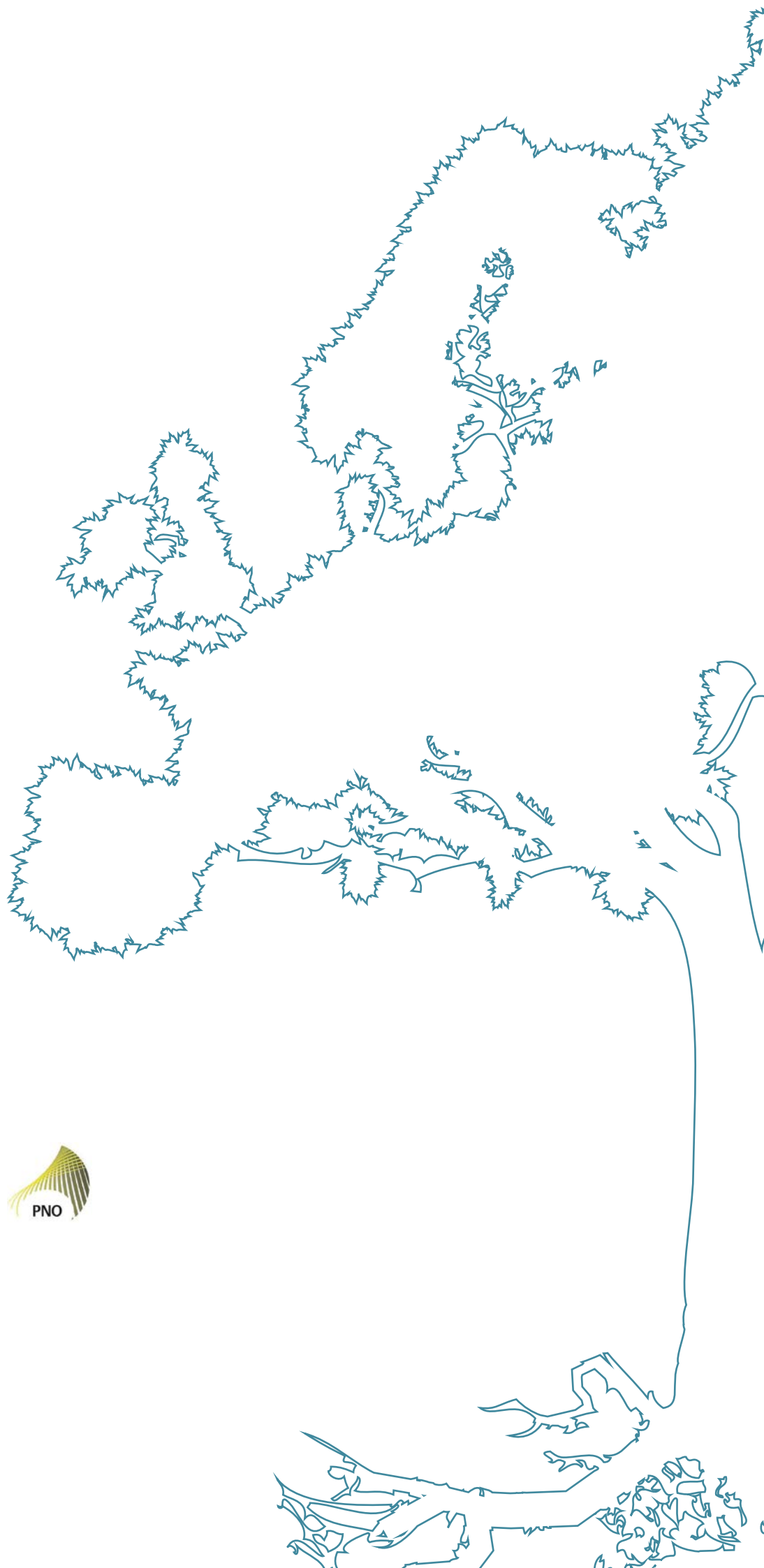


SPIRE ROADMAP

FOR MORE INFORMATION ON SPIRE:
WWW.SPIRE2030.EU





Developed and written
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EXECUTIVE SUMMARY

SPIRE for EUROPE2020

The Sustainable Process Industry through Resource and energy Efficiency (SPIRE) is a proposal for a Public Private Partnership (PPP) driven by the European Process Industry and fully aligned with the strategic goals defined by the European Commission in the Europe 2020 strategy and across its various flagship initiatives such as the “Innovation Union”, an “Industrial Policy for the Globalisation Era”, “Resource efficient Europe” and an “Agenda for new skills and jobs”. The realization of SPIRE is essential in order to rejuvenate the European process industry, to make it more competitive and sustainable, and lead to European growth and jobs.

The European process industry is uniquely positioned to drive the work towards these objectives as it represents the economic roots of the European economy (by transforming raw materials into intermediate and end-user products). It thus sits at the core of most industrial value chains via discrete manufacturing into e.g. automotive and housing sectors. SPIRE brings together cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, steel and water sectors, several being world-leading sectors operating from Europe. All having a high dependence on resources (energy, raw materials and water) in their production and striving for long-term sustainability, they all have a clear and urgent interest in improved efficiency and competitiveness which will actually drive the implementation of many European policies. The sectors united in SPIRE represent a major part of the manufacturing base in Europe (EU27), including more than 450,000 individual enterprises. They have over 6.8 million employees, generating more than 1,600 billion € turnover. As such they represent 20% of the total European industry, both in terms of employment and turnover.

The magnitude of the societal challenges to which the process industry is of strategic importance and the magnitude of the challenges facing the process industry itself have made clear in the last couple of years that industry cannot tackle these issues alone. These facts call for a joint public-private endeavour and a collaborative approach towards:

- The existence of market failures (where environmentally and socially desirable improvements are not necessarily economically viable at early stages of technology development);
- high risks and long-term investments with long return on investment timeframes inherent to these sectors;
- the need for long-term cooperation along the value chains that can make a difference for Europe's competitiveness at global level;
- the complexity of and the synergies needed between the new technologies and business models (within and between the process industry sectors) that would be able to put the European industry ahead in the race for competitiveness and sustainability.



SPIRE Research & Innovation Agenda

The cross-sectorial and holistic SPIRE research and innovation roadmap that is presented here provides the pathway for the process industry to decouple human well-being from resource consumption and achieve increased competitiveness in Europe. It is the result of:

1. an extensive process of cooperation and coordination of the innovation and business strategies of the eight SPIRE industry sectors (along and across their value chains),
2. an extensive process of exchange with and input from the wide range of the SPIRE research and technology organisations (RTOs) and academia across disciplines,
3. a consultation with other sectors like glass, paper and pulp,
4. consultations with the European Commission services, and
5. a wider audience through a public consultation¹.

SPIRE will implement its research and innovation roadmap through six Key Components that are at the core of a resource and energy efficient process industry:

1. **Feed:** Increased energy and resource efficiency through optimal valorisation and smarter use and management of existing, alternative and renewable feedstock.
2. **Process:** Solutions for more efficient processing and energy systems for the process industry, including industrial symbiosis (e.g. cross-sectorial application of technologies).

3. **Applications:** New processes and materials for market applications that boost energy and resource efficiency throughout the value chains.
4. **Waste2Resource:** Avoidance, valorisation and re-use of waste streams within and across sectors, including recycling of post-consumer waste streams and new business models with the ambition to closing the loop.
5. **Horizontal:** Accelerated deployment of the R&D&I opportunities identified within SPIRE through e.g. robust sustainability evaluation tools, skills and education programmes, as well as enhanced sharing of knowledge and best practices.
6. **Outreach:** Reach out to industry (especially SMEs), policy makers, investors and citizens to support the realisation of impact through awareness, stimulating societal responsible behaviour.

This roadmap will be updated through an open and consultative process during the lifetime of the PPP to reflect progress as well as possible changes in priorities. Key Actions have been developed for each Key Component, enabling an ambitious, realistic and measurable agenda-driven approach towards fulfilling the SPIRE objectives and consequently achieving impact to overcome technological and non-technological barriers.

SPIRE ambitions

Through this roadmap, SPIRE aims at integrating, demonstrating and validating systems and technologies capable (across all SPIRE sectors) of achieving two key resource and energy efficiency² targets:

- A reduction in fossil energy intensity of up to 30% from current levels through a combination of, for example, introduction of novel energy-saving processes (including enhanced use of optimisation techniques, monitoring and

¹ See Annex I "Results of the Public Consultation"

² Energy and non-renewable, primary raw material intensity are definitions based on Eurostat data, and definition of 'current level' is the period 2008-2011.

modelling via ICT tools), process intensification, energy recovery, sustainable water management, cogeneration-heat-power and progressive introduction of alternative (renewable) energy sources within the process cycle.

- A reduction of up to 20% in non-renewable, primary raw material intensity compared to current levels, by increasing chemical and physical transformation yields and/ or using secondary (through optimised recycling processes) and renewable raw materials. This may require more sophisticated and more processed raw materials.

For both targets a life cycle analysis is required to consider effects along the value chain and to demonstrate the sustainability advantage. In addition both targets will make a significant contribution to the political and societal objectives of drastic efficiency improvement in CO₂-equivalent footprints of up to 40%.

SPIRE added value

For the first time, SPIRE brings together at least 8 sectors within the process industry in a value chain and objective-driven programme that wishes to benefit from this multi-sectorial approach by:

- identifying innovations in one sector that have proven to increase resource and energy efficiency and that can be adapted and transferred to another sector, accelerating the innovation rate and the positive environmental and competitive impacts within the industry and along the respective value chains
- co-developing solutions for resource and energy efficiency within the sectors and across value chains through converging technologies (e.g. steel and chemistry, or minerals and water, etc)
- using technology building blocks across sectors such as modelling, monitoring and automation
- developing innovations targeting multi-sectorial deployment along the value chains with the aim to increase impact of such innovations in Europe

The current roadmap represents a coordinated and integrated framework from research to business following a staged approach with short-term, medium-term and long-term objectives and

benefits. It allows therefore a strategic and time-framed basis for driving and investing in specific innovation areas that are concretely and practically contributing to achieving the sustainable growth objectives. It represents an articulation of the various sectorial innovation priorities and agendas for the next years that will provide a synergistic effect (i.e. "1+1=3") compared to individual initiatives. It requires but also guarantees therefore sustained effort and investment over multiple years.

The establishment of A.SPIRE aisbl with open membership to members from industry, research and technology organisations, universities and other stakeholders and associations working in the field of resource and energy efficiency for the process industry, representing the private side in the partnership, shows, on the one hand, the strong attraction that this PPP has as a common and shared long-term vision in the process industry sectors and, on the other hand, enables a steady and rigorous follow-up on the implementation of the roadmap and its strategic re-adaptation to meet the set objectives. This will be measured by a defined set of KPIs.

In these areas of high capital-intensive process industries that need long-term investment plans where risks are rather high due to long return on investments, a strategic agenda-driven public-private partnership offers a certain security of political drive and commitment (along with a kick-start Horizon2020 financial contribution) for the European process industry, as compared to individual calls.

Based on the estimated industrial contribution from the various sectors in research, pilot and demonstration projects that fall within the scope of SPIRE, the private contribution to the PPP budget is estimated at around 1.4B€. SPIRE looks for co-funding under the Horizon 2020 framework programme as well as other programmes.

With sectors such as chemicals, steel, cement that show a large number of important production operations throughout Europe, the SPIRE innovation and retrofitting potential (in line with further specialisation of the sectors such as high-tech steel and specialty chemicals and combined with stricter environmental standards) is enormous. As such the current manufacturing facilities establish an enormous leverage base for SPIRE innovation, in some cases (e.g. new process control) offering double digit replication potential compared to the initial single pilot project in which a novel SPIRE technology will be proven and demonstrated. As the chain of



development goes through many steps with corresponding increased amounts of investment, support measures such as the PPP are needed to cross the valley of death from laboratory level technology to mini-plant or pilot and further to the build-up of demonstration capability. Once there is successful technology demonstration in SPIRE, the most expensive step of deployment (typically with factors of 5 to 10+ higher than for a demonstration capability) will be made by industry.

Given the nature of the process industries, having one step into downstream markets and inducing a wide range of new infrastructure and service markets development, SPIRE is also looking for further downstream innovation activities in order for the products / processes to reach the market or create / develop new markets (e.g. environmental technologies and renewables³) for the process industry itself and for downstream industries. This would also allow for an impact at, on the one hand, continent scale through technology transfer, standardisation, within and between sectors involved in (or related to) SPIRE. On the other hand, it benefits regional and local scale industry through dissemination and adaptation to specific needs and markets, often involving SMEs. The role of the European associations, RTOs and technology platforms of SPIRE is key to achieving this objective.

A couple of examples of concrete cross-sectorial impacts of successful SPIRE projects could be cited such as:

- recuperation of 15% heat loss and the associated reduction of energy costs and of CO₂ emissions through process optimisation
- 20-50% energy reduction in industrial processes through new energy storage systems
- 10-20% less production time and 10% less off-spec products through sensor-enabled refractory materials
- 30% higher asset utilisation of wind and solar installations through hydrogen production
- 20% more resource efficiency through more efficient ovens, furnaces, boilers, separators, pumps, heat exchangers and systems
- laying the foundations of a CO₂ economy by using CO₂ as a renewable feedstock, reducing the pressure on fossil fuels, biomass and land use substantially

The progressive execution of the SPIRE roadmap will address also the socio-economical dimension as there will be an increased demand for professionals with (new or adapted) skills, for the process industry but also for the related and spin-off industries, facilitating the transition to a greener and more competitive European industry. Workforce training and education programmes across and within sectors will be one of emphasised components of the business uptake strategies.

The SPIRE PPP has defined its scope and strategy as a vital complement to the existing and proposed initiatives under Horizon 2020. At its boundaries, it has identified synergies and established docking points with other PPPs. These will be formalised once the programmes start running. Furthermore, SPIRE is unique in having established links with the other societal challenges oriented innovation initiatives such as the European Innovation Partnerships on Water, Raw Materials and Smart Cities and Communities, and the Key Enabling Technologies; through the active involvement of its members, the SPIRE technological solutions have been introduced in the development of the EIPs with the expectations that the EIPs will address the non-technological barriers in these areas.

The commitment and dedication of the SPIRE stakeholders to the vision and objectives are demonstrated through the bottom-up approach of its initiators, driven by a need and desire to grow in the European region and based on the opportunity seen for doing this through Sustainable Innovation resulting in a globally competitive lead. The SPIRE R&I roadmap, its vision and objectives are the result of over two years of extensive consultation and confirmation, taken spontaneously by the partners in the private sectors. At various stages the *raison d'être* and the impact for Europe of the SPIRE PPP have been confirmed by the European Commission through letters from the Commissioners of DG RTD, ENTR, ENV, ENER, TRADE, as well as by the incorporation of Sustainable Process Industry into the Horizon 2020 proposal in November 2011.

This contractual PPP, based on the Article 19 of the Horizon 2020 Regulation, is foreseen to be established through a contractual arrangement between the European Commission and A.SPIRE aisbl and based (through its governance structure) on the principles of constructive exchange, openness, transparency and, most of all, on the commitment to a shared vision (as outlined in this roadmap) and to success.

³ See page 62 for estimations of markets volumes





PART 1. VISION 2030

Background of the SPIRE initiative

The SPIRE PPP will be instrumental in addressing the **Grand Societal Challenges defined within the EUROPE 2020 Agenda** through the broad correlation that SPIRE has across various flagships initiatives (Innovation Union, Resource Efficient Europe, New Skills for New Jobs and Industrial Policy for the Globalisation Era).

In the latter initiative the European Commission specifically addresses the need for public-private collaborations to ensure uptake of resource and energy efficiency innovations:

“ IN THE CONTEXT OF THE DISCUSSION ON FUTURE RESEARCH PUBLIC-PRIVATE PARTNERSHIPS, CONSIDER AN ENERGY-INTENSIVE INDUSTRIES LOW CARBON IMPLEMENTATION INITIATIVE, BRINGING TOGETHER THE RELEVANT TECHNOLOGY PLATFORMS WITH THE EU AND MEMBER STATES, TO ENSURE THE APPROPRIATE R&D, FINANCING AND DEPLOYMENT STRATEGIES FOR LOW-CARBON PRODUCTION⁴. ”

The process industry is uniquely positioned to drive this initiative as it transforms raw material feedstock into intermediate and end-user products and thus sits at the core of every value chain. There it fulfils an enabling role for improved competitiveness whilst drastically reducing resource and energy inefficiency and the environmental footprint of our industrial activities. SPIRE brings together cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, steel and water, that all have a clear and urgent interest in improved efficiency and can play an essential role in driving the resource efficiency agenda due to their **high dependence on resources** (energy, utilities and raw materials) in their production. These industries also share the **potential high impact** they may have on the environment through their daily operations as well as the contribution they make to the European economy. Together they represent a major part of the manufacturing base in Europe (EU27) including more than **450,000 individual enterprises**. They have over **6.8 million employees**, generating more than **1,600 billion € turnover**. As such they represent 20% of the total European manufacturing industry⁵, both in terms of employment and turnover. European industry accounted for more than a quarter of total energy consumption in 2010 in Europe⁶ with a significant portion of that used within the process industry.

⁴ COM(2010) 614, An Integrated Industrial Policy for the Globalisation Era Putting Competitiveness and Sustainability at Centre Stage, p30.

⁵ Eurostat; <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>

⁶ Eurostat; <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>

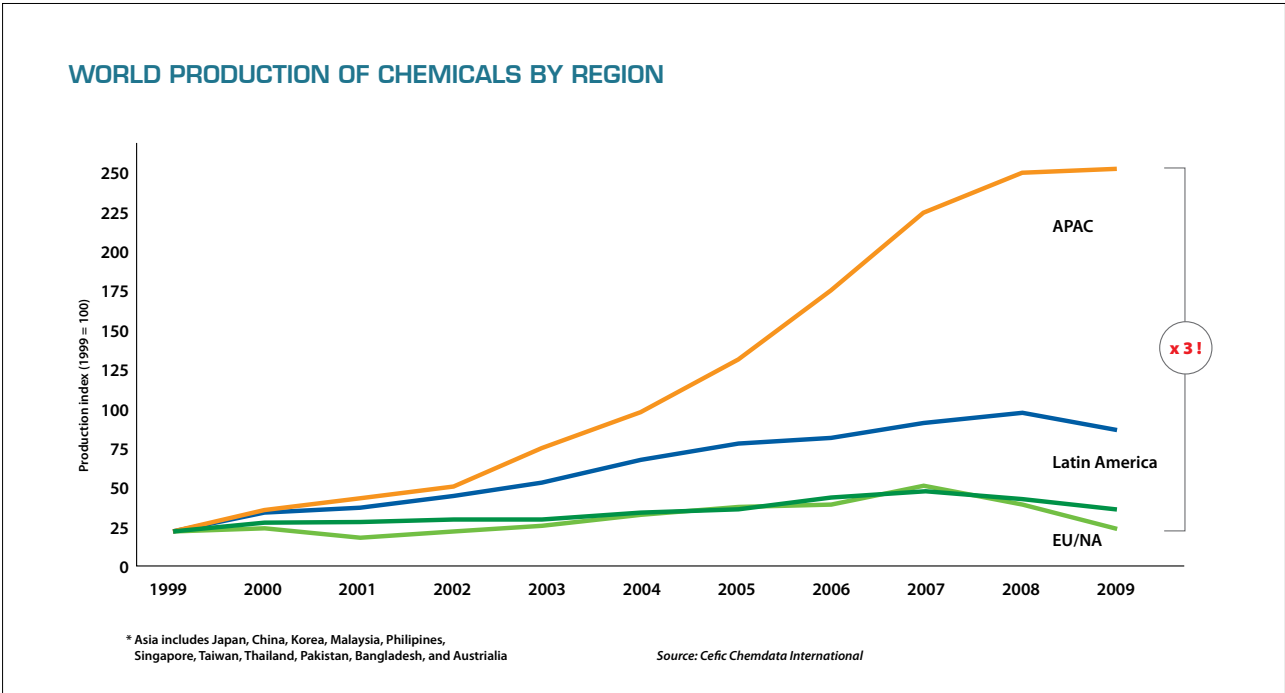
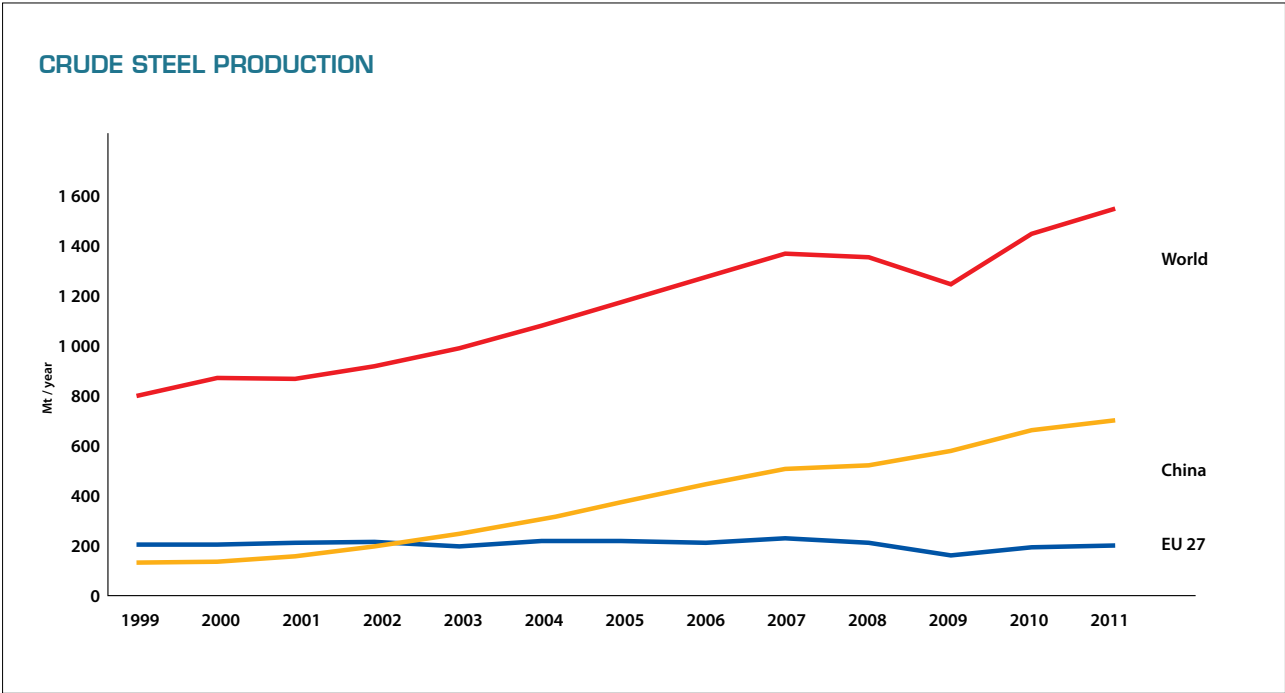


FIGURE 1: Global trends in Steel and Chemicals production

A substantial resource efficiency improvement has already been achieved in these industries over the past years⁷ but for various reasons, further technological breakthroughs are needed to pass beyond current day limitations.

- Globalization - the increased world population and the rise of emerging economies has resulted in increased competition for natural resources globally. In Europe, many resources are subject to depletion or are not easily extractable.
- For European companies, inaccessibility of resources leads to high dependence on imports compared to their international competitors, who also face less stringent environmental policies.

This leads to decreasing competitiveness for the European process industries on a global level, including the loss of traditionally dominant positions for the European process industry in terms of global production. The examples in Figure 1 from the steel and chemical industries show how regions outside Europe have experienced very high growth whereas Europe is stagnant. Further, the absolute production rates for steel have already been higher for other regions for decades but recently this is now also the case for the chemical industry and many other sectors. This trend has to be stopped if we are to maintain Europe as a region

that offers the right conditions to its citizens to lead healthy and comfortable lives providing opportunity to engage in rewarding and sustainable lifestyles.

Innovation is the only way out and the SPIRE participants acknowledge **the importance of resource and energy efficiency as a viable strategy** to drive innovation. Resource and energy efficiency will bring cost reduction, and increased productivity as a basis for increased competitiveness, while at the same time disconnecting growth from its environmental footprint. Simultaneously there needs to be a focus on product quality improvement to further strengthen competitiveness. The challenge will be to **exploit new business opportunities resulting from the transition to a more sustainable, resource efficient and low carbon economy** as stated in the Europe 2020 Flagship Initiative "An industrial policy for the Globalisation Era"⁸ and in the Industrial Policy Communication Update⁹. **Industry will need to develop processes for a complete range of new products and services**, based on high longevity of materials and products, low embodied water, as well as low-energy and material content. This will be achieved through a transition of industrial processes, to become less carbon and material intensive while at the same time preserving jobs or reinvesting in completely new employment opportunities¹⁰.

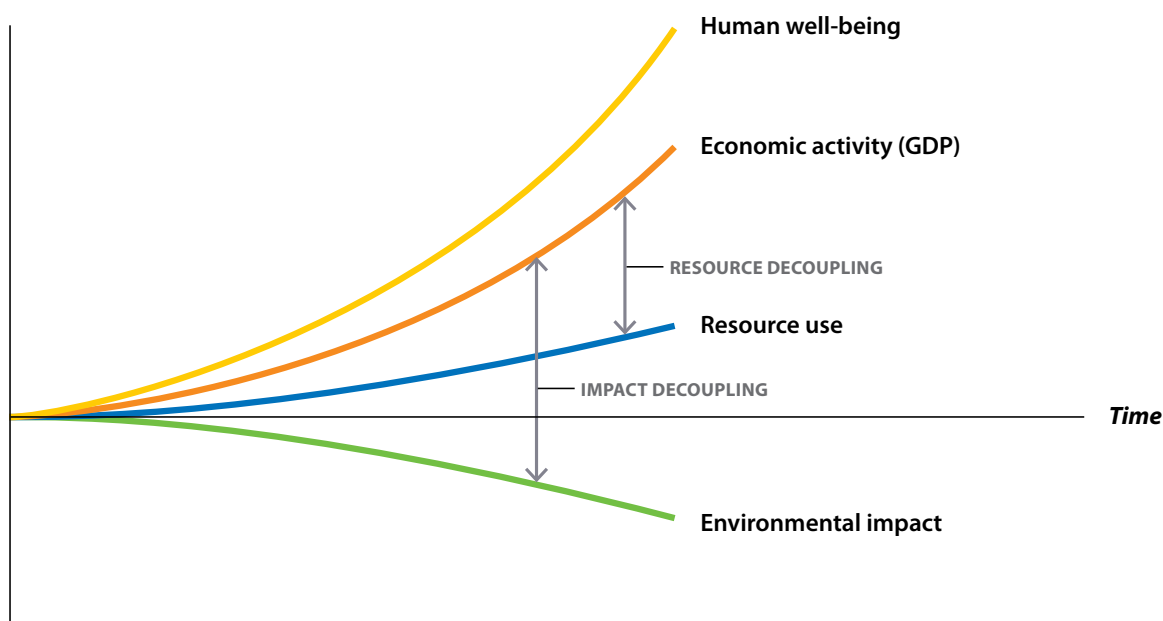


FIGURE 2: Impact of decoupling human well-being from resource consumption (UNEP)

⁷ Study on the competitiveness of European Companies and Resource Efficiency; Ecorys for: European Commission - DG Enterprise and Industry; February 2011

⁸ An Integrated Industrial Policy for the Globalisation Era Putting Competitiveness and Sustainability at Centre Stage, Brussels, COM(2010) 614.

⁹ A stronger European Industry for Growth and Economic Recovery, COM(2012)582 final

¹⁰ The World Business Council for Sustainable Development (WBCSD), Vision 2050: the new agenda for businesses. <http://www.wbcd.org/pages/edocument/edocumentdetails.aspx?id=219&nosearchcontextkey=true>

As an example a UNEP study noted that **green economy scenarios predict higher economic ROI in the longer-term**, compared to BAU (Business as Usual) scenarios, featuring 25% higher return through to 2050 and yielding, on average, over US\$ 3 for each US\$ invested. Such a **resource-efficient and low-carbon economy would:**

- Boost economic performance while reducing resource use;
- Identify and create new opportunities for economic growth and greater innovation and boost the EU's competitiveness;
- Develop solutions against climate change and limit the environmental impacts of resource use.

The cross-sectorial SPIRE roadmap provides a pathway for the **Process Industry to decouple human well-being from resource consumption. This is at the heart of a transition to a Green Economy**¹¹ defined as one resulting in “improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities” (Figure 2). **Decoupling** has been recognized as the **key indicator of positive trends in sustainability and resource efficiency**¹². This represents a separation of the impacts of an activity from its improved outputs, thus removing the link and interrelationship between these variables. **Decoupling is an objective for sustainability in de-linking economic growth and activity from environmental impacts.** Examples include weakening the link between an increase in Gross Domestic Product (GDP) or Gross value Added (GVA) and an increase in Greenhouse Gas (GHG) emissions, or the link between increasing industrial output and increasing resource inputs (for further detail please refer to the impact chapter).

Although investment in resource efficiency is assumed to create a **win-win situation** for investors and society, the business economics do not automatically support this. The time horizon for investment, the payback time and the certainty of the business environment are also important factors when performing at costs and benefits analysis for investment in resource efficiency¹³. Furthermore, compared to other world regions, Europe's geographical fragmentation and complex regulatory and innovation eco-system, establishes a challenge for industry to accelerate the innovation processes.

A **public contribution will therefore be instrumental** to overcome such initial barriers towards European innovation and competitiveness while improving energy and resource efficiency. The stakeholders from eight process sectors across all European countries joined forces in SPIRE to propose a Public Private Partnership programme together with the European Commission, that can jointly identify, develop and deploy effective and sustainable routes towards realizing a drastic reduction in resource and energy intensity while achieving increased competitiveness in the European process industry¹⁴.

¹¹ United Nations Environment Programme UNEP (2011) Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Henricke, P., Romero Lankao, P., Siriban Manalang, A., Sewerin, S. Copyright © United Nations Environment Programme, 2011.

¹² Sustainable Industry: Going for Growth & Resource Efficiency, European Commission, Directorate General Enterprise and Industry, Unit B1 Sustainable Industrial Policy, http://ec.europa.eu/enterprise/index_en.htm

¹³ Study on the competitiveness of European Companies and Resource Efficiency; Ecorys for: European Commission - DG Enterprise and Industry; February 2011

¹⁴ SPIRE: Sustainable Process Industry: European Industrial Competitiveness through Resource and Energy Efficiency: 2011

Overall Vision 2030 and research and innovation strategy of the industrial sectors involved

PROCESS INDUSTRIES IN THE VALUE CHAIN

The manufacturing industry can essentially be classified into two main categories: **process industry** and **discrete product manufacturing**. The process industry transforms material resources (raw materials, feedstock) during a (typical) (semi)continuous conversion into a new material that has significantly different physical and chemical performance than the starting substance. This material is then usually shaped by discrete manufacturing into an end user product or intermediate component; often this requires combining several different and discrete manufacturing operations to result in the final consumer product.

The SPIRE PPP will bring together all actors along the full value chain – from different types of feedstock supply through industrial transformation into intermediate products and applications. The target is to drastically reduce the environmental footprint and increase competitiveness of industry by **“doing more and/or better with less”**

(considering a complete system performance not simply a single materials contribution). To do this successfully one has to consider all the major components in the process industry holistic value chain (Figure 3); this should include **raw materials, feedstocks and their source, conversion processes, intermediate and/or end-user needs** and certainly also **waste streams**. It is therefore important that both the separate components and especially the integrated **holistic view** are taken into account, including significant horizontal issues.

At the core is the process industry, one of the key industrial sectors in Europe, and therefore an essential precursor for improving competitiveness and sustainability for almost all industrial value chains and applications, from automotive to construction, from renewable energy applications to lighting, aeronautics, health care and many others. This is why the stakeholders united in SPIRE are uniquely positioned to drive this initiative.

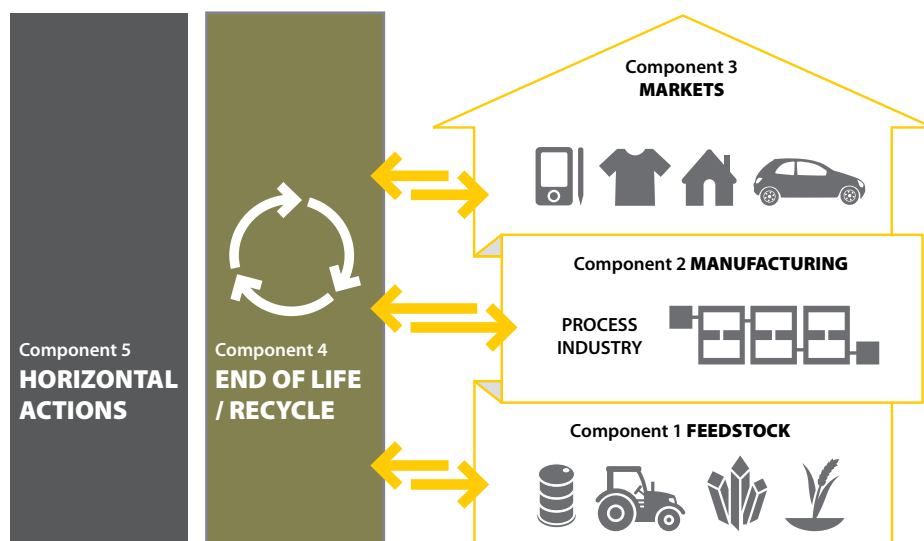
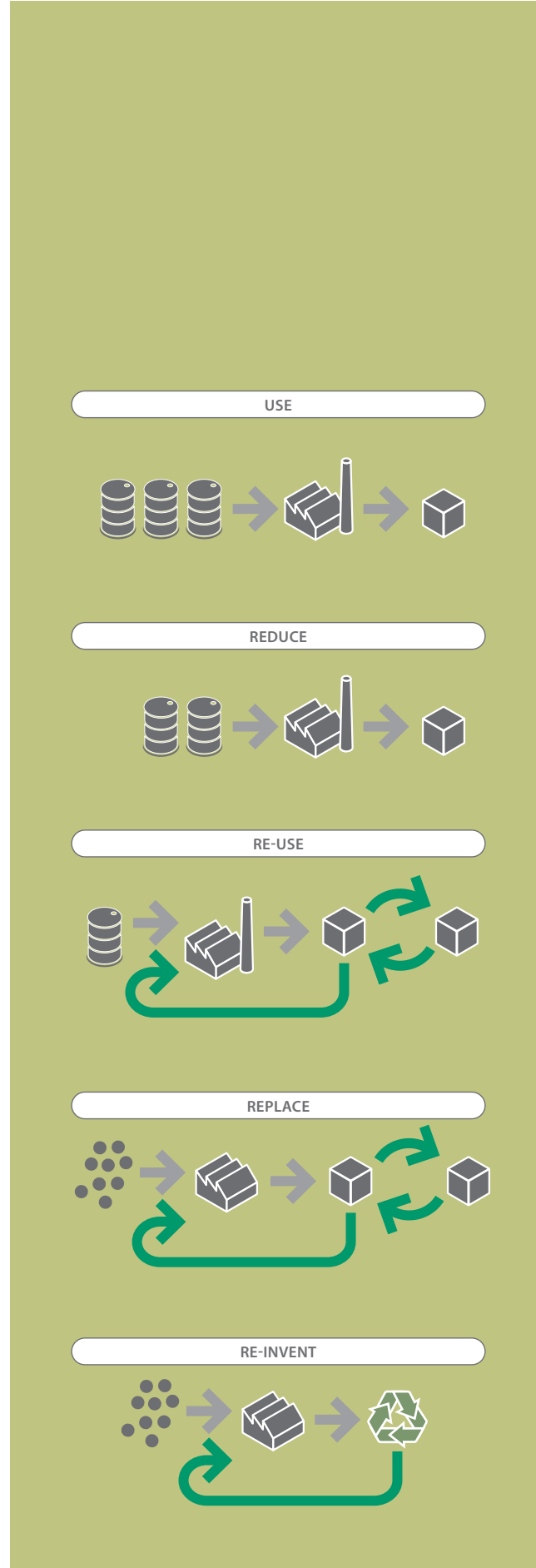


FIGURE 3: Value Chain schematic

A CROSS-SECTORIAL VISION WITHIN THE PROCESS INDUSTRY

SPIRE distinguishes itself through its visionary cross-sectorial approach in tackling key societal challenges. Novel and radically improved production processes are key to increasing the energy, resource and CO₂ efficiency in industrial value chains. Addressing these challenges require the appropriate technologies, processes and products with intelligent product design as well as smart processes over the value chain to:

1. **USE** energy and resources more efficiently (**reduce**) within the existing installed base of industrial processes. **Reduce**, prevent waste.
2. **RE-USE** waste streams and energy within and between different sectors, including recovery, recycling and re-use of post-consumer waste;
3. **REPLACE** current feedstock by integrating novel and renewable feedstock (such as bio-based) to reduce fossil feedstock and mineral raw materials dependency while reducing the CO₂ footprint of processes or increase the efficiency of primary feed stock. **Replace** current inefficient processes for more energy and resource efficient processes when sustainability analysis confirms the benefits;
4. **REINVENT** materials and products to have a significantly increased impact on resource and energy efficiency over the value chain as a result of for example, integration of recycled materials, easy recyclability and re-usability as well as improved material properties such as lighter weight (for lower fuel consumption vehicles) and improved insulation (for energy efficient buildings) through close collaborations with other European programmes.



Adapted from the Rotterdam Port Vision 2030

For some sectors, processes previously considered as breakthrough have now become outdated due to energy inefficiency, technical problems (e.g. corrosion), high consumption of expensive resources and other similar reasons. Alternative processes are being studied but development is often still in the R&D stage and the performance has not yet been demonstrated on pilot or pre-industrial scale. Moreover, some solutions for increasing energy and resource efficiency may already exist for one sector, but are unknown or not tailored for another. One of the fundamental goals of SPIRE will be boosting the deployment of innovative resource and energy efficient solutions **and practices** among the partners **facilitating their adaptation, transfer and take-up in a cross-sectorial way**. SPIRE will be instrumental for drastically **accelerating innovation and resource efficiency within the European process industry in the short to medium term**.

Nowadays, developing new processes is often too costly and risky for a single company. **Sharing costs between companies, value chains and sectors** in an open innovation community would allow the development of new processes and provide the means to succeed in a comprehensive way. Sharing of costs would permit many industries, including large numbers of SMEs, to develop processes that they would not be able to develop on their own because of a lack of resources. There is a huge potential to promote a cross-sectorial approach of R&D&I through different industries in order to identify new ideas, transfer new technologies from one sector to another one, and to reach critical mass to develop advanced and breakthrough technologies. It is necessary to integrate the development of these enabling technologies with demonstration units to prove their integration capability in the whole product network. In all activities the aim is also to improve economic feasibility and hence increase adoption.

Broad strategic objectives of the PPP initiative and role of the PPP in the overall industrial strategy

Based on extensive consultations with sector organizations, industries, academia and Universities, SPIRE has developed this PPP programme with the aim of integrating, demonstrating and validating systems and technologies capable of achieving two key resource and energy efficiency targets:

- **A reduction in fossil energy intensity of up to 30%** from current levels through a combination of, for example, cogeneration-heat-power, process intensification, introduction of novel energy-saving processes, energy recovery, and progressive introduction of alternative (renewable) energy sources within the process cycle;
- Up to **20% reduction in non-renewable, primary raw material intensity** compared to current levels, by increasing chemical and physical transformation yields and/or using secondary (through optimised recycling processes) and renewable raw materials. This may require more sophisticated and more processed raw materials from the raw materials industries.

For both targets a full life cycle cost analysis is required to consider all effects along the value chain (including all recycling or re-use loops - see, for example, water usage) and to prove the sustainability advantage. In addition both targets will make a significant contribution to the political and societal objectives of drastic **efficiency improvement in CO₂-equivalent footprints of up to 40%**. Indeed such improvements will have an effect beyond "industry" to all economic sectors such as transport, construction, water, electronics etc.

To reach the strategic objectives described above and overcome typical bottlenecks of fragmentation amongst sectors and within Europe, the concept of the SPIRE PPP is based on the following principles:

- **Life Cycle and Cost thinking, monitoring and steering** along the value chain: SPIRE will aim for the targets outlined above by identifying, selecting, adapting, developing, deploying and replicating cost efficient solutions that have a resource and energy efficient impact based on Life Cycle and Cost thinking from the production of raw materials and utilities, through their transformation

in the process industry, and the CO₂ equivalent footprint of final products, including their recycling and re-use;

- **Systemic analyses of alternative resource streams** for a given process (raw materials, energy and other utilities, including waste streams) within the various process sectors, and development of novel solutions that allocate these resources for their most resource efficient application (cascading approach) within the sector and across sectors;
- **Identification and cross-sectorial transfer of resource and energy efficiency technologies, solutions and practices**, with the aim of accelerating the realization of their impact within the European process industry;
- **Multi and cross-sectorial development of new resource and energy efficient solutions** that have significant impacts either through their first application, or through their replication throughout the community of process industries;
- **A staged approach**, explained below, is needed since the process industry time horizon for investment and payback is typically long. Indeed, rejuvenation of the process base can only be realized in the short to medium term by introducing innovations in the installed base, while further large impact measures will require significant capital investments and can only be realized on the longer term;
- **Creating the right skills, knowledge, standards and mechanisms**, to overcome traditional barriers between sectors and stimulate cross-sectorial, as well as value chain, collaboration to implement the SPIRE programme and reach its targets.

This SPIRE concept of a **cross-sectorial target driven energy and resource efficiency and competitiveness programme for the process industry** is described in the following image (Figure 4).

One of the main obstacles to accelerating resource efficiency impact in the process industries is the high capital expenditure necessary for any change in the established process base. As the return on investment can be quite long, some industries are reluctant to implement new equipment that requires large investment. SPIRE therefore proposes a three stage approach:

- **Stage 1: Shorter to medium term impact measures** (with resource and energy efficiency impact by 2016 – 2019): targeting projects that can generate and demonstrate “immediate” resource efficiency opportunities resulting from the SPIRE vision, including identification, benchmarking and cross-sectorial transfer of good energy and resource efficiency solutions and practices;
- **Stage 2: Medium term impact measures** (with resource and energy efficiency impact by 2018 – 2025):

targeting those projects that may not be implemented “immediately” in the installed base, but could be done later through a quick migration (evolution) towards more adapted and improved processes;

- **Stage 3: Medium to longer term impact measures** (with resource and energy efficiency impact by 2020 – 2030) targeting those projects that revolutionise the process industry through breakthrough developments but may require significant capital investments in new processes.

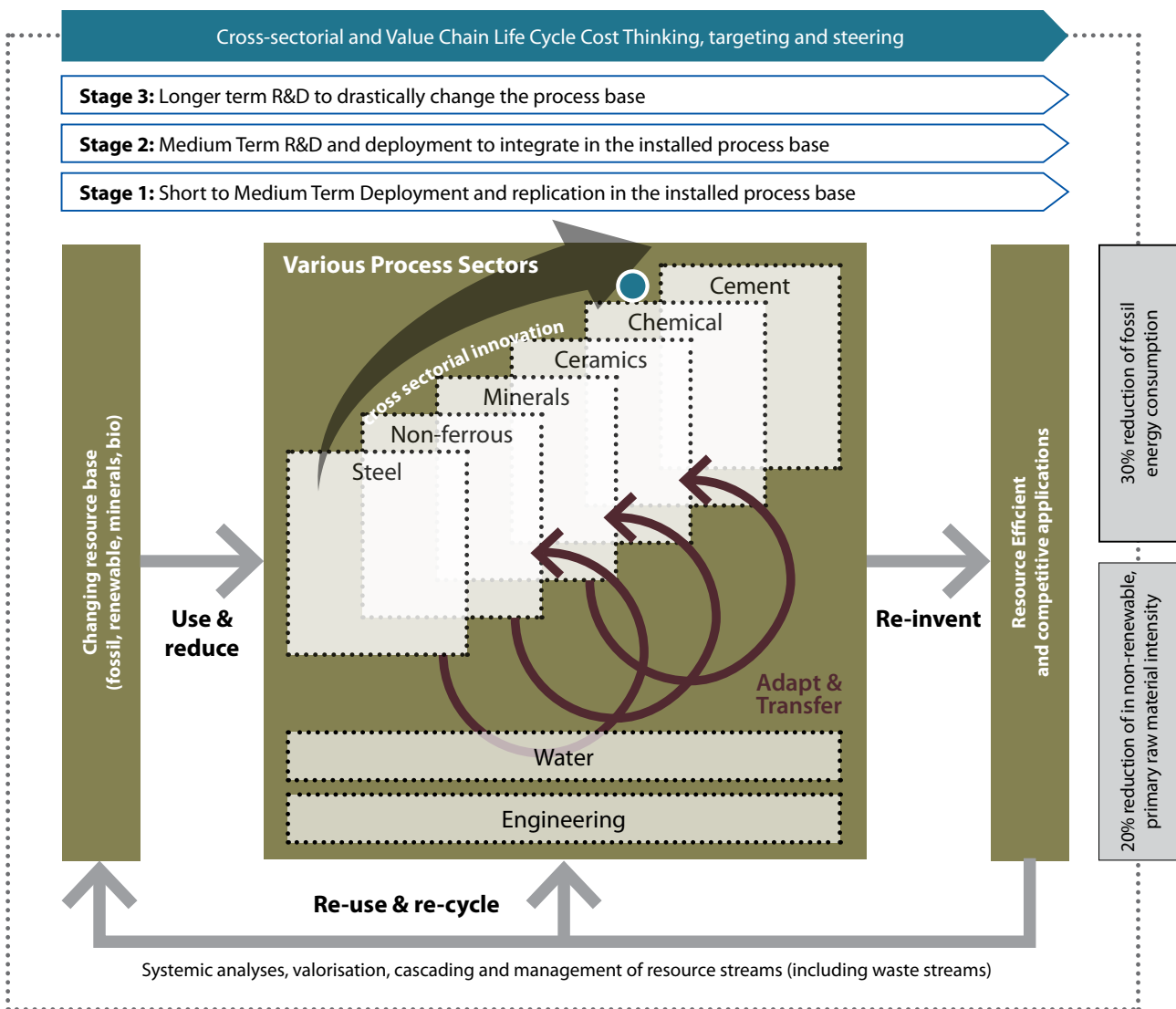


FIGURE 4: The SPIRE concept - A cross-sectorial target driven resource efficiency and competitiveness programme for the process industry

Commitment of industry/partners to the overall vision and objectives and in particular to the PPP goals

The commitment and dedication of the SPIRE stakeholders to the vision and objectives can easily be demonstrated when considering the history of the initiative. It illustrates that this is very much a bottom-up approach, driven by a need and desire to grow in Europe and based on the opportunity seen for doing this through Sustainable Innovation resulting in establishing a global competitive lead. The vision and objectives were first developed by the stakeholders starting with 2009 and have been further fine-tuned and confirmed by them on various occasions since then. The efforts asked of the stakeholders in completing these multiple steps have been considerable, yet taken voluntarily and willingly based on inner motivation.

The first steps in joining forces to address European industrial competitiveness in the process industry were taken in 2010 when an informal partnership of energy and resource intensive industries was formed under the name Resource and Energy Efficiency Partnership (REP). The initiators for REP comprised a broad range of major European Industry Associations and European Technology Platforms. REP issued a white paper to the Commissioners of DG ENTR, ENV, TRADE, RTD, and ENER oriented towards policy actions to improve European competitiveness in the process industry. Following the positive reaction to the white paper, REP then decided to elaborate a programme focussed on the actual delivery of Resource and Energy R&I developments that would help significantly boost the sustainability for our industry as well as for our value chain partners.

This roadmap is therefore the result of a wilful coordination and integration of the various sectorial innovation priorities and agendas for the next years. In these areas of high capital-intensive process industries that need long-term investment plans where risks are rather high due to long return on investments, a strategic agenda-driven public-private partnership requires but also guarantees sustained effort and investment over multiple years.

The SPIRE sectors show a large number of important production operations throughout Europe; therefore, the SPIRE innovation and retrofitting potential is enormous. In some cases (e.g. new process control) it offers double digit replication potential compared to the initial single pilot project in which a novel SPIRE technology will be proven and demonstrated. As the chain of development goes through many steps with corresponding increased amounts of investment, support measures such as the PPP are needed to cross the valley of death from laboratory level technology to mini-plant or pilot and further to the build-up of demonstration capability. Once there is successful technology demonstration in SPIRE, the most expensive step of deployment (typically with factors of 5 to 10+ higher than for a demonstration capability) will be made by industry.

The progressive execution of the SPIRE roadmap will address also the socio-economical dimension as there will be an increased demand for professionals with (new or adapted) skills, for the process industry but also for the related and spin-off industries, facilitating the transition to a greener and more competitive European industry. Workforce training and education programmes across and within sectors will be one of emphasised components of the business uptake strategies.

The stakeholders that have committed themselves to execution of this roadmap and the associated objectives and vision, have organised themselves in the Association SPIRE AISBL (A.SPIRE). A.SPIRE represents the private sector in the SPIRE Partnership and intends to assist the public sector in the execution of the PPP.





PART 2. RESEARCH AND INNOVATION STRATEGY

Technical content: overview of the industrial needs and the related research and innovation challenges to go beyond the state-of-the-art; main sub-domains and related priority areas

SPIRE will implement a rolling work programme, through six Key Components targeting the four building blocks of a resource and energy efficient process industry:

- 1. FEED:** Increased energy and resource efficiency through optimal valorisation and smarter use and management of existing, alternative and renewable feedstock;
- 2. PROCESS:** Solutions for more efficient processing and energy systems for the process industry, including industrial symbiosis;
- 3. APPLICATIONS:** New processes to produce materials for market applications that boost energy and resource efficiency up and down the value chain;
- 4. WASTE2RESOURCE:** Avoidance, valorisation and re-use of waste streams within and across sectors, including recycling of post-consumer waste streams and new business models for eco-innovation;
- 5. HORIZONTAL:** Underpinning the accelerated deployment of the R&D&I opportunities identified within SPIRE through sustainability evaluation tools and skills and education programmes as well as enhancing the sharing of knowledge, best practices and cross-sectorial technology transfer;
- 6. OUTREACH:** Reach out to the process industry, policy makers and citizens to support the realisation of impact through awareness, stimulating societal responsible behaviour.

Different Key Actions have been developed for each Key Component within SPIRE, enabling an agenda-driven approach towards realising impact. Also, being at the roots of all product value chains, the SPIRE group is fully aware that strong interfacing and collaboration will be required with value chain partners throughout the market to leverage their innovation proposals with a potential dramatic resource and energy efficiency impact. It is therefore the explicit intention of SPIRE to leave space for a substantial **“bottom-up” objective driven approach**, leaving sufficient flexibility for entrepreneurial and market inventiveness, in proposing innovative solutions that have a drastic impact on resource efficiency down the value chain, and require contributions from the process industry.

The Components are logically interconnected within the overall SPIRE vision and system approach, as indicated in the following flow-diagram (Figure 5). All components, individually and in their interconnectivity, could be supported by tools such as data processing and related ICT technologies that would enable an improved process monitoring and control.

The 6 Key Components have been broken down into 21 essential and complementary Key Actions (KA):

1. Key Component FEED

- **KA 1.1:** Enhancing the availability and quality of existing resources
- **KA 1.2:** Optimal valorisation of waste, residue streams and recycled end-of-life materials as feed
- **KA 1.3:** Optimal and integrated (re) use of water
- **KA 1.4:** Advancing the role of sustainable biomass/renewables as industrial raw material

2. Key Component PROCESS

- **KA 2.1:** Novel advanced energy technologies
- **KA 2.2:** Energy harvesting, storage and reuse
- **KA 2.3:** Process monitoring, control and optimization
- **KA 2.4:** More efficient systems and equipment
- **KA 2.5:** New energy and resource management concepts (including industrial symbiosis)

3. Key Component APPLICATIONS

- **KA 3.1:** New materials contributing to development of energy and resource efficient processes
- **KA 3.2:** New processes for energy and resource efficient materials applied in sectors down the value chain

4. Key Component WASTE2RESOURCE

- **KA 4.1:** Systems approach: understanding the value of waste streams
- **KA 4.2:** Technologies for separation, extraction, sorting and harvesting of gaseous, liquids and solid waste streams
- **KA 4.3:** Technologies for (pre)treatment of process and waste streams (gaseous, liquids, solids) for re-use and recycling
- **KA 4.4:** Value chain collection and interaction, reuse and recycle schemes and business models

5. Key Component HORIZONTAL

- **KA 5.1:** Identification, benchmarking and cross-sectorial transfer of good energy and resource efficiency solutions and practices
- **KA 5.2:** Methodologies and tools for cross-sectorial Life Cycle and Cost Assessment as well as novel social Life Cycle Assessment of energy and resource efficiency solutions
- **KA 5.3:** Develop skills and education programmes required for the development and deployment of novel energy and resource efficiency solutions and practices
- **KA 5.4:** Enhancing innovation and entrepreneurial skills and culture

6. Key Component OUTREACH

- **KA 6.1:** Analysis and establishment of efficient technology dissemination methodologies, mechanisms and frameworks
- **KA 6.2:** Develop social responsibility for the process industry

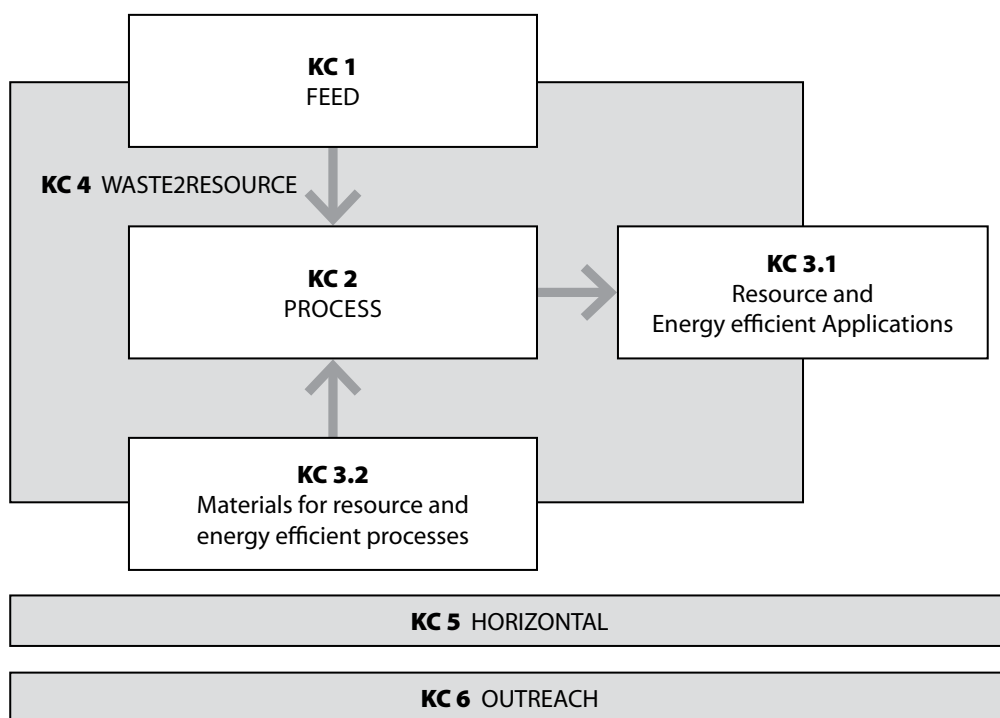


FIGURE 5: Integrated view of the SPIRE components

The Key Components and Key Actions are essentially targeting SPIRE's multi-sectorial set-up (any of the sectors e.g. chemicals, steel and minerals etc.), each managing **different feedstock streams** (ores, minerals, fossil, bio-feedstock, water and re-used waste streams), being transformed within the **different process industries** into materials used for a **wide range of applications**.

The **different Key Actions** are positioned in this feed-to-applications process, and aim to have an energy and resource efficiency impact. This involves **current and alternative raw materials or feedstocks** that need to be produced (e.g. through biorefineries), prepared and processed in a smarter way. It also concerns different feed streams that can be **used and re-used more efficiently**, e.g., by managing a closed

water-cycle, using waste heats or by using waste streams as feedstock (e.g. using captured CO₂ emissions as a building block in the chemical industry). **New separation, extraction and pre-treatment technologies** as well as **value chain business models** will be needed and the overall feed and waste streams need to be valorised within a **systems approach**, using the feedstock for the most value-added process, in a cascading approach. Further new flexible energy and resource management concepts such as industrial symbiosis need to be developed to migrate to the energy and resource efficient zero-waste process industry of the future. In the context of SPIRE, waste that can be directly used as feed into a production process will be dealt with in Key Component FEED, while waste that requires upgrading and pre-treatment before it can be used as a feedstock will be part of Key Component WASTE2RESOURCE.

The PPP includes actions focussed on developing the processes to produce materials for applications with very low CO₂ footprint during manufacturing while also reducing environmental impact down the value chain such as clinker-based low CO₂ cements, highly efficient energy production and storage for industry and the smart grid etc. Other user products, like consumer products (e.g. detergents, diapers, shavers etc.) require integration of suitable renewable feedstock, a sustainable and smart supply chain, a unique energy neutral production process, consumer education on renewable behaviour and an integrated waste-to-worth recycling scheme. Last, but not least, the SPIRE roadmap will be supported by a set of **horizontal actions** required to **boost energy and resource efficiency across sectors and value chains**.

The **HORIZONTAL** component will **facilitate the cross-sectorial potential benefits that are at the core of this PPP**. The fact that SPIRE brings together different process sectors is its strength and potential. At the same time exploiting this strength requires the removal of significant and important bottlenecks that have so far proven to be barriers for **cross-sectorial knowledge and technology transfer and to synergetic optimisation and sharing of resource streams**. This horizontal component will drive cross-sectorial synergies by stimulating the identification of good resource and energy solutions and practices from one sector and promoting their transfer to another. Furthermore, cross-sectorial Life Cycle Cost assessment methodologies, tools and standards will be fostered to create a level playing field for the emerging eco-innovation market (e.g. for novel businesses based on the collection and exploitation of waste streams such as urban mining and industrial mining as a novel resource base), and also to promote novel products that have a significantly better sustainability impact performance down the value chain, based on agreed LCA and LCC standards. Also new social Life Analyses will be taken into account. Finally, skills and educational programmes will be put in place that will prepare the workforce needed to deliver the development, transfer and adoption of novel resource and energy efficient solutions and practices.

In the **OUTREACH** component, the SPIRE proposal combines research with studies on socioeconomics, analysis and quantification of the impact of growth, employment, investment and industrial competitiveness within the framework of the projects undertaken. Therefore, studies on the social and economic impact of the different technologies available and the use of resources, as well as the feasibility and impact of investments in resources and energy, to provide a comprehensive view will be encouraged, thereby integrating science and technology into society. Due to this cross sectorial view, SPIRE can play a significant role as a key agent offering advice to organisations when preparing strategic plans and energy programmes thanks to the developments and barriers overcome within this initiative. The assessments accomplished within SPIRE will offer to companies solutions based on eco-innovation studies related to their processes and products, including economic factors, the environmental impact and social aspect of the activities they perform.

The following chapter outlines the main industrial needs and related R&D&I challenges for each of the SPIRE Key Components. Several innovations contribute to some or all key components, e.g. re-use of waste streams and recycled end-of-life materials, the role of water, bio-based usage etc. For clarity purposes we have placed them under the single Key Component where the most significant contribution of that innovation is expected e.g. Waste2Resource for re-use of waste streams, Feed for bio-based usage and the role of water.

MAIN INDUSTRIAL NEEDS AND RELATED R&I CHALLENGES

In order to face the challenges of increased competition, the required environmental impact reduction, as well as the retention of high-quality process industries and jobs in Europe, a systems approach will be necessary. Maximum value must be generated from energy and resource streams by using them for the most resource efficient purpose (cascade approach). The next generation, highly efficient process industry is zero-waste and has a competitive advantage in producing materials and products in the most sustainable way. This requires research and innovations that enable a **combination of evolution and revolution of the installed process base** in Europe towards the realisation of the SPIRE vision.

1. Key Component FEED: *Increased energy and resource efficiency through optimal valorisation and smarter use of existing, alternative and renewable feedstocks*

The feed section in industrial production processes deals with the material and utility streams required for the subsequent conversion/transformation operations. Examples of components/streams that are often found as input for industrial processes are reactants, solvents, process aids like catalysts or gases to prevent oxidation, energy and water¹⁵. Breakthroughs to realize a significantly lower consumption of these primary resources or feedstocks requires an integral approach which:

- Stimulates and enables the use of **renewable resources** such as biomass;
- Improves the utilization and **valorisation of secondary feedstocks** like residue and waste streams and recycled end-of-life materials of industrial and social origin. These secondary feedstocks can be organic or inorganic as well as solid, liquid (e.g. water) or gaseous;
- Creates **sustainable alternatives** to enhance the availability and quality of essential primary resources.

It is important to note that resource efficiency is not solely related to the feedstocks that are being used, but can also be created at other places in the production process or value chain. Examples of innovations that can significantly improve resource (and energy) efficiency are the use of process optimisation intensification/advanced reactors and catalysts that improve the selectivity and yield of conversion and separation or improved materials/products that deliver a similar or even improved performance whilst using much less material (e.g. light weight constructions in transport and civil industry). These topics will be covered under SPIRE's Key Components PROCESS and APPLICATIONS.

A second aspect is that technical feasibility of resource efficient options is only part of the solution. SPIRE will focus on breakthroughs that are sustainable which means that the innovations are **economically viable, environmentally friendly** and **socially acceptable**.

This boundary condition means for instance that the solutions should not lead to scarcity, that the products cannot end up in landfill, that the energy consumption in recycling of secondary resources must be less than the energy used for primary production and they may not lead to other significant waste or emissions.

A third aspect comes with defining the quality of alternative feedstocks including wastes and other unconventional feeds. A key enabling activity for Key Actions 1.1, 1.2, 1.3 and 1.4 is to develop new characterization techniques that appropriately predict the processing characteristics of alternative feedstocks in conjunction with both existing and new processes. For example, reactivity, oxidation or reduction rates, levels and behaviours of impurities of alternative feedstocks may be very different from conventional feedstocks, making new characterization techniques necessary to predict parameters such as energy demand, yield, product and by-product quality.

Re-use of waste and residue streams from industry as well as post-consumer end-of-life materials will significantly impact the composition of the feed stream. This important topic will be dealt with both in Key Component FEED and WASTE2RESOURCE.

¹⁵ Energy is a key utility in almost all industrial production processes and therefore could fit under the Key Component FEED. However typically most energy is consumed and released in the conversion, separation and purification sections of the production process, it was decided to position 'energy' under the Key Component PROCESS.

If the centre of gravity of required R&D&I is more on the integration of waste and residue streams into feed, the topic will be dealt with in this Key Action. If it is more about taking a total systems approach, assessing the value of waste and residue streams, separation, extraction, sorting and pre-treatment techniques, the topics will be dealt with in Key Component WASTE2RESOURCE.

The primary target for the impact of the Key Component FEED in SPIRE is a reduction of 5-10% in the use of primary resources/feedstock intensity in 2030. Resource efficiency will consequentially be accompanied by energy efficiency and reductions in the amount of waste and emissions to soil, air and water. The above impacts will be realised as a result of the following four Key Actions.

Key Action 1.1: Enhancing the availability and quality of existing resources

The grades of raw fuels, ores and other virgin materials are varying and declining over time. These changes will require development of primary separation, treatment and processes.

■ **Alternative sources for fossil resources for chemicals and fuels**

A more sustainable energy and chemical future will include a combination of fossil fuels and renewable sources in order to meet the growing global demand. Although many of the world's remaining supplies of oil and gas are increasingly more difficult to extract, fossil fuels will still supply a significant portion of world's energy and raw material for chemicals supply for years to come. Technological advances are required to maximize the output from existing oil and gas resources and are necessary to increase the energy efficiency of existing operations and facilities. New and unconventional sources for fossils have to be explored. From natural gas trapped tightly in rock pores to petroleum recovered from oil sands, utilization of these resources requires technologies to safely and responsibly access these feeds.

Natural gas, the cleanest burning fossil fuel, provides an environmentally acceptable feed and liquefied natural gas technology provides a cost-effective way to bring these gas

supplies to growing markets. The versatility of gas in the energy mix is one of the key benefits of this resource. New technologies can convert gas to valuable liquid products. For example, LNG as a transport fuel, an alternative to diesel or as a marine fuel. Natural gas can also provide a clean source of electricity for electric vehicles. Another example is gas-to-liquids (GTL) technology, converting natural gas into other higher-value liquid transport fuels and chemicals. Future technology advancements can open up new resources of natural gas and help meet Europe's rising demand for more, cleaner energy and fossil raw materials.

Managing the growing energy demand while managing CO₂ emissions requires further advances and will be a critical element of a sustainable future. Fuels produced from tar sands emit CO₂ at levels that require technological innovation to reduce / avoid emissions. While coal is one of the world's most abundant resources, significant challenges still exist in utilizing it in a cost-effective and environmentally responsible way. Continued advancements in the area of clean conversion and carbon capture and storage / utilization (CCS / CCU) will be required to convert coal into a useable energy alternative while responsibly managing emissions.

The gas supply revolution provides an opportunity to meet surging demand for energy in many areas of the world. Tight gas, shale gas and coal bed methane are all gas deposits trapped in very tight or impermeable rock. While these are difficult resources to access, advances in drilling and hydraulic fracturing technologies have significantly improved the safety aspect of accessing this resource. The development of the next generation technologies will be critical. Optimization of hydraulic fracturing fluids and development of technology that keeps water consumption and greenhouse gas emissions to a minimum is necessary to access these resources in a sustainable way. Technology is the key enabler.

Shale gas has experienced a revolutionary development in the USA, where it is now contributing a significant amount to indigenous production (about 35%). This has been realized by major technology breakthroughs in the area of horizontal drilling, hydraulic fracturing technology and cost-efficient production planning and drilling.

The potential regions for exploitation of the unconventional shale gas resource and its sister resource coal bed methane (CBM) are very widespread across Europe. In conventional reservoirs, gas is found freely in spaces and porous areas within rocks. However, shale gas is partly adsorbed in the rock minerals and, as shale has extremely low permeability (the capacity for gas to flow), the gas needs to be extracted from the rock itself, rather than the pores within it. The aim of hydraulic fracturing (fracking) is to enhance the permeability of the rocks, allowing gas to pass out more easily.

■ Securing the quantities and quality of primary resources for materials and metals

Primary ores are the basis of virgin metals and minerals for the industrial sector. In this respect it is important to emphasize the fact that the concentration of metals in extracted ores has decreased and is expected to continue to decrease over time as ore grades degrade in existing mines. Existing refining technology already presents some deficiencies especially for certain technology metals, which are very often critical, and/or (in certain cases) for the yield metals. In the future, industry will face even greater technological challenges as lower level grade concentrates will need to be treated. Maximum valorisation of the ore as a whole, with optimized recovery of both main target and secondary minerals and metals, is vital to improving mining and processing efficiency. Products from mining are the primary feed to many process industries including non-ferrous and ferrous metals, ceramics, glass industries, cement and chemicals.

Key areas for development are:

- Integration and optimization of mining and processing via geometallurgy, where the primary ore characteristics are considered for a variety of potential processing options, is an important approach requiring further development and demonstration. Other more efficient and lower environmental impact mining and processing techniques such as continuous excavation and underground pre-processing of the ore prior to lifting offer significant potential. Further development of feed characterization techniques such as degradation and reducibility to reflect process developments in minerals and metals processing and the increased complexity of feed materials, including e.g. recyclable streams as resources, is also an important aspect.
- Valorisation of current waste tailings by recovery of secondary products using new or improved separation techniques and their use in other applications is important both for reducing raw material intensity and reducing waste generation.
- Improved ore dressing, agglomeration and refining techniques to counter declining ore grades. For example, iron ores for sintering are becoming finer-grained and less efficient to sinter. Ores with lower iron grade and higher in deleterious elements including SiO_2 , Al_2O_3 , P and S lead to higher energy costs in processing and environmental control.
- Substitute carbon feeds by replacing some coking coals with, for example biomass-based carbon or waste sources, should be investigated (fundamental research, cross-over with process) or the use of gaseous fuels (such as natural gas and Coke Oven Gas) for the pre-reduction of iron.
- Alternative reduction processes which allow for production of metals without agglomeration. In the context of the ULCOS project¹⁶ (Ultra Low CO_2 for Steel production) some concepts such as HISARNA¹⁷ a new direct reduction and smelting reactor for iron production, ULCOS-BF¹³ a Blast Furnace with Top Gas recycling (TGR) after CO_2 separation, or ULCORED¹⁸ for new pre-reduction of iron ore are in preliminary development phases and further development can be considered.

¹⁶ http://www.ulcos.org/en/about_ulcos/home.php

¹⁷ The HISARNA steelmaking process is a process for primary steelmaking in which iron ore is processed almost directly into steel. The process is based around a new type of blast furnace called a Cyclone Converter Furnace, which makes it possible to skip the process of manufacturing pig iron pellets that is necessary for the basic oxygen steelmaking process. Without the necessity for this preparatory step the HISARNA process is more energy-efficient and has a lower carbon footprint than traditional steelmaking processes (see <http://www.ulcos.org/en/research/isarna.php>). The ULCOS-BF is a new Blast Furnace where the BF gas is recycled into the blast furnace after CO_2 separation. ULCOS-BF is more energy efficient and has a lower carbon footprint (with and without CCS) than traditional BF.

¹⁸ http://www.ulcos.org/en/research/advanced_direct_reduction.php

Key Action 1.2: Optimal valorisation of waste, residue streams and recycled end-of-life materials as feed

Optimal valorisation of waste, residue streams and recycled end-of-life materials can be done within the same sector but also between different sectors (e.g. in the context of industrial symbiosis). What is today considered as an industrial waste or residue stream will be entirely or mostly used as feed, e.g. part of the raw material mix, by other industrial sectors in 2050. This will contribute to increased resource and energy efficiency in a very visible manner. The aim is to develop and apply technical solutions for maximising the substitution of resource and energy intensive mass commodities or their raw materials by industrial waste, residue streams and recycled end-of-life materials. The following key developments illustrate why and how SPIRE wants to valorise and deploy various sources of waste, residue streams and recycled end-of-life materials as secondary feedstock for the Process Industry.

- **Valorisation of inorganic waste, residue streams and recycled end-of-life materials as feed** can significantly reduce the primary resource consumption in, for instance, the metal and mineral industries. A powerful example of the impact of these anticipated innovations is the valorisation of inorganic waste, side products and recycled end-of-life materials in cement production. The potential impact is a simultaneous and significant reduction of resource and energy consumption and CO₂ emissions: approaches to valorise waste, side products and residue streams include incorporating waste slags, dusts, and sludge from metal making or fly ash significantly beyond current technology limits or broadening the scope towards reactive inorganic waste, side products and residue streams such as steel slag, slags and dusts from non-ferrous metal production, residues from the glass or ceramic industry or incinerator bottom ash. Developing in-depth understanding of the reaction mechanisms will be required as a first step allowing maximum inorganic waste/residue uptake at similar product performances as state-of-the-art technologies.

Quality concepts, test procedures and product standards will be developed in parallel. Recovery and recycling of metals such as V, Ti, Zn or production of industrial minerals such as Portland cement concrete (PCC) from slags and waste sludge, which can replace virgin raw materials and, in the case of carbonated minerals such as magnesium and calcium carbonates, simultaneously sequester CO₂ in mineral form can also offer significant promise. Manure can potentially be utilized and valorised as an alternative source for compounds with N, P or K. Attention will be devoted also to the range of possible technical solutions aiming at processing low grade or complex raw materials.

- **Valorisation of organic waste, residue streams and recycled end-of-life materials** as feedstock for new molecule production in the (bio) chemical industry as reducing agents or for energy production across different sectors. Significant volumes of various industrial and municipal waste, residue streams and recycled end-of-life materials are available. Examples are waste, residue streams and recycled end-of-life materials from the food, forestry and pulp & paper industries, biomass/sludge from municipal waste water treatment and municipal waste from vegetables, fruit and garden. For example only 0.04% and 33% respectively from lignin and extractives in kraft pulping liquor, are currently utilized for chemical production. Dissolved hemicelluloses and hydroxy acids have so far remained totally unexploited as raw materials for the chemical industry. These by-products have potential to be used in a wide variety of applications including biofuels, resins, dispersants, detergents and feedstock for other chemicals. There are also substantial harvest residues remaining in the forests. The production of biogas from mixed streams with relatively low concentrations of valuable components is another opportunity to create secondary feedstocks or alternative, CO₂ neutral energy. Nitrogen containing components in biomass like proteins can be an interesting feedstock/starting materials for N-containing chemicals like polyamides. The presence of N in the starting material can prevent later N introduction in carbohydrates by a reaction with NH₃, which is an energy intensive reactant.

- **Valorisation of process flue gases.** At various stages in the process industry gases are emitted which contain components that can be valorised by using them as feedstock that can be converted into valuable applications. Non-exhaustive examples of components that could be utilized are: CO₂, H₂, CO, Syngas (as a result of municipal solid waste or industrial waste gasification), and CO₂/H₂ mixtures, all of which are often produced by industrial processes in changing composition or in concentrations that cannot directly be purified, can all be converted into fuels and chemicals. While conversion of CO₂ to value-added products requires reduction – either directly with renewable sources of H₂ or electricity, or indirectly via its reaction with energy-rich substances – available markets already exist for polymers and fine chemicals synthesized from CO₂ and selected substrates. In the short-term overcoming technological hurdles for commercial introduction of these high-value added CO₂-derived polymers and fine chemicals would generate the scientific and social momentum required to tackle the more difficult challenges related to the multi-electron reduction of CO₂ to fuels. A further key breakthrough in the use of this most abundant resource (CO₂) for the production of a new group of renewable materials would be the development of novel intensified processes that reduce energy consumption and use renewable energy (e.g. wind and solar) at overproduction capacity peaks (peak shaving). In order to make a meaningful contribution to the EU climate change objectives, CO₂ utilisation options having the potential to yield a significant, net reduction of CO₂ emissions, will be considered.

Key Action 1.3: Optimal and integrated re-use of water

Probably every manufactured product uses water during some part of the production process. Industrial water use includes water used for such purposes as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility. Resource-efficiency measures in urban and industrial areas often offer win-win situations, with technologies that cut water use and simultaneously accomplish a significant reduction in the amount of energy and chemicals needed,

for example, in water production and/or waste water treatment. The direct reuse of warm and cold water streams, also by treatment close to, or as part of, an individual process step, reduces the amount of energy needed for heating and cooling these water streams. Treatment close to individual steps, instead of end-of-pipe treatment, increases the possibilities to regain raw materials and products.

Secondly, industrial and social developments can lead to a different role of water in process industry. For instance, the production of chemicals from biomass by means of industrial biotechnology in the Bio-Based Economy will often lead to a situation that the product has to be separated from a relatively dilute and complex aqueous stream. Closure of the water, nutrients and minerals cycles in these novel industrial processes will require novel developments in water technology.

Water symbiosis and delivery of fit-for-purpose water are considered as key elements to ensure and enable the optimal and integrated (re)use of water. Water producers and water intensive process industries, like the food, chemical, paper & pulp and textile industries, will need to co-operate in the following areas to create the required breakthrough solutions.

- **Systems and tools (including in-line monitoring) for assessment and control of quantity and quality**
 Within the overall paradigm of Industrial Symbiosis water symbiosis can become a relevant tool to get closed water cycles in or around industrial parks. Treated water from one company could be used as a valuable resource by others. The same counts for urban waste water. There is a need for the development of methodologies and tools to evaluate and monitor water symbiosis, and novel economic models (including co-investments, guaranties etc.) need to be demonstrated with partners from different sectors. Tools that are able to simulate adapted water systems and assess the effect of circuit closure in terms of water quality demands, costs and possible risks are needed to give industries quick insight on the opportunities of water reuse and closure of the water cycle.

■ **Systems to guarantee water availability in case of temporary water scarcity.**

According to analysis by WssTP, many areas in Europe suffer increasingly from temporary or permanent water scarcity. Water scarcity may be primarily a water quantity issue, but it can also occur as a consequence of a deterioration of water quality or lack of appropriate water management. Flexible and adaptable solutions to cope with water scarcity are needed to reduce the vulnerability of European industry and ensure that the available water is used in the most efficient way. Natural systems for water storage during periods of excess water (e.g. aquifer recharge) should be promoted. Additionally aquifer re-charge could be used to improve the water quality, especially for micro-pollutants.

■ **Control of impurities in closed water cycles**

The use of water in closed circuits will imply the accumulation of impurities and result in water quality not being adequate for its purposes. Tools are needed to predict the effect of water cycle closure on water quality demands for the specific water use. New real time monitoring systems are needed to control this problem and selective separation processes will be required (as described under Key Action 4.2). These separation processes will produce new kinds of sludge which will need novel decentralized or centralized solutions. For the control of impurities in closed water systems/water cascades there is a need for combination of real time monitoring tools/sensors/ systems and highly selective separation processes. Novel highly selective separation technologies could be needed for impurities present in relatively low concentrations. Adsorption or ion exchange systems are examples of technologies potentially suited for this purpose.

■ **Integration of water and energy**

Water efficiency measures should be aligned with targets on reduced energy consumption. Water quantity and water quality are closely connected, and reducing pollution is also an important efficiency measure. It is envisioned that energy consumption must become a critical indicator when developing new technologies for water management and water treatment in the European Process Industry. Integrated tools for energy and water optimisation are needed. A special effort should be made to promote the use of renewable energy or recovered waste heat in water production and treatment systems.

Key Action 1.4: Advancing the role of sustainable biomass/ renewables as industrial raw material¹⁹

A recent study by CE Delft²⁰ identified possible breakthrough abatement technologies allowing for reduction of GHG emissions of between 50 and 100 % in 2050 compared to current, conventional processes for the production of ammonia, olefins and aromatics (BTX). The use of biomass as a raw material or processes powered by renewable power are essential to prevent greenhouse gas emissions in the three processes assessed.

It is important for the bio-based economy to increase the potential of plant-based biomass²¹ (including crops, trees and algae) to ensure the sufficient and sustainable supply of biomass as an industrial raw material. This can be achieved by; (i) increasing or changing land use and (ii) improving the productivity of plants for higher biomass and yield content. Plant productivity can be improved by breeding of high yielding plants and/or adapting plants to specific soil and climate conditions. Key in the plant based biomass production is intensified cultivation of plants and on-site harvesting, fractionation and densification in order to reduce transport and conservation logistics. Only by combining modern plant breeding with optimal plant material processing can the challenges of a sufficient and sustainable supply of plant-based biomass be successfully solved. Implementation of new technologies to generate materials and energy has to be balanced with the major societal challenge which is to secure an adequate food supply for an ever growing human world population. Thus, the full value chain will need to be used from food/feed to chemicals/materials and finally to energy (cascade approach), leaving nothing un-valorised. Residues at the level of agriculture, processing and consumption should be re-used or recycled according to these principles taking into account the complexity and heterogeneity of the residue composition.

There are 3 major components to act upon in order to significantly increase the role of biomass as an industrial raw material: biomass feedstock and logistics, biomass processing technologies, and integration aspects. These are well connected to the Commission's new strategy on the Bioeconomy²² launched in February of 2012, and with activities under the European Bioenergy Industrial Initiative of the SET-Plan²³.

¹⁹ Major references for this part of the roadmap: Star-Colibri documents (European Biorefinery Joint Strategic Research Roadmap and Joint European Biorefinery Vision for 2030) and CEPI "The Forest Fibre Industry – 2050 Roadmap for low carbon bio-economy"

²⁰ A long term view on the production of basic chemicals, J. Benner, M. van Lieshout and H. Croezen, Delft (The Netherlands), CE Delft, January 2012.

²¹ Plants and algae are considered also as biomass in this document.

²² http://ec.europa.eu/research/bioeconomy/policy/index_en.htm

²³ <http://setis.ec.europa.eu/>

Each of these key aspects is important to enable SPIRE to reach its objectives. To this end, SPIRE is very supportive of the Bio-based Industries PPP initiative (BRIDGE), that a large group of industrial stakeholders has proposed, to implement the Bioeconomy strategy. SPIRE and BRIDGE have jointly identified docking points between the two PPPs to ensure mutual support and complementarity. BRIDGE projects will lead to new sourcing options for bio-based platform chemicals in Europe, whereas SPIRE projects will generate additional options to establish new markets for bio-based products.

Examples of the content to be addressed in the three components are discussed below.

BIOMASS FEEDSTOCK & LOGISTICS

Each link within the value chain has to work optimally to ensure success and this starts obviously with the availability of biomass feedstock and the appropriate logistical network to deliver it from source to where first conversion takes place.

Although availability/collection of biomass feedstock is not currently within the scope of SPIRE, quality, quantity and sustainability of bio-based feedstock supply are important prerequisites. This may require significant innovation in the field of biomass feedstock and logistics. For SPIRE stakeholders, certain aspects of bio-based feedstocks are key to meeting the process industry objectives:

Sustainable long-term supply, considering different scenarios related to the production and demand of biomass by different industrial sectors, e.g. by 2020, 2030 and 2040. These need to be supported by analysis on interlinks between all land-use sectors and different industrial sectors along with effects of legislation and policy aspects;

Sufficient quantity of supply. To meet increased supply quantity requirements, it is expected that improvements in biomass production/yield will be required. This could be achieved through

- adapting crops to less-favourable soil and climate conditions or cultivating new feedstock (e.g. orphan crops, new terrestrial or aquatic plant species and algae). This will allow production of plant-based biomass in non-arable land and aquatic environments;

- development and implementation of key enabling technologies to speed up the plant breeding and selection process: systems biology, genomics, metabolomics, marker-assisted (molecular) breeding and field phenotyping/sensor technologies. Due to their high data output, all enabling technologies have to be connected with a strong informatics and mathematic modelling platform;
- extensive collection and advanced use of various residues (e.g. wood bark, harvesting residues, straws);
- improving biomass output yield through development and demonstration of advanced harvesting technologies and machinery;

High quality, through developments such as improved characteristics of cellulose, lignin, starch, fibre, oil and other secondary plant compounds to improve harvesting, fermentation and processing accessibility;

Efficient logistics. Develop new approaches, such as efficient means for on-site fractionation, sorting and compression of biomasses to maximize the efficiency of supply.

BIOMASS PROCESSING TECHNOLOGIES

Key technologies need to be developed and optimised for the sectors and new value chains identified above.

- New pre-treatment processes to facilitate further selective fractionations and processes, including fractionations where all major and minor biomass components can be isolated in their natural, intact forms.
- New selective biotechnical, chemical, thermal, and catalytic processes for the conversion of the biomass fractions to the desired raw materials (such as sugars, lignin, biogas) that can be converted in a resource and energy efficient way into specialty and bulk products, including platform chemicals. Examples of the key technologies include the production of phenols and aromatic hydrocarbons from lignin, the large-scale production of bioplastics from carbohydrate sources, as well as the development of technologies, like gasification or pyrolysis. These latter technologies can valorise

both biomass which is not suitable for conversion into food and chemicals and the residual biomass from prior conversion into food and chemicals into valuable products that could replace a primary resource like natural gas.

- Development of new products with novel properties and functionalities for a variety of identified applications to replace those currently prepared from non-renewable raw materials and also to bring totally new products to the markets (new molecules with more sustainable applications).
- Development of optimal integration of biofuels production processes into other biomass fractionation and processing systems.

INTEGRATION ASPECTS

In order to create optimal valorisation of biomass material and its energy content, it is necessary to co-locate and integrate different processes that are symbiotic in nature. This is a key factor to achieve resource efficiency and thereby economic viability, which is an imperative to make the new value chains commercially implemented. In order to support the integration of new industrial processes there will be a need for:

- Development of comprehensive process optimization tools which incorporate environmental costs in parallel to process yield and energy efficiency.
- Development of decision-making procedures to analyse potential industrial approaches and which role different sectors can play in the new value chains.
- Development of research and test facilities for the industry, e.g. laboratory equipment and mobile test facilities. Construction of European level flexible pilot- and demonstration-scale infrastructure. Pro-active collaboration with end-users to tailor development against the critical components that the materials will require.
- Pro-active collaboration with end-users to tailor development against the critical components that the materials will require.
- Development of an understanding of seasonal variation of availability of different sources of biomass and seasonal variation of the demand of products from the processes. This would make it possible to co-locate processes that are seasonally symbiotic to make full use of plant investment.

2. Key Component PROCESS: Solutions for more efficient processing and resource and energy efficient systems for the process industry, including industrial symbiosis

From a resource point of view an industrial production unit can be positioned within a hierarchy of resource related concentric layers as visualised in Figure 6. In the centre is the core activity where raw materials are processed into finished products. This typically requires several steps including pre-treatment, reaction, separation and finishing. The second concentric layer represents the supply and recovery of energy and water into and out of that process. The third layer represents (often external) utility services for the process to deliver steam for heating, provision of cooling, electricity and gases. The outermost layer represents the connection to the value chain, supplying resources typically featuring two main types:

1. The supply of raw materials (see FEED) involving supply chain partners requiring provision of logistics when at different locations.
2. Value chain integration based on the concept of industrial symbiosis.

Because of the interconnectivity of these different resource-related concentric layers it is important to maintain a systems approach when driving towards greater process sustainability.

More efficient processes

In spite of the fact the existing production processes have often been operated for decades, they can still be significantly or radically improved in terms of triple bottom line sustainability (i.e. People, Planet and Profit). No one single route to such improvement exists but rather there is a multiplicity of approaches that can be applied. For example, alternative raw materials may be used to produce the required finished products. An alternative process path involving different reaction intermediates may be taken from start to finish of the process. The kinetics of the process could be improved by the use of better catalysts. Alternative changes to equipment, process and system designs can achieve significant improvements, for example by moving from a batch to a continuous process dramatically improving the energy and resource efficiency of the process.

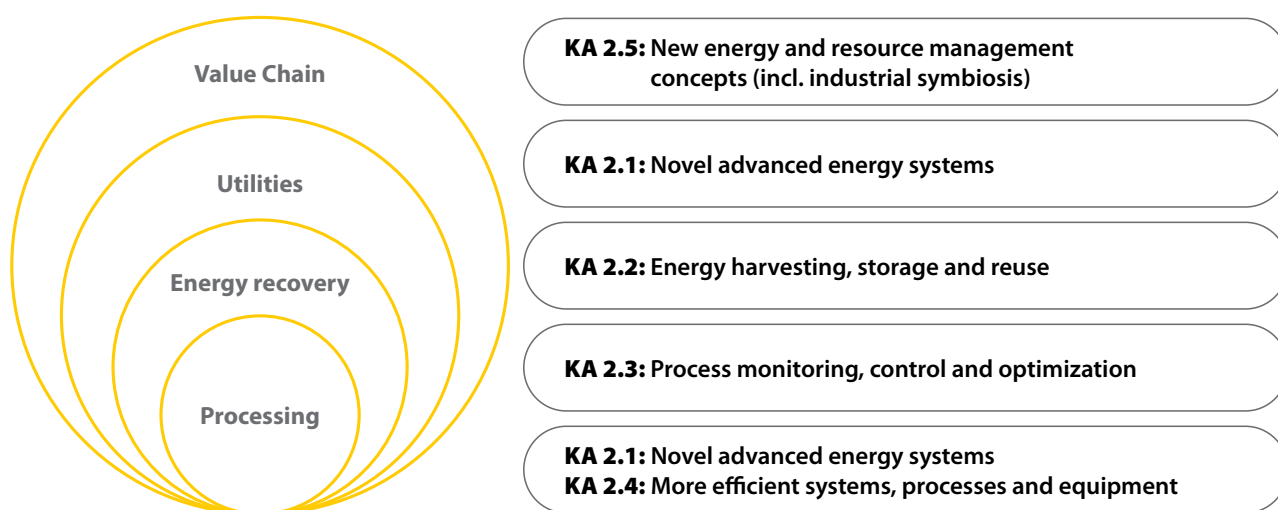


FIGURE 6: Position of Key Actions in process layers

In the context of resource efficient (cross-)sectorial innovative advances towards **Process Intensification** are required to bring dramatic improvements in processing, substantially decreasing the equipment- size/production-capacity ratio, energy and resource consumption, or waste production, and ultimately resulting in cheaper, sustainable technologies as a result of process and chain efficiency and reduced capital and operating expenses. These innovative advances can generally be divided into two main areas:

- **process-intensifying equipment**, such as novel reactors and furnaces, and intensive mixing, heat-transfer and mass-transfer devices; and
- **process-intensifying methods**, such as integration of reaction and separation, heat exchange, or phase transition, techniques using alternative energy sources, and new process-control methods.

Design and systems engineering methodologies, such as process modelling, simulation and control strategies are essential to optimize existing and prospective processes. Additionally it is crucial to enable the transfer and replication of advanced process technologies into a wide range of different industrial production units. Using process modelling based on eco-efficiency and economics is a requirement for knowledge-based decision making to enhance process sustainability. All modelling, simulation and control strategies need to be tested and validated in realistic process environment conditions as well as validated against the regulations and quality standards of the respective production environment as a basic requirement for industrial implementation of innovative process approaches.

Current measurement systems only partly meet the need of comprehensive production monitoring since parameters such as - reaction temperatures, pressures, etc. can be measured but these do not directly signify the more important parameters of product quality. Achieving comprehensive production monitoring will contribute significantly to the 2030 target of enhancing resource and energy efficiency.

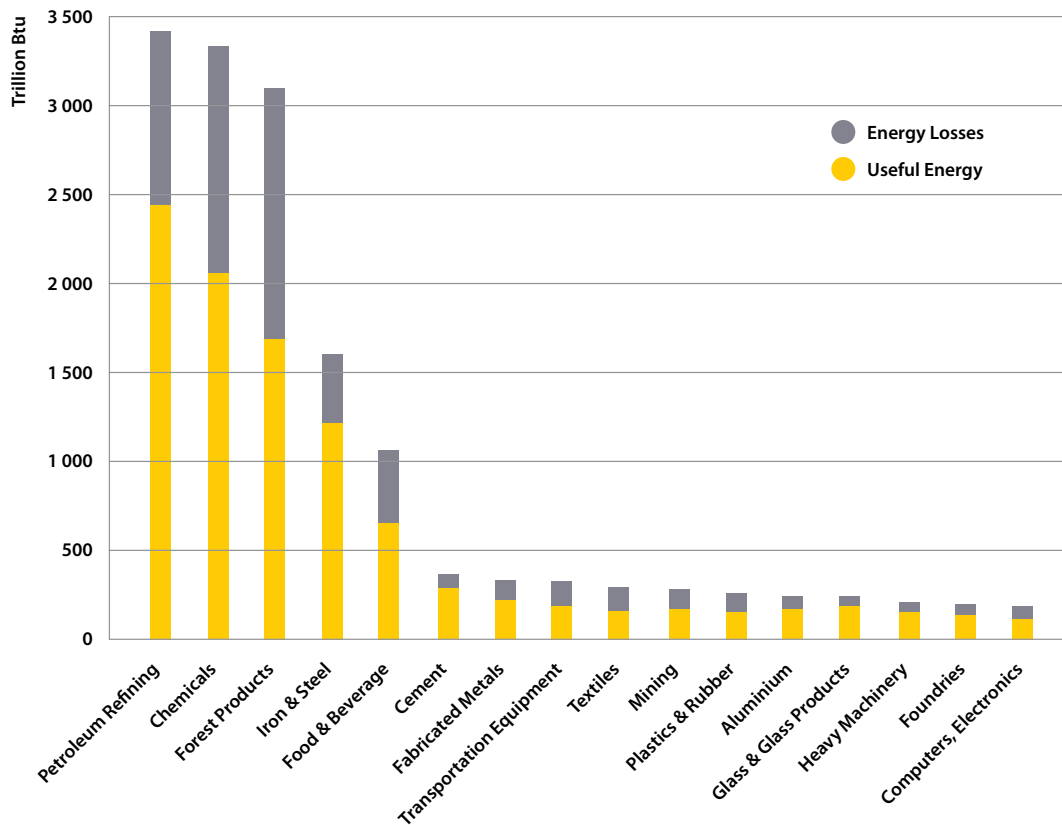


FIGURE 7: Overview of energy losses within sectors

Improved recovery and re-use of energy, water and other residual resource streams

It is estimated that 20-50% of the energy used in industrial processes is lost in the form of hot exhaust gases, cooling water and heat losses from equipment and products. The Figure 7 (extracted from an IEA-IETS report) compares the energy use and energy losses in industry sectors in the US to illustrate the potential that exists in re-utilising waste heat streams as a resource.

Recovery of energy from production processes represents the greatest single opportunity for reducing energy use, and solutions are frequently cross-sectorial. Despite the significant environmental and energy savings benefits of waste heat recovery, its implementation depends primarily on the economics and perceived technical risks. Industrial

manufacturing facilities will invest in waste heat recovery only when it results in savings that yield a “reasonable” payback period (<< 3 years) and the perceived risks are low. A key objective in any R&D&I effort, therefore, should be maximising the economic returns of waste heat recovery technologies. Another important factor is the misfit (in time) between supply and demand of recovered/reused energy. This means that reliable, cheap energy storage is as essential as recovery and energy management.

Modelling and simulation is required to show how heat recovery systems coupled with energy storage systems could be deployed in processing operations. Energy storage will be a fundamental need in a future where fluctuating renewable energy plays a major role particularly approaches for storage of low-grade energy.

Water plays an important role in almost every process within the intensive industrial activity. Water as a resource and its systems are envisaged to be fully integrated in the design of the production plants. In addition, “water and energy” interaction, by means of optimising joint management of energy and water, will contribute to minimising the consumption of both resources. Successful demonstration of energy and water-saving technologies is expected to lead to more widespread take-up at other industrial sites.

Also the recovery and re-use of **other non-energy and water residual and waste streams** from industrial and post-consumer end-of-life materials will have a significant impact on the overall resource intensity of the production system. This is dealt with within the Key Components WASTE2RESOURCE (for extraction, separation, sorting and pre-treatment) and FEED (for re-integration into the feed-stream).

This Key Component however, will deal with the important trend towards industrial symbiosis, to align and optimally manage resource streams within industrial parks, optimising both input and re-use of raw-materials, energy and water streams in a synergetic way.

Summarising, novel production processes are key to increase energy, resource and/or carbon-neutral efficiencies. They also contribute to the reduction of Greenhouse Gas (GHG) emissions in combustion devices. Addressing these challenges require appropriate technologies, processes and products and demand intelligent product designs as well as smart processes over the value chain. This will be realised as a result of the following five Key Actions.

Key Action 2.1: Novel advanced energy technologies

Industrial processes in Europe need to overcome the existing technology limits in order to fully take advantage of the planned system integration of advanced energy systems and novel combustion and gasification technologies. The complex relationships between the different energy generating and consuming facilities need to be better understood, especially with regard to integration of new processes while improving quality and

purification issues, to support choices for improvement. This involves large through-process developments of all energy streams. The improvement of the energy efficiency (including alternative sources) and the reduction of energy cost penalties will lead to advancement in competitiveness. This can be achieved by the increased integration of a portfolio of energy resources and technologies, such as by the integration of a flexible cogeneration of electricity, fuels, heating and cooling, Renewable Energy Systems (RES), as well as the utilization of storage and demand response options across different supply systems. SPIRE will promote a drastic increase in energy efficiency of the process industry through e.g.:

- Novel combustion and gasification techniques also utilising alternative energy sources for all type of production plants;
- Combining Heating Hybrid Alternative ways of high temperature technologies using electricity and biomass as energy sources;
- New techniques for industrial furnaces for reheating, melting of materials, etc...;
- Novel carbon capture and usage (see also Key Component FEED);
- Optimum design for electrical generation systems by integrating renewable energy, co-generation heat and power (CHP) and storage systems in the various industry process.

Key Action 2.2: Energy harvesting, storage and reuse

Waste heat is a by-product common to all industries. R&D efforts in energy upgrading need to be targeted at further developing and demonstrating emerging and innovative technologies targeting recovery (harvesting), storage and reuse. This includes low and high temperature heat pumps, heat pumps with high temperature lift and thermally driven cold supply, where upgraded waste heat can either replace steam or electricity. In general this covers all novel processes to transfer sensible heat from a medium where this heat can currently not be utilised into a medium which makes this energy available at maximum exergy. A target is to have low cost, efficient and reliable very high flux heat exchangers working at high temperature (up to 1200°C),

high dust concentration (up to 1kg/m³) and in corrosive environment. In energy conversion technologies, further development is needed on efficient and cost-effective alternatives to existing waste heat to electricity technologies, considering new approaches such as ORC (Organic Rankine Cycle) or KALINA cycles, in order to improve the global efficiency and to implement the better way to integrate with different processes, including heat storage systems. Novel efficient heat and energy storage technologies (see also **Key Component APPLICATIONS**) will play a significant role in the future, allowing industries to balance their energy consumption by means of fully integrated and monitored processes. In addition, thermal heat storage will enable flexible use of waste heat and optimised use and capacity of components by compensating for temporal fluctuations on demand. SPIRE will target accelerated progress in recovering, storage and use of large quantities of waste energy through e.g.:

- Improving the characterisation of heat transfer (lining and instruments for measuring heat transfer by radiation);
- Storage of energy at different temperatures;
- Develop processes at different temperatures compared to today's technology;
- Gas separation techniques at high temperatures;
- Development of cooling or solidification or cleaning processes with heat recovery instead of water quenching.

Key Action 2.3: Process monitoring, control and optimization

In a production process with a number of consecutive steps, sometimes at different locations, there is a risk of sub-optimising the overall process. Existing systems are often difficult to upgrade and fully integrate along the production chain and not properly tailored to the intensive industry requirements. Therefore, significant adaptations and new hardware and software solutions are required to achieve better process integration and optimisation. In-/on-line monitoring and real time measurement, will enable better plant control on a more

efficient basis. Improvements in process monitoring and measurement are key to delivering better process control and hence more sustainable processes. Innovations in process measurement are needed which relate more closely to final product quality allowing better process control. Substantial reduction in the cost of measurement devices will allow much greater implementation of these devices again leading to better process control. Models based on a more complete process understanding are necessary for predictive / intelligent control systems. Substantial benefits will be delivered by new through process optimization methods, as well as new techniques for rapid measurement of physical properties, especially in solids and structured liquids accompanied by the development of adequate process measuring and monitoring systems, to be embedded in the relevant processes, covering the whole production chain from feedstock to application.

This will need to be realised by:

- Implementing measurement devices for all aspects of intermediate/final product quality and their integration into process control;
- Robust optimization methods to local targeted process control and energy supply;
- Simulation methods for the analysis, characterisation and study of systems, material, equipment and processes;
- Low cost measurement devices to enable high levels of process monitoring;
- Understanding and modelling multi-phase and multi-physic phenomena in products and process.

Key Action 2.4: More efficient systems and equipment

An integrated approach to process innovation is required covering design, simulation, operating conditions and process management together with breakthrough technology in using new raw materials as feedstock, heating technologies, insulation designs and energy intensive operations such as grinding. These can all significantly contribute to resource efficiency (e.g. reduction of fossil-based feedstock) and a reduction in emissions, waste, energy consumption and waste water as well as the environmental footprint (up to 50% of energy is actually lost via heat transfers and gas waste into the environment). Systematic integration of best practice technologies into existing large and small scale plants (retro-fitting) is essential to achieving efficient processes.

The introduction and further penetration of process intensification technologies will lead to faster, smaller, more flexible, modular, safer, standardised and cheaper production equipment with higher yields. In this sense modularized, compatible, and flexible production units (comprising equipment items, process control and the manufacturing platform) can play a decisive role, when it comes to fast market introduction of new products (materials, molecules) as well as for the rapid integration of innovative and more sustainable technologies in a highly competitive production environment. This will also be of great importance for the spread of standards and best practices across the process industry. Greater intensification and reduced capital per unit output will enable distributed manufacturing. It will also enable accelerated innovation towards a wider portfolio of end products due to its flexible and multipurpose operational modes. Better process understanding is needed to enable more rapid process design and achieve a more precisely defined product quality. With such understanding kinetic barriers to conversion can be reduced by, for example, using better catalysts leading to better process economics and smaller environmental footprint. Use of different or novel solvents or solvent-free conditions can beneficially change reaction conditions and process thermodynamics. Process improvement is also required, at the work-up stage particularly, when products are solids or structured liquids.

Maximization of inter and intra molecular reactions via innovative catalysts will reduce activation energy consumption and increase the reaction specificity. The integration of conversion with purification via, for example in-situ product recovery, will change reaction equilibria and optimize the (bio)chemical reactions. Giving each molecule the same processing history in continuous and tubular reactor systems will reduce energy input and reaction times combined with increased conversion yields and reduced reaction time. New ways of targeting energy input via electrochemical, light and ultrasound based systems will direct the reaction to the right target with less energy input.

The bio-based economy, which makes use of bio-based resources but also CO₂ and other waste gases, is expected to enable a step change in sustainability for the process industry. Sustainable feedstocks are not sufficient alone. Also the bioprocesses themselves (e.g. fermentations and downstream processing) will have to be sustainable. This can be accomplished, amongst others, by applying and implementing the above described principles of process intensification on bio-based processes.

There is a need for new materials, new equipment, new reaction technologies, more effective and efficient techniques for processing solids and structured liquids, disposable or recyclable as organic and inorganic streams process components, new grinding and separation technologies, new hybrid technologies, advanced process control including self-adapting methods, extended use of on-line analysis, improved energy integration, and new supply chain concepts. Therefore significant opportunities exist to join forces across sectors targeting:

- Design, redesign and retrofitting of existing and new equipment and processes;
- Development of more flexible and scalable processes at lower capital and operating costs.;
- Process understanding to enable rapid process design and precisely defined product quality;
- More controlled and reproducible production of formulated products and materials;
- Research of new design for process and equipment enhancing efficiency (energy, material yield, productivity).

Key Action 2.5: New energy and resource management concepts (including industrial symbiosis)

The progressive development of low carbon industrial firms and industrial parks will require that socio-economic barriers be overcome: these include technological barriers, environmental barriers, and 'human' barriers. Significant improvement of the energy consumption and CO₂ emissions of industry in Europe will be achieved thanks to the optimization of interdependencies both among stakeholders inside industrial parks ("endogenous interdependencies") and outside the park ("exogenous interdependencies") and to the identification of technology components, which will allow breakthrough CO₂ cuts at acceptable investment levels.

At micro level, **new holistic energy and resource management systems** including water and emissions footprints will bring all relevant data into the daily routine of the plants. Energy Management Systems (EMS) demand new concepts due to the challenges that industry faces today to be competitive. This requires integrating demand side management and decentralised energy and resources into the existing system. EMS must offer standardized holistic new approaches that perform cost-saving optimizations of energy and resources supply and demand in selected areas on the basis of energy and exergy balances, pinch analysis, prediction of energy demand, diagnostic and optimisation, including heat recovery, by taking into consideration both economical and sustainability constraints. Analysis of further improvement possibilities and how to overcome non-technical barriers are also a matter for further developments with an appropriate evaluation methodology with regard to energy and resources efficiency, environmental relevance and economy. We should assess not only an isolated industry but also **energy and resources flows of an entire industrial park** based on the concept of industrial symbiosis.

At macro level, the positive interactions between the different actors (companies, neighbouring municipalities, infrastructure administrations) will lead to several positive outcomes in terms of accrued economic value, higher level of attractiveness to inward investors, new clients, number of jobs created, city planning and sustainable development promotion by local authorities, other public organizations, industrial parks managers, industries and policy makers.

New business models and **service concepts** should be realised to address the barriers, which have so far prevented regionally or locally adapted solutions, with an emphasis on non-technological aspects such as legal, regulatory or cultural.

Historically the trend has been towards integration and aggregation of process steps with complex logistics networks used to convey intermediates onto further processing or products onto customers. New more intensified, lower capital, but more flexible production units could allow greater distribution of process manufacturing closer to end-users and customers. As transport energy costs rise this will generate economic and environmental footprint benefits. This trend is also consistent with a move to even greater product differentiation towards a batch size of one. Via holistic analysis of the value chain, it could be important to decide whether large investments need to be co-located, co-invested or dispersed over geographies.

3. Key Component APPLICATIONS: New processes for sustainable materials and market applications that boost energy and/or resource efficiency across the value chain

As a cross-sectorial PPP rooted in different process industries contributing to the development and manufacturing of practically all products in society, SPIRE can provide important contributions towards a resource and energy efficient society and economy.

To be successful in developing the materials and processes according to the priorities set within Europe both across and along different value chains it will be essential to connect to already on-going public supported innovation initiatives like the current recovery plan PPPs (Factory of the Future, Energy Efficient Buildings and Green Cars) as well as potential new initiatives that may be supported under Horizon 2020 (e.g. Bio PPP). Strategic EC programmes, e.g. the SET plan or the Water EIP, will be other important bodies for consultation. In particular the Key Component APPLICATIONS collaboration within the value chain will be fundamental. It is the explicit intention of SPIRE to take a less "agenda-driven" and more of a **"bottom-up"** driven approach, leaving room for proposed market needs solutions that have a drastic impact on resource and energy efficiency down the value chain, and require contributions from the process industry.

In deciding for which applications and value chains new technology developments will be initiated, we would like to focus on those where the developments could contribute to sustainability in both the process industry itself as well as to other parts of the value chain (e.g. energy storage), and to those value chains where the impact on energy, resource and/or CO₂ improvement would be most significant. The data reported by the International Energy Agency (IEA) in Figure 8 can be used as an initial reference. According to the IEA the energy sector (41%), transportation (22%) and industry (20%) are the main contributors to global CO₂ emissions, followed by the building sector (7%). In the industrial area steel (6%), cement (5%) and chemicals (3%) are the largest source of CO₂ emissions.

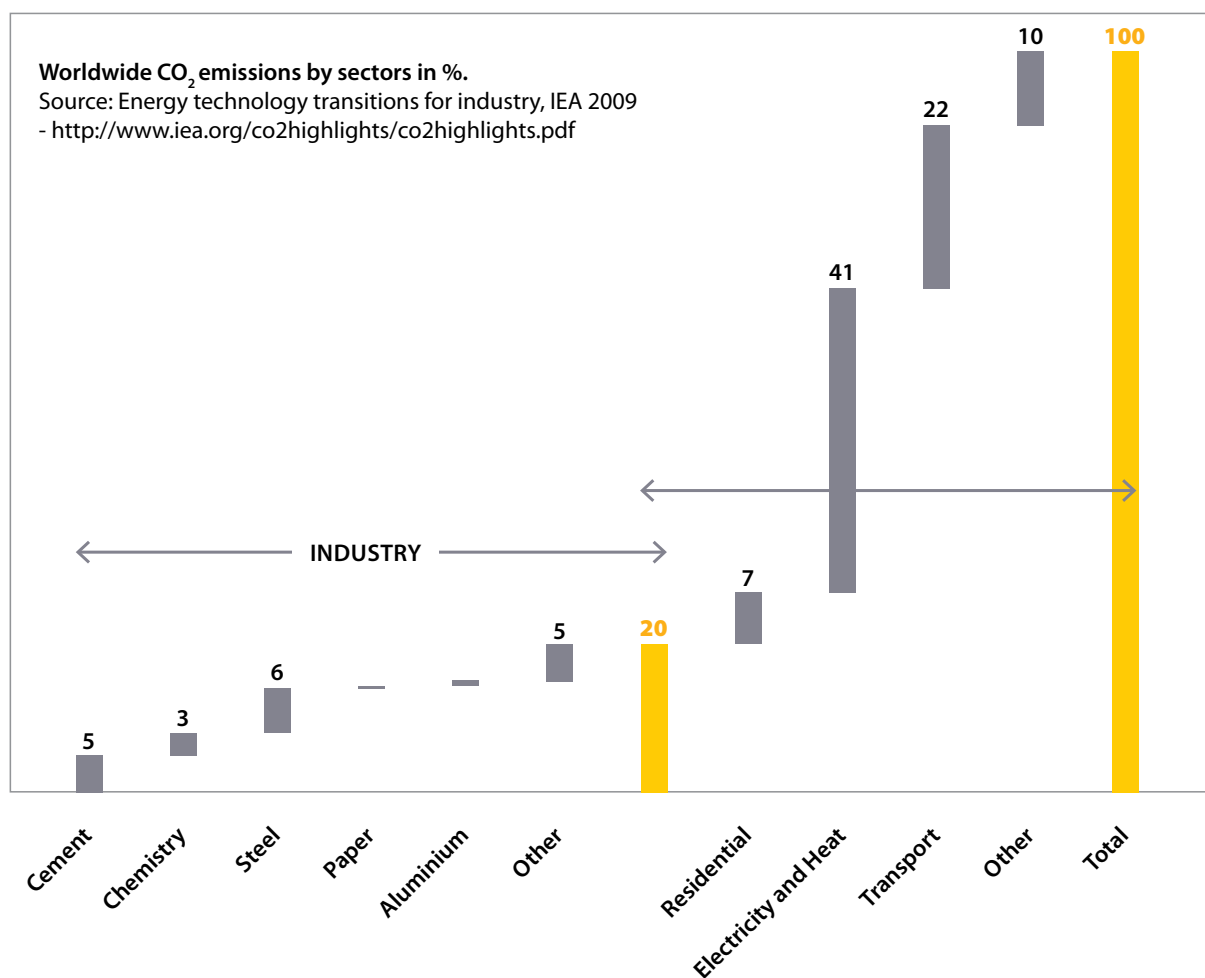


FIGURE 8: Worldwide CO₂ emissions by sectors in %.

The data confirms that SPIRE and the process industries within it are indeed in a position to make a significant contribution to energy and resource efficiency within their own industries (representing 20% of the global CO₂ emissions). In that sense the contribution of SPIRE can be foreseen in two main directions (Figure 9):

1. More sustainable processes contributing to the development of novel materials with less CO₂ and energy footprint that are fundamental cornerstones for energy and resource efficient applications down the value chain (e.g. LEDs, PVs, etc.).
2. New sustainable materials that will help the process industry itself to develop more energy and resource efficient processes (i.e. energy storage materials, materials for high temperature processes) and that can also be of potential applicability when considered in sectors down the value chain.

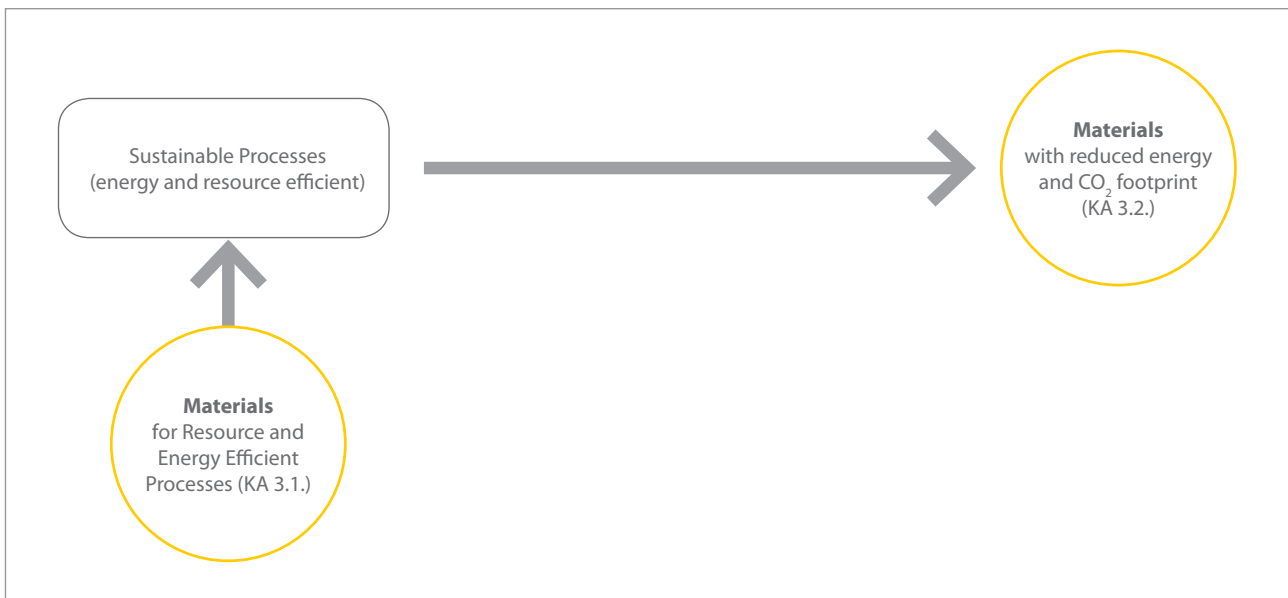


FIGURE 9: The two contributing directions of the SPIRE Key Component APPLICATIONS

These contributions will be targeted through the following two Key Actions.

Key Action 3.1. New materials contributing to develop energy and resource efficient processes

Good examples are refractories and highly efficient insulation materials/systems. Research and development in processes to produce those new materials will be essential for new insulation designs, equipment and materials” as well as “new adiabatic systems and furnaces

with 100% insulation”. Sustainability compared to present technologies has to be improved. Further demonstration is needed to extend solutions and application in the process industry. Other examples are steels, super alloys, metals and ceramics for high temperature application, and materials withstanding higher temperatures for ovens and furnaces: maximum temperatures in cement kilns reach 1800°C, in glass furnace 1600°C, and reheating furnaces 1300°C. There is a lack of experience on performance and scaling-up of developed new materials as well as a need to improve the ratio of performance/cost.

Specifically we also want to consider here the need to implement more methods for cost efficient energy storage. This is essential to provide the flexibility to adopt more use of renewable energy sources as well as benefit from harvesting of waste energy. These could be through battery technology, fuel cells, super capacitors as well as through novel thermo-chemical solutions for local storage. Generation of renewable energy through improved photovoltaic technology is also a requirement for success, while concentrated solar power could be used when very high temperatures need to be generated. Some of these technologies will also find application in other parts of the value chain (energy, transport and construction sector) through higher resource efficient electrification of society (smart grids, building heating/cooling, transport propulsion etc.).

Lithium ion batteries are a popular power source for portable electronic devices, but not yet sufficient for industrial or automotive goals. Other energy storage solutions (e.g. chemical storage, fluid transportation etc.), will require the development of novel materials (i.e. inorganic phase change materials (PCM) for high temperatures, high heat capacity (e.g. > 800°C) and PCM materials based on organic and polymeric molecules) as well as their production processes. Chemical storage of non-standard energy fluids will require research on solutions that both meet the needs of high storage capacity and encompass moderate operating temperature, fast kinetics, low cost and/or excellent reversibility and low toxicity. Regarding Hydrogen storage materials (HSM) research is still on-going to find materials meeting the above mentioned needs (e.g. hydrides) as well as routes to process them.

In order to address the challenges that are outlined above it will be necessary to develop a comprehensive analysis taking into account all the different aspects involved (i.e. sustainability of the process, eco-design, recyclability, required materials performance, cost-effectiveness etc.). The Materials Roadmap Enabling Low-Carbon Energy Technologies²⁴ published by the European Commission at the end of 2011 outlines the materials research and innovation priorities in the field of energy technologies, and thus provides a good basis, on which SPIRE could build.

Key Action 3.2.: New processes for energy and resource efficient materials applied in sectors down the value chain

An important contribution of the process industry will be to enable energy and/or resource efficiency down the value chain. Illustrative examples will be more sustainable processes to develop materials with a potential impact on the efficiency and durability of industrial and transport systems, such as (bio-) lubricants for industrial applications and coatings to reduce the effect of wear, erosion, corrosion and/or to improve thermal barrier properties. Other examples could be more energy and resource efficient processes to develop inorganic light emitting diodes (LEDs) as well as organic light emitting diodes (OLEDs) with longer lifetime. Additional areas could include new sustainable processes for novel composites (bio-based and non-bio-based), new thermoelectrical materials or coated materials with new functionalities as well as materials for potential future use in the construction sector (i.e. thermo-electrical roof tiles, energy storing clay blocks, ultra-high-performance concrete, lightweight construction composites etc.) as well as for example sustainable processes for materials used in the energy sector such as for cost-efficient wind-turbines having superior energy conversion capacity and novel materials with applicability in energy efficient power plants.

All these approaches will necessarily require collaboration between structural material industries (i.e. non-ferrous metals, concrete, cement, wood, glass, plastics and cardboard) as well as a number of manufacturing sectors such as automotive, construction, etc. to effectively integrate the key players in the whole value and supply chains throughout the product life cycle.

4. Key Component WASTE2RESOURCE: Valorisation and re-use of waste streams, including recycling of post-consumer waste streams and new business models

In SPIRE, the word “waste” is understood in a broad sense as any substance or object which the holder discards or intends or is required to discard (DIR 2008/98 - on waste and repealing certain Directives). At the same time, however, SPIRE also focuses on materials that are or will be defined as by-products. In the latter, SPIRE makes use of the End of Waste criteria for by-products.

²⁴ http://setis.ec.europa.eu/activities/materials-roadmap/Materials_Roadmap_EN.pdf/view

This means that the waste status may be revoked if:

- the substance or object is commonly used for specific purposes;
- there is an existing market or demand for the substance or object;
- the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products);
- the use will not lead to overall adverse environmental or human health impacts.

Drawing the line between waste and by-products serves an important purpose in SPIRE. It helps in a conceptual separation of materials and material flows belonging to Key Component FEED and Key Component WASTE2RESOURCE. The basic principle is that materials that can be used as raw materials as such (i.e. those currently or in the foreseeable future fulfilling the End of Waste criteria) belong to Key Component FEED. Materials that require processing prior to re-use (i.e. materials not fulfilling the End of Waste criteria) belong to Key Component WASTE2RESOURCE.

Key Component WASTE2RESOURCE also includes “waste” from downstream industries using our production, not only those of SPIRE partners. Lastly, it also includes disregarded final products after use, which can be re-used/recycled, thus becoming resources for new products. As the processes used for the preparation of these recycled products are very similar to those used for treatment of wastes. It deals with gases, solids and liquids in our processes, those of downstream industries and treatment after used of final products. The ambition for SPIRE regarding resource efficiency is that “by 2030, up to 20% reduction in non-renewable, primary raw material intensity versus current levels”. SPIRE’s Key Component WASTE2RESOURCE will thus be instrumental in implementing the objectives defined in the recently published ‘Roadmap to Resource efficient Europe’ (EC COM (2011) 571 Final) by enabling cost competitive and environmentally friendly technologies, products and services such that by 2020: 1) waste is managed as a resource, 2) waste generated is in absolute decline, 3) recycling and reuse of waste are economically attractive options for public and private actors,

4) more materials, including critical raw materials are recycled, and 5) energy recovery is limited to non-recyclable materials and landfill is virtually eliminated.

Within this Key Component, SPIRE will therefore develop and demonstrate solutions that increase waste collection rates, increase reuse and recycling rates, reduce the generation of waste, increase the yield of recycled materials, the quality of recycled materials and enable access to and use of wastes and low yield materials through improved processes. A LCA approach will be adopted to assess the suggested innovative solutions.

SPIRE operates in the spirit of: “there is no such thing as waste, there is only resource” aiming to close the loop especially for materials that do not lose their properties through the recycling process (e.g. metals). Waste is a business opportunity, especially if we take a cross-sectorial approach in extracting, treating and re-using valuable “waste” components within and between sectors, driving the emerging eco-innovation market: SPIRE will contribute significantly to eco innovation by developing technologies, processes and services that contribute to the avoidance, valorisation and re-use of waste streams within and across sectors thus reducing the impact on the environment, enhancing the resilience to environmental pressures and responsible use of natural resources. As such, waste is an opportunity to create markets for recycled and reused products, with a positive effect on related job creation in Europe. Furthermore, European entrepreneurship will be stimulated by increasing the export of recycling technologies and services while simultaneously reducing the environmental impact of waste handling. Besides material efficiency, recycling could also contribute strongly to energy efficiency.

Secondary raw materials constitute a growing proportion of raw material feedstock as the economy moves towards a closed-loop society. The paradigm shift from a “hunter-gatherer” economy to an industrial activity, that will have to take place, needs to be carefully prepared²⁵. In view of the context of declining primary resource availability, urban mining will be one of the main sources of metals and minerals and reusable/recyclable materials for the European industry²⁶. For example, existing residential buildings, which are no longer in use, create a potential source of raw materials such as mineral raw materials and metals. This store of materials is

²⁵ Steel Technology Platform

²⁶ ETP-SMR Minerals Strategic Research Agenda

likely to keep growing (20 % by 2020)²⁷. One important factor is valorisation of end-of-life products, i.e. the process of avoiding degradation in quality of materials to be recovered from end-of-life products and re-used in the value chain.

The target is that recovered materials from end-of-life products have as high a quality as possible and as close as possible to the primary materials used in the production of the products.

Also bio-based non-fibrous raw materials will be increasingly used to reduce fossil CO₂ emissions and consequently, there will be a growing need to recycle them²⁸.

Recycling constitutes a fundamental key element in a holistic LCA approach and therefore it will be necessary to involve different stakeholders across the value chain (i.e. process industry, product designers and manufacturers, end users, etc.) to ensure that the most efficient recycling existing or novel technologies²⁹ are fit-for-the-purpose.

The value proposition posed in this component is therefore the transformation of Waste into a Resource, so what is considered waste in one context can be transformed into a resource in a different context. In order to contribute to realising the vision and the value proposition in Key component WASTE2RESOURCE four Key Actions have been developed:

1. Systems approach: understanding the value of waste streams;
2. Technologies for separation, extraction, sorting and harvesting;
3. Technologies for (pre)treatment of process and waste streams;
4. (Cross-sector) Value chain collection, re-use and recycle schemes and business models.

²⁷ German Raw Material Strategy

²⁸ CEPI Roadmap 2050 regarding non-fibrous raw materials

²⁹ SusChem Strategic Research Agenda

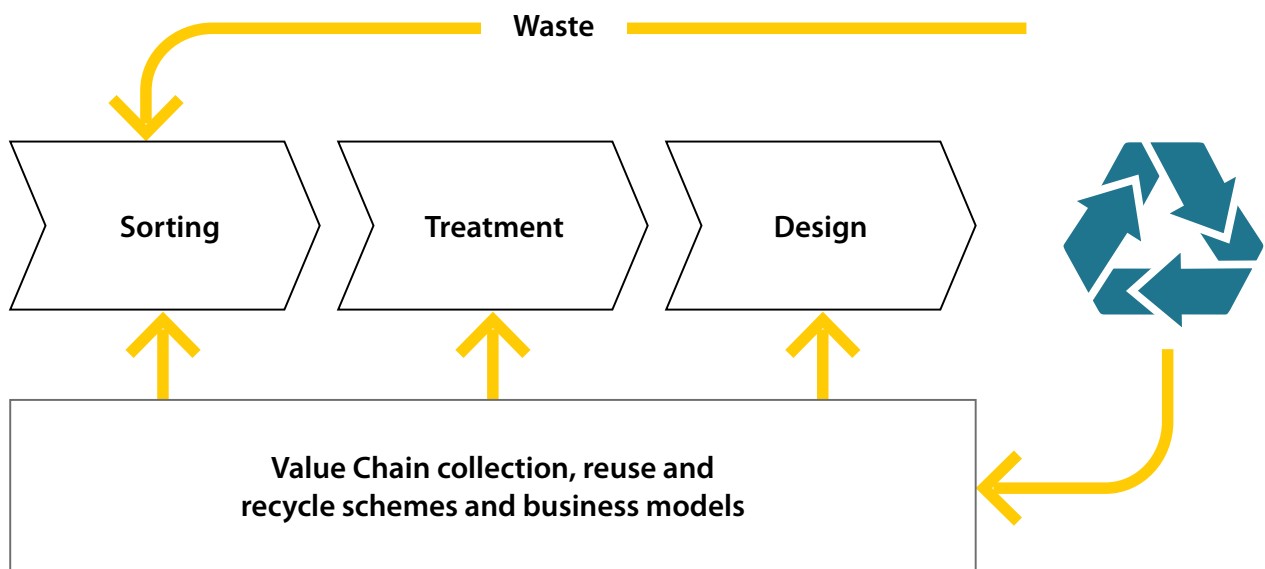


FIGURE 10: The four steps involved in Key Component Waste2Resource

The Figure 10 visualises the 4 different steps involved in this key component WASTE2RESOURCE: first we employ a systems approach in order to increase the understanding of the value within the waste streams; second, separation and capture of the valuable elements; third, treatment of the valuable elements to increase the reuse and recycle potential of the elements; and fourth, value chain collection reuse and recycle schemes and business models as a step towards increasing the eco-innovation potential and creating economically attractive business opportunities.

Key Action 4.1: Systems approach: understanding the value of waste streams

Because of factors, such as the complexity of waste flows, volatility of material prices, rapid changes in business environment, lack of information about the availability and properties of waste streams, and multi-stakeholder decision-making in the value chains, it is often very challenging to assess economic viability and sustainability

of recycling and reuse of waste materials. In order to optimise the processes the potential for integration of various waste streams should also be considered. Understanding of synergies between sectors and value-chains enables development of industrial symbiosis concepts, providing a great opportunity for approaches that will allow multiple industries to benefit simultaneously from cascading the material and/or energy flows.

One of the challenges in estimating economic viability and sustainability of recycling and reuse of various waste streams, as well as in identification of raw material potential of waste streams, is the poor availability of up-to-date basic data. In addition, supply and demand do not meet because of lack of communication between waste producers and potential users. This calls for **better means for information collection, management and transfer**. SPIRE will stimulate development of (cross-sectorial) databases and resource maps.

Furthermore, in order to enable exploitation of cross and intra sectorial synergies in development of sustainable European recycling **business, tools and methodologies** (including materials flow analysis) are needed to open the way for more holistic and systematic analysis. Models for dynamic simulation and optimization of both individual recycling processes as well as complex systems should be introduced for better understanding of in which kind of recycling or reuse process does each waste or material stream have its highest added value. One of the challenges in enhancement of recycling and reuse is better understanding, modelling of and experimenting with multi-stakeholder and multi-criteria decision making in waste value chains, including within industrial symbiosis situations. The applicability of integrated modelling concepts including novel cross-sectorial Life Cycle and Cost Assessment indicators and standards (see **Key Component HORIZONTAL**) for selection of optimal recycling strategies and development targets will be demonstrated in selected case studies both within and between sectors.

Key Action 4.2: Technologies for separation, extraction, sorting and harvesting of gaseous, liquids and solid waste streams

Europe must ensure its access to critical materials as industrial production in Europe is dependent on these resources. The region can take a world lead in exploiting existing materials in waste streams if we can create innovative and profitable methods for separating and capturing valuable materials. A joint effort is necessary to establish these methods – both from a systems perspective and from a technological solutions perspective. Waste can be in different physical states i.e. gaseous, liquid and solid, and process steps are required that can deal with waste in several states. It is crucial to optimise the process of sorting and capturing the valuable elements in waste streams by developing sustainable technologies for efficient separation, extraction, sorting and harvesting of waste streams. Important innovations required are:

- **Technological innovations for valuable material in waste streams.** It is important to make an inventory of products containing critical and valuable materials and industries in need of these materials and also the requirements for the purity of these materials. Reduction of losses of critical and valuable materials by rethinking of waste separation chains (enrichment of critical materials instead of losing them during processing and cross-sectorial effects of waste streams) is also necessary to develop economically achievable and environmentally efficient technologies for the recovery of (small) valuable elements / fractions from waste streams (including processes water).
- **Efficient sorting, separation and recovery technologies.** There is a need for developing more efficient pre-sorting (understanding of product design), sorting, separation and recovery technologies, including detection, identification and real-time analysis methods, which are less sensitive to impurities (including urban mining). The challenge is to identify the most efficient combinations of methods for the complete value chain including mechanical and sensor-based sorting, thermal, chemical and metallurgical treatment/extraction methods. Urban mining needs public awareness and willingness to contribute to recycling. This has to be highlighted and enforced by governments and politicians.
- **Automatic disassembly and comminution technologies and design.** In Europe automatic disassembly or comminution technologies are necessary to recover valuable elements and materials. In order to separate these valuable elements and materials, economically and environmentally viable processes for liberation are required. Furthermore, an industrial network approach needs to be considered in the design phase taking into account the selection of optimal sorting technologies in terms of cost and properties. Therefore actors across the value chain should participate in the development and implementation of scrap sorting technology and processes, (by investing in scrap sorting plants) that allow them to purchase lower cost scrap early in the recycling loop and to separate and up-cycle this low-grade scrap to the specifications of their own products. This KA has linkages to the Design for Reuse KA in the Applications component.

- **New technologies for selective separation for recycling of valuables from water and integrated re-use.** In many cases water impurities are valuable compounds (metals, nutrients, salts, organic building blocks), which could be used as raw material. Current water treatment methods are mainly aiming at removal and stabilization of impurities producing waste sludge or solid waste, which is difficult to reuse. The main challenge is that the concentration of valuables is often too low and the amount of water too high to justify recovery and reuse from an economic point of view. Technology concepts integrating smart, low-cost pre-concentration methods, energy efficient technologies for separation and recovery of impurities in a form fit for use as raw material or further processing and for water reuse need to be identified and their commercial feasibility demonstrated. Thus separation processes need to be developed, with the challenge that many applications are unique, i.e. the solutions have to be adaptable to different pre-requisites in order to reach a sufficient market size.

- **Demonstrate sustainable process models for selected waste streams.** Demonstrate/pilot economically and environmentally sustainable and technically feasible process models for selected waste streams (aiming for radical improvement of recovery efficiency of critical and valuable compounds, but also including efficient recovery of residues).

- **Develop relevant economically achievable technologies for the treatment of low-grade waste streams containing solid and gaseous components**
To avoid depositing low grade containing streams, including residual streams from recovery of valuables, recycling processes need to be developed. Low grade containing streams pose challenges in terms of developing economically viable processes and products. The option to adapt processes in order to create higher concentration streams should be investigated.

In general it can be said that different technologies and combinations of them can improve the recycling yield and the potential to recycle ever increasingly complex materials/products. Recycling these complex products is already a challenge, especially the recycling of some technology metals (very often critical and often in small quantities), as adequate refining technology (environmental & economically achievable) is often missing.

Key Action 4.3: Technologies for (pre)treatment of process and waste streams (gaseous, liquids, solids) for re-use and recycling

In the coming decades Europe will face critical challenges related to raw material shortages, therefore it will be very necessary to develop (novel) technologies oriented to increase the production and use of high value co-products, -recycling and reuse rates. A challenge for industry is to be able to produce recycled materials retaining the quality, i.e. processing capabilities and material properties, similar to primary materials. A further challenge is that treatment of materials must result in the qualities demanded by the market at an acceptable price. The treatment process must be economically and environmentally friendly, and waste streams employed to give new products with no or minimal residue for landfill.

Important innovations required are:

- **Develop robust pre-processing steps for concentration of valuables and removal of components degrading the product quality.**
Components based on hybrid structures as well as other components need to be recycled in the future. Also treatment of process streams into high-value co-products, pre-treatment of secondary raw materials (i.e. scrap) is necessary in order to integrate it back into existing processing lines. Therefore new processes and design for eliminating unwanted elements and concentrating valuable elements are needed. Experiences from other industries (e.g. mining industry) using the same concept could be used as references or examples.
- **Improving the yield of already recovered substances. The development of solutions in this direction face challenging steps such as implementing process control while avoiding hazardous methods/additives.** It will also be necessary to obtain reliable figures that allow quantification of losses. Minimising the generation of losses through adoption of best available methods is possible, but the cost must be acceptable. Furthermore, significant innovations will be needed in order to achieve cost-effective solutions.
- **Demonstrate commercially available technology to manage and control impurities and unwanted and harmful elements.** Reliable measurement techniques are essential for both process control

and development for individual technologies and the complete value chain. Demonstration of commercially available technology such as Environmental Technology Verification (ETV) to manage and control impurities and trace elements in order to attain robust qualities is the goal. On-line industrial solutions for quantifying these impurities and trace elements are required. Today there is often no clear correlation between measurement techniques and product performance. There is therefore limited knowledge of the effects of many trace elements on product performance.

- **Demonstrate concepts for local small-scale pre-treatment plants and large scale treatment factories for waste streams (gaseous, liquids, solids, also including water).** For several material streams concepts combining small-scale pre-treatment plants separating and pre-concentrating valuables and large-scale factories for further treatment of the pre-concentrated waste streams coming from separate sources, could be an economically efficient solution. Demonstrating the efficiency of this kind of treatment concept will be important to develop various economically competitive solutions for consumers as well as producers. To be efficient the concept requires further development of economical pre-separation solutions and tools for value chain management.
- **New waste/residue materials.** The European process industries are enabling new products and applications by supplying materials that are then transformed in new products further down the value chain. Many of these new products/applications will create energy and/or resource efficiency during their use as further outlined in this Roadmap under the Key Component Applications. However, the novel production processes and the new products derived from novel materials may also give rise to new waste and residue streams. Illustrative examples of developments/products that may generate new waste/residue streams are: Light Emitting Diode (LED) lightning, Photovoltaic (PV) solar cells, water and salts/minerals from the future biorefineries and Genetically Modified Organisms (GMO) typically originating from white biotechnology in non-EU regions. SPIRE will create energy and resource efficient solutions to re-use these “new waste/residue streams” in coordination with Key Component APPLICATIONS.

Key Action 4.4: Value chain collection and interaction, reuse and recycle schemes and business models

In order to improve recycling and reuse rates in Europe from current levels, several actions are required. One important action is to reduce the export of secondary raw materials from the EU, thus making more secondary streams available for European companies. Actions relating to policy/legislation are required, but also it is necessary to underpin recycling by developing innovative collection, reuse and recycling schemes, thus making recycling and reuse more efficient, easier to handle and transparent for consumers, industries and recycling companies. Another action is to develop new value chain collection schemes and business models that will improve the cost challenges facing European companies in comparison with low cost countries. Resource streams modelling, analyses and data collection could be further explored.

Important innovations required are:

- **New user-friendly and sustainable service business concepts and business models**
New business opportunities for secondary materials need to be identified and developed in order to make companies more competitive and more environmentally responsible by safeguarding key natural resources and decreasing the use of energy in the production process. Innovative business concepts for recycling and reuse must be developed that are easy to understand for users, easy to implement and cost competitive. When developing new business concepts and business models, a whole life cycle approach considering the advantages of closed loop and open loop recycling³⁰ need to be considered.
- **Value chain management and monitoring models**
Tools for intra-sectorial as well as cross-sector value chain collection need to be developed considering the full value chain and able to enable development and deployment of waste streams as feed stocks. It is furthermore important to enable information transfer between different actors in complex value chains to increase the knowledge of recyclers about product specifications. This can be achieved by demonstrating products where value chain considerations have been integrated into the products through information exchange and between producers and recyclers in the product design phase.

³⁰ The closed-loop recycling process is when a product is recycled back into the same product. Open loop recycling occurs when products at end of useful life are used as a resource to manufacture other products.

■ **Demonstration and market replication of collection and reuse schemes**

Robust methodologies, models and tools are required to consider the suitability of the schemes and business models for application within the European business context including data collection on waste stream composition that will allow companies to realise what is technically/economically feasible to recover and obtain proper collection schemes. One example is learning from best practice for collection and reuse schemes from other industries, product groups and Member States, in order to develop new schemes to be replicated throughout the European process industry. Another potential example will be the case of the multi-metal recycling approach through an innovative end-of-life products management. Timeline: medium-term demonstration.

■ **Value chain interaction: Inter-industry waste flows and inter-organisational relationships**

Knowledge from industrial ecology (materials flows) and organisational aspects (sociology, regional development, industrial organisation, etc.) will be combined in order to optimise industrial symbiosis within an industrial park or a region. Open innovation between and within sectors in combination with proximity are important factors for knowledge exchange as well as for the efficient transforming of waste flows from one sector into valuable feed in another sector (key component WASTE2RESOURCE). New insights into the conditions that underpin industrial symbiosis and associated framework conditions, as well as how different actors within value chains establish and maintain inter-organisational relationships to develop processes for industrial symbiosis, thereby optimising waste valorisation within and between sectors will be developed. The target is demonstration projects involving different industry sectors and actors employing a trans-disciplinary perspective leading to best practice examples for the organisation of cross-disciplinary industrial symbiosis.

5. Key Component HORIZONTAL

The various thematic components within SPIRE will be underpinned by an important Horizontal Key Component that will be targeted at **facilitating the cross-sectorial potential benefits that are at the core of this PPP**. The fact that SPIRE brings together different process sectors is both its strength and potential. At the same time exploiting

this strength requires various important bottlenecks to be overcome that hitherto have proven to be barriers for **cross-sectorial knowledge and technology transfer** as well as for **synergistic optimisation and sharing of resource streams**, which would boost resource efficiency in Europe. The horizontal component will drive the cross-sectorial synergies by stimulating the identification of good resource and energy solutions and practices from one sector and their transfer to another. Furthermore, cross-sectorial Life Cycle Cost (LCC) assessment methodologies, tools and standards will be fostered to create a level playing field for the emerging eco-innovation market (e.g. for novel businesses based on the collection and exploitation of waste streams as a new resource base), but also to promote novel products that have a significantly better environmental impact performance down the value chain based on the agreed LCA and LCC standards. Collaboration with standardisation bodies on these topics will be envisaged. Also new Social Life Cycle Analysis will be taken into account. Finally, skills and educational programmes targeted at the development, transfer and adoption of novel resource efficient solutions and practices, will be put in place to accelerate the impact of SPIRE where required.

Key Action 5.1: Identification, benchmarking and dissemination of cross-sectorial transfer of good energy and resource efficiency solutions and practices

One of the benefits of bringing together a large group of process industries in a single PPP programme is that it allows us to accelerate resource and energy efficiency impact by learning from each other. Innovative solutions with significant impact are being developed between suppliers, knowledge institutes and industries in all sectors, but with a specific focus on that sector.

SPIRE wishes to leverage its multi-sectorial character by:

1. Joining forces to carry out R&D&I activities with a focus on developing solutions that may be applied in multiple sectors (as described in the various other Key Actions in this document).
2. Setting-up mechanisms and developing financial incentives to systematically identify, evaluate, benchmark, adapt and replicate energy and resource efficiency technologies, solutions and practices, from one sector to another (in this Key Action).

As this Key Action will be targeted at accelerating innovation in sectors through cross-fertilisation, we will initially take a bottom-up approach to invite projects to identify, adapt and replicate solutions between sectors. Selection will take place based on the sustainability of the innovations, meaning that the projects with the highest potential for energy and resource efficiency impact will be considered.

At the same time a support action will be launched to carry out resource and energy efficiency studies across the various sectors to analyse and benchmark potentially transferable solutions and practices as an input to potentially more agenda-driven market replication actions where this is possible.

The necessary dissemination measures will be contemplated to ensure information reaches the interested community of stakeholders at large.

Key Action 5.2: Methodologies and tools for cross-sectorial Life Cycle and Cost Assessment as well as novel social Life Cycle Assessment of energy and resource efficiency solutions

Sustainability is a holistic, multidimensional and multi sectorial concept and assessment of sustainability requires a multidisciplinary approach. Sustainability assessment is a combination of different assessment methods and tools including environmental, economic and social aspects. When assessing sustainability, a life cycle approach must be applied to avoid problems shifting from one life cycle stage to another. Life Cycle Assessment (LCA) is a methodology to evaluate the environmental impacts throughout the life cycle of a product. Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) aim to complement the environmental LCA. Eco-design takes the environmental aspects into account already at the product design phase and aims at reducing the environmental impact of products throughout their entire life cycle. Eco-efficiency assessment is an environmental management tool which enables the consideration of life cycle environmental impacts of a product system alongside its product system value to a potential user or customer. Furthermore methodologies like risk assessment can also be applied.

In order to develop more resource and energy efficient process streams, utilize waste streams and improve recycling in a sustainable manner **modelling and assessing all the**

interacting value chains is essential. The content of the assessment depends on the product in question and the geographical location of the operations. None of the above mentioned methodologies are sufficient alone to boost intelligent energy and resource efficient solutions and waste recovery innovations, while both environmental impacts and financial competitiveness are crucial. A holistic approach is needed to identify and select **appropriate assessment methodologies and impact parameters and further develop and demonstrate in real industrial pilot case suitable macro and meso-indicators across sectors** to meet the needs of a specific assessment. Better integration of the modelling and assessment approaches (process and system analysis, scenario analysis, sustainability assessment, material management models and common databases) is also needed for selection of optimal development targets and design of sustainable recycling processes and concepts as well as new applications of recycled raw materials. Different approaches may be desirable for different value chains according to the specificities, recyclability and value of the material. Metals for example can be recycled again and again without losing their properties. It is therefore important to also promote recycling at end-of-life. In addition it is worthwhile highlighting that considerations related to Life Cycle Inventory (LCI) will need to be taken into account as well. It should be remembered that LCI is part of the LCA approach dealing with data collection, calculation of an inventory of materials, energy and emissions related to the systems. Data processing and cloud technology could be useful tools for further development of novel LCA approaches.

Key Action 5.3: Develop skills and education programmes required for the development and deployment of novel energy and resource efficiency solutions

Key Action 5.4: Enhance innovation and entrepreneurial skills and culture

The EU's new strategy for sustainable growth and jobs, EUROPE2020³¹, puts innovation and green growth at the heart of its blueprint for competitiveness. Different research studies show that the transition to a green economy could potentially act both as a driver and as an engine for job creation. A study recently commissioned by the UK government estimated that 400 000 gross jobs could be created by 2015 if plans to reduce greenhouse gas emissions were realized³² and a recent paper shows that in the US

³¹ http://ec.europa.eu/europe2020/index_en.htm

³² Innovas (2009). Low carbon and environmental goods and services: an industry analysis. For UK Department for Business, Enterprise and Regulatory Reform. Winsford: John Sharp, Innovas Solutions Ltd.

money invested in energy efficiency and renewable energy is estimated to produce between two and a half and four times as many jobs as the same dollar invested in producing energy from oil³³.

From a broad conceptual perspective it has been recognized³⁴ that employment will be affected in at least four ways as the economy is oriented toward greater sustainability:

- Newly created jobs (as in the manufacturing of pollution control systems and equipment).
- Substitution of jobs (e.g. in the transition from waste incineration to recycling).
- Elimination of certain jobs without direct replacement (e.g. when packaging materials are discouraged or banned and their production is discontinued).
- Redefinition of jobs as day-to-day skill sets, work methods, and profiles are 'greened'.

In the future, every job will be a green job³⁵ in the sense of contributing in varying degrees to the continuous improvement of energy and resource efficiency. Nevertheless it is necessary to take into account that understanding the sustainability impact of an occupation needs to be mainstreamed into (novel) education and training systems that promote co-operation between educational establishments and enterprises. Besides developing special expertise in environmental and sustainability issues and the green economy (e.g. environmental impact assessment, sustainability economics, technology, law and policy), there is also a need to increase the awareness and know-how in all lines of work (i.e. plant or process managers, designers, factory workers and service staff) to ensure that sustainability impact is maximised in all tasks and professions.

In the context of a green economy directed towards generation of new jobs and skills and fostering novel education paradigms, the SPIRE roadmap constitutes a key initiative taken by the European process industry.

As an integral part of the SPIRE roadmap, education and skills development will embrace technical,

business, entrepreneurial and innovation content for industry, research organizations and education institutions (teachers and students). The SPIRE roadmap contributes, from the perspective of a future Sustainable Process Industry, to the EU's reinforced collaborative spirit between industry and academia³⁶ while connecting with the main political agendas to favour the creation of jobs for Europe³⁷.

As an illustration of sectors and innovations directly contemplated in the SPIRE roadmap, studies indicate that a comprehensive low-carbon steel strategy could save more than 50 000 jobs in Europe (compared with 80 000 threatened in a business as usual scenario³⁸); other studies foresee considerable future job potential over the next decade or so, possibly 580 000 jobs in biomass heating, 424 000 jobs in biofuels, and as many as 2.7 million jobs in biogas³⁹.

The SPIRE roadmap proposes key actions beyond traditional dissemination and exploitation of activities by using outputs from SPIRE projects, as well as cross sectorial exchanges, to **drive enhanced innovation value and improve innovation skills capacity across the value chain of the EU Process Industries.** The objective of these key actions will contribute to reinforce and adapt future educational / training programmes as well as strengthening future innovation skills availability.

In that sense the SPIRE roadmap paves the way to accelerate the development of the new skills required to facilitate the transition to a greener economy and to provide a related reinforced skilled workforce for business. Moreover the SPIRE roadmap will facilitate the matching of skills supply with labour market needs, in particular in terms of newly-emerging and expanding skills such as those required by green jobs.

Apart from the education, dissemination and exploitation actions linked to individual projects that will be executed as part of the SPIRE programme, SPIRE will establish and maintain a framework aimed to enhance the technical, scientific, innovation and entrepreneurial skills of future generations of scientists, engineers and technologists by:

³³Pollin, R.; et al. (2009). The economic benefits of investing in clean energy: how the economic stimulus program and new legislation can boost US economic growth and employment. Amherst: PERI – Political Economy Research Institute, University of Massachusetts.

³⁴Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World, UNEP/ILO/IOE/ITUC, September 2008.

³⁵Green jobs" are jobs that reduce the environmental impact of enterprises and economic sectors, ultimately to levels that are sustainable. This definition covers work in agriculture, industry, services and administration that contributes to preserving or restoring the quality of the environment (Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World, UNEP/ILO/IOE/ITUC, September 2008).

³⁶Europe 2020 Flagship Initiative Innovation Union, SEC(2010) 1161.

³⁷An Agenda for new skills and jobs: "A European contribution towards full employment" COM(2010) 682 final. See also: Towards a job-rich recovery, COM(2012)173.

³⁸Sophie Dupressoir et al., *Climate Change and Employment: Impact on Employment in the European Union-25 of Climate Change and CO₂ Emission Reduction Measures by 2030* (Brussels: European Trade Union Confederation, Instituto Sindical de Trabajo, Ambiente y Salud, Social Development Agency, Syndex, and Wuppertal Institute, 2007).

³⁹Low carbon Jobs for Europe: Current Opportunities and Future Prospects, WWF-World Wide Fund for Nature (2009)

- Capturing examples of innovation and innovative approaches emerging from SPIRE R&D&I projects that can be translated and used as case studies by European training and educational institutions;
- Facilitating constructive dialogue and exchange of ideas between stakeholders in EU industry and academia on the best ways to use the innovative outputs of SPIRE projects in academic teaching;
- Designing appropriate educational resources that can be used at undergraduate and postgraduate levels, and life-long learning to develop the skills needed to enhance sustainable innovation;
- Disseminating good practices in relation to teaching methodologies, curricula design, development of industry-academia relationships and the value of active learning for teaching staff in higher education institutions;
- Contributing to the development of future educational / training programmes specially focusing on business-oriented programmes.;
- Contributing to the development of future innovation skills capacity and culture.

6. Key Component OUTREACH

SPIRE combines research with studies on socioeconomics, analysing and quantifying the impact of growth, employment, investment and industrial competitiveness within the framework of the projects undertaken. Therefore, studies on the social and economic impact of the different technologies available and the use of resources, as well as the feasibility and impact of investments in resource and energy, providing a comprehensive view is encouraged, integrating science and technology into society. Due to this cross sectorial view, SPIRE can play a significant role as a key agent offering advice to organisations when preparing strategic plans and energy programmes thanks to the developments and barriers overcome within this initiative. The assessments accomplished in SPIRE will offer to companies solutions based on eco-innovation studies regarding their processes and products bearing in mind, as well as economic factors, the environmental impact and social aspect of the activity they perform.

Through dissemination mechanisms and frameworks SPIRE reaches out to all involved sectors, industrial and academic stakeholders as well as policy makers and citizens to foster accelerated adoption, further development and impact of SPIRE results.

Key Action 6.1: Analysis and establishment of efficient technology dissemination methodologies and mechanisms and frameworks

SPIRE will establish and develop:

- Efficient coordination and dissemination of SPIRE project outputs across the programme to facilitate the market uptake of innovative solutions;
- Early awareness of key innovation themes emerging from the projects to the entire SPIRE stakeholder community as well as sectors in close relationship to the process industries (i.e. end users).

In order to achieve the desired objectives of this key action SPIRE will create and maintain a framework to facilitate the effective exploitation of projects results that:

- Captures and efficiently distributes the knowledge generated from projects through research papers, innovation themes, and new methodologies / approaches etc.;
- Captures and disseminates the value (tangible & intangible) derived from project outputs (commercial, social, environmental, etc.);
- Ensures that innovation outputs are effectively translated and deployed into industry and academia (research organisations / HEIs);
- Identifies and exploits 'best practice' in dissemination processes and technology;
- Engages effectively with stakeholders to meet their identified needs;
- Contributes to the delivery of exploitable results;
- Informs the future development / shaping of SPIRE innovation priorities;
- Identifies knowledge gaps in fundamental academic as well as applied research and development.

The framework will pay special attention to SMEs both as innovation generators as well as fast adaptors able to exploit in a rapid manner novel market niches and business opportunities.

Key Action 6.2. Develop social responsibility for the process industry

The EUROPE 2020 strategy is about delivering growth that is smart, sustainable, and inclusive. Together with governments and NGO's, process industry is a critical player in this agenda towards a new business model. Process industries are indeed clearly committed to sustainable development by ensuring, for instance, a transition to the low-carbon economy. Yet, the social value of the process industry, in particular materials, is often neglected in the debate. Among the different reasons for this are: (1) social issues are often limited to human resource aspects inside a company (Social Life Cycle Assessment), and (2) when actions like stakeholder engagement are developed, outcomes are rarely measured.

The ambition of SPIRE is to demonstrate and develop better awareness about the role and the social value of materials within a modern and greener economy.

- A first approach will be the development of inclusive business, which is defined as profitably engaging low-income populations across companies' value chains and developing affordable products and services

that meet their needs (*of low income populations*). Through active local achievements it is critical that process industries support the sustainable growth of the so-called Base of the Pyramid (BOP) and better understand their needs and constraints: they are indeed both suppliers and future clients. SPIRE will draw lessons from experiences, identify stakeholders, challenges, and opportunities, and propose actions to leverage good practices.

- A second approach, which is inspired from well-being indicators proposed by the OECD, will develop a measurement to value this social responsibility commitment, in order to demonstrate positive contributions to income and wealth, jobs and earnings, health and safety, environmental quality, education and skills, civic engagement and governance etc.. These indicators will of course be combined with environmental and economic indicators to provide comprehensive sustainability metrics.

Other complementary approaches will be developed as companies producing materials are often important international groups having a large social influence in the countries where they are located. They are able to react rapidly at a worldwide level and collaborate with all the economic and scientific actors as well as being important opinion makers to foster an important and major change process towards sustainability in Europe's industry. They will become key innovation drivers in the transition to a sustainable world!

Indicative timeline and proposed budget distribution

The main obstacle to accelerate resource efficiency impact in the process industries is the high capital expenditure necessary for changes in process equipment including those associated with change to process routes that excludes working units in actual production chains. As the return on investment can be quite long, some industries are reluctant to implement new equipment that requires large investment. SPIRE therefore proposes a three stage approach:

1. Stage 1: Shorter to medium term impact measures (resource and energy efficiency impact by 2016 – 2019)

Stage 1 will target projects that can generate and demonstrate “immediate” resource efficiency opportunities resulting from the SPIRE vision, including the following actions:

- Identification, benchmarking and cross-sectorial transfer of good energy and resource efficiency solutions and practices;
- Improvement in measuring systems, process control and process optimization that can be integrated to significantly increase energy and resource efficiency in the “installed base”;
- Use of industrial waste and residue streams in existing processes or as a resource or substitution material in the production of mass commodities;
- Renewable feedstock that can be integrated with contained capital investments within existing processes (e.g. for co-firing);
- New resource efficiency applications that can be realised by novel combinations of existing processes;
- Other incremental innovations that have a significant resource and energy efficiency impact.

2. Stage 2: Medium term impact measures (resource and energy efficiency impact by 2018 – 2025)

Stage 2 will target those projects that may not be implemented “immediately” in the installed base, but target a quick migration (evolution) towards improved processes, including the following actions:

- Development and testing of migration packages for increased energy and resource efficiency processes;
- Novel design of process components, equipment and systems that can be integrated as a novel component in existing processes (e.g. new furnaces, ovens, grinding techniques, etc.);
- New solutions that can be integrated as a sub-process within the overall installed base;
- Re-use and integration of waste streams in the industrial process that requires redesign of parts of the process;
- Improved technologies for energy recovery or material recovery which will enhance existing recovery chains or establish new ones;
- New resource efficiency applications that require development of new process components and/or sub processes within the installed process base;
- New skills and educational programmes;
- Methodologies and tools for cross-sectorial Life Cycle and Cost Assessment as well as novel social Life Cycle Assessment of energy and resource efficiency solutions.

3. Stage 3: Medium to longer term impact measures [resource and energy efficiency impact by 2020–2030]

Stage 3 will target those projects that revolutionise the process industry through breakthrough development, and require significant capital investment in new processes, including the following actions:

- Replacement of fossil-based materials by bio-based materials requiring complete new processes;
- Re-use of waste streams that require complete redesign of materials, products and related production processes;
- New resource efficient applications that require completely new designed processes;
- Complete redesign of industrial parks to realise industrial symbiosis;

SPIRE experts analysed for each Key Component and Key Action, to what extent innovations in that domain are potentially leading to early or later stage impact, estimating for each Key Action the relative share of Stage 1,2 and 3 proposals (**Impact Delivery Stage**). Subsequently, it has been estimated in what phase of the PPP implementation the resources need to be spent in order to realise this impact delivery (**Phase Effort**). The SPIRE PPP phases have been divided as follows:

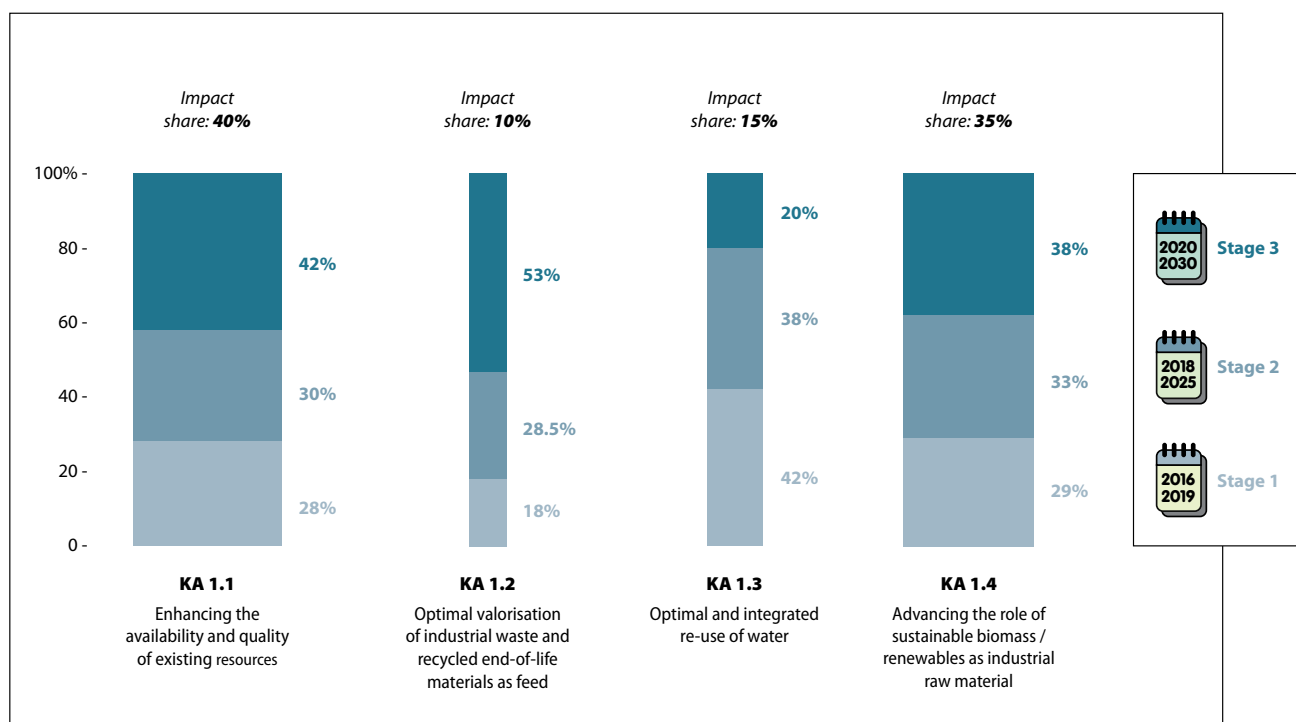
1. Phase 1: Year 2014 - 2016
2. Phase 2: Year 2017 - 2018
3. Phase 3: Year 2019 - 2020

IMPACT DELIVERY STAGES AND EFFORT PHASES PER SPIRE COMPONENT

Key Component FEED

Within FEED, significant impact is expected from KA's 1.1. (changing quality of fossil feedstock) and KA 1.4. (bio-based feedstock) with respectively 40% and 35% impact contributions. KA 1.1. will have an important impact already in early stages due to adaptations to the changing feedstock quality, which is relevant for the entire installed process base, and for maintaining EU competitiveness on the shorter to medium term. Also within KA 1.4. impact is expected relatively early, with increasing impacts towards Stage 2 and 3 .

Within KA 1.2. (valorisation of waste) the larger impact is expected on the longer term towards stage 3 (2020 – 2030), while KA 1.3. (water) is expected to have the largest impact on resource efficiency in stage 1 of the PPP (2016 – 2019) as a result of closing water loops.



Required effort spread over the PPP to realise predicted impacts is expected to be as follows.

	Effort-phase				
	Phase 1 (2014-2016)	Phase 2 (2017-2018)	Phase 3 (2019-2020)		
	34%	35%	31%		100%
KA 1.1: Enhancing the availability and quality of existing resources	28%	30%	42%		45%
KA 1.2: Optimal valorisation of industrial waste and recycled end-of-life materials as feed	25%	30%	45%		5%
KA 1.3: Ensuring the optimal and integrated re-use of water	42%	43%	15%		10%
KA 1.4: Advancing the role of sustainable biomass / renewables as industrial raw material	41%	37%	22%		40%

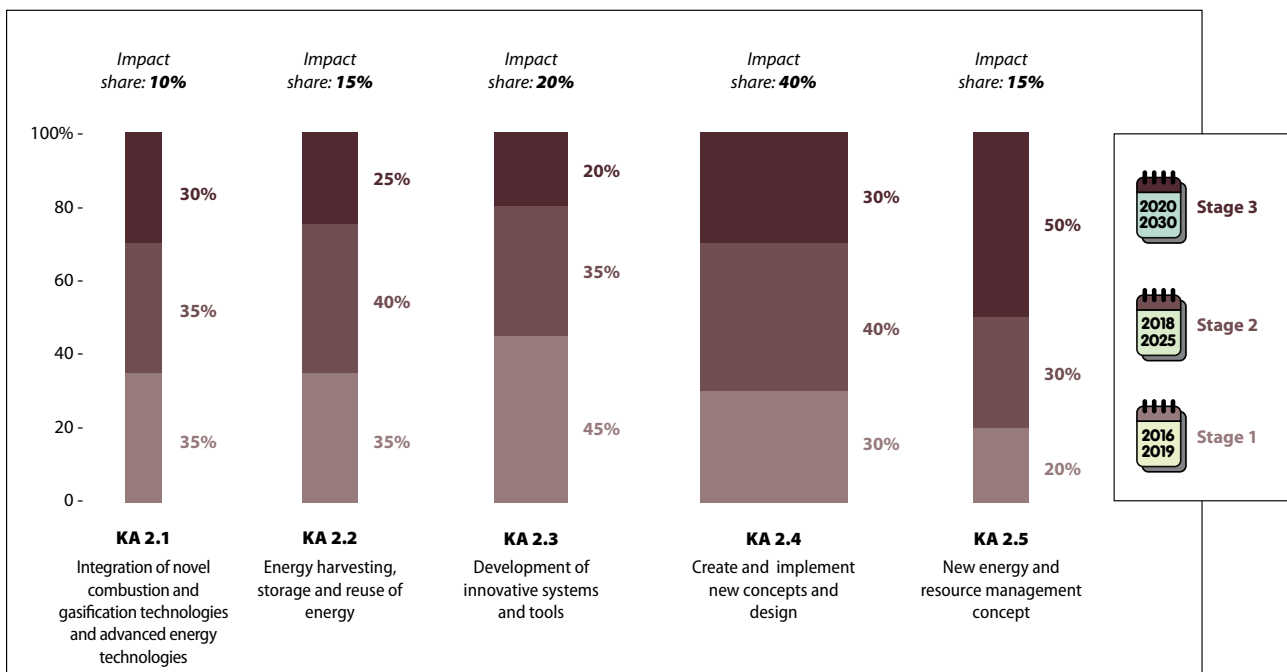
The four Key Actions in FEED have a strong focus on the investigation of alternative fossil resources (LNG, BTL, GTL, shale gas, heavy oil etc. in KA 1.1) and innovative resources based on biomass (KA 1.4) in an equal distribution between alternative resources for fossils and biomass. These are completed by optimal valorisation of industrial waste, residue streams and recycled end-of-life materials as feeds in KA 1.2 and ensuring the optimal and integrated re-use of water in KA 1.3 as important for the water intensive industrial processes and process technology with a special attention to 'fit for purpose cascades'.

Key Component PROCESS

Breakthrough process improvements through new concepts and design (KA 2.4) have the potential to increase the efficiency substantially. It represents the largest impact of Process Key Component, most likely to be delivered to the market in medium term. It will require a vast investment in defining, developing and providing proper systems in the short term. Relevant investment and technical effort are required during the first years of the PPP which will progressively fall but still require significant attention in different sectors and for its full deployment in existing and future plants. As an example,

the ceramics sector expects to save over 30 % of current CO₂ emissions through the replacement of natural gas by syngas in its firing kilns. The impact can be expected by 2030 (scope of SPIRE) but once developed in this sector it will facilitate uptake in other high temperature sectors (800° to 1200°C) so even larger impacts can be expected towards 2050 thanks to it.

Innovative systems and tools in KA 2.3. (hardware and software) will enable the development of advanced process control and subsequently improved yield. Effort will be allocated predominantly in phase 1 of SPIRE (60% in 2014 – 2016) due to good short-term applicability. This will result in significant resource and energy efficiency impact once multi-phase and multi-physic phenomena is better understood and controlled in different applications, processes and systems. As an example, in the chemical sector, new solutions in this field will enable higher reaction rates leading to low-temperature processes and smaller equipment, better selectivity leading to minimization or elimination of waste, reduced requirements for separation operations (responsible for ~40% of energy consumption in chemical and related industries) as well as the possibility for tailored manufacturing of new, advanced products.



Integration of novel combustion and gasification technologies and advanced and proper energy systems (KA 2.1) and a special focus on energy harvesting, storage and reuse of energy (KA 2.2) will require significant investment in the short term (phase 1), mainly targeting heat recovery and reuse of energy. Demonstrations of the optimisation of heat recovery systems and use of biomass as a secondary source of energy are foreseen at different stages and phases within SPIRE.

Lastly, related to KA 2.5 (New energy and resource management concepts) industry still is at the beginning of tapping the potential of industrial parks. Waste heat and resources from one industry can be a resource for another industry. Fluctuating energy inputs (e.g. coming from renewables) and fluctuating demands call for micro and macro optimisation, removing the obstacles for energy and material integration, which accordingly will

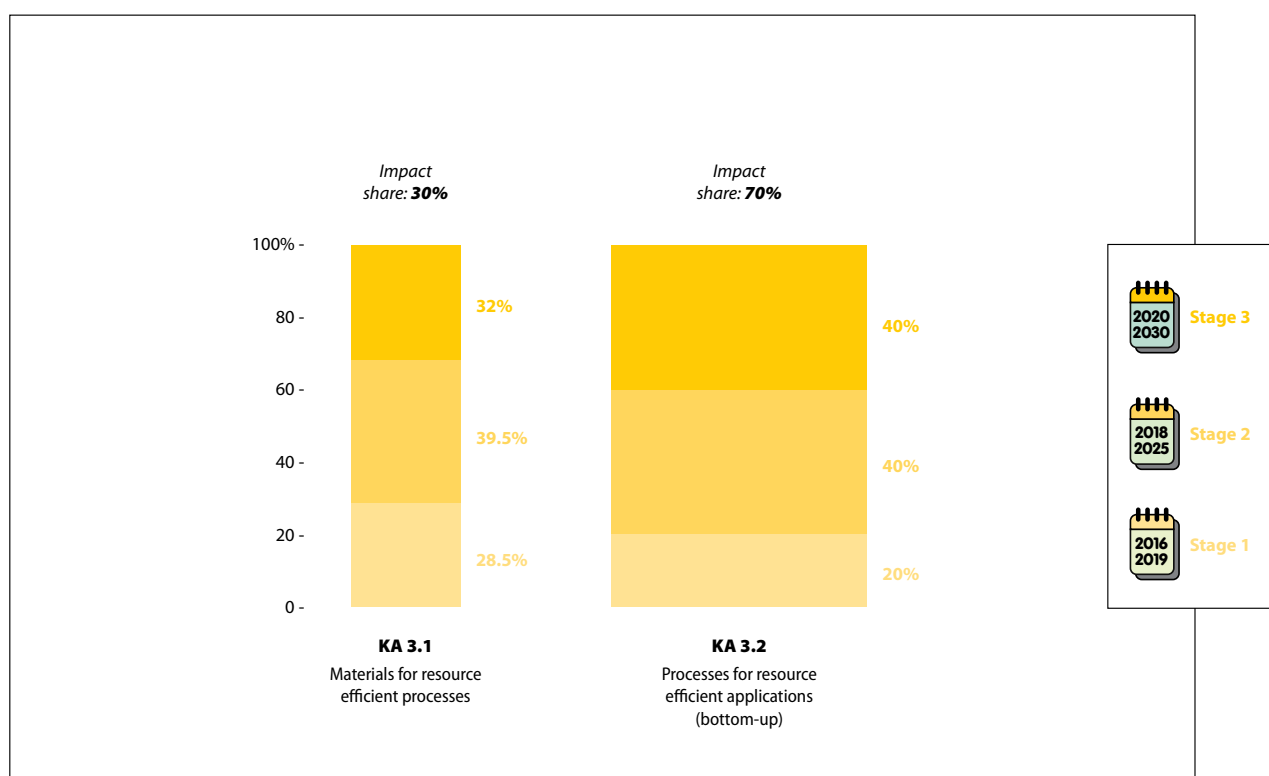
improve the design and operation of plants. This reflects a major challenge with a **significant longer-term impact**. Within SPIRE focus will predominantly be on developing and testing new concepts with integrated cross KA demonstrations, showcasing novel solutions from KA 2.1 – 2.4 within industrial parks targeting symbiosis. New concepts for industrial symbiosis and management concepts within industrial parks are expected to have huge impacts but would require very high investments that are beyond the scope of SPIRE, and should leverage on other financial instruments such as structural funds, European Investment Funds or capital markets. It would lay the foundation of a future fully integrated industrial symbiosis, reducing significantly the use of resources and energy in intensive industries.

Required effort spread over the PPP to realise predicted impacts is expected to be as follows.

	Phase-Effort			
	Phase 1 (2014-2016)	Phase 2 (2017-2018)	Phase 3 (2019-2020)	
	44%	33%	23%	100%
KA 2.1: Integration of novel combustion and gasification technologies and advanced energy technologies	40%	35%	25%	15%
KA 2.2: Energy Harvesting, storage and reuse of energy	50%	30%	20%	15%
KA 2.3: Development of innovative systems and tools	60%	30%	10%	15%
KA 2.4: Create and implement new concepts and design	40%	35%	25%	45%
KA 2.5: New energy and resource management concept	35%	35%	30%	10%

Key Component APPLICATIONS

Key Component APPLICATIONS takes two complementary approaches with a consequence for impact assessment and budget division. **KA 3.1 Materials for resource efficient processes** takes a more agenda driven approach, targeting materials for energy storage in processes, and materials for applications at different temperatures, such as more efficient ovens and furnaces. For these innovations SPIRE estimates that significant research is still required at the early stages to generate impacts at the later stages of the programme.



KA 3.2. Processes for resource efficient applications, takes a bottom-up approach, creating an open invitation to the market to propose innovations where process industry can contribute by changing existing or developing new processes for materials that have a significant impact down the value chain in terms of resource, energy efficiency and competitiveness. SPIRE expects this KA to have a large potential to contribute to tackling the grand societal challenges. As an example already today, the chemical industry has enabled a four metric tonne CO₂ abatement further down the value chain for every one metric tonne CO₂ emitted, and has an even higher potential to further reduce CO₂ eq impact down the value

chain in a wide range of applications such as insulation, lighting, packaging, automotive weight etc⁴⁰. Due to the bottom-up character of this KA it is difficult to estimate impact delivery stages up front, not knowing which innovations will be proposed by the market. Nevertheless, we estimate that while some process adaptations required for resource efficient materials and applications can already be realised in the first stages of SPIRE (e.g. new insulation materials), the larger part will require new process developments that can only have significant impact in stage 2 and 3, e.g. through the introduction of novel bio-based packaging materials or novel lightweight composite materials in cars.

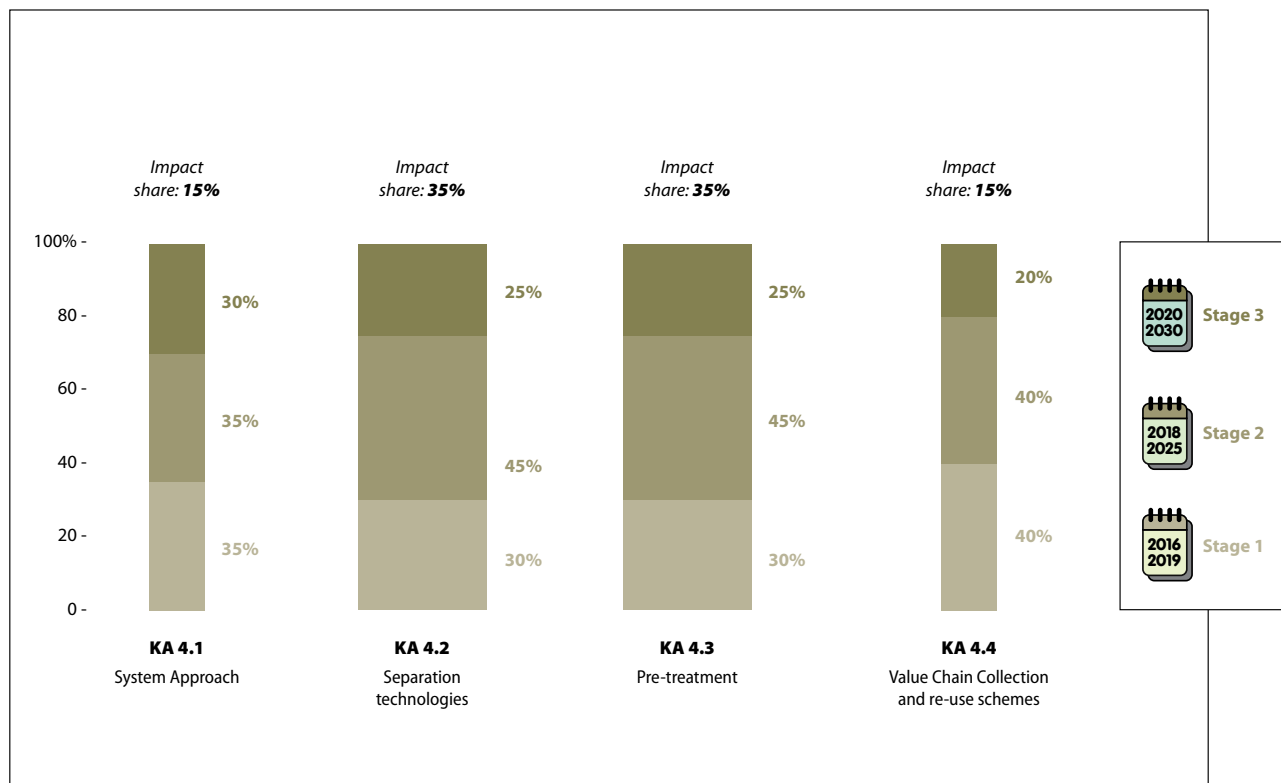
⁴⁰Mc Kinsey 2030 scenario's for the International Council of Chemical Associations (ICCA), 2009

Required effort spread over the PPP to realise predicted impacts is expected to be as follows:

	Phase-Effort			
	Phase 1 (2014-2016)	Phase 2 (2017-2018)	Phase 3 (2019-2020)	
	41%	33%	26%	100%
KA 3.1: Materials for resource efficient processes	40%	33%	27%	30%
KA 3.2: Processes for resource efficient applications	42%	32%	26%	70%

Key Component WASTE2RESOURCE

The main emphasis in the W2R component will be on Key Action 2 and 3 (separation and pre-treatment technologies), as these require more resources for technological development and demonstration. Also their impact share is expected to be significant, as this is the part of the reuse and recycle chain with the highest possibilities for increasing the output, and high replication potential.



Early impact (stage 1 and 2) can be expected from Value Chain Collection and re-use schemes and business models, targeting early demonstrations and replication of recycling and re-use opportunities based on the existing resource streams within and between sectors.

Required effort spread over the PPP to realise predicted impacts is expected to be as follows:

	Phase-Effort			
	Phase 1 (2014-2016)	Phase 2 (2017-2018)	Phase 3 (2019-2020)	
	51,5%	28,5%	20%	100%
KA 4.1: System Approach	55%	25%	20%	15%
KA 4.2: Separation technologies	50%	30%	20%	35%
KA 4.3: Pre-treatment	50%	30%	20%	35%
KA 4.4: Value Chain Collection and re-use schemes	55%	25%	20%	15%

OVERALL SPIRE SPENDING

Based on the estimated impact delivery stages and related phase efforts as outline above, the intent is to allocate the SPIRE budget to the different components as follows:

Estimated budget	200M€/yr		Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7
Key Component 1	Feed	20%							
Key Component 2	Process	40%							
Key Component 3	Applications	10%	10%	15%	20%	15%	15%	15%	10%
Key Component 4	Waste2Resource	20%							
Key Component 5 and 6	Horizontal & Outreach	10%							



PART 3. EXPECTED IMPACTS

Scale of the resources involved and ability to leverage additional investments in research and innovation

Based on the estimated industrial contribution from the SPIRE sectors in research, development and innovation projects that fall within the scope of SPIRE, the private contribution to the PPP budget would be estimated around 1.4B€. SPIRE looks for co-funding under the Horizon 2020 framework programme as well as for co-funding for further downstream activities in order for the products / processes to reach the market. Based on the analysis of investment in RD&I by the stakeholders the budget should be split over the different Key Components approximately as follows:

	Estimated yearly industry commitment		Total private budet (M€)
	200M€/yr		1400
Key Component 1	Feed	20%	280
Key Component 2	Process	40%	560
Key Component 3	Applications	10%	140
Key Component 4	Waste2Resource	20%	280
Key Component 5 & 6	Horizontal & Outreach	10%	140

The sectors involved in SPIRE represent a significant portion of the European economy (circa 20%), including more than **450 000 individual enterprises**. Calculating the exact leverage factor of SPIRE innovations is a challenge, especially given the complex and variegated sectorial landscape of process industries participating within the SPIRE initiative (>8 sectors). For the chemical industry, which is one of the key contributors to the SPIRE investment in innovation, a significant replication and leverage potential of the SPIRE investment becomes evident taking into consideration the number of chemical clusters that exist over Europe.

Europe remains one of the leading regions in the world for the chemical industry, with a large number of factories and plants located within the European Union, where successful SPIRE innovations can be taken-up once they have been proven, leading to a significant leverage by industry compared to the initial SPIRE investment in RD&I. As an example many of the top five of the world's largest chemical companies are headquartered in Europe with production and sales facilities across the region. Many of these production facilities operate within an integrated network for example in one major chemical complex in Ludwigshafen alone, 200 production facilities are intelligently linked.

Similarly to the chemical industry, other SPIRE sectors feature large numbers of operations in Europe that establish the replication base for SPIRE innovations. The cement industry features more than 1000 cement mills in Europe that have enormous innovation and retrofitting potential⁴¹. Alongside chemicals, the steel industry is one of the key industrial sectors in Europe. One of the leading steel companies in Europe currently operates around 60 steel plants in the region. Each year the sector produces around 200 million tonnes of crude steel and employs roughly 400 000 people in the EU-27.

Together, the SPIRE process industries show a large number of production operations throughout the EU landscape, many of them with important requirements for innovation and retrofitting in line with further specialization of the sectors (e.g. high-tech steel, specialty chemicals) and to comply with stricter (future) environmental standards. As such this installed base establishes an enormous leverage base for SPIRE innovation in some cases (e.g. new process control) offering double digit replication potential compared to the initial single pilot project in which a novel SPIRE technology will be proven and demonstrated.

Apart from the sheer number of facilities that require upgrading there is the size of the financial investment to consider. The chain of development, from concept idea to commercial implementation, goes through many steps where each step down the chain requires increased amounts of investment and thus will only be taken when the risk of loss of investment is minimised. The investment needed to scale-up laboratory level technology to mini-plant or pilot scale level is typical part of an R&D budget (1-10M euro). The next step of building demonstration capability is much larger (10-100M euro) with a significant risk of both technology and market introduction failure and therefore support measures to continue to drive innovation forward are key (bridge the valley of death). Then once there is successful technology demonstration at market scale and market acceptance the step of commercialising the technology needs to be taken. This is the most expensive step, typically with factors of 5 to 10+ higher than for a demonstration capability, even for a single commercial plant. This is the investment that the industry needs to make and will be very willing to make for the successful projects that emerge from SPIRE as they will want to see a return on the significant R&I investment (200M euro/year) made in the PPP.

⁴¹JRC EUR 24592 EN - 2010 Energy Efficiency and CO₂ Emissions: Prospective Scenarios for the Cement Industry

Expected impacts on industry and society

INTRODUCTION

Defining it in simple terms, a **green economy** is one which is **low carbon, resource efficient and socially inclusive** (i.e. following the final declaration of RIO+20, green economy can only be conceived “in the context of sustainable development and poverty eradication”).

In a green economy⁴², growth in income and employment should be driven by public and private investments that increase competitiveness, reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services.

The SPIRE **roadmap** combines the **joint efforts** and **consultation** of **European key actors** across the different sectors related to the Process Industry **around two fundamental priorities in direct connection for advancing towards a Green Economy scenario: energy efficiency and non-energy resource efficiency** (e.g., materials, water, waste etc.). The SPIRE roadmap considers for each of these priorities the **specific technological and non-technological challenges needed to develop sustainable solutions** along the value chain that are required to reach long term sustainability for the European Process Industries in terms of global competitiveness, ecology and employment across sectors.

The SPIRE roadmap pursues an **overarching and cross-sectorial innovation approach**, which whilst including research and technological progress, also encompasses **novel business models, design, branding and services.**

It includes public sector and social innovation concepts, commercial innovation as well as education for future professionals and European society at large. The SPIRE roadmap addresses environmental, economic, and social issues in a single coherent framework by generating systemic, broad and **cross-sectorial collaborative scenarios** that, over time, will stimulate the main short-, medium- and longer-term impacts of investing in a green economy.

It is necessary to emphasize once more that EUROPE 2020 is the EU’s growth strategy for the coming decade that will lead the way to transform the EU into a **smart, sustainable and inclusive economy**. In this context, without the contribution of a **Sustainable Process Industry**, it becomes difficult to imagine that the objectives of Europe 2020 will be achieved.

The execution of the SPIRE roadmap contributes directly and in a multidimensional manner to the EUROPE 2020 strategic objectives and impact establishing the steps for a coherent, continuous and coordinated effort beyond the Horizon 2020 scenario.

⁴² UNEP, 2011, Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers, www.unep.org/greeneconomy

A RESOURCE EFFICIENT ECONOMY

The SPIRE PPP roadmap envisages two clear impact goals in connection to the Grand Societal Challenges defined within EU 2020 Agenda⁴³ particularly from the environmental and sustainability perspective:

- 1. A reduction in fossil energy intensity of up to 30%** from current levels through a combination of, for example, cogeneration-heat-power; process intensification, introduction of novel energy-saving processes, and progressive introduction of alternative (renewable) energy sources within the process cycle.
- 2. Up to 20% reduction in non-renewable, primary raw material intensity** versus current levels, by increasing chemical and physical transformation yields and/or using secondary (through optimised recycling processes) and renewable raw materials.

The achievement of these two objectives clearly aligns with the pursued impacts reflected in the EUROPE 2020 flagship initiative “A resource-efficient Europe”⁴⁴ aiming to deliver smart, sustainable and inclusive growth. In the same context **the SPIRE roadmap offers a clear guidance towards a resource-efficient and low-carbon economy** which will contribute to:

- Boost economic performance while reducing resource use;
- Identify and create new opportunities for economic growth and greater innovation and boost the EU's competitiveness;
- Develop solutions against climate change and limit the environmental impacts of resource use.

The importance of decoupling growth from resource consumption to make it sustainable was already explained in the background section on page 5.

BOX 1. FUTURE GROWTH IN GREEN MARKETS: EXAMPLES.

At present, the global market volume for environmental technologies (products and services) represents about \$1,370 billion (€1,000 billion), according to German-based Roland Berger Strategy Consultants, with a projected \$2,740 billion (€2,200 billion) by 2020. The firm offers the following estimates for individual market segments that are directly related to the SPIRE roadmap:

- Energy efficiency technologies (appliances, industrial processes, electrical motors, insulation, etc.): \$617 billion (€450 billion) at present; \$1,233 billion (€900 billion) by 2020.
- Waste management/recycling: \$41 billion (€30 billion); \$63 billion (€46 billion) by 2020.
- Water supply/sanitation/water efficiency: \$253 billion (€185 billion); \$658 billion (€480 billion) by 2020.

Source: Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World, United Nations Environment Programme/UNEP/ILO/IOE/ITUC, September 2008. Cited Source: Summary of a Roland Berger Strategy Consultants study published by Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), "GreenTech Made in Germany. Umwelttechnologie-Atlas für Deutschland," at www.bmu.de/files/pdfs/allgemein/application/pdf/umwelttechnikatlas_zsf.pdf.

⁴³ http://ec.europa.eu/europe2020/index_en.htm

⁴⁴ Innovating for green growth: Drivers of private sector RD&D, World Business Council for Sustainable Development (WBCSD), 2010.

The **SPIRE roadmap** proposes concrete innovation steps in critical industrial sectors towards **achieving future scenarios with more eco-efficient and sustainable use of resources**. Several of these scenarios on a global scale have already been extensively analysed considering the macroeconomic consequences of investing (% global GDP) **both from the public side and private side** in the environment and concluding that it delivers a positive macroeconomic result. It is worthwhile mentioning the study realized by the United Nations Environment Programme (UNEP) Green Economic Report largely drawing upon the Threshold 21⁴⁵ family of models created by the Millennium Institute.⁴⁶ This study analyses investment scenarios⁴⁷ up to 2050 realizing **a decline in total CO₂ emissions from key manufacturing sectors (the majority of them directly involved in the SPIRE roadmap such as Chemicals and Plastic, Aluminium, Iron and Steel)** to 1.3 Gt in the Green case (G2 scenario) from 2.7 Gt in the Business As Usual (BAU) alternative (BAU2 scenario). In this model at the industry level, the avoided energy consumption averages 52 % by 2050 – comparing G2 to BAU2 (or 52 % relative to BAU2), resulting in avoided costs of up to US\$ 193 billion relative to BAU2 per year, on average, between 2010 and 2050 depending on the industry considered.

The chemical and plastics sector provides the greatest opportunity, with a potential of US\$ 193 billion relative to BAU2 in yearly avoided energy costs. Steel follows with an average US\$ 115-136 billion potential savings per year. Aluminium foresees a US\$ 44 billion of yearly avoided energy cost in the G2 case.

The case of **waste recycling as a fundamental pillar in the SPIRE roadmap** is also worthwhile mentioning. In the green economy scenario stated by the UNEP Green Report (ref. 36), a total of US\$ 118 - 198 billion per year on average is invested in the waste sector to increase waste collection rate and promote recycling and composting practices. The higher collection rate of wastes (around 82 to 83 % between 2010 and 2050) as well as the projected economic development in the green scenarios are projected to increase the total usable waste volume in BAU and green scenarios by 2 to 3 % in 2020 and 9 to 12 % in 2050. However, owing to the significant **improvement in waste recovery** (e.g. recycling rate is 7% in green scenarios, 2.2% in BAU in 2050); the annual amount of waste directed to landfills in the green scenarios will be much lower than the BAU scenario by 2050.

Future scenarios considering energy consumption⁴⁸ foresee the huge impact potential for innovative technologies applied to reduce energy demand and CO₂ emissions for the process industry as contemplated in the SPIRE roadmap through, for example, improved efficiency of motors, pumps, boilers and heating systems, increased energy recovery in materials-production processes, increased recycling of used materials, adoption of new and more advanced processes and materials, and a higher efficiency of materials use. New cutting-edge industrial technologies with substantial potential to save energy and CO₂ emissions include: advanced membranes that can replace distillation in some petrochemical processes; “direct casting” in iron and steel; and the use of bio-feedstock in the petrochemical industry to replace oil and natural gas. Several major impact opportunities (also contemplated in the SPIRE roadmap) have been identified for the process industry in order to contribute to energy efficiency. Just as an illustration it is worth mentioning:

- In primary steel production efficiency improvements on the order of 20 to 30% are available based on existing technology;
- Improvements to steam supply systems and motor systems offer efficiency potentials on the order of 15 to 30%;
- Combined heat and power generation can bring 10 to 30% fuel savings over separate heat and power generation;
- The production of paper from pulp could substantially reduce energy needs with more efficient drying and gasification technologies;
- Using biomass feedstock and recycling more plastic waste could reduce life-cycle CO₂ emissions substantially;
- CO₂ capture and valorisation could be applied to several industries on scale, especially in the production of chemicals, iron and steel, cement etc;
- Carbon dioxide utilisation technology (CCU) should be fostered converting CO₂ into fuels, polymers and chemicals, therefore creating value rather than generating waste.

⁴⁵ Bassi, A.M., and Shilling, J.D. (2010). “Informing the US Energy Policy Debate with Threshold 21.” *Technological Forecasting & Social Change*, 77 (2010) 396–410. See also Millennium Institute. (2005). “Threshold 21 (T21) Overview.” Arlington, VA.

⁴⁶ United Nations Environment Programme UNEP, 2011, *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*, www.unep.org/greeneconomy

⁴⁷ The two green scenarios (G1 and G2) assume increased investments over the period 2010 to 2050 on an annual basis, and these are contrasted with two respective business-as-usual scenarios (BAU1 and BAU2) in which the same amounts of investments are simulated, but allocated according to existing patterns. The BAU1 and BAU2 scenarios assume additional investments, as in the green cases, but project the continuation of the current trends for resource use and energy consumption, among others. The Scenario G1 assumes that 1 per cent of global GDP is channeled annually through green investment while Scenario G2 assumes that 2 per cent of global GDP is channeled annually through green investments.

⁴⁸ Energy Technology Perspectives: Scenarios and Strategies to 2050, (in support of the G8 plan of Action), OECD/IEA, 2006.

The costs of achieving a more sustainable energy future are not disproportionate, but they will require substantial effort and investment by both the public and private sectors. PPPs on R&D&I have already been acknowledged as key vehicles for promoting near-to-market research especially in the case of low-carbon technologies. In this area a PPP is also recognized as a major facilitator, given the complexity of the technologies involved, the levels of capital required, and the common need for cross-sectorial knowledge⁴⁹.

INNOVATION AND COMPETITIVENESS

The SPIRE roadmap will stimulate the **exploitation of the new business opportunities resulting from the transition to a more sustainable, resource efficient and low carbon economy** as stated in the EUROPE 2020 Flagship Initiative “An industrial policy for the Globalisation Era”⁵⁰ and in the Industrial Policy Communication Update⁵¹.

The **realization of the SPIRE roadmap will allow for a complete range of new products and services**, based on high longevity, low embodied water, as well as low-energy and material content due to the transition regarding industrial processes to become less carbon and material intensive while at the same time preserving jobs or reinvesting in completely new employment opportunities⁵².

As an example with the UNEP study (ref. 36) note that **green economy scenarios indicate higher economic Return on Investment (ROI) in the longer-term**, outperforming BAU scenarios by over 25 % through to 2050 yielding, on average, by 2050 over US\$ 3 for each US\$ invested. More specifically, in the medium- to longer term economic and social development in a green economy is expected to outperform the BAU cases. Moreover, the **green scenarios always see lower negative impacts on the environment (e.g. energy intensity, emissions and footprint), which contribute to the faster medium- to longer-term economic growth** observed in green scenarios relative to BAU examples. Results of the BAU and green scenarios indicate that global real GDP would reach between US\$ 175 and US\$ 199 trillion by 2050 respectively in the G1 and G2 scenarios, which exceeds the US\$ 164 trillion in the BAU1 and US\$ 172 trillion in BAU2 cases, by 6 % and 16 % respectively. The model projections also indicate that GDP in the BAU1 and BAU2 scenarios in 2050 is lower than in G1 and G2 due to natural resource depletion and the higher energy costs.

The **SPIRE roadmap considers the full life-cycle and chain of supply and demand proposing a range innovation measures along a full production-consumption-recycle value chain** connecting in this manner with key EC Flagship Initiatives such as the “Innovation Union”⁵³. Significantly, this considers a full value-chain perspective that reflects product and service combinations as well as producer and user or consumer challenges. **The main contribution of a Sustainable Process Industry as reflected in the SPIRE roadmap will be upstream and directly connected to base process industries such as steel and iron, cement, chemicals, paper and pulp and aluminium, ceramics, industrial minerals, etc. – all industries that supply primary materials for the manufacturing of products such as commodities, cars, buildings and refrigerators that end-users/citizens know from their daily life.** Considering the full value chain the SPIRE roadmap identifies a range of areas for sustainable innovation, such as process modification and control and new, cleaner technologies and processes. These become the building blocks in either a supply or demand-side strategy for improving resource efficiency in a cross-sectorial approach. In this sense a supply-side strategy from the perspective of the SPIRE roadmap (Process Industry) involves redesign and improving the efficiency of processes and technologies employed in the major materials-intensive sector (ferrous metals, aluminium, cement, plastics, etc.). This strategy entails fundamental impacts as have been already considered⁵⁴ in terms of:

- **Re-design of products and/or business models** so that the same functionality can be delivered with fundamentally less use of materials and energy;
- **Substitute** green inputs for brown inputs wherever possible. For example, introduce biomass as a source of chemical feedstock. Emphasize process integration and intensification and upgrade of process auxiliaries such as lighting, boilers, electric motors, compressors and pumps, etc;
- **Recycle** internal process wastes, including wastewater, high temperature heat, back pressure, etc. Use materials and energy with less environmental impact, e.g. renewables or waste as inputs for production processes. Advance recyclability of materials used and find or create new markets for process wastes;
- **Introduce new, cleaner technologies** and improve the efficiency of existing processes to leapfrog and establish new modes of production that have a fundamentally higher material and energy efficiency.

⁴⁹ Innovating for green growth: Drivers of private sector RD&D, World Business Council for Sustainable Development (WBCSD), 2010.

⁵⁰ An Integrated Industrial Policy for the Globalisation Era Putting Competitiveness and Sustainability at Centre Stage, Brussels, COM(2010) 614.

⁵¹ A stronger European Industry for Growth and Economic Recovery, COM(2012)582 final

⁵² The World Business Council for Sustainable Development (WBCSD), Vision 2050: the new agenda for businesses. <http://www.wbcscd.org/pages/edocument/edocumentdetails.aspx?id=219&nosearchcontextkey=true>

⁵³ Europe 2020 Flagship Initiative Innovation Union, Brussels, 6.10.2010 COM(2010) 546 final.

⁵⁴ Tukker, A. and Tischner, U. (2006). New Business for Old Europe. Product Service Development, Competitiveness and Sustainability, Greenleaf Publishing, Sheffield, UK.

The SPIRE roadmap also represents a unique opportunity for European SMEs related to the Sustainable Process Industry value chain⁵⁵. The technological and non-technological challenges reflected in the SPIRE roadmap will allow SMEs to innovate in a **dynamic and flexible** manner and generate, acquire and apply different kinds of knowledge to those in large corporations in order to modify their processes or their goods or services to improve productivity. SMEs **have a greater need to innovate** than big corporations because for them to maintain and improve their competitive position in the market is a matter of survival and this keeps SMEs very active in terms of generation of ideas and innovative projects.

BOX 2. INNOVATIONS THAT WILL MAKE A DIFFERENCE.

The SPIRE roadmap proposes the realization of different key innovations across the variety of industrial sectors forming the Process Industry. The following paragraph illustrates the potential impact of some selected innovations.

- Enough biomass in the right density and composition in a sustainable way would lead to > 50% - 70% or even higher reduction in GHG emissions compared to fossil-based (chemistry);
- ULCOS Blast Furnace- top gas recycling with carbon-capturing and sequestration (CCS) might represent a 50% CO₂ reduction and a 15% energy reduction compared to average blast furnace (Steel);
- ULCOS new direct reduction and smelting processes with or without CCS might represent 80% CO₂ reduction compared to average blast furnace with CCS, and 20% energy and CO₂ reduction without CCS as compared to reference technology today (Steel);
- Clinker based -low CO₂ cement might represent up to 65% reduction for certain cement types compared to average cement production. CO₂ from fuel consumption as well as from decarbonisation of the raw materials is affected (Cement);
- Biomass and alternative fuels might represent a 35% CO₂ reduction from fuel combustion compared to average cement production (Cement);
- Electrolysis might represent a total independence of fossil fuel in the production process (Chemical);
- The net effect of successfully deploying inert anodes for aluminium production could represent a reduction in electricity consumption of 10 to 20% compared to advance Hall-Héroult smelters (from 13 to 11 kWh/kg aluminium). Apart from the electricity savings, oil and coal consumption would be reduced by 18 GJ per tonne of aluminium, because the use of carbon anodes would be avoided (Non-ferreous).

Adapted from: Harry Croezen, Marisa Korteland, Technological developments in Europe. A long-term view of CO₂ efficient manufacturing in the European region. Delft, CE Delft, June 2010. ULCOS project http://www.ulcos.org/en/about_ulcos/home.php. Energy Technology Perspectives: Scenarios and Strategies to 2050, (in support of the GB plan of Action), OECD/IEA, 2006. "IEA Cement Technology Roadmap 2009 - Carbon emissions reductions up to 2050" on "potential low-carbon cements".

⁵⁵ SMEs Facing Innovation. Study Cotec Foundation for Technological Innovation 2012.

In extrapolating how the SPIRE roadmap will contribute to fostering SMEs competitiveness it is worth mentioning some statistical results from the Eurobarometer⁵⁶ survey stating that half (52%) of the SMEs in the EU that currently offer green products or services offer products and services with environmental features. 29% offer green services or produce green products in the area of recycled materials and 20% in renewable energy or solid waste management all of which are significant areas in direct connection to the SPIRE roadmap. SMEs which offer green products and services are most likely to report that their green sales represent 1-5% of their annual turnover (30%). For 17% of SMEs, green products or services represent more than 75% of their annual turnover. Large companies report that these green products or services represent 6-10% of their annual turnover (24% vs. 15% for SMEs). Also 35% of SMEs in the EU indicate that measures to improve resource efficiency have reduced their production costs.

In addition the SPIRE roadmap will stimulate the engagement of SMEs through consolidating their entrepreneurial culture and giving greater added value to their **ability to undertake new activities**. New and young firms are particularly important for radical green innovations as they often exploit technological or commercial opportunities which have been neglected by more established companies or even challenge the business models of existing firms⁵⁷. The cross-sectorial character of the SPIRE roadmap will facilitate the formation of SME clusters to expand their innovation capacity and leverage shared knowledge.

Regarding the life cycle approach it is worthwhile mentioning the positive impact linked to competitive business opportunities that it will result for the process industry in the context proposed by the SPIRE roadmap (i.e. considering the whole (cross-sectorial) value chain). In this approach new business models⁵⁸ will emerge out of the consideration of supply and demand side strategies to close the resource and energy use cycle in manufacturing⁵⁹. Such strategies will enable more rapid decoupling of environmental damage from economic growth and improve the longer term competitiveness and added value of the European process industry. At the process industry level, the greening transformation will necessarily entail the consideration of a value chain starting with the re-design of sustainable products, energy and resource efficient production systems and business models, and leading to extended producer responsibility in the form of remanufacturing and recycling on a much larger scale than currently. In this respect, the case of metal stocks is illustrative. While only a few metals currently have an end-of-life recycling rate of more than 50 %, many opportunities exist that can help to improve recycling rates and increase secondary production, which requires potentially only a fifth of the energy and causes up to 80 % fewer GHG emissions than primary production.

NEW SKILLS AND JOBS

We should emphasize the socio-economical dimension that the progressive execution of the SPIRE roadmap will bring for Europe and that connects as well to critical needs such as job creation. The SPIRE roadmap will constitute a key element that will increase demand for professionals in the Sustainable Process Industry with new skills required to facilitate the transition to a greener model and to provide a related reinforced skilled workforce for its newly derived businesses. This line of action therefore establishes a direct connection to the goals and impact pursued in the EUROPE 2020 strategy related to employment (employment rate target for women and men of 75% for the 20-64 years age group by 2020)⁶⁰.

SPIRE **fully connects** with other EC initiatives that complement the Europe 2020 agenda such as the **Eco-innovation Action Plan (EcoAP)**⁶¹ and the Energy Education and Training Roadmap developed under the SET-Plan. It is relevant to point out that The "Industrial Policy for a Globalized Era" places the EcoAP as one tool to identify and implement measures for the deployment of key environmental technologies, to enhance coordination and cooperation between the EU and Member States and to generate awareness of the potential of new technologies. The Agenda for new Skills and Jobs⁶² calls for the EcoAP to **support competences for sustainable development, and promote appropriate skills development and tackle skills mismatches**. A future Sustainable Process Industry entails changes in the level and composition of jobs. In the metals value chain, for instance, significant green job creation opportunities are expected from the use and recycling of valuable by-products and scraps. While the impact of greener practices on employment should not be overestimated, the empirical evidence supports positive effects of green practices on jobs⁶³. This indicates that the economy would gain, especially in employment terms, from the introduction of greener production systems. Industries such as steel and aluminium can expect growing demand from new markets in the form of clean-tech being an important source of materials and components required for these markets. These potentials can be identified by considering industries not in isolation, but as part of a broader value-chain that contains future economic opportunities. Significant opportunities also lie in the area of industrial symbiosis as considered in the SPIRE roadmap also highlighting the importance of broader systemic (cross-sectorial) impacts. As an illustrative example taking again the results of the study realized in the UNEP Green Report (ref. 39) economic development in a green economy pushes total global employment up to 4.8-4.9 billion⁶⁴ in the G1 and G2 scenarios (3 - 5 % above BAU). Driven primarily by green investments and the subsequent push to economic development, total net direct employment in the sectors analysed is projected to boost employment in the medium to long run (2-3 % above BAU scenario and 8 to 14 % above BAU in 2050).

⁵⁶ Flash Eurobarometer 342: SMES, RESOURCE EFFICIENCY AND GREEN MARKETS REPORT, Fieldwork: January - February 2012, Publication: March 2012. EC, Directorate-General for Communication.

⁵⁷ OECD WORKING PARTY ON SMES AND ENTREPRENEURSHIP (WPSMEE) 'BOLOGNA+10' HIGH-LEVEL MEETING ON LESSONS FROM THE GLOBAL CRISIS AND THE WAY FORWARD TO JOB CREATION AND GROWTH PARIS, 17-18 NOVEMBER 2010.

⁵⁸ It is interesting to notice in this context how for example new business models will need to take into account the existence of fragmented value chains including distributing manufacturing and how this will influence in order to realize superior value systems. Several studies and initiatives are on-going, see for example "A landscape for the future of high value manufacturing in the UK" (Technology Strategy Board, 2012) or "The pathway to a Low Carbon Sustainable Economy" National Industrial Symbiosis Programme (NISP), UK, 2009.

⁵⁹ Manufacturing: Investing in energy and resource efficiency, United Nations Environment Programme, 2011.

BOX 3. NEW SKILLS AND JOBS FOR THE SUSTAINABLE PROCESS INDUSTRY

The following table exemplifies some of the foreseen skills required for the new employment in the transition towards a Green Economy and that are also in close connection to the opportunities that will emerge during the realization of the SPIRE roadmap.

Skills for a Green Economy	Skills needs
Skills supporting resource efficiency	<p>All businesses need generic or green skills including:</p> <ul style="list-style-type: none"> ■ Strategic business management to build resource-efficient business models leading to bottom line benefits and in preparation for new regulations; ■ Business/financial accounting services around carbon and natural environment accounting; ■ Skills to design and adopt technologies, products and processes increasing resource efficiency, including lean manufacturing; ■ Project management skills with clear understanding of resource efficiency; ■ Operator level actions to maximise resource efficiency (e.g. reducing waste in production).
Skills supporting low carbon industry	<p>Low carbon industry focuses on energy generation and industry with high energy requirements. Skills include:</p> <ul style="list-style-type: none"> ■ Scientists and engineers with training or transferable knowledge for renewable energy (including wind and marine); ■ Technicians with training or transferable knowledge to install energy efficiency measures and retrofit at a household and industrial business premises level; ■ Skills to design and adopt technologies, products and processes to minimise carbon emissions; ■ Operator level actions to minimise carbon emissions.
Skills supporting climate resilience	<p>Business requires the capacity to adapt to changes in climate. The necessary skills include:</p> <ul style="list-style-type: none"> ■ Scientific and technical skills such as modelling and interpreting climate change projections; ■ Risk management such as assessments of future resource availability; ■ Skills to design and adopt technologies, products and processes to improve climate resilience; ■ Operator level actions to improve climate resilience (e.g. retrofitting water efficient technologies in households and business premises).
Skills to manage natural assets	<p>Natural assets underpin all business practice. Skills to protect and manage them include:</p> <ul style="list-style-type: none"> ■ Accounting services for the natural environment; ■ Understanding of environmental impact assessments; ■ Understanding and interpretation of environmental legislation targets, ecosystem services design and management and land use planning; ■ Skills to design and adopt technologies, products and processes to manage natural assets. <p>Source: Institute for Learning, Green economy survey (2011). http://www.ifl.ac.uk/</p>

⁶⁰ An Agenda for new skills and jobs: A European contribution towards full employment, Strasbourg, 23.11.2010 COM (2010) 682 final.

⁶¹ Innovation for a sustainable Future - The Eco-innovation Action Plan (Eco-AP), EC COM(2011) 899 final.

⁶² An Agenda for new skills and jobs: "A European contribution towards full employment" COM(2010) 682 final.

⁶³ Lutz, C. and Giljum, S. (2009). "Global resource use in a business-as-usual world up to 2030: updated results from the GINFORS model" in Bleischwitz, R., Welfens, P., and Zhang, ZX (eds) (2009). Sustainable Growth and Resource Productivity. Productivity, 30-42. Greenleaf, Sheffield, UK.

⁶⁴ Total population is projected to grow by 29 per cent in the period 2010 – 2050, reaching 8.9 billion people, matching historical data from World Development Indicators (WDI) from the World Bank and future projections from World Population Prospect (WPP) from United Nations.

As an illustration concerning the waste sector thanks to the improvements in upstream waste treatment, its employment will reach 25-26 million jobs in 2050, which is 2-3 million higher than under BAU (the employment gain in 2020 is 0.4-0.54 million). It is worth mentioning the contribution of recycling to reducing energy demand and emissions as well as production costs: all positively affecting industrial GDP.

In relation to how the SPIRE initiative will favour the creation of employment in the SME sector it is worthwhile mentioning the results highlighted in ref. 49 of the Eurobarometer survey again indicate that the estimates for EU SMEs suggest that the proportion of companies with green jobs will increase in the next two years.

Naturally the creation of new skills and jobs related to a Sustainable Process Industry will be directly influenced by the identification and development of new business opportunities both at the level of each sector individually but more importantly in a cross-sectorial manner. All process industries would need to consider how they can adopt a synergic approach for understanding how energy and resource efficiency might shape profitability across operations and produce new sustainable growth opportunities.

VALUE CREATION IN A GLOBALISED WORLD

A recent study⁶⁵ shows that companies that succeed in improving in their energy and resource use optimization are likely to develop a structural cost advantage, improve their ability to capture new growth opportunities and reduce their exposure both to energy, resource- and environment-related interruptions to their business and to resource price risk. Based on the findings of this study with respect to future business opportunities related to a more efficient management of energy and resources it is possible to identify in very preliminary way examples of SPIRE key component where novel value propositions can be created (see table 1).

Given the nature of these process industry sectors, a significant number of the SPIRE PPP members are global players. Therefore, global trends, tailored international cooperation and approaches to global markets are part of their R&I strategy and, therefore, have been taken into consideration in the development of the present roadmap in order to ensure that, first and especially, the European industries become more sustainable and competitive for the sake of the European economy and, consequently, contribute to addressing the global challenges.

⁶⁵ Resource Revolution: Meeting the world's energy, materials, food and water needs, McKinsey Global Institute (2011). Available at: http://www.mckinsey.com/Insights/MGI/Research/Natural_Resources/Resource_revolution

Value Creation Business Area	Value Creation Field	Business Opportunity	SPIRE key component examples
GROWTH	Composition of business portfolio	Novel investment/ divestment opportunities at portfolio level based on energy and resource efficiency cost-competitive considerations.	KA 2.1
	Innovation and new products	Develop cost-effective resource and energy efficient production methods products and technologies.	KA 3.3
	New markets	Innovative and cost-effective resource-related opportunities in new market segments and geographies.	KA 1.2
RISK MANAGEMENT	Regulatory management	Innovative risk mitigating strategies connected to new business opportunities coming from regulation.	KA 4.5
	Reputation management	Innovative corporate responsibility methodologies and strategy.	KA 4.5
	Operational risk management	Innovative methodologies and strategy to manage risk of operation disruptions (from resource and/or energy scarcity, climate change impacts, etc).	KA 1.4
RETURN ON CAPITAL	Green sales and marketing	Novel marketing and sales strategy centred in energy and resource-efficiency attributes (of processes, products, etc).	KA 4.4
	Sustainable value chains	Innovative resource management strategies focused on effectiveness and sustainability of energy and/or resources across (cross-sectorial) value chain(s) and oriented to cost-effectiveness and improvement of products' and/or processes' value propositions.	KA 2.5
	Sustainable operations	Reduce operating costs through improved internal resource management (e.g., water, waste, energy, carbon, hazardous material).	KA 2.3

TABLE 1: Examples of Potential areas for emergent business opportunities related to the SPIRE key components (based on ref.58)

Additionally to existing activities, added value of action at EU level and of public intervention using EU research funds

The SPIRE initiative distinguishes itself from other initiatives targeting resource and energy efficiency in process industries by explicitly taking a **cross sectorial approach**. Many on-going national and European initiatives are often either sector oriented (e.g. national innovation contracts for the bio-economy, European Research Fund for Coal and Steel, etc.) or *technology driven* (e.g. Nanoscience).

SPIRE for the first time brings together more than 8 sectors within the process industry in a **Value Chain and objective driven programme**, which explicitly wishes to benefit from the multi-sectorial approach in three ways:

1. By identifying **innovations in one sector** that have proven to increase resource and energy efficiency and that can be **adapted and transferred to another** sector to accelerate the innovation rate and environmental impact within the process industry ;
2. By **co-developing resource and energy efficiency (material) solutions** with contributions from multiple process industries (e.g. steel and chemistry, minerals and water etc.);
3. By developing innovations with resource and energy efficiency benefits, **targeting multi-sectorial replication from the outset**, with the aim to increase impact of such innovations in Europe.

As such, SPIRE links to the philosophy of Horizon 2020 to contribute to solving the grand societal challenges. Compared to the “regular” calls for proposals within Horizon 2020, SPIRE aims to add a specific element that – we believe – will contribute significantly to accelerating the process towards realizing impact and developing **resource and energy efficient solutions by and for multiple process industries**, which are at the core of all value chains.

In order to overcome traditional barriers between these sectors as well as with their value chain partners, SPIRE will foster collaboration between the sectors that have committed to SPIRE and their collaboration with their value chain partners.

This will require a sustained effort and secure public investment over multiple years that offer these process industries the security they need to develop longer term investment plans. This will be especially required due to the long return on investments in these typically high capital intensive process industries.

The recovery plan PPP's started under FP7 (FoF, E2B, Green Cars) have proven to be an ideal basis for driving R&I in specific platform areas. They have provided a good basis for commitment from both the industrial and public stakeholders and have created enough flexibility to adjust strategy in line with changing conditions (global, societal, technological etc.) – a key requirement in successful R&I development. The agenda-driven PPP programme based on a roadmap, that has been developed between a broad industrial basis and the Commission, has been demonstrated as a more appropriate instrument than regular call processes within FP7 leading to much larger industrial participation and take up. Furthermore the transparent and open call and evaluation process applied has proven to be an excellent mechanism to manage calls and has kept the overall administrative burden under better control. The transparency and widely accepted procedures and funding rules create a level playing field for all potential participants to SPIRE calls for proposals in the future.

Due to its large stakeholder community spreading over more than 8 sectors and reaching out to all value chains in the market, SPIRE – by its nature – needs to be a very open programme. Whereas a large number of stakeholders, including some major industries within the sectors involved, have been mobilized as founding members of the A.SPIRE aisbl, the programme will continue and strengthen its advocacy and communication/ dissemination activities towards the wide and highly fragmented stakeholder community, opening opportunities for them to participate both in future SPIRE roadmap updates as well as future calls for proposals within the SPIRE PPP.

The implementation of the SPIRE roadmap can be a success only through a mutual collaboration between the public and private partners in the SPIRE contractual partnership, all committed to the achievement of its vision and strategic objectives.

Expected impact of achieving the specific research and innovation objectives

The following section considers the impact of the PPP SPIRE at the level of the Key Components and Key Actions. Different illustrative but non-exhaustive examples are provided to give a quantified approach based on well-established estimations.

Key Component FEED

The Process Industry has a large installed base and a limited flexibility and possibility to radically change its primary feedstock and utilities. Keeping the installed base competitive by introducing various alternatives is the key element behind the impact strategy for the KC FEED. Improved competitiveness boils down to a Sustainable Process Industry which retains its current position as a key contributor to the European economy and welfare. For society, it implies that current jobs are retained and new jobs are created, while simultaneously positive effects on the environment are realized. More concretely, the deployment of alternative feedstock (various sources for fossils, metals, minerals and ores in KA 1.1), secondary feedstock (waste, residue streams and recycled end-of-life materials KA 1.2) and/or renewable feedstock (biomass in KA 1.4) feedstock and utilities (efficient water use in KA 1.3) will boost sustainability by significant, double digit reductions in energy consumption, GHG emissions, fresh water intake, and waste water production as illustrated by the accompanying examples. Biomass, biogas and shale gas are examples of alternative resources that can significantly contribute to making Europe less dependent on primary resources coming from political and economically unstable regions.

Key Action 1.1: *Enhancing the availability and quality of existing resources*

The search for alternative sources for fossil resources for chemicals and fuels and securing the quantities and quality of primary resources for materials and metals in KA 1.1 are developing strongly now and will lead to strong demonstration potential in the third period of this PPP especially to make the technology feasible under stringent environmental boundary conditions. As such SPIRE will contribute to the pillars of RMI and the Raw Materials EIP⁶⁶.

Key Action 1.2: *Optimal valorisation of waste and side streams as feed*

In KA 1.2 on waste, the valorisation of inorganic waste, residue streams and recycled end-of-life materials is on-going and ready for demonstration, whereas the valorisation of organic waste, residue streams and recycled end-of-life materials will need more time to come to full demonstration. Valorisation of process and flue gasses will have huge impact and lead to a serious breakthrough by the end of this PPP period and will have a strong emphasis on integration (e.g. the combination of chemical, steel- and coke industries). Also combination with renewable energy (especially peaks in the production) will create huge opportunities.

⁶⁶ http://ec.europa.eu/enterprise/policies/raw-materials/index_en.html

Key Action 1.3: Optimal and integrated (re) use of water

The water fit for purpose programme in KA 1.3 will develop monitoring tools for quality and quantity with demonstrations in the early period. The needs for water availability in case of temporary scarcity and for the control of impurities in closed water cycles will force the development of these tools and concepts at the latest towards the middle period, whereas integration of water and energy will be a continuous element in the water processes. Demonstration will depend on the different processes and their own development speeds.

Key Action 1.4: Advancing the role of sustainable biomass/renewables as industrial raw material

KA 1.4 on biomass will invest strongly in integration (collaboration with agri-food, pulp & paper, etc.) in the early phase and in demonstration (new bio-based products) in a later phase. The biomass feedstock and logistics issue has been mentioned before as a prerequisite to be addressed for a significant increase in uptake of biomass. The Bio PPP and SPIRE will operate in a complementary way to deliver success in the bio-economy.

Overall, the FEED Key Actions will have a relative balanced timing and budget distribution and its envisaged all KAs will, at the minimum, lead to demonstration activities and in some cases and niches to full implementation. As illustrative examples it is worthwhile mentioning the cases

of bio-based economy, the use of inorganic waste and residue in cement, and more efficient management of water resources by industry.

Considering the bio-based economy⁶⁷ the increased production and industrial utilisation of both terrestrial and aquatic biomasses has reached a level where up to 30% of total chemicals production in Europe is bio-based, resulting in strongly reduced dependence on oil-based manufacturing by 2030. It is anticipated that this development is especially remarkable in the areas of fine and specialty chemicals where more than 50% of their production will be bio-based. Also, increasing share of plastics, resins, and other key polymers will also be bio-based. Novel composites and other materials, based on bio-refinery processes, will have been developed for a variety of industrial applications, including construction. Due to the development of advanced zero-waste biorefinery processes, the share of bio-based fuels will have increased to 25% in the transport sector. In addition, as much as 30% of European heat and power production will be bio-based.

In reference to inorganic waste and residue in cement⁶¹, the table below shows energy consumption and clinker to cement ratios projection from the IEA/ WBCSD Cement Technology Roadmap 2009 – Carbon Emissions Reduction up to 2050:

	2010 World	IEA/WBCSD 2009 Roadmap 2050
Cement production	3.3 billion tonnes cement	3.7 to 4.4 billion tonnes cement
Thermal energy input	3.9 GJ/tonne clinker	3.2 GJ/tonne clinker
Clinker to cement ratio	77%	71%

⁶⁷ STAR-Colibri (2011) Joint European Biorefinery Vision for 2030 and European Biorefinery Joint Strategic Research Roadmap for 2020.

⁶⁸ Outlook 2050 provided in the IEA WBCSD Cement Technology Roadmap 2009. It is nevertheless necessary to take into account this numbers just as starting point / baseline for our further expert estimations / calculations of the impact of additionally performing within SPIRE.

Developing new innovative solutions for using inorganic residues and by-products from other sectors such as granulated ground blast furnace slag, fly ashes from power plants, glass or ceramic industry in cements may allow to further lowering the clinker / cement ratio to 40 to 50% by 2050. A consideration of the projected cement volumes reveals the enormous CO₂ saving potential attributed to such innovation. Apart from the technical barriers that are intended to be solved through this research, it has to be noted that there are at non-technical factors that can limit implementation of the technical possibilities such as regional availability, prices of substitution materials, national standards and common practices and acceptance. The intended research in this field of clinker substitution in cement would be a key factor in enabling the European cement industry to translate future environmental challenges into business opportunities. It provides a strong lever to further develop the competitiveness of the European cement industry in an environment facing increasing competition from companies based in countries with less environmental regulations.

Regarding more efficient management of water resources by industry⁶⁹ it is well known that Europe has various water intensive process industries like the chemical industry, food, textiles, paper & pulp, etc. There is a need to increase eco-efficiency in industrial water management. The recently started EU FP7 project E4Water aims to develop, test and validate new integrated approaches, methodologies and process technologies for a more efficient and sustainable management of water in chemical industry. The expected impact is a reduction of 20-40% in water use, 30-70% in wastewater production, 15-40% in energy use and up to 60% direct economic benefits its industrial case study sites. It is anticipated that the results of the six demonstration projects can be rolled out at various places in the chemical industry with cross-fertilization possibilities to other industrial sectors.

Key Component PROCESS

Key Action 2.1: Novel advanced energy systems.

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. A broadened portfolio of technical solutions will be further developed and applied in real sites. Each of these technology gaps will deliver an important contribution, for instance, top gas recycling with carbon capture might represent a 50% CO₂ reduction compared to the average blast furnace in the steel sector. In the cement sector, 90% CO₂ reduction compared to average kiln (almost complete CO₂ capture) by using oxyfuel firing with CC is achievable. A considerable CO₂ reduction is also achieved if the electricity used is renewable.

Key Action 2.2: Energy harvesting, storage and reuse

To be able to use waste heat from one process as energy input in the same process step or for a different process the heat recovery components and materials have to be developed for high temperatures. This is a prerequisite for any efficiency improvement not yet accomplished. Novel efficient heat recovery, reuse and conversion processes, and energy storage technologies will play a significant role in the future to help industries to balance their energy consumption by means of fully integrated and monitored processes. Furthermore, it opens possibility to utilise hitherto unavailable large quantities of waste heat sources.

Key Action 2.3: Process monitoring, control and optimization

Any action, which improves yield, will have a stronger impact than any efficiency increase. Innovative systems and tools (hardware and software) will enable the development of process control and subsequently improve yield. Optimisation of the process chain has a high potential, which has not been tapped yet. As an example, molecular reaction control will enable higher reaction rates leading to low-temperature processes and smaller equipment, better selectivity leading to minimisation or elimination of waste, reduced requirements for separation operations, which are responsible for ~40% of energy consumption in chemical and related industries, as well as the possibility for tailored manufacturing of new, advanced products⁷¹. Furthermore, all data collected will be used as key information for ecodesign of products and will be needed for overall lifecycle assessment.

⁶⁹ Economically and Ecologically Efficient Water Management in the European Chemical Industry (E4Water project), www.e4water.eu

⁷⁰ Adapted from: Harry Croezen, Marisa Korteland, Technological developments in Europe. A long-term view of CO₂ efficient manufacturing in the European region. Delft, CE Delft, June 2010 and ULCOS project http://www.ulcos.org/en/about_ulcos/home.php

⁷¹ Research arch Agenda for Process Intensification Towards a Sustainable World of 2050, Creative Energy, Energy transition, Delft Skyline Debates, Dutch Institute for Sustainable Process Technology (ISPT) and is supported by the Netherlands Ministry of Economic Affairs, Agriculture and Innovation.

Key Action 2.4: More efficient systems and equipment

Breakthrough process improvements have the potential to increase efficiency substantially. They represent the core of the Key Component Process not only in terms of resource and energy savings but also in terms of concerns for investments and required efforts. The engineering industry itself will undergo drastic changes linked to continuous processes and integrated downstream processes. In addition, modularisation will lead to an increasing number of factories and apparatus produced and to significant reductions in equipment costs and shorter product life cycle.

Key Action 2.5: New energy and resource management concepts (incl. industrial symbiosis)

Lastly, industry is still at the beginning of tapping the potential of industrial parks. Waste heat and resources from one industry can be an energy and resource source for a different industry. Fluctuating energy inputs (e.g. from renewables) and fluctuating demands call for micro and macro optimisation, removing obstacles for energy and material integration, which will improve the design and operation of plants. This reflects a major challenge with a significant long term impact.

As an overall illustrative example of potential impact related to the KC Process it is worthwhile considering the shift to syngas in the ceramic brick and roof tile industry. The industry aims to replace 75% of its natural gas consumption in the kiln by syngas (the remaining 25% are at lower temperatures and could pose problems). On average a kiln represents 80% of the natural gas consumption of a clay production unit so 60% of the consumption of the unit. A dissemination rate of 80% throughout Europe is expected as switching to syngas brings cost savings and only very small kilns would not switch. In this way 50% of the total European natural gas consumption of the brick and roof tiles industry would be replaced by syngas. CO₂ emissions in the brick and roof tiles sector come, roughly speaking, 20% from process emissions and 80% from natural gas consumption. In the assumption that 80% of the syngas would be biogenic, it is expected that over 30% of the current CO₂ emissions would be saved.

Key Component APPLICATIONS

Key Action 3.1: New materials contributing to development of energy and resource efficient processes

The process industry has enormous potential to develop new sustainable materials that will be themselves fundamental to achieving more energy and resource efficient processes in the process industry itself and will also have potential application in other sectors down the value chain. Two sufficiently illustrative examples are given in the areas of **High temperature insulation (HTI) materials and coatings.**

The increasing cost of power and the rapid depletion of conventional sources of energy highlight the need for effective heat management and energy conservation in industrial processes. HTI materials such as refractories provide high compressive strength and low shrinkage at high temperatures; and thus offer a cost-effective energy management solution for industrial processes. The global HTI products market - defined as insulation products with maximum operating temperature over 1000° C - is witnessing tremendous growth due to increasing awareness of energy saving, cost effectiveness and emission reduction. The global HTI products market is estimated to grow from \$2.7 billion in 2011 to \$3.5 billion in 2016⁷². While Europe led the global HTI market in 2011 with a 39% share, India, China, Russia and Middle East have registered dynamic growth rates. Therefore novel high performance HTI products will provide an excellent sustainable and competitiveness opportunity in the coming years. Major industrial sectors for future applications are petrochemicals, cement and iron and steel industries amongst others. Energy forms the largest cost component of HTI products, accounting for about 40 - 50% of the total production cost. Thus, energy efficiency in the manufacturing process could significantly lower the cost of the end-product.

Corrosion and wear affect the metallic surfaces of industrial equipment and lead to progressive deterioration that can reduce plant efficiency and cause equipment failures and/or plant shutdowns. The annual cost of corrosion for US industry in various industrial processes totals \$3.7 billion in the petroleum refining industry, \$1.7 billion in the chemicals industry, and \$5.9 billion in pulp and paper production and processing. A 10% reduction in corrosion costs in these three industries alone using improved materials could save \$1.1 billion each year⁷³. Advanced protective coatings have been used with great success to protect surfaces from wear and corrosion in harsh environments. Nevertheless chemical, structural, and processing innovations in coatings are necessary to reduce corrosion in biomass systems and improve oxidation resistance in many industrial processes.

⁷² 2012 Report: High Temperature Insulation Market - HTI Application (petrochemicals, glass, ceramics, and others) and Temperature Range - Global Trends & Forecasts (2011 - 2016). Published by <http://www.marketsandmarkets.com/>

⁷³ Materials: Foundation for the Clean Energy Age (2012). The Minerals, Metals & Materials Society (TMS) report sponsored by the U.S. Department of Energy Advanced Manufacturing Office (AMO). <http://energy.tms.org/>

Key Action 3.2: New processes for energy and resource efficient materials applied in sectors down the value chain

As has been stated previously, the approach taken to create **impact will be driven bottom-up**. Nevertheless an illustrative example is provided to highlight the potential of the process industry in terms of developing more sustainable processes contributing to the advance in manufacturing novel materials with reduced CO₂ and energy footprints that are fundamental cornerstones for energy and resource efficient applications down the value chain. Future Solid-State Lighting (SSL) sources (i.e. LEDs) are expected to outperform all other light sources in terms of efficiency, offering energy savings of 50% over the present installed base. When SSL is combined with intelligent light management systems to regulate the output according to ambient lighting conditions or to people's presence and activities, additional savings of 20% are anticipated⁷⁴. Nevertheless LEDs contain a large number of earth metals, such as lead, copper, nickel, silver, gold and arsenic, which have toxic properties and/or are scarce. As the use of LEDs increases⁷⁵, so will their contribution to waste, which raises concerns about how to manage their end-of-life, with fears that they could eventually have similar environmental impacts as other electronic waste, such as computers and mobile phones. Also, although impacts on resource depletion currently seem small this could increase, especially with the development of high power LEDs. Better processing and recycling technologies and a more sustainable redesign of LEDs to use fewer rare metals could help reduce these impacts⁷⁶.

Key Component WASTE2RESOURCE

The main emphasis the W2R component will be on **KA 4.2: Technologies for separation, extraction, sorting and harvesting of gaseous, liquids and solid waste streams and KA 4.3: Pre Technologies for (pre)treatment of process and waste streams (gaseous, liquids, solids) for re-use and recycling**. These two KAs require extensive modelling and experimentation devoted to technological development, and demonstration. The associated costs are higher than for development of modelling tools, databases and business models. As for the expected impact, this will be highest in separation and extraction technologies as collecting waste and sorting it optimally (value chain consideration) is the part of the reuse and recycles chain with the highest possibilities for increasing output⁷⁷.

An example of high impact on resource efficiency is the development of sorting technology based on real-time analysis of content in waste streams (separation of the

materials, not to make an unusable mix). The successful demonstration and market introduction of these technologies will improve the value of recovered materials, thus having effects in the complete value chain for reuse and recycling. Furthermore, it is crucial to pre-treat the sorted material. Pre-treatment can remove particles, utilize heat content, improve quality, reduce the amount of dross and improve yield. An example is the aluminium industry. Today there are 693.8 Million tons of aluminium in use and 11 Million tons of scrap is recycled each year. Soon much of the aluminium in use will approach the end of its life (Rombach, 2012, Erzmetall) and it is of urgent importance to establish routines/technology/ knowledge for handling this in a sustainable way. Using secondary aluminium as feedstock reduces energy production by 95% in addition to conserving resources.

An example of market replication with a high potential impact on resource efficiency is the RECOGEN project. In this project exhaust pickle liquors are recycled through an innovative process entailing Recovery of high quality Zn-Fe sulphates for the fertilizers industry and production of regenerated hydrochloric acid for the steel industry. Replicating this project in other markets will remove unwanted elements (sodium, iron and vanadium in aluminium) from the SPL, utilize the chlorine and recycle the remaining SPL material. Thus the requirements on resources and the amounts of hazardous waste destined for landfill will be reduced.

Key Component HORIZONTAL

Key Action 5.1: Identification, benchmarking and dissemination of cross-sectorial transfer of good energy and resource efficiency solutions and practices

It is widely recognized that the effectiveness and efficiency of innovation is determined to a considerable extent by the degree and quality of linkages and interactions among the various value chain actors. Consequently the realization of innovation requires a balance between 'push' and 'pull' of technological and non-technological factors along the innovation chain. In this sense the innovation diffusion across different process industry sectors will require the development of novel and flexible collaborative models to catalyse action towards the rapid increase in the scale and speed of deployment of sustainable solutions and practices. This KA will aim to accelerate innovation in various sectors through novel technology transfer and cross-fertilisation cooperation schemes making an impact through crucial factors such as "reduced time to market" and cross-sectorial solution replicating potential⁷⁹.

⁷⁴ Photonics: our vision for a key enabling technology in Europe, Photonics21 ETP, 2011.

⁷⁵ The global lighting market is projected to grow from today's €50 billion, of which less than €5 billion is based on SSL technology, to a €120 billion market in 2020, of which more than €90 billion will be accounted for by SSL (taken from Ref.1).

⁷⁶ Seong-Rim, L., Kang, D., Ogunseitan, O.A. & Schoenung, J.M. (2011) Potential Environmental Impacts of Light-Emitting Diodes (LEDs): Metallic Resources, Toxicity and Hazardous Waste Classification. Environmental Science & Technology, 45:320-327.

⁷⁷ UMICORE, Meskers 2012, WEE-recycling

⁷⁸ See for example: Open Innovation in Global networks, OECD 2008.

⁷⁹ Innovation and Technology Transfer: Framework for a Global Climate Deal, Shane Tomlinson, Pelin Zorlu and Claire Langley, An E3G report with contributions from Chatham House, November 2008.

Key Action 5.2: Methodologies and tools for cross-sectorial Life Cycle and Cost Assessment as well as novel social Life Cycle Assessment of energy and resource efficiency solutions

Despite recent advances, the challenge to unambiguously determine and measure sustainability performance, especially for products and processes, still remains. The maturity of methods and tools is different for the three sustainability dimensions (environmental, economic and social). While the environmental dimension can be covered rather well today, the economic and social indicators and evaluation methods still need fundamental scientific progress. Life Cycle Thinking, Carbon and Water Footprinting, Life Cycle Assessment, Resource- and Eco-efficiency Assessment etc. are useful tools for supporting sustainable production and consumption, if their results are interpreted with proper consideration of their respective limitations. However, the comprehensive concept of Life Cycle Sustainability Assessment (LCSA) is gaining momentum as the route to follow⁸⁰. This KA will consider the process industry from a holistic perspective (also cross-sectorial) with the aim to develop novel sustainability assessment models and methodologies based on existing knowledge. The targeted impact will be to develop the powerful and credible science-based techniques required to generate knowledge in the area of energy and resource efficiency and then translate a better understanding of the product and production process into actions contributing to a Green Economy with sustainable consumption and production patterns.

Key Action 5.3: Develop skills and education programmes required for the development and deployment of novel energy and resource efficiency solutions and practices

A sustainable process industry generates demand for new education and skills as its value chain stakeholders reorient their activities towards new sustainable markets, processes and products⁸¹. The aim of this KA will be to anticipate future demand by launching initiatives oriented to elaboration of novel educational and training programmes and complementary cross-sectorial exchange of professionals to enhance the innovation skills capacity across the value chain of the EU Process Industries. The impact of these actions will translate directly into a better matching of skills supply with labour market needs, in particular in terms of newly-emerging and expanding markets involving green jobs.

Key Action 5.4: Enhancing innovation and entrepreneurial skills and culture

SPIRE will complement KA5.3. with this KA which will have a primary focus on future generations of scientists, engineers and technologists. The main impact will be to boost entrepreneurship culture among young Europeans taking advantage of the different success case studies generated by SPIRE projects. A side benefit, that is equally important, will be the communication of a culture of sustainability among the young academic community.

Key Component OUTREACH

Key Action 6.1. Analysis and establishment of efficient technology dissemination methodologies and mechanisms and frameworks:

The cross-sectorial character of SPIRE makes necessary the establishment of novel dissemination mechanisms that allow for a holistic exploitation of project results. Therefore SPIRE will create and maintain a framework to facilitate the effective dissemination and exploitation of project results. The impact of this action will immediately translate into the **optimisation** of the value of the project, **strengthening** its overall impact, **transferring** its findings to other contexts and **integrating** it into the broader European context (i.e. the SPIRE value chain approach considering process industry as solution provider to end-using sectors). This will allow the PPP to continue to build upon its projects after its lifetime by enabling others to apply the findings or take developments to the next step.

Key Action 6.2: Develop social responsibility for the process industry

A resource and energy efficient process industry needs to take into account sustainability, economic growth, social equity and human development as equal driving forces⁸². The aim of SPIRE is to contribute towards achieving a Green Economy that at the same time is socially responsible. The green economy model seeks a more balanced portfolio of investment of social, human, natural, financial and physical capital. It recognizes the value of markets, but is not tied to markets as the sole or best solution to all problems. In this sense the SPIRE roadmap foresees the launching of initiatives dedicated to the identification of sustainable and inclusive development strategies linked to novel and/or improved existing models and practices along and across the process industry (i.e. inclusive business models around social capital gain goals, socially aware investment models, socio-technological integrative innovation strategies for low-energy and resource consumption, etc)⁸³.

⁸⁰ Towards a Life Cycle Sustainability Assessment, UNEP, UNEP/SETAC Life Cycle Initiative Report (2011).

⁸¹ Skills for green jobs, European Synthesis Report, European Centre for the Development of Vocational Training, 2010.

⁷⁵ Working towards a Balanced and Inclusive Green Economy: A United Nations System-wide Perspective, (2011) published by the United Nations Environment Management Group.

⁷⁶ From Green Economy to Green Society: Bringing the Social to Rio+20, The United Nations Research Institute for Social Development (UNRISD), 2012.

Proposed arrangements to monitor and assess progress towards achieving desired effects

The objective of the SPIRE roadmap Key Performance Indicators (KPI) is to highlight and exemplify some evaluation guidelines that will contribute to performing an impact assessment on SPIRE. This impact assessment will be a tool to evaluate SPIRE against its identified objectives as well as to contribute to improving the quality and coherence of its development process. As main points the impact assessment will:

- Detect potential operational issues related to the implementation and execution of SPIRE and point towards correction actions and measures.
- Quantify the advancement of SPIRE towards the achievement of its concrete technological and non technological objectives and offer additional information towards future deployment of call topics and innovation coverage.
- Operational KPIs: that will serve to evaluate SPIRE as an organizational and funding instrument and therefore its organizational structure and bodies.
- Sustainability, Innovation and Competitiveness KPIs: that will focus on SPIRE outputs in relation to sustainability, industrial competitiveness and innovation.

It is useful to divide the KPIs into two large groups to facilitate an impact evaluation exercise:

It is of course understood as well that these two types of KPIs are closely interrelated.

OPERATIONAL KPIS

The main focus of the operational KPIs is to evaluate SPIRE as a tool and its suitability to facilitate the achievement of the SPIRE objectives. Table 2 summarizes some essential KPIs that will be considered.

KPIs

Contribution of the SPIRE PPP model to the objectives pursued.

Effectiveness of the PPP SPIRE model as an appropriate tool for increasing (short, mid and long-term) research and innovation investment.

Effectiveness of SPIRE PPP model as for networking/pooling various stakeholders between the public and private sectors and in combining private sector investment and European public funding.

Level of participation (per call and topic) in the different topics of SPIRE (per sector, per organization type, etc).

Number of project proposals submitted (per call and topic) and quantified per sector as well.

Number of proposals above the threshold (per call) and quantified per sector as well.

Percentage of proposals reaching negotiation and measurement of the time from submission till project kick-off.

Budget allocation across different industrial sectors and entities (large industry, SMEs, Academia, etc).

Budget allocation across different activities (R&D, Demonstration, Exploitation, etc).

Sufficiency of funding levels to reach project objectives.

Number of project fulfilling proposed objectives.

Participation pattern in terms of geographical coverage.

Participation pattern in terms of gender balance.

Effectiveness of the Association created in the frame of SPIRE for contributing to reach the objectives and promoting the participation of industry, SMEs, academia, etc, gathering stakeholders, promoting innovation and openness, etc.

Contribution of SPIRE as an instrument to enhance the deployment of the EU policy of resource efficiency.

TABLE 2: Examples of SPIRE Operational KPIs.

The above illustrative examples have been selected based on the official impact assessment reports of the EC for FP7 and previous Framework Programmes as well as other different EC documents giving guide lines on impact assessments.⁸⁴

The KPIs in table 2 can be complemented with question of more general character and open nature that will prove highly valuable to discover operational qualitative influencing factors as well as a consultation basis for suggested enhancements such as:

- What can be done to improve the effectiveness of SPIRE?
- What could further be done to improve the role of the Association?
- What could further be done to ensure Europe's best researchers from industry and academia are involved in projects supported by SPIRE?
- What could further be done to ensure that European industry, including SMEs, are involved in projects supported by SPIRE?
- What would be your main recommendation concerning the future of the PPPs?
- What could be done to enhance the cross-sectorial involvement?
- What could be further done to boost the participation in SPIRE of sectors directly and indirectly connected and benefiting by the process industry value chain?

The list is not exhaustive and it will be necessary to arrive at the best and more complete version with the help and consultation of SPIRE stakeholders.

SUSTAINABILITY, INNOVATION AND COMPETITIVENESS KPIs

The evaluation of an initiative such as SPIRE in terms of its global contribution to the macro eco-socio-economic picture related to sustainability, competitiveness and innovation is a complex exercise. Nevertheless it is perfectly possible to evaluate SPIRE in terms of concrete performance at the project level. Such an evaluation constitutes an important and necessary exercise which can provide concrete indications pointing towards the success of SPIRE in achieving concrete results that contribute to the route towards a global green economy scenario.

The following table exemplifies a set of non-exhaustive KPIs that can be used to gather representative data and provide solid judging elements and information to assess the progress of SPIRE towards its stated objectives. In the development of table 3, three main sources of information providing KPIs have been taken into account:

- The Innovation Union Scoreboard 2011⁸⁵, which includes innovation indicators and trend analyses for the EU27 Member States, as well as other European Countries.
- The European Competitiveness Report 2011⁸⁶, which within the context of the Europe 2020 Strategy is designed to contribute to the analytical underpinning of the promotion of competitiveness in the European Union. It presents a macro analysis of the developments of overall competitiveness performance and focuses on various drivers of productivity and sustainable growth as well as on competitiveness changes in particular industries.
- The different official studies available reporting on the impact analysis of the different Framework Programmes (i.e. FP5, FP6 and FP7)⁸⁷ which also provide valuable KPIs especially at the project level.

⁸⁴ See for example http://ec.europa.eu/governance/impact/key_docs/key_docs_en.htm and Interim Assessment of the Research PPPs in the European Economic Recovery Plan, DG RTD, 2011.

⁸⁵ Innovation Union Scoreboard 2011. Research and Innovation Union scoreboard. Available at: http://ec.europa.eu/enterprise/policies/innovation/facts-figures-analysis/innovation-scoreboard/index_en.htm

⁸⁶ European Competitiveness Report 2011, Commission staff working document SEC(2011) 1188. Available at: http://ec.europa.eu/enterprise/policies/industrial-competitiveness/competitiveness-analysis/european-competitiveness-report/index_en.htm

⁸⁷ See for example Official EC reports available at: http://ec.europa.eu/research/evaluations/index_en.cfm?pg=fp7

It will also be necessary at a technology and project delivery level to develop the appropriate standardized KPI's to measure quantitatively and qualitatively the impact of innovation in resource and energy efficiency. In this context it will be beneficial to establish collaborative contacts with organizations such as CEN and CENELEC. The cross-sectorial participation and cross-sectorial objectives of SPIRE make that typically single component KPIs will not suffice to measure performance and that different projects may require different KPIs. Initial examples of some KPIs that may be appropriate for the various key components in SPIRE are shown in table 4.

KPI Area	KPI
NEW JOBS & SKILLS	Number of researchers participating in projects.
	Number of PhDs obtained through project activities.
	Number of training courses/activities realized.
	Number of training activities enhancing knowledge base and skills (i.e. green jobs).
	Number of project reporting evidence of (green) job creation and/or maintaining jobs.
	Number of projects evidencing contribution to improvement of employment levels.
OPEN, EXCELLENT AND SOCIALLY RESPONSIBLE R&D&I ECOSYSTEMS	Number of publications in peer review journals.
	Number of participations (presentations or posters) in conferences, symposia, etc.
	Number of events related to exchange of good practices.
	Number of events related to dissemination of industrial results.
	Number of projects evidencing communicating project results to society.
	Number of projects increasing the access to expertise and establishment of critical mass of R&D&I.
	Formation of new partnerships and R&D&I linkages (quantification).
	Number of projects evidencing multi/cross-sectorial participation (quantification at sector participation level).
Number of projects evidencing cross-sectorial benefits (i.e. technology transfer, best practices, etc).	

KPI Area	KPI
INNOVATION AND INDUSTRIAL COMPETITIVENESS	Number of patents registered.
	Number of copyrights/trademarks/ registered designs.
	Number of software packages/applications developed.
	Number of innovations related to development of measurement techniques, control devices and instruments, software/ simulation models, characterization tools, production concepts, organisational models, improved knowledge management tools
	Number of projects reporting evidence of commercial return.
	Number of projects evidencing higher benefits than costs.
	Number of spin-off companies created.
	Number of standards/normalisation bodies projects contributed to.
	Number of projects evidencing ability to carry out new activities or enter new areas (specification and quantification parameters).
	Number of projects evidencing improved competitive position of the participating entities.
	Number of projects evidencing quantified improved commercial performance (i.e. increased turnover, profitability, productivity, market share, etc).
	Number of projects evidencing the generation of S&T results beyond state of the art, achievement of innovative breakthroughs.
	SUSTAINABILITY AND ECO-EFFICIENCY
Number of projects evidencing enhanced ability to produce, deliver or exploit new sustainable products, processes or services (quantification by impact area according to SPIRE KCs and KA).	
Number of projects evidencing innovations and/or results for reducing GHG emissions (quantification by impact area according to SPIRE KCs and KAs).	
Number of projects evidencing innovation and/or results for reducing resource and energy consumption (quantification by impact area according to SPIRE KCs and KAs).	
Contribution of SPIRE projects to EU resource efficiency policy.	

TABLE 3: Examples of KPI for the evaluation of SPIRE.

SPIRE Key Component	Key Performance Indicators	Expected outcomes for the SPIRE Stakeholders	Related to SPIRE Key Action
FEED	By 2020 the technical feasibility of implementing waste, residue streams and recycled end-of-life materials in cement has been proven. Clinker based low CO ₂ binder prototypes with a clinker to cement ratio of around 60% have been successfully developed.	Waste streams like blast furnace slag, fly ashes and recycled end-of-life materials are valorised as secondary raw material.	KA 1.2: Optimal valorisation of waste, residue streams and recycled end-of-life materials as feed
	By 2020 the EU will be leading in the re-use of CO ₂ emissions and their transformation into chemical products or methane and fuels for chemical energy storage making use of peaks in renewable energy productions.	Start of a CO ₂ -based economy by using excessive peaks in energy production.	KA 1.2: Optimal valorisation of waste, residue streams and recycled end-of-life materials as feed
	By 2020 the results of demonstrations on efficient water management in the chemical industry in at least 4 demonstrations in chemical industry and the role out to at least 2 other sectors is started. Each demonstration targets at 20-40 % lower water use, 30-70% less waste water and 15-40% lower energy consumption.	More efficient water usage in water intensive process industries by fit-for-purpose and water cascade approaches, thus significantly improving the economic and environmental performance.	KA 1.3: Optimal and integrated (re)use of water
	By 2020 the number of bio-based resources used in the chemical industry will be increased by 20% leading to 10 new bio-based products coming on the market of which at least 4 will be new molecules (not mimics or the same molecules as petroleum based).	More efficient use of bio-based materials and resources at competitive prices	KA 1.4: Advancing the role of sustainable biomass as industrial raw material
PROCESS	By 2020, the use of new material will not only allow recovery of heat lost through the gases to preheat the raw material or the air to be mixed with the gas or fuel, but also to make use of these properties, to reuse this heat in the same facilities, as for example to exchange in electricity, in air conditioning etc.. In addition with better insulation properties the materials should allow a decrease in energy consumption to obtain the desired temperature and so the development of more efficient energy equipment. Indirectly, as the energy consumption will be reduced, lower CO ₂ emissions and other greenhouse gases will be emitted. In the ceramic sector this is expected to allow feedstock savings greater than 11%, operating cost reduction of at least 19%, productivity increase of at least 22%.	Enlargement of waste heat recovery systems, specifically designed for different industrial sectors (gases with dust, abrasive gases etc..)	KA 2.2: Energy harvesting, storage and reuse

SPIRE Key Component	Key Performance Indicators	Expected outcomes for the SPIRE Stakeholders	Related to SPIRE Key Action
	By 2020, new innovative processes may allow the production of short series at the same cost as present large ones by development of more efficient melting, holding and sintering processes. In the chemical sector, new solutions in this field will enable higher reaction rates leading to low-temperature processes and smaller equipment size, better selectivity leading to minimization or elimination of waste, reduced requirements for separation which are responsible for ~40% of energy consumption in chemical and related industries.	Novel micro reactor and continuous flow technologies at manufacturing scale, as well as process intensification for whole process.	KA 2.4: More efficient systems and equipment.
	By 2020 process intensification will lead to large efficiency increases in the pharmaceutical and fine chemicals sectors and will start to become implemented in some first bulk chemicals production.	Process intensification will support the establishment of new lead plants for the future in Europe.	KA 2.4: More efficient systems and equipment.
WASTE2RESOURCE	By 2020 modelling tools and cross-sectorial databases for more holistic and systematic analysis of the viability of recycling opportunities developed.	More efficient exploitation of cross and intra sectorial synergies to develop sustainable European recycling business enabled. Identification of new recycling opportunities and more efficient recycling concepts. Framework for selection of optimal recycling strategies and development targets.	KA 4.1: Systems approach: understanding the value of waste streams.
	By 2025 novel integrated modelling concept demonstrated at least 5 case studies.	New recycling business opportunities. Availability of selected raw materials improved. Less use of virgin materials, reduced footprints of production.	
	By 2025 novel recycling process concepts for at least 5 different (complicated) waste streams demonstrated and ready for market.	Recovery efficiency and process economy improved. Amounts of residues to landfill reduced. (As in 4.2) New recycling business opportunities. Availability of selected raw materials improved. Less use of virgin materials, reduced footprints of production.	KA 4.2 Technologies for separation, extraction, sorting and harvesting of gaseous, liquid and solid waste streams

SPIRE Key Component	Key Performance Indicators	Expected outcomes for the SPIRE Stakeholders	Related to SPIRE Key Action
	The development projects show that the material losses in the selected existing recycling processes can be reduced by 70%.		KA 4.3: Technologies for pre-treatment of process and waste streams (gaseous, liquids, solids) for reuse and recycling.
	Development of efficient pre-processing technologies for complicated waste streams enable economically viable recovery of selected scarce minor compounds.		
	Collection efficiencies for mobile phones and other small electronic appliances improved by 50 % compared with current efficiencies. At least 5 new cross-sectorial waste valorisation concepts developed by 2025.		KA 4.4: Value chain collection and interaction, reuse and recycle schemes and business models
APPLICATIONS	By 2020 improved processes have incorporated key innovative materials contributing to increase sustainability.	New products/applications for suppliers of materials and more energy and resource efficient manufacturing in process industry.	KA 3.1: New materials contributing to develop energy and resource efficient processes.
	By 2020 at least 4 projects have been realised which report added value from the process industry to end-user sectors.	Improved competitiveness and sustainability for multiple players in the value chain.	KA 3.2: New processes for energy and resource efficient materials applied in sectors down the value chain.
	By 2020 the production of so called clean technology materials, which create energy and/or resource efficiency in endproducts, has become more sustainable.	Improved sustainability scores over the whole value chain due to more sustainable production..	KA 3.2: New processes for energy and resource efficient materials applied in sectors down the value chain.
HORIZONTAL & OUTREACH	By 2020 novel LCA cross-sectorial indicators, methodologies and approaches have been developed.	Novel cross-sectorial sustainability indicators and methodologies to approach a holistic process industry synergy.	KA 5.2: Methodologies and tools for cross-sectorial Life Cycle and Cost Assessment as well as novel social Life Cycle Assessment of energy and resource efficiency solutions.

SPIRE Key Component	Key Performance Indicators	Expected outcomes for the SPIRE Stakeholders	Related to SPIRE Key Action
	By 2020 a new framework to realise technology transfer in a cross-sectorial manner has been established and at least 20 cases have been successfully realised.	Mature framework and methodology to realise cross-sectorial technology transfer of ideas and practices.	KA 5.1: Identification, benchmarking and cross-sectorial transfer of good energy and resource efficiency solutions and practices
			KA 5.5: Analysis and establishment of efficient technology dissemination methodologies, mechanisms and frameworks.
	By 2018 at least 1 cross-sectorial University Masters Programme is delivered for students on Sustainable Process Industry across different EU universities. By 2020 at least 10 training courses on related skills dealing with cross-sectorial practices for the Sustainable Process Industry have been realised.	Continuous education of future process industry professionals.	KA 5.3: Develop skills and education programmes required for the development and deployment of novel energy and resource efficiency solutions and practices.
	By 2020 SPIRE has been fully disseminated across the EU with emphasis on societal responsibility components.		KA 6.2: Develop social responsibility for the process industry.

TABLE 4: SPIRE KPIs examples at KC and KA level

For a thorough evaluation of the sustainability impact of SPIRE it will be necessary to go beyond those indicators mentioned above and design a tailored methodology based on a combination of project specifics combined with proven methodologies. We consider that it goes beyond the scope of this roadmap document to extensively provide a complete analysis of the methodologies and KPIs proposed by different expert organizations, since it will be necessary to have a panel of experts that agree on an accepted procedure and KPIs. In this sense and with the sole aim to provide an example we refer to *The Organisation for Economic Co-operation and Development (OECD) Sustainable Manufacturing Toolkit*⁸⁸ which is the result of a two-year consultation process involving many practitioners and experts. The framework it establishes is largely based on the existing variety of measurement and reporting initiatives around the world.

⁸⁸ OECD Sustainable Manufacturing Toolkit .Start-up Guide: Seven steps to environmental excellence, OECD 2011. Available at: www.oecd.org/innovation/green/toolkit.

Data items		OECD Sustainable Manufacturing Indicators																		
		Non-renewable materials intensity	Restricted substances intensity	Recycled / reused content of input materials	Water intensity	Energy intensity	Renewable proportion of energy	GHG intensity	Residuals intensity (mass balance approach)	Residuals intensity (waste output approach)	Intensity of residual releases to air	Intensity of residual releases into water	Proportion of natural land	Recycled/reused content of products	Recyclability of products	Renewable materials content of products	Non-renewable materials intensity of products	Restricted substances content of products	Product energy consumption intensity	Product GHG emissions intensity
		I1	I2	I3	O1	O2	O3	O4	O5a	O5b	O6	O7	O8	P1	P2	P3	P4	P5	P6	P7
MATERIALS (to be collected for each input material)	Units of materials consumed	●	●	●	○	○		○	●											
	Weight per unit	●	●	●	○	○			●											
	Proportion of non-renewable content (%)	●																		
	Proportion of restricted substances contained (%)		●																	
	Proportion of recycled content (%)			●																
	Proportion of reused content (%)			●																
	GHGs (CO ₂ e) released per unit of material during its production							○												
WATER	Units of water consumed in production process				●															
	Units of water consumed in overhead				●															
	Factor to calculate water consumed during the production of materials				○															
ENERGY (to be collected for each type of energy source)	Units of energy consumed in production process					●	●	●	●	●										
	Units of energy consumed in overhead					●	●	●	●	●										
	Proportion of renewable content						●													
	Energy content (MJ) per unit [look-up value]					●	●													
	GHG emissions (CO ₂ e) per unit [look-up value]							●		●										
	Weight per unit [look-up value]								●											
factor to calculate energy consumed during the production of materials [look-up value]					○															
INFRA-STRUCTURE	Facility land area												●							
	Natural land cover area												●							
TRAVEL AND LOGISTICS (to be collected for each mode)	Distance travelled by all employees for business purposes							●												
	Distance of transporting input materials from suppliers to the facility							○												
	Distance of transporting products from the facility to the purchasers							○												
	Distance travelled by all employees for commuting							○												
	GHG emissions (CO ₂ e) per distance [look-up value]							●												

FIGURE 12: OECD Sustainable Manufacturing Indicators (taken from ref.81)

Data items		OECD Sustainable Manufacturing Indicators																			
		Non-renewable materials intensity	Restricted substances intensity	Recycled / reused content of input materials	Water intensity	Energy intensity	Renewable proportion of energy	GHG intensity	Residual intensity (mass balance approach)	Residual intensity (waste output approach)	Intensity of residual releases to air	Intensity of residual releases into water	Proportion of natural land	Recycled/reused content of products	Recyclability of products	Renewable materials content of products	Non-renewable materials intensity of products	Restricted substances content of products	Product energy consumption intensity	Product GHG emissions intensity	
		I1	I2	I3	O1	O2	O3	O4	O5a	O5b	O6	O7	O8	P1	P2	P3	P4	P5	P6	P7	
RELEASES	Weight of releases into air from production process																				
	Weight of releases into air from overhead																				
	Weight of releases into surface water from production process																				
	Weight of releases into surface water from overhead																				
	Weight of releases into land from production process																				
	Weight of releases into land from overhead																				
	Weight of releases into landfills from production process																				
	Weight of releases into landfills from overhead																				
	Weight of transfers into disposal from production process																				
	Weight of transfers to disposal from overhead																				
	Weight of transfers for treatment from production process																				
	Weight of transfers for treatment from overhead																				
	Weight of transfers to recycling from production process																				
	Weight of transfers to recycling from overhead																				
	Weight of transfers for energy recovery from production process																				
	Weight of transfers for energy recovery from overhead																				
	Weight of transfers to sewage from process																				
	Weight of transfers to sewage from overhead																				
Weight of additional GHG emissions released from production process																					
Weight of additional GHG emissions released from overhead																					
PRODUCTS (to be collected for each product)	Average product weight																				
	Number of products produced																				
	Proportion of recycled materials in products (%)																				
	Proportion of reused materials in products (%)																				
	Proportion of reused content in products (%)																				
	Proportion of renewable materials in products (%)																				
	Proportion of restricted substances in products (%)																				
	Average annual energy consumption (MJ) per product																				
	Average annual GHG production (CO ₂ e) per product																				
	Expected lifetime of product																				

FIGURE 13: OECD Sustainable Manufacturing Indicators (taken from ref.81)

This tool aims to provide a practical starting point for businesses around the world to improve the efficiency of their production processes and products enabling them to contribute to sustainable development and green growth. The Toolkit includes an internationally applicable common set of indicators helping businesses measure their environmental performance at the level of a plant or facility. Figure 12 and Figure 13 provide examples of the type of indicators elaborated by the OECD. Of course it is understood that other sources of data can be used in combination⁸⁹.

SPIRE intends to leverage existing instruments under the FP7 framework (e.g. NMP.2013.3.0-1 Tools for Monitoring and Assessing Resource-efficiency in the Value Chain of Process Industries) as well as dedicated efforts under SPIRE calls to further develop the appropriate KPIs.

⁸⁹ See for example EUROSTAT, <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>





PART 4. GOVERNANCE

The current roadmap represents a coordinated and integrated framework from research to business following a staged approach with short-term, medium-term and long-term objectives and benefits.

It represents a valuable European industry offer and articulation of the various sectorial innovation priorities and agendas for the next years that will provide a synergistic effect (i.e. “1+1=3”) compared to individual initiatives. It requires but also guarantees therefore sustained effort and investment over multiple years. In these areas of high capital-intensive process industries that need long-term investment plans where risks are rather high due to long return on investments, this strategic agenda-driven public-private partnership offers the political drive and a joint commitment for the European process industry and for dealing with the challenges ahead.

The community of SPIRE stakeholders is spread over more than 8 sectors and is reaching out to all value chains; thus, SPIRE requires a programme empowering a cross-sectorial dialogue. In need for a suitable environment for the development and success of research and innovation activities in process manufacturing, SPIRE seeks to benefit from an objective-driven, efficient and transparent working structure between the public and private sides, allowing a level playing field for all stakeholders; hence this intention to base the partnership and its governance on a contractual Public-Private Partnership (cPPP) framework (based on and further developed from the recovery package PPPs).

Description of the governance model of the Public-Private Partnership

The SPIRE cPPP would be established based on Article 19 of Horizon 2020 regulation, through a contractual arrangement between the European Commission and the A.SPIRE aisbl. The contractual arrangement specifies the objectives of the partnership, respective commitments of the partners, the indicative financial envelope for the EC contribution for the whole of Horizon 2020 (to be formalised via work programmes), a monitoring and review mechanism using key performance indicators, and outputs to be delivered including the identification of research and innovation activities that require support from Horizon 2020. The contractual arrangement would have the legal nature of a Memorandum of Understanding and would not be legally binding. It would outline the governance structure, including the mechanism by which the Commission would seek advice from the private partners during the partnership. Following a Commission Decision and the signing of the contractual arrangement, the SPIRE cPPP would be implemented through competitive calls included in the normal research and innovation work programmes and with the rules for participation of Horizon 2020.

The European Commission and the A.SPIRE aisbl would establish a **Partnership Board as the main mechanism for dialogue** to reach the aims foreseen in the contractual arrangement. The Partnership Board would have the appropriate Terms of Reference dealing with confidentiality and potential conflict of interest. A.SPIRE aisbl would nominate their representatives for the Partnership Board, to be then endorsed by the Commission lead service. The Commission services that provide financial support to the SPIRE cPPP would also have representatives in the Partnership Board. The Parties would also meet regularly at high level to take stock of the progress achieved in the SPIRE cPPP and possibly discuss further ways to enhance mutual collaboration.

The Commission would commit to take into account inputs and advice from A.SPIRE aisbl in order to identify research and innovation activities to be proposed for financial support under Horizon 2020. The Commission would commit to maintain regular dialogue with A.SPIRE during the preparatory phase of the drafting of the Work Programmes foreseen in the Specific Programme.

A.SPIRE aisbl would decide on its own governance structures and implement the appropriate consultation processes, based on openness and transparency, to ensure the adequate involvement of all relevant stakeholders in the preparation of the inputs to the Commission. A.SPIRE aisbl commits to provide inputs and advice to the Commission to achieve the objectives of the public-private partnership, in particular to identify research and innovation activities to be proposed for financial support under Horizon 2020. The Private Side would provide evidence of fulfilling its commitment to the objectives of the partnership, addressing the key performance indicators, and ensure that the specific commitments expressed in terms of investments are respected.

The Parties would conduct at least one review, on the basis of which they may request amendments to the contractual arrangement or decide its termination, in particular if the commitments have not been fulfilled. The Parties would regularly inform and consult each other, as appropriate, in particular in relation to the progress of the PPP towards its objectives and to assess the impact of its activities and the leverage of additional investments.

TERMS OF REFERENCE FOR THE PARTNERSHIP BOARD

The Private Side of the Partnership Board would be composed of representatives of key industries, including SMEs, research centres and universities. A.SPIRE aisbl, acting on behalf of the Private Side in the SPIRE cPPP nominates the Private Side members of the Partnership Board who would be then endorsed by the Commission lead service, ensuring a proper representation of the wider community of stakeholders. These members would commit themselves to provide advice in their relevant fields of expertise to the best of their ability and in the best interest of Community research and innovation. The Partnership Board may operate with a variable composition according to specific needs, but ensuring a degree of continuity and collective memory. All the Commission services which provide financial support to the SPIRE cPPP would be represented in the Partnership Board. The Partnership Board meetings would be co-chaired by an official of the Commission lead service and a co-chairperson from the Private Side.

The Partnership Board members from the Private Side would be responsible for preparing any updates of the Multi-annual Roadmap, in a dialogue with the Commission side, and for giving advice on annual priorities in a timely manner to enable the Commission services to prepare, draft and adopt the periodic Work Programmes. This may include presentations by the co-chairperson of the Partnership Board from the Private Side to the relevant Programme Committees. The inputs and advice to the Commission would be the result of discussions within the Partnership Board and would be expected to represent the views of the wider community of stakeholders. The Commission would make publicly available, including on the Internet, the names of all Partnership Board members from the Private Side, as well as any specific reports that they prepare and are deemed to be of public interest.

The Partnership Board members of the Private Side must not seek or act in a way to take undue advantage of, or exercise undue influence, on the implementation of Horizon 2020. They must not be involved in any way in the Evaluation of proposals for Community funding if they have contributed to the discussions to prepare that call. Should any item on the agenda or any subject discussed in a given meeting be a matter of relevance for projects or proposals under the Horizon 2020 that a member, or the department in the organisation to which he/she directly belongs, has submitted or is intending to submit, the member should inform the Commission and the Partnership Board.

The Partnership Board members would be required not to divulge information given in the context of the work of the Partnership Board when it has been indicated to them that the information is confidential.

The Partnership Board members from the Private Side would not be reimbursed from public funds for attendance and participation at meetings or any work associated with fulfilling their tasks.

A.SPIRE aisbl - modus operandi

The non-profit international association A.SPIRE aisbl⁹⁰ was founded in 2012 by the stakeholders who acknowledged the need, for the process industry, to help the development of enabling technologies and solutions along the value chain in order to improve the resources and energy efficiency in the process industry, key to the European economy. Thus, the consortium of industry and research organizations has agreed on a common goal towards a long-term sustainability for Europe in terms of global competitiveness, ecology and employment. To realize these objectives, A.SPIRE has been preparing for the engagement in a public private partnership with the European Commission and will represent the Private Side in the contractual PPP. A.SPIRE provides support to its members throughout the development and implementation of the above-mentioned contractual agreement and regularly checks progress. Through purposeful cooperation across all sectors involved, A.SPIRE has developed this multi-year, strategic and dynamic roadmap to address research, development and innovation needs as well as policy objectives towards the realization of SPIRE goals and targets.

A.SPIRE members are committed to unyielding integrity and will act in a good faith and transparency to other members and the society throughout their engagement in the SPIRE cPPP. The membership to the Association is open to:

- industrial and commercial companies and trade associations active in the field of process technologies,
- research institutes and universities active in the field of process technologies and process manufacturing in general, as well as
- trade associations, non-governmental organizations and other stakeholders that have an interest in the other areas relevant to SPIRE.

A.SPIRE has put in place a simplified application for membership procedure which consists of signing a Memorandum of Understanding between the joining entity and A.SPIRE, and followed by the Board of Directors' approval.

A.SPIRE is ruled by a General Assembly which is composed of all members of the association. Its competence extends from the approval of the administrative conduct of the association to the approval of the main policy lines to be followed by A.SPIRE.

A.SPIRE is governed by a 19-member elected Board of Directors representing all process industry sectors engaged as well as research and technology organisations. The Board of Directors has full power of management of the association and prepares the consolidated work programme of A.SPIRE. To assist in this latest competence, the Board has established an Industrial Research and Innovation Advisory Group which serves as an advisory body on the research and innovation work programmes and also as a connection to the Topic Groups. This Advisory Group will also represent the Private Side within the SPIRE PPP Partnership Board. The A.SPIRE office, headed by an Executive Director, looks after the daily management of the association and ensures proactive, transparent and open flow of information on the A.SPIRE activities within the association and towards stakeholders.

Six Topic Groups (corresponding to the 6 main elements of the strategic roadmap) have been established by the Board to ensure appropriate and efficient development and implementation of the strategic roadmap throughout a large representation of all A.SPIRE members. These expert topic groups are committed to work in a transparent process towards achieving cross-sectorial participation and successful results.

This work will also be supported and, in turn, disseminated through a series of workshops, events and other communication tools to ensure constructive external input, broad outreach and, ultimately, broad impact and replication of successful outcomes. Information, dissemination of results and IPR, within the association and towards stakeholders, will be handled in compliance with Horizon2020 Rules of Participation.

⁹⁰ <http://www.spire2030.eu/uploads/Modules/Documents/20120907-final-statutes-of-a-spire---en.pdf>



ANNEX I: RESULTS OF THE PUBLIC CONSULTATION

The SPIRE draft roadmap was submitted in July 2012 to a public consultation process (Figure 14) which allowed the opportunity to submit comments, clarifications and/or suggestions not only from the process industry community but from other different bodies and actors across the European Research Area (ERA).

Timing



FIGURE 14: Timing for the SPIRE roadmap public consultation process.

The main actions linked to the planning and execution of the public consultation process can be summarized as:

- Wide dissemination of the SPIRE draft Roadmap among the Process Industry stakeholders community and beyond via dedicated website (www.spire2030.eu) as well as leveraging on the extensive reach of different European Technology Platforms, Sector Organizations, National Platforms etc..
- Elaboration of a tailored questionnaire available online from July 27th to October 1st: <http://www.spire2030.eu/spire2030-ppp-roadmap-public-consultation> to support the gathering of responses and facilitate the easy access by the general public regarding the opportunity to provide feedback. The structure of the questionnaire was divided into questions dedicated to specific scoring of the different roadmap sections as well as questions allowing the submission of explanatory comments.
- Wide awareness campaign of the questionnaire directed at different levels and organizations (i.e. academia, industry and other stakeholders through the large SPIRE network) to ensure a wide and significant number of responses.

More than 450 responses were received via the online questionnaire. Together with responses received outside the questionnaire format, they constituted the basis for analysis and evaluation. The following messages summarize key points coming from this analysis:

- The answers showed a wide coverage along different value chains (upstream industry included) as well as across the SPIRE sectors and other organizations (i.e. SMEs, large Industry, RTOs, Academia, NGOs etc.).
- Scoring questions demonstrated the high levels of acceptance of the SPIRE roadmap among different sectors and communities (Figure 15).

QUESTIONNAIRE	AVERAGE SCORE RECEIVED 1 (lowest)/5 (highest)
How would you rate the overall SPIRE vision to contribute to the challenge listed in the EUROPE 2020 strategy?	4.3
How well does SPIRE address the sustainability R&D&I interests of the process industry?	4.3
Will SPIRE bring added value to sustainable innovation in your sector?	4.0
Are the SPIRE targets both ambitious and realistic	4.0
How would you rate the balance in SPIRE between (Research - Development - Innovation efforts)?	3.9
How would you rate the balance in SPIRE between (Short - Medium - Long impact)?	3.9
How would you rate the balance in SPIRE between the 5 key components (feed, process, applications, waste2resource, horizontal)?	3.9

A more qualitative analysis of the all responses received allowed the extraction of the following key messages:

- **The consultation process showed an overarching positive feedback across many different actors in the European Research Area (ERA).**
- **The level of responses and the spread of those sectors and organizations constituted a fair sounding board that served to incorporate valuable suggestions in the SPIRE roadmap as per this revised version.**
- **The highly positive acceptance level of the contents and structure of the SPIRE roadmap reflected the main challenges and interests of the process industry stakeholders.**
- **The high acceptance levels of the SPIRE roadmap resulting after the public consultation reinforced the plurality and openness already exercised during the initial roadmap development.**

The comments and suggestions have been considered by the experts of the SPIRE working groups and have been included in the current version of the SPIRE roadmap.



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