications and plant maintenance
* Need to improve standardization of software interfaces
* Need for efficient and safe use of cloud/data platforms/computing possibilities
* Need for advanced and reliable process analytics (e.g. cognitive-computing, data-utilization of high performance computing (HPC)
* Need for methodologies to retrofit brownfield assets
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**Strategic Energy Technology Plan**Action 6
 "Make EU industry less energy intensive and more competitive"

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| Implementation Plan – Activity Fiche |
| **Main key Action:** Action 6: Energy Efficiency in Industry**Priority Name**: 5- Improving system integration, optimal design, intelligent and flexible operation, including industrial symbiosis (within the principles of circular economy), to increase energy and resource efficiency while striving to reduce GHG emissions |

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| **Activity number**: 5.3  |
| **Activity Leader:** *European Platform of Universities in Energy Research and Education (EUA-EPUE)* |
| **Title:** a concise but informative title of the R&I Activity (max. two lines)*Improving exchange of technological, economic, behavioural and social knowledge; training, capacity building and dissemination* |
| **Targets:** the targets of the Declaration of Intent the Activity will help to achieve*R&I Targets (baseline 2015): By 2025, develop and demonstrate solutions enabling small and large industries to reduce their energy consumption by 20% while striving to reduce GHG emissions proportionally.* | **Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS*Observation of results based on the indicators included in the “Declaration of intent” and in the section “Impact” of this Activity Fiche:*- **Market stakeholders with increased multidisciplinary skills/capability/competencies** (for example to be measured in number of people participating in trainings, workshops, mobility schemes etc. including either short-term or long lasting tools)- *“Impact”*- **Number of people/enterprises engaged in activities contributing to enhanced energy culture** documenting why and how changes are an effect of particular measures taken, as well as in terms of the sustainability of the behavioural change - *“Impact”***- Reduction of “energy intensity”,** i.e. reduction of the ratio of energy consumption to turnover (MJ/€), and the same for the CO2, i.e., kgCO2/€. |
| **Description:** a summary of the R&I Activity including the goals and a justification of why the Activity is key*In accordance with the principles of a circular economy, this R&I Activity should aim at* *increasing cooperation between major stakeholders* (*academia, industry, authorities, research institutions, communities) in order to adopt a total industrial district approach opened also outside industrial plant perimeters (e.g. buildings, DHC, etc). All energy providers and users as well as major stakeholders should be adequately involved in the process. For example:* ***Mapping the methodological approaches and tools available in academia, research organisations and best practices from industry*** *(the evaluation of energy efficiency methodological approaches and tools should also include carbon footprint impact). Maps should be accessible to industry and should be disseminated to training providers in order to coordinate training efforts across Europe. These tools may be applied for example to diagnosis, evaluation and optimisation of energy efficiency of systems and processes. The possible actions proposed could be** *Developing networks of pilot plant installations for highly advanced energy efficiency technologies.* The objective is to *generate optimal technology networks in order to utilise resources and transform them to useful products and energy services.*

Contributing to the development of innovative business and contracting models along the value chain, also facilitating actual implementation of energy cooperation between businesses and between universities, research organisations and businesses.This would allow fostering collaboration from lab to pilot scale and from pilot scale to industrial demonstration.***Improve the level of awareness and overall ‘energy culture’ of industrial companies and SMEs*** *(as indicated in SET-Plan Integrated Roadmap, Annex I, Part I Energy Efficiency, p61-2, `INNOVATIVE AND MARKET UPTAKE PROGRAMME`). This includes:** *Providing exchange of knowledge between universities, research organisations and industry, including training to industry on how to best use methodological approaches and tools available in academia and research organisations.*
* *Providing training and capacity building programmes to industry staff at all levels towards the promotion and implementation of an energy efficiency culture in industry. A clear participation of both managerial and operational staff must be ensured.*

*This objective should duly take into account the impact of policy measures in improving the energy culture of industrial companies and SMEs.* |
| **Impact:** **- Market stakeholders with increased multidisciplinary skills/capability/competencies (**for example to be measured in number of people participating in trainings, workshops, mobility schemes etc. including either short-term or long lasting tools)- **Number of people/enterprises engaged in activities contributing to enhanced energy culture** documenting why and how changes are an effect of particular measures taken, as well as in terms of the sustainability of the behavioural change- **Reduction of “energy intensity”,** i.e. reduction of the ratio of energy consumption to turnover (MJ/€), and the same for the CO2, i.e., kgCO2/€. |
| **TRL:** *TRL at start: 5 (Methods, technologies and pilot plants are already available); TRL at the end: 7 (The tools, methods shall be utilised in industrial practice and design). Start TRLs below 5 should be considered in the case of start-ups, spin-offs or innovative businesses at early stages of their creation and development. Concerning training and capacity building activities, the TRL at the end would be level 9.* |
| **Total budget required**between EUR 1 and 2 million per project/deliverable |
| **Expected deliverables** | **Timeline** |
| 1. ***Maps*** *related to energy efficiency in industry as detailed below [[21]](#footnote-21).*
	1. *Mapping of a “network of pilot plant installations” in universities, other research organisations and industry. The mapping of pilot plant installations must be accompanied by the development of innovative business models on how to jointly utilise such installations to reduce time to market. It should include also innovative business and contracting models contributing to increase energy cooperation between businesses with a view to better industrial symbiosis.*
	2. *Mapping of existing business and contracting models as explained in deliverable 3. This would as well create synergies with the previous point on mapping of pilot plant installations.*
	3. *Mapping of methods: analytical methods and simulations aiming at improving value chain optimisation (‘total industrial district’ integration as well as industrial symbiosis and symbiosis between industry and buildings, in the wider context of a circular economy). For all these approaches there are numerous methods available in universities, research centres, companies and other stakeholders.*
2. ***Dissemination activities and training courses on energy and resource efficiency:*** *Training in analysis methods and value chain optimisation methods for energy and resource efficiency. These training and dissemination activities can be targeted towards SME and larger industry, helping the transfer of new technology and scientific knowledge generated by universities and research centres to business or from businesses to businesses. Cross-border collaboration among industries should be fostered and peer-to-peer exchange should be facilitated. The expected results would be an improved energy culture of industrial companies and SMEs towards energy efficiency. A map of educational professional training bodies should facilitate this task.*
3. ***Analysis of existing business and contracting models and proposals for new business and contracting models, taking into account organisational, financial, legislative, social and technological barriers.*** *This activity would contribute to increase energy cooperation between businesses in view of industrial symbiosis under the principles of a circular economy. Similar to deliverable 1 and 2, existing business models including especially the innovative ones should be mapped. Based on those, innovative models should be proposed.*
4. ***Guidelines on multidisciplinary approaches*** *in higher education and research programmes (particularly in Master, Doctorate and Research Programmes) for industrial processes and development of innovative business models. These guidelines should become a reference point for the upgrade of existing programmes or the generation of new ones.*
 | Project Month (start = project Month 0) |
| **Parties / Partners** (countries / stakeholders / EU)*Stakeholders: academia, industry, research institutions, financial institutions, local and national authorities, communities* | **Implementation financing / funding instruments**A mixture of national, European and private funding  | **Indicative financing contribution**between EUR 1 and 2 million per project |
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| **Ongoing R&I Activities (Flagship activities or not): relevant to this new activity proposal***Below some specific examples of successful projects and initiatives:** *The Energy Efficiency Platform: tool provided by the JRC to facilitate knowledge exchange in the online community of energy efficiency experts[[22]](#footnote-22).*
* *Previous and ongoing* [*Intelligent Energy Europe*](https://ec.europa.eu/energy/intelligent/) *(IEE) and Horizon 2020 Energy Efficiency projects supporting capacity building and increasing knowledge on energy efficiency in industries. The list of projects and programmes relevant to this activity which are gathered in CORDIS and in the IEE project database or in other information systems of the European Commission could be collected in a unified excel document. The exercise would facilitate the identification of specific gaps and shortcomings.*

*National strategies such as in Sweden and Germany* * *UNI-SET: UNIversities in the SET-Plan[[23]](#footnote-23). Contributes to:*
	+ *Deliverable 1 through the* [*European Atlas of Universities in Energy Research & Education*](http://universities.uni-set.eu/Survey/Intro)
	+ *Deliverable 2 and 3 by facilitating the exchange of information about training, dissemination and business models in the framework of the* [*Energy Clustering Events*](http://uni-set.eu/index.php/events/clustering-events)
	+ *Deliverable 4 through the Roadmap for European Universities in Energy.*
* *Bio Energy Train[[24]](#footnote-24) Curricula development for Biorefinery Engineers and Bioresource Value Chain Managers. . Contributes to:*
	+ *Deliverable 2 through the training of students in key bioenergy disciplines in two new Master curricula “Bio refinery Engineer” and “Bio resource Value Chain Manager”*
	+ *Deliverable 4 through linking business and Higher Education Institutions (HEIs) on bioenergy education and creating regional outreach networks and quality standards*
* *“Support and Training for an Excellent Energy Efficiency Performance” (STEEEP[[25]](#footnote-25)) project. Contributes to:*
	+ *Deliverable 2 through cross-sector tailored training and guidance to SMEs on effective energy management tools and practices*
	+ *Deliverable 3 through knowledge sharing on innovative business models at SME level*
 |
| **Name** | **Description** | **Timeline** | **Location/Party** | **Budget** |
| *Fill in one line per ongoing R&I Activity* | explanation on how its contributes to the target(s) and, if it is the case, why it is considered as Flagship activities | start and end dates | (countries / stakeholders / EU) | M€ |
| **Gaps**: Barriers or shortcomings that stand in the way of meeting the goal*Lack of awareness; lack of knowledge; lack of tools* |

1. Energy Union Package, COM (2015)80 final. [↑](#footnote-ref-1)
2. (C(2015) 6317 final). [↑](#footnote-ref-2)
3. https://setis.ec.europa.eu/system/files/integrated\_set-plan/declaration\_action6\_ee\_industry\_0\_0.pdf [↑](#footnote-ref-3)
4. Final energy consumption, EE potential, Energy intensity: ICF 2015a, based on Eurostat 2013 data for EU28 [↑](#footnote-ref-4)
5. No of employed (2012), Value added (2013): Eurostat [↑](#footnote-ref-5)
6. Energy saving potential considering a deployment by 2030 of the technologies that are today already existing and economically viable with a payback not longer than 2 years. (source: ICF2015a, not endorsed by industry) . [↑](#footnote-ref-6)
7. Sum of energy saving potentials of all technically feasible technologies, regardless of economic or mutual compatibility constraints (source: ICF2015a, not endorsed by industry) [↑](#footnote-ref-7)
8. Energy cost intensity, i.e. the proportion of the energy cost in the value added of the product [↑](#footnote-ref-8)
9. Stakeholders agreed a payback of 3years (not 2) is more realistic (vs energy prices) and still a reasonable economic threshold [↑](#footnote-ref-9)
10. There is no ranking among the five priorities. They are numbered for easy reference. [↑](#footnote-ref-10)
11. Businesseurope has been consulted but is not part of the agreement [↑](#footnote-ref-11)
12. Concawe has been consulted but is not part of the agreement [↑](#footnote-ref-12)
13. Orgalime has been consulted but is not part of the agreement [↑](#footnote-ref-13)
14. <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52014XC0627(01)> [↑](#footnote-ref-14)
15. <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014XC0628%2801%29> 6 [↑](#footnote-ref-15)
16. <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C_.2014.188.01.0004.01.ENG> [↑](#footnote-ref-16)
17. <https://ec.europa.eu/commission/commissioners/2014-2019/oettinger/blog/luxembourg-launches-supercomputing-project_en> [↑](#footnote-ref-17)
18. <http://s3platform.jrc.ec.europa.eu/> [↑](#footnote-ref-18)
19. <http://www.eib.org/efsi/>; <https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan_en> [↑](#footnote-ref-19)
20. Could be interesting for R&I projects in the steel industry requiring co-funding of not more than around EUR 3 million (<http://ec.europa.eu/research/industrial_technologies/rfcs_en.html>) [↑](#footnote-ref-20)
21. For example, to be added to the collection of maps in the European Atlas of Universities in Energy Research & Education, available at: <http://uni-set.eu/index.php/atlas/>. The Atlas includes (among other data) relevant information of master, doctorate and research programmes in the field of energy efficiency. [↑](#footnote-ref-21)
22. https://e3p.jrc.ec.europa.eu/ [↑](#footnote-ref-22)
23. http://www.eua.be/activities-services/projects/current-projects/research-and-innovation/uni-set.aspx [↑](#footnote-ref-23)
24. http://www.bioenergytrain.eu/ [↑](#footnote-ref-24)
25. www.steeep.eu [↑](#footnote-ref-25)