# European Steel Technology Platform – ESTEP

## Strategic Research Agenda (SRA)

(This is an electronic version of the SRA, last updated on 5th September 2017)

# Foreword

Steel is strategic for key European industries like automotive, construction, energy and engineering as well as for space and defence. Steel is one of three areas, along with space and defence, where the Juncker European Commission proposes specific policy measures. This is timely for a sector facing strong global competition (cf. doubling of the Chinese steel production in the last ten years).

The challenges for European steel, including global overcapacity, were highlighted by President Juncker and vice-President Katainen at the 28 February 2017 - the European Industry Day. As Commissioners Bienkowska and Moedas underlined, we need to shift from a defensive to a pro-active approach, embracing the COP21 and Millennium goals. In addition, we must facilitate the steel industry's successful transition to a low-carbon economy based on technological breakthroughs.

This is why the ESTEP Strategic Research Agenda is highly welcome. It builds on past experience and existing knowledge but it looks ahead with a strong push towards the circular economy and life cycle assessment. Competitiveness and environmental sustainability are two sides of the same coin. Steel is an outstanding material in terms of tensile strength, stiffness, deformation ability and recyclability. Further research and innovation, supported notably through RFCS and Horizon 2020 (SPIRE), will help keeping the technological edge.

The 2030 European targets on CO2 emissions reduction, on energy efficiency improvement and on increasing the share of renewable energy sources are strong pillars of the EU political landscape. The Energy Union and the circular economy are now well-established concepts, as are resource efficiency and recycling behaviour. This is challenging for an energy-intensive sector like steel, but it could be rewarding in the long-term if the industry can transform to fit the sustainability agenda.

I welcome that the Strategic Research Agenda intelligently builds on the conclusions of the 8 March 2017 seminar on the Future of European steel. The focus on energy savings and environmental aspects of the steel production as well as on advanced high strength steel (innovative construction and automotive applications) is paving the way towards a genuine 'European steel' brand.

At global and European levels, developments in artificial intelligence and digitisation are revolutionising manufacturing processes. The Steel factory 4.0 is adapting to this new reality of automation, data sharing and management. This complements the traditional steel industry goals of cost-effectiveness, safety and reliability. Within the new industrial revolution, the European steel should integrate new business models and social innovations, new applications for high-quality steel products and dynamic skills in the sector.

A competitive, innovative and environmentally-friendly steel industry is crucial for the European Union. A major step, well described in the ESTEP Strategic Research Agenda, is the initiative on ultra-low carbon future European steelmaking that can ensure global leadership of the EU steel industry. I strongly support this initiative, which is an excellent contribution to the modernisation and reindustrialisation of our economy.

Peter Dröll, Director for Industrial Technologies, European Commission, DG RTD

# Introduction

As being the second largest steel producer in the world, the European steel industry has a vital role in contributing to the EU's low carbon energy transition, achieving the Energy Union ambitions and meeting the circular economy targets. At the same moment global overcapacity and unfair trade practices are creating additional challenges. Thus, the road ahead for the European steel sector clearly shows the need for a fast introduction of innovative technologies while ensuring the competitiveness of the sector.

In the context of circular economy and a low carbon economy, the EU steel industry is a world leader in $CO_2$ emission reductions and is today very close to the physical limits of conventional steelmaking technologies. Only disruptive innovations may deliver emission reductions in line with the expectations as described in the Paris Agreement. The long term competitiveness of energy-intensive industries depends on their ability to develop breakthrough technologies in areas such as energy efficiency or carbon capture and utilisation. Public and private investments in innovation, research and new technologies will therefore be needed. The EU steel industry is since many years at the forefront of R&D into breakthrough technologies. Furthermore, positive incentives and continued investments in demonstration projects of those technologies are essential to remain a frontrunner.

As highlighted on the European Steel Day 2017, steel will be the solution for climate and societal challenges. Indeed, steel is infinitely recyclable, which means that it will be used even more in the future. The sustainability of steel should not only consider today's emissions but also the long-term possibility that steel can become a fully circular commodity. Moreover, as the world is continuously developing, there will be more materials and more waste products. Recycling of end-of-life waste for new material and displace the use of natural resources will become the "New Normal". This is particularly true for the carbon cycle and the use of energy: steelmakers also need to look for solutions to use (external) renewable power and re-use the waste carbon and hydrogen from the primary steelmaking processes instead of incinerating this waste for power production.

In order to face global competition, EU-wide innovative solutions are required. In this regard, the ESTEP's "Big Scale" innovation initiative on ultra-low carbon European steelmaking is very important. This project aims to develop technological alternatives and tailor-made solutions in order to accelerate the demonstration at industrial scale. This Big Scale initiative fits perfectly into the Strategic Research agenda that sets outs what must be done over the coming decades. It also perfectly illustrates ESTEP's mission statement:

> "to engage in collaborative EU actions (projects) on technology & innovation, which are tackling EU challenges (renewable energy, climate change (low-carbon emission), circular economy) in order to create a sustainable EU steel industry".

Futures aspects of ESTEP will also cover the questions of hydrogen supply use and transport as well as energy storage in general.

The ESTEP working groups are the backbone of the ESTEP activities, as clearly shown in ESTEP's activity report. I am looking forward to the ongoing support of their members to the benefit of the EU steel sector.

Carl de Maré, Chairman of ESTEP, VP - Head of Technology Strategy - ArcelorMittal

# Executive summary

This document is the 2017 updated version of the Strategic Research Agenda of the European Steel Technology Platform (ESTEP), which was officially launched in 2004. It offers a global vision on the innovation and R&D initiatives which will lead to the achievement of the objectives identified in the frame of a sustainable leadership of the EU steel sector in the coming decades.

The ambition of the EU steel industry is to maintain and reinforce a global leadership, which is both sustainable and competitive, given the strong development in other parts of the world, notably Asia.

Seven working groups (WG) involving now around 200 persons have developed several R&D themes and research areas gathered under large and complementary R&D industrial programs with large societal impacts:

- Sustainable steel production
- Safe, cost-effective and lower capital intensive technologies
- Appealing steel solutions for end users, focusing on three main areas (transports, Construction and Energy) and a transversal theme regarding the human resources aspects has been also developed
- Attracting and securing qualified people.
- Enabling the digitisation of the steel sector

Together the working groups aim at playing a major role in boosting competitiveness, economic growth and the related impact on employment in the EU. The corresponding R&D themes and areas that have been identified in these programs bring a strong contribution to the sustainable development.

This updated version was prepared by ESTEP's working groups and it was decided to keep the structure of the document according to the three industrial programs with large societal impacts. Hence, the structure of this new document remains similar to the first version. However the content of each chapter has been thoroughly rewritten, taking into account on one hand what has been done over the past seven years and on the other hand the orientations of Horizon 2020.

This updated version has been endorsed by the Steering Committee in August 2017. In the framework of this Strategic Research Agenda, the transport, construction and energy sectors are regarded as priorities.

Protecting the environment (greenhouse gas emissions and more particularly $CO_2$ emissions) and increasing resource efficiency (including energy) both constitute major transversal issues in the universe of the RTD programs that are proposed. Security and safety represent the third very important objective to be addressed, not only in the relevant industries but also in customers' everyday lives as users of steel solutions (surface transport, buildings, energy production, etc.) by developing new intelligent and safer steel solutions.

A major transversal theme regarding human resources has also been taken into consideration (attracting and securing qualified people to help meet the steel sector's ambition). In this respect, a large European network of universities, involved in education, training, communication and dissemination activities has been identified among the stakeholders of the EU steel technology platform. This network should play a leading role in analysing how the education system could meet the future requirements for qualified people of the European steel industry, and in devising effective approaches to address its anticipated shortcomings.

Industry 4.0 and digitisation are since the 1990s very important for the ESTEP community and the working group Integrated Intelligent Manufacturing (I2M) was finally established. Envisioning smart process factories characterised by vertical, horizontal and transversal integration is the focus of these activities.

ESTEP already integrates the European RTD partnership built in the frame of the previous ECSC Treaty (more than 8,000 researchers) and the Framework Programs. Indeed it constitutes large partnerships involving the whole European steel industry, its suppliers and customers (transport industry, construction sector and the energy sector), SMEs, private and public research, public authorities and representatives of trade unions. The Research Fund for Coal and Steel (RFCS) which has followed successfully the ECSC from 2002. Both within the RFCS and the Framework Program, the collaborative research within the European steel sector was fostered and reinforced over the past 10 years. ESTEP's Mirror Group gathers representatives of 20 Members States among the EU-28.

The implementation of this roadmap should take place from 2018 to 2030 especially supported by instruments of Horizon 2020 (and its successor, FP9) and of RFCS. In particular, on an annual basis, the priorities of the Research Fund for Coal and Steel (RFCS) program should be devoted to foster programs of this SRA, leading to the implementation of sectoral consensus-based R&D activities.

# ESTEP at a glance

Created in 2004, ESTEP is a European Technology Platform (ETP) acknowledged by the European Commission, which serves as a spokesman for the whole steel sector in terms of technological foresight, innovation and R&D and as a privileged interlocutor to the Commission. ESTEP can thus be defined as a think tank, with representatives of the stakeholders of the steel industry (including its value chain and the research and academic institutions that are related to), focusing both on foresight and on actions on the roadmaps that it produces collectively with its members.

ESTEP's **mission** aims to engage in collaborative EU actions and projects on technology, which are tackling EU challenges (notably on renewable energy, climate change (low-carbon emission), circular economy) in order to create a sustainable EU steel industry. This is namely done by disseminating results of projects, by facilitating a supportive environment for collaborative projects, by the Strategic Research Agenda and by the active network of ESTEP's community.

The operation and governance structure of ESTEP is explained as follows: two committees, a Steering Committee and a Support Group, steer the Platform.

**The Steering Committee**. Its missions are to:
1) Define long-term priorities for R&D within the steel sector;
2) Decide strategic R&D actions to support innovation;
3) Approve a Strategic Research Agenda;
4) Monitor and coordinate long-term actions.

In order to create an efficient and flexible body, as recommended both by the European Commission and the decision-makers of the steel industry, this Steering Committee comprises a limited number of high-level personalities (20), appropriately balanced. The Steering Committee has an annual meeting usually hold in March.

**The Support Group.** The size and composition of this body is also defined according to the technical priorities of the Platform. Its mission is to prepare a Strategic Research Agenda, to facilitate its implementation and the relevant follow-up. The Support Group constitutes the management level and the working body of the platform, reviewing the activities developed within the thematic Working Groups. Its participants are representatives of the main stakeholders. The Support Group holds three meetings per year.

In addition, a **Mirror Group** is composed of the Members of the Steering Committee and Member States representatives. The Mirror Group holds a meeting every 18-24 months. It serves to provide information and communication between the Steering Committee and Member States, as regards the implementation of this SRA within the different European funded programmes.

The work is carried out by experts representing its members in the **7 Working Groups**, also called the production unit, which convene to meet about 3 times a year. As being the core of the ETP, these 7 WGs have been dealing with the implementation of the SRA in different domains. Even if each WG has its own scope, today's challenges generate stronger cooperation between them. Indeed, as shown in figure1, even if each WG has its own industrial program, European projects within the EU framework such as Industry 4.0, circular economy, digitalisation, light weight solution and ultra-low carbon steel making project, foster a collaborative approach among the WGs.

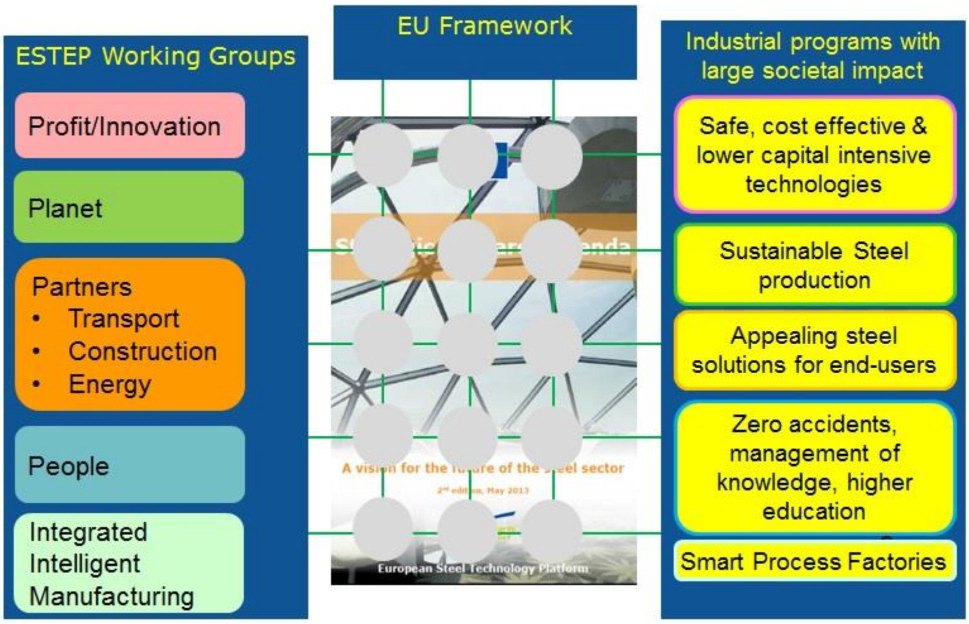




**Figure 1**: Structure of ESTEP's working groups

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# Part 1. Background

The Steel sector has long been essential to the economy and the competitiveness of Europe and it will remain important for a long time in the future. EU-28's steel industry has a total annual production of approximately 190 million tons over the past 10 years and generates more than € 190 bn in annual turnover. It provides direct employment to about 360,000 European Union citizens, and several times this number is employed indirectly in its processing, in the user and in the recycling industries. Steel is a worldwide commodity and world crude steel production is still growing. It exceeded 1 billion tons for the first time in 2004 and was at 1.6 billion tons in 2016 with 621 million tons in EU28. Global steel demand is still expected to increase in the future, owing to the increased growth of emerging countries like China and India. Various scenarios (BAU and others) project a worldwide crude steel production between 2.0 and 2.5 billion tons in 2050.

The steel industry is the source of millions of other jobs, in many industrial activities, as steel is a key material for many of them (road, rail, sea and air transportation, construction, energy, chemical industry, household appliances, etc.). For example, the European steel construction industry and the automotive sector represent more than 2,000,000 jobs (EU-28). It is therefore vital for the future of Europe and of its citizens to maintain an active and competitive steel industry.

## 1.1. Ambition and long-term vision of the steel sector

The ambition of the European steel industry is to maintain and reinforce its global leadership in the world, and thus to remain sustainable and competitive in the face of the strong development of the steel sector elsewhere in the world, notably in Asia.

## 1.2. Main challenges for a sustainable global competitiveness

### 1.2.1. The impact of globalization and unfair trade

The globalization of steel customers has resulted in increased market power, stricter product requirements and standardization.

Collaboration with its traditional customers has been so deeply rooted in its culture that the European steel industry has taken the necessary steps to continue to satisfy their needs in terms of services, quality and economics wherever they are located. Thus, many of the European steel companies have established facilities in other regions of the world or developed strategic alliances overseas.

However, the steel industry remains less concentrated than its major supplier or client industries. Thus, it has been hard pressed to accelerate its concentration and rationalization on a global scale, to boost its ability to serve its customers, worldwide, with the same quality of products and services they already enjoy locally.

Moreover, the trend towards more international steel trade, and thus towards increased international competition, has become more and more obvious. The steel industry, faced with this growing impact of globalization and responding to pressure on its markets, needs that the rules of fair trade be enforced fairly, worldwide. On the European side, the industry is facing fierce dumping and unfair trading practices by third country competitors[1].

### 1.2.2. Matching steel supply and demand

Past experience shows that crises in the steel industry have had their roots in imbalances caused by rapid fluctuations in demand combined with supply structures that are too rigid and with global overcapacity. Fluctuation in demand is related to business cycles but also to deeper structural changes. Economic cycles control steel demand, as steel is used to make both consumer and investment goods. Thus, when the financial crisis hit in 2008, it impacted European Steel with a drop in production from 200 Mt to 135 Mt in 2009 (crude steel). A significant but partial recovery occurred in 2010, 2011 and 2012 with production moving up to 170, 177 and 169 Mt respectively. In the future, the consolidation of demand in Europe will be strongly linked to the recovery of the global steel value chain.

The European Union's vision for 2030/2050 sets strategies and pathways to shift the European economy towards a sustainable and efficient global energy system, the renewal of transport fleets (air, water, land) coupled to the establishment of a smart transport management system, the refurbishment of all buildings and their integration in smart supply grids.

This vision is intensive in materials and thus the availability of advanced materials, like steel, at the proper level of quality, volume and price is a prerequisite to the successful implementation of that vision. In terms of steel quality, the industry is preparing the emergence of new, high added value steel products through research and

[1] EUROFER, Activity report 2017, p. 3

development, which should result in an increased demand in highly developed countries (durable consumer products, capital goods). European steel production and exports ought to focus increasingly on these higher value-added products.

## 1.2.3. Fourth phase of the EU ETS

The most important piece of EU legislation for the EU steel industry is the greenhouse gas Emissions Trading Scheme (ETS), which has been introduced in order to enforce commitments made by EU Member States in the context of the Kyoto Protocol. Across the whole EU economy, the costs for implementing these commitments are considerable. With the fourth phase of the EU ETS (period 2021-2030), the risk that European steel producers will see a further loss of business to non-EU competitors, which are not subjected to any $CO_2$ emissions limitations, is of major importance. Legislative proposal for the revision of the EU ETS was presented by the European Commission in July 2015. Shaping the ETS Innovation Fund mechanism will be an important objective.

### 1.2.4. Other EU environmental regulations

Regarding environmental policy, various instruments are being introduced or under review at EU or national level. Initiatives with a potentially significant impact for the steel industry include:

- Integrated Pollution Prevention And Control (IPPC) permits,
- the Industrial Emissions Directives called (IED), which is the revision of this IPPC directive with the implementation of the BAT conclusions (Best Available Techniques) being the legal reference for permitting of installations,
- the new product and waste legislation (such as the Life Cycle Assessment approach and eco-design as well as PEF, the product environmental footprint),
- thematic strategies on natural resources, waste prevention and recycling,
- the EU legislation on chemicals ('REACH')
- the new Energy Efficiency Directive (EED)
- Circular Economy

In the pipeline are the implementation of the roadmap to a resource efficient Europe and the 7th Environmental Action Program.

## 1.2.5. Infrastructure

With a production of 160 million tons of steel in the EU28, nearly 250 million tons of iron ore, coal, scrap and other raw materials need to be transported to the steel plants, and 160 million tons of steel will be transported to the customers. However, most of the infrastructure in many parts of Europe was erected many decades before and suffers from the usage over all the years.

Not only roads and railways, but lock ship canals show as well wear out, malfunction and lack reliability. For industrialized economies such as the EU 28, the transportation infrastructure is the backbone and basis for the industrial value chain. However, in the years after the financial crisis, most countries have reduced their spending on the infrastructure.

For the upcoming years, the deficiencies of European infrastructure put the functioning of the steel industry as center piece of the European industrial supply chain at risk. Immediate measures to ensure the reliability of the European infrastructure are required in most countries of the EU.

## 1.3. Steel, an outstanding material

Steel is an important material in our societies and is bound to remain an important one in the future. Iron ore is abundant and energy required to produce the metal is relatively small, compared to other metals. Thus, steel has been developed into the most extensive alloy family in the engineering world over historical times, with a very broad range of applications.

Steel is rather inexpensive and offers a broad variety of functions and services, due to a unique combination of properties. First comes its tensile strength. Compared to other common materials like wood, concrete, stones or plastics, it exhibits high resistance under tension. This is the main reason for its huge success during the first industrial revolution. It can also be rather easily shaped using a wide variety of processes. This is the main reason why the ferrous sector, globally speaking, is contributing to several value chains, having thus a very large number of direct and indirect employees. Another interesting property is its high stiffness; this is very important for some applications. Its main drawbacks are its density (compared to lighter metals such as Aluminium, Titanium or Magnesium) and its corrosion resistance in air.

Steel is often pictured as a material of the past. Iron and Steel are indeed enduring materials based on cumulative technologies, invented in the Neolithic period. The metallurgical sophistication of ancient swords made of Damascus steel, in the Middle East or in Japan, is astounding! But steel is also a very modern material and a material of the future, because of its wide range of properties: iron based alloys with some minor addition of other elements still offers many opportunities.

The present research agenda structures future prospects for new steels, according to their final application: transport, construction & buildings, energy production, storage & transport. This is the clearest way to identify what progress is required to reach the targets of our society for the years to come. However, a more transversal and abstract view may be useful as it can provide a guiding light for the analysis. The metallurgy of steel can progress significantly along the following lines:

- increase strength at more or less constant deformation ability,
- or, conversely, improve deformation ability at more or less constant strength.

Figure 2 gives an example of such an approach and of the trade-offs that this entails.

On the vertical axis, elongation is a measurement of the formability of steel. Tensile strength is on the horizontal axis. The range of strength is wide, an order of magnitude between the stronger and the milder steels. Most families of steels are grouped inside the "banana" curve. Labels show specific metallurgical structures. A second generation of steel categories is shown, such as Complex Phase (CP), Dual Phase (DP) and TRansformation Induced Plasticity

(TRIP) steels as well as a new third generation under development, the L-IP, TWIP steels and the new austenitic stainless steels, with large contents in alloying elements such as manganese, and, more classically also, chromium or nickel.

In order to extent the application of steel in particular in the automotive for protection of passengers during crash press-hardened steel were developed with tensile strength of 2000 MPa.

Beyond these new developments in metallurgy, a number of difficult technical questions have to be solved to properly answer market needs.

Beyond the conventional steel grades steel has one of the first smart materials so called electrical steel. Electrical steel is base material for supply chain of energy transformation, energy storage and energy transport. Due to its special and highly optimized electromagnetic properties it essentially contributes to the energy efficiency in electric systems. Furthermore electrical steel has already an important role in the energy turnaround and will be increasingly significant for the electric mobility.

For example, steel needs quite often to be welded and the reliability of the welds under critical conditions has to be demonstrated. In case of carbon steel, it needs to be coated to withstand corrosion: the usual solution is zinc coating, but new steels that contain easily oxidized elements do not as a rule accept galvanizing; beyond zinc, new coating solutions based on other metals are under development. For higher temperature applications, a lot of new solutions are still under development. Last but not least, these new steels and new metallurgies have to be produced in large quantities with a very narrow control of process parameters in order to exhibit a specific range of properties.

Another very important iron-based material is stainless steel due to its application in e.g. household, medicine, food and chemical industry. Cutlery and pots are probably the most popular things in each household. In surgery: tools, implants and covering made out of stainless steel are essential due to hygiene requirements in combination with the need of strength or hardness. The refinement of pre-curser or final products under high pressure in a highly corrosive and hot environment demands the use of stainless steel in chemical reactors or pipe systems.

Steel is an important material for the fabrication of industrial installations, machinery and tools, necessary also in other materials value chain.

Optimal processing of these steel products of the future is a difficult challenge that can be addressed either by improving existing production technologies or by developing new processes or new technologies in combination with the new alloy design.

Based on its deep knowledge of the potential of its material, the European steel sector has been constantly addressing the challenge of meeting the demands of its customers to deliver a broad variety of ever more versatile high-performance materials. To achieve these goals, direct partnerships between steel producers and their direct customers are a necessary approach. This constitutes the core of the development and promotion of new products by the steel industry.

Beyond these developments in fairly classical directions, longer term efforts are addressing more challenging issues than the strength or formability of steels.

On the one hand, the density of steel is one area of development, as the present density of 7.8 is not a barrier and there are ways to reduce it by 10 to 15%, thanks to the addition of specific alloying elements, such as aluminium. This is a promising approach to reduce the

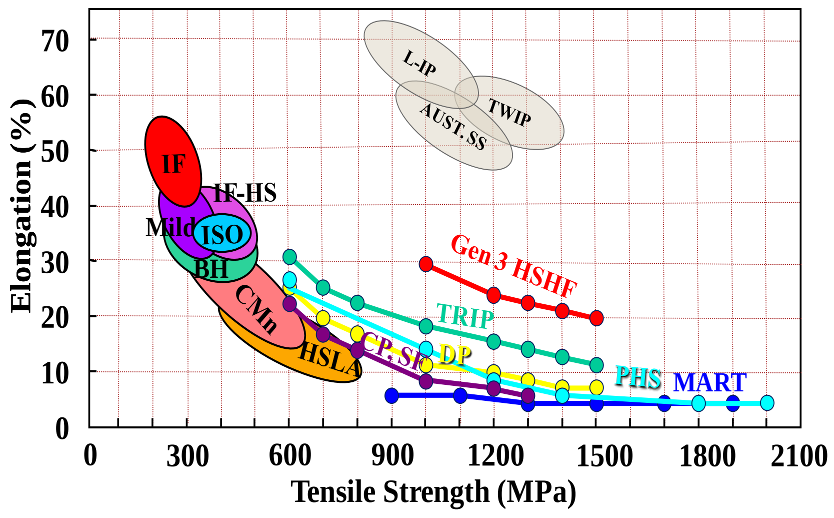




**Figure 2:** Range of mechanical properties of various steel grades

weight of steel objects beyond the increase in strength (AHSS), which was presented previously.

Similarly, Young's modulus is not upward bound by the classical value of 210 GPa. Various paths are being explored, among which the design of a new steel grade that would be a metal matrix composite with ceramic compounds, such as $TiB_2$ precipitates. This would also help reduce weight, without being limited by the value of Young's modulus, when thickness becomes small.

Multilayer steels are also at the core of new development efforts: the point is to associate steel qualities with very different properties (strengths) by joining them into layers (5-7), a kind of revival of Damascus steel, beefed up by the concepts of modern metallurgy. Defining the process used to create this lamination is at the core of the investigation: co-rolling, co-casting, etc.

Finally, one might stress the point that nanostructures have been present in steels, since long before the name of nanomaterials was coined - perlite and precipitates like NbC have nanometric dimensions - and that further efforts are devoted to developing the concept (Nanosteel, USA).

The SRA is engaging or planning to engage stakeholders in the automotive, construction and energy sectors, as a priority.

## 1.4. Strategic objectives

The strategic objectives are developed around concepts based on the four pillars of sustainable growth: Planet, Profit, Partners and People, the 4P's.

- **Planet**: propose innovative technologies, including breakthroughs, to meet environmental requirements, promote sustainable steel production and develop Life Cycle Thinking, Life Cycle Assessment and especially Circular Economy.

- **Profit**: ensure profit-making through innovation and new technologies within the production processes:
  - innovate with new production technologies
  - reduce time to market and implementing the supply chain concept

- **Partners**: respond to society's needs by working with partners of the steel sector for proposing innovative steel products and steel solutions in :
  - the transport sector
  - the construction & infrastructure sectors
  - the energy sector

- **People**: attract and secure human resources and skills
  - Become a worldwide reference for health and safety at work
  - Attract and secure human resources skills in a dynamic way
  - Optimize the deployment of human resources as a key to the successful implementation of steel industry's competitive strategies
  - Accommodate concerns of external stakeholders (clever and safer steel products)

- The importance of ICT is followed by the Working Group Integrated Intelligent Manufacturing (I2M).

## 1.5. R&D&I approach: three industrial programs with large societal impacts

To face such important challenges and to meet the objectives of the European Steel Technology Platform, it was decided in 2017 by the ESTEP Steering Committee to launch resolute and structured long term R&D actions. Seven working groups corresponding to the 4 pillars of sustainable development of the Platform as well as Integrated Intelligent Manufacturing are working on 3 industrial programs with large societal impacts each of them encompassing several R&D themes and research areas. These themes and areas are continued of the last SRA. In March 2016, it was decided to update this SRA with this present third edition in electronic format before the next booklet that will be printed in 2018. The structure of the industrial programs remains the same, but the research areas have been totally reviewed and completed by the Working Groups. The present ESTEP organization is shown in figure 3. The approach and the structure of R&D themes and areas are shown in the figures 4 and 5.

The 3 industrial programs with large societal impacts are the following:

- Sustainable steel production
- safe, cost-effective and lower capital intensive technologies
- appealing steel solutions for end users

to which two transversal objectives regarding human resources and ICT have been added:

- attracting and securing qualified people to help meet the steel sector's ambition
- integrated intelligent manufacturing

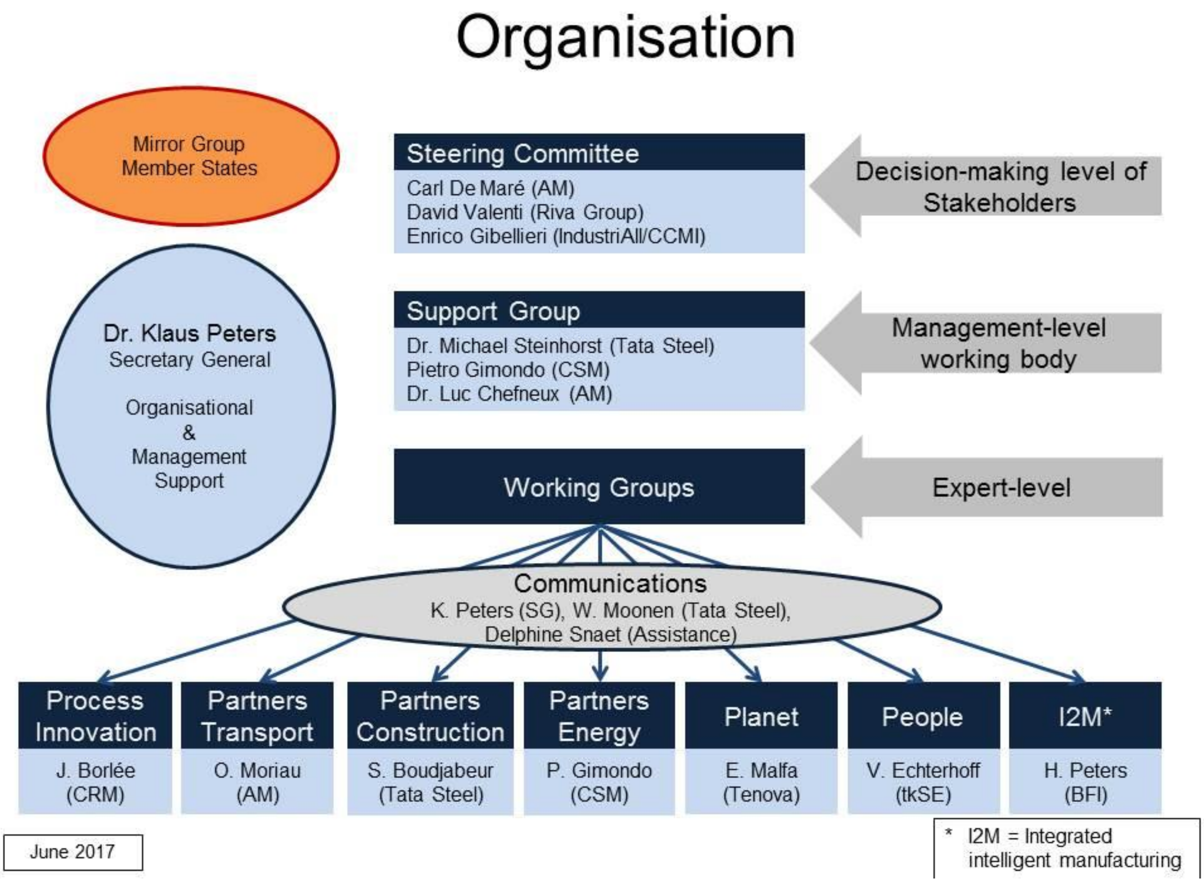


**Figure 3**: Organisational chart of the Steel Technology Platform

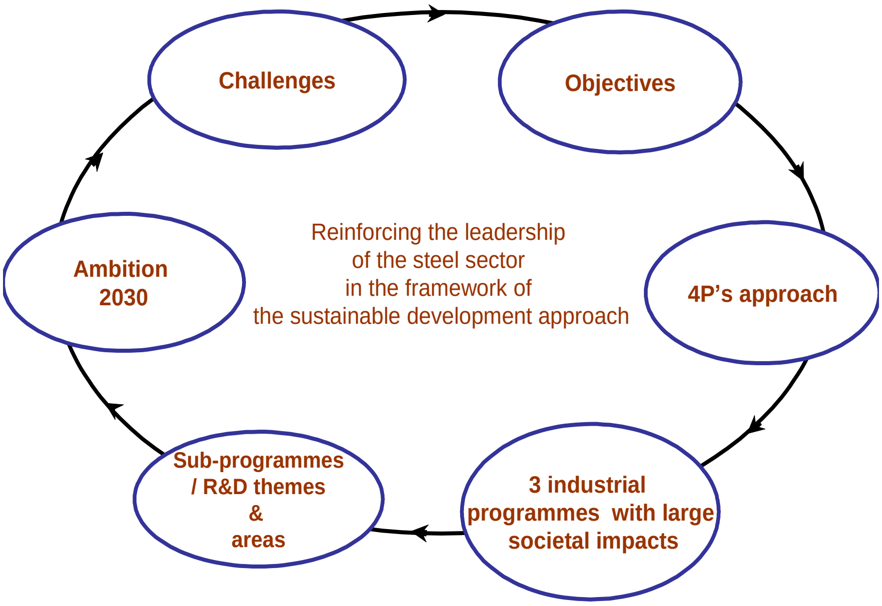


**Figure 4**: How to achieve ESTEP's long term ambition through innovation and R&D&I

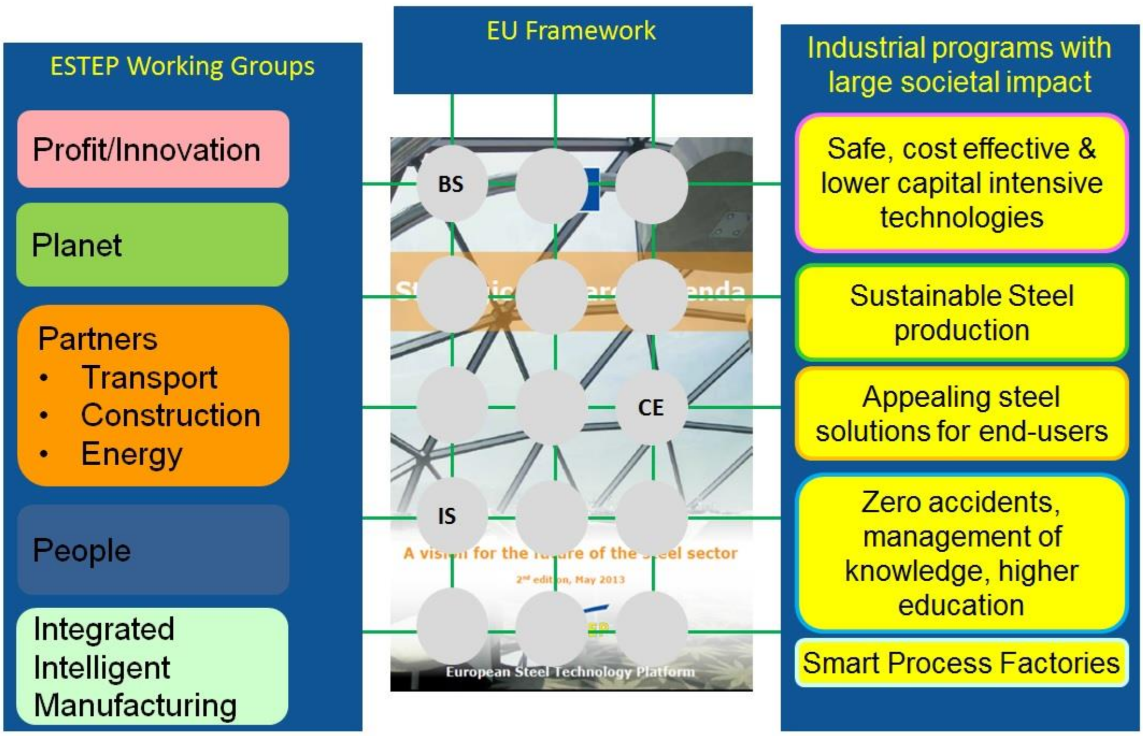


**Figure 5**: Structure of ESTEP's working groups dealing key issues (for e.g. CE = Circular Economy, IS = Industrial symbiosis, BS = Big Scale low-carbon innovation initiative)

# Part 2. Research & Innovation approach

This chapter presents the Research and Innovation areas that ought to be developed within the next 10 years. The 3 industrial programs presented in the previous chapter and the transversal activities regarding human resources have been fleshed out by the 7 ESTEP working groups. The respective R&D&I themes and areas of the working groups are presented from chapter 2.1. to chapter 2.7.

## 2.1. Sustainable steel production (Planet)

### 2.1.1. Introduction: context, ambition & foresight

Steel is 100% recyclable and for endless times and **by-products** from steelmaking process has to be considered as a real alternative to traditional raw materials that can be valorised either within the steelmaking process or in other industrial sectors avoiding the depletion/ consumption of natural resources. Therefore steel and steel by-products are essential materials for the circular economy.

At the same time more holistic, prospective and longer term issues must be tackled to meet both economic and environmental regulation targets synergistically in the day to day business of the steel industry. In this contest, in which a strong synergy between ESTEP WGs is required, Planet covers the following area:

- Life cycle assessment (LCA) and life cycle thinking (LCT)
- Digital technologies for environmental impact assessment (see also WG I²M)
- Circular economy:
    - Resource issues due to energy and raw materials supply
    - Scrap vs. steel quality
    - Energy recovery and upgrading (see WG Profit)
    - Carbon-lean steelmaking (see WG Profit)
    - Transform by-products to new feedstock or (secondary) raw materials for Internal recycling or other industries
    - Re-use of residues and by-products of other industries in the steel plant
- Ecodesign of processes and steel solutions as a method to integrate the above concepts and methodologies and turn them into operational tools
- Work synergistically with nature (biomass, biomimetics, etc.) and integrate steel's activity with ecosystem services (how to deal with biodiversity in the steel's business model)
- Other emerging global issues (acid rain and dust are becoming global issues) and future rules for setting long term targets for the environment, as well as toxicity and ecotoxicity issues

### 2.1.2. Exploring solutions: the R&D&I approach

#### *a) Low-carbon steelmaking*

In order to contribute to the Paris agreement, and thus to reduce GHG emissions, the steel industry's players are redoubling their efforts to accelerate the transformation of the European industry towards carbon limitation and neutrality. The **Big Scale initiative**, which is the large scale ultra-low carbon future steelmaking project, is heading towards this achievement.

The company-driven initiatives of the Big Scale are dealing towards the smart, low-carbon industry of the future based on two main pathways:

- Carbon direct avoidance (CDA), which substitutes carbon as the reducing element with hydrogen or via the use of electricity
- Low carbon without $CO_2$ emissions (LCWCE), which further optimises carbon-based metallurgy and applies carbon capture and utilisation or storage methods to mitigate greenhouse gas emissions.

The Big Scale is further explained in chapter 2.2. Process (section 2.2.2 e)).

#### *b) Life Cycle Assessment (LCA) and Life Cycle Thinking (LCT)*

LCA is nowadays a consolidated and widely exploited technique to assess environmental impacts associated with all the stages of the life of a product from cradle to grave. The most commonly used approach describes the world as it is today, so called attributional LCA. More forward looking methodologies are being developed, such as foresight LCA, dynamic LCA, social LCA, Life Cycle Costing (LCC)[2]. Furthermore, questions of ecotoxicity are to be

[2] Birat, J.-P. "Life-cycle assessment, resource efficiency and recycling" Metallurgical Research and Technology, vol. 112(2), 2015.

addressed further in the methodology, but also the request for sustainability assessment (Figure 6)[3].

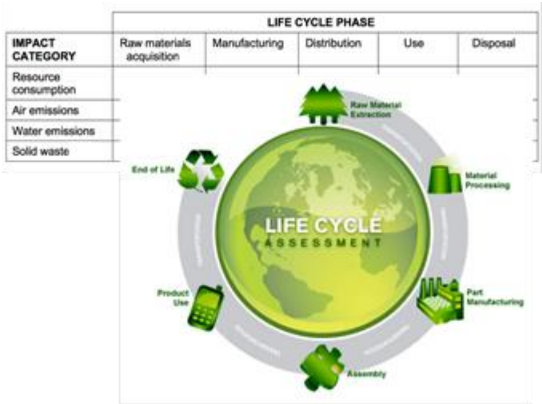


Figure 6: Full Life Cycle Assessment

This required introducing the Life Cycle Thinking (LCT), which is a recognized worldview as beneficial to society and European Steel wishes to promote it. However, the present methodology is still not perfect and other methodologies are needed to complement it. To move away from the micro-economic description of the economy related to choosing the functional unit as the central concept of LCA, one should open the scope to macro-economic thinking with Material Flow Analysis (MFA) or Energy & Exergy Flow Analysis, which lies at the core of the analysis of recycling, a major issue for steel and metals in general and many other materials (Figure 7).

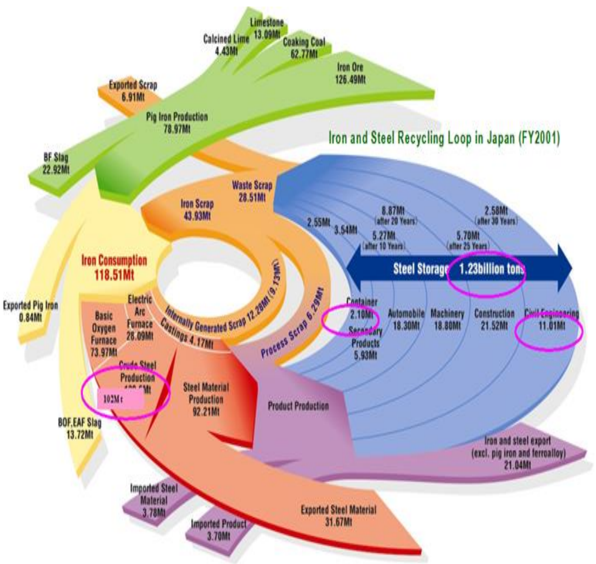


Figure 7: Material Flow Analysis (MFA) and Energy Flow Analysis

This might be insufficient to deal with the main open issues and challenges: thus, more ambitious methodologies, going beyond LCA and MFA have to be developed, or, rather, their development has to be further encouraged. In the steel and structural material sectors, this corresponds to the SOVAMAT initiative, which puts forward the concept of "social value", which is close to a more holistic definition of sustainability. The steel sector needs to be at the forefront of methodological innovation in this area, in order to create a dynamics that would open up to interdisciplinary cooperation, from sociology, socio-economics to scientific ecology by encompassing the various communities of LCA, MFA, economic global modellers, etc.. Steel industry launched several projects in the frame of Research Found for Coal and Steel – RFCS and are partners of European Research Framework Program Horizon 2020 - H2020 projects (STYLE, SAMT and MEASURE) dealing with sustainability toolkit and cross-sectorial sustainability assessment by thus accomplishing part of the actions planned in the ESTEP's SRA (http://www.spire2030.eu/projects).

### c) *Digital technologies for environmental impact assessment*

Cyber-Physical Systems, Internet of Things (IoT) and Big-Data Technologies are nowadays pervasive and will be intensively applied to improve process flexibility and reliability as well as total product quality control. However, such techniques can be successfully applied:

- To continuously monitor and assess the environmental impact of the production processes (e.g. through a network of sensors and tools for easy interpretation of the collected data);
- To improve control of both production and auxiliary processes (e.g. water and off-gases treatment plants) which have an impact on the environmental performance of the steel production.
- To provide key performance indicators for sustainable resource efficiency

Such tools will be coupled with advanced modelling and simulation tools supporting both control tasks and scenario analyses aimed at evaluating the actual environmental benefits and the technical and economic feasibility of major process modifications and new operating practice.

This kind of technologies can greatly support also the task of energy efficiency, through the development of intelligent systems for flexible energy management and smart interaction with energy grids.

### d) *Circular economy*

The Circular Economy is a contemporary and popular concept based on waste prevention and re-use, repair and recycling of products and superior products design for long life. It implies that resources are brought back into the supply chain after the end life of the product. In a circular economy:

- the products and materials are used for as long as possible;

[3] US Environmental Protection Agency, *Defining Life Cycle Assessment (LCA)*, 17 October 2010.

- waste and resource use are minimised;
- and resources are kept within the cycle when a product has reached the end of its life, to be used over and over again.

The European Commission adopted an ambitious Circular Economy Package that establishes a concrete and ambitious programme of action, with measures covering the whole cycle: from production and consumption to waste management and the market for new (secondary) raw materials.

In terms of primary raw materials for the iron and steel industry such as iron ore, coal and natural gas, the access is not a short term issues but may create large price fluctuations and force players in the field to adjust their strategy to accommodate this kind of business risk. A slightly different scenario should arise regarding alloying elements, where tension on prices may reflect some short term scarcity. On the other hand, new (secondary) raw materials constitute a growing proportion of raw material feedstock, where quality is an important question for recycling.

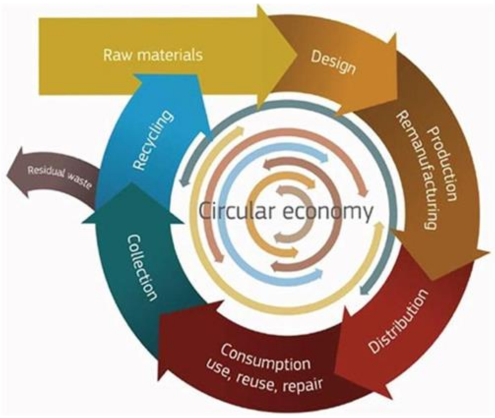


**Figure 8**: EU view on Circular Economy

The most important (secondary) raw material is ferrous scrap. Continued recycling is essential to keeping scrap in a constant loop. In such a way, steel can be classified as a Permanent Material that once produced can be recycled or reused without the loss of quality, regardless of how often the material is recycled. However, in "the current situation" of insufficient supply of scrap, a circular system cannot be realised yet, while in "the future perspective" at some point in time a balance can be created (Figure 9)[4].

Steelmaking also results in useful by-products, such as process gases and ferrous slag, which substitute natural resources in other sectors and contribute to resource efficiency. Process gases are used for electricity generation for industrial and domestic applications, replacing fossil fuels and natural gases. Ferrous slag is used in a range of applications (e.g. civil engineering like road construction, fertilizer and cement production etc.), saving millions of tons of natural resources annually.

[4] Steel and Circular Economy, EUROFER

Therefore, the steel production has been working on circularity since its existence as yield improvement and energy savings: cascading use of resources, waste recycling, internal residues recovery and recycle are only some of the circular actions put into practice during the daily steel production. Steel sector is committed to progress further and to develop solutions for turning into an even leaner sector also, through innovation, reuse has and can be increased.

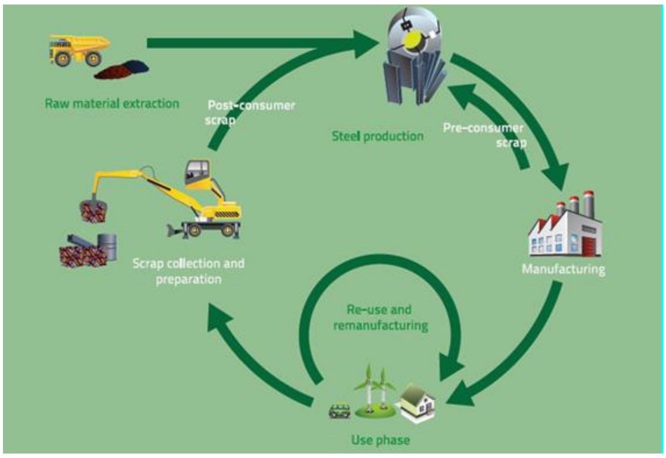


**Figure 9**: The recovery and steel recycling cycle

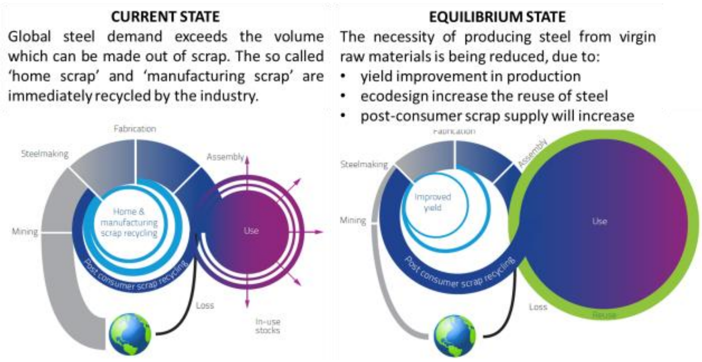


**Figure 10**: Scrap in the circular economy

Circular Economy contains of several circles, each of them, with its own life cycle frequency but also many circles of different sectors are intertwined (industrial symbiosis). Circular Economy is more than Waste Management and Materials loops: it is an «economic plan» based on the sustainability framework and following an «integrated approach» that includes the target for materials industry to by-product as feedstock and reduces primary raw materials to produce "virgin" material. Re-use and remanufacturing of products are seen as integral part of a circular economy. Steel products and parts can be part of this, which has implications on steel production and possibly business models.

This requires addressing different aspects:

- Resource issues due to energy and raw materials supply
- Scrap vs. steel quality
- Energy recovery and upgrading (see WG Profit)

- Carbon-lean steelmaking (see WG Profit)
- Use by-product for Internal recycling or other industries
- Re-use of residues and by-products of other industries in the steel plant
- Development of value of technologies, value-chains and business models for re-manufacturing and re-use

## *Resources issues due to energy and raw materials supply*

Europe has become attuned to the issues of resource scarcity in relation to rare earth and the international trade tensions that they have raised. This is an interesting revival of a concept which was somewhat discredited after the first report of the Club of Rome, but which now stresses that resources come from a finite earth, both fossil resources and renewable ones, which are also bound by competition for land.

A more balanced view is thus being framed, acknowledging that many resources will remain abundant but that the growth of demand related to population growth and urbanization may have a faster dynamic than what the supply side of the economy can provide, thus creating a tension and a volatility on prices. The ideas of a lean economy and of resource preservation by increasing energy and material efficiency are thus getting stronger,. This includes recycling of steel in particular and recycling and use of the all the large volume of industrial residues – waste and by-products - generated by the sector.

The steel sector has to imagine incremental solutions to a leaner steel sector, which is again part of the task of the working group on process innovation (Process), but ought to maintain a global picture to prioritize the more ambitious parts of the potential technological agenda for dealing with these matters. Transversal, through-process issues are key, as well as the quick integration of new technologies developed outside of the sector and cooperation with other economic actors (see further).

## *Scrap vs. steel quality*[5]

A major part of long products can be manufactured from large portions of obsolete scrap without a significant alteration of their processing parameters and of their final properties. The same accounts for many hot rolled commercial strip grades, although the level of tramp elements needs to be carefully controlled. One of the issues with increasing amount of scrap is how to produce high-quality products from scrap: tramp elements can influence the quality of low and ultra-low carbon steels, low nitrogen steel grades are difficult to produce via an electric steelmaking route.

Although specific studies and investigations have been done several issues have also to address:

- Industrial and economic feasible solutions for refining steel melts to remove non-volatile tramp elements like copper and tin;
- Scrap (pre-)processing for improving scrap quality:
  - removal of metallic coatings of tin zinc (limited economic viability solutions based on hydrometallurgy or thermal treatment are currently available)
  - separation of scrap into low and high residual fractions is partially feasible through the application of advanced physical separation techniques (sorting, shredding, size and density classification, …).
  - improvements on the whole value chain, which even might imply changes in the design of products to allow for easier separation of unwanted compounds in steel scrap
- Better tracing of critical alloys elements along the recycling value chain

## *Use by-products for internal recycling or other industries*

On average, the production of one tonne of steel results in 200 kg (in electric arc furnace steelmaking) to 400 kg (in blast furnace steelmaking) of residues. These include slags, dusts, sludges and other materials. All these residues – be they waste or by-products - contain a relevant fraction of iron and metal oxides (Figure 11)[6].

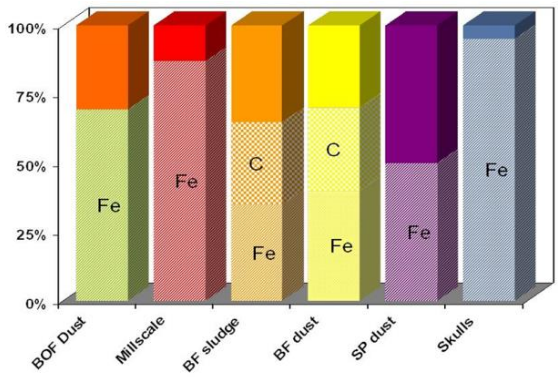


**Figure 11**: Iron & steelmaking residue

Therefore, iron & steelmaking residues must be revalorized either within the steelmaking process or as industrial by-product as raw materials source via industrial symbiosis or internal cascading use, for several reasons:

- The tightening environmental legislation makes the landfill disposal of wastes more expensive;
- The high content of iron and metal oxides makes residue valuable raw material for BOF and EAF charge.

[5]Marique C.(coordinator), "Recycling of scrap for high quality products" (ECSC Steel RTD programme -7210-CB/205…1994-1997)
Marique C., Steel recycling: A key element of the circular economy- ESTEP-EUROFER Circular Economy Workshop – October 19, 2016

[6] Malfa E. , *Environmental Impact and Climate Change*, EUROSTEELMASTER 2015, Terni, Italy, 13th May 2015.

- The chemical and physical properties allow re-use of residues and by-products of steel plant in other industries or contexts.

New solutions require often technical development as well as new business models that reflect the needs of the business partners and allow for more circularity.

### *Slags*

Concerning the slag generated in the liquid processing phase of iron and steelmaking has been already classified at REACH[7].

| Family no. | Common name | | EINECS name | EINECS No. CAS No. |
|---|---|---|---|---|
| 1 | Granulated Blast furnace Slag | GBS | **Slag, ferrous metal, blast furnace** (granulated) | 266-002-0<br>65996-69-2 |
| | Air-cooled Blast furnace Slag | ABS | **Slag, ferrous metal, blast furnace** (air-cooled) | 266-002-0<br>65996-69-2 |
| 2 | Basic Oxygen furnace Slag (converter slag) | BOS | **Slag, steelmaking, converter** | 294-409-3<br>91722-09-7 |
| 3a | Electric Arc Furnace slag (from Carbon steel production) | EAF C | **Slag, steelmaking, elec. furnace** (carbon steel production) | 932-275-6<br>294-410-9[a]<br>91722-10-0[a] |
| 3b | Electric Arc Furnace slag (from Stainless/ high alloy steel production) | EAF S | **Slag, steelmaking, elec. furnace** (stainless/high alloy steel production) | 932-476-9<br>294-410-9[a]<br>91722-10-0[a] |
| 4 | Steelmaking slag | SMS | **Slag, steelmaking** | 266-004-1<br>65996-71-6 |

Table 1: Slag families and corresponding CAS- and EINECS-numbers; [a] = "old" EINECS or CAS numbers

**Figure 12**: Slags families and corresponding CAS & EINECS No.

Examples of use of the GGBS (vitrified, with hydraulic properties) as cement or concrete addition according to EN 197-1 and EN 15167-1, respectively, of the ABS, BOS and EAFs C as aggregates for concretes, asphalts, ceramics and road bases are available in some countries. Less demanding applications include fillings, ballast and soil conditioning. SMS has a high expansion potential and its use is mainly oriented to re-injection in EAF, soil stabilization, fertilizer. Additional research is necessary to evaluate its combination with other slags and its use in special concretes (SCC) as well as EAFs S need further research and long term analysis to assess durability and environmental/health risk (Figure 13[8]).

The main driver is the economic viability: a new trend is to valorise, when possible, the recycled material in the local economy, to limit transport and logistics costs and to effectively create economic value in the Region. However inhomogeneous legislative frame in EU and future threats for by-products and wastes are the stronger constrain to develop common approaches.

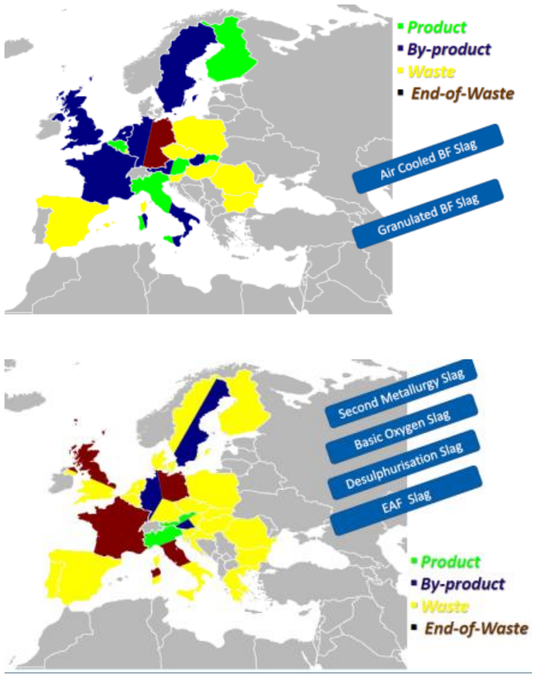


**Figure 13**: (Simplified) Legal situation of Slags

### *Dusts and sludge*

Dusts and sludge are mostly coming from the pollution abatement equipment that clean the gases and wastewater discharges from the various iron and steelmaking processes. In the past years, significant improvement has been realised reducing the level of materials sent to landfills. These residues are increasingly being reprocessed internally, at least at the integrated steelmaking route. The recycling of converter dusts via briquetting and returning to the BOF is well established technique. Recycling of BF dust has been developed and implemented[9]. Technologies were investigated to manufacture self-reducing briquettes out of iron oxides residue and to recycle them in EAF without influence on the performance and on the environment.

Another point to note is that whilst slag tends to be used 'internally' or 'externally' to site, dust and sludge utilisation is on the whole recovered using 'internal' processes but still there is material sent to landfill or to external site for further treatments. This different approach to the two residues streams suggests that slag is viewed more as a

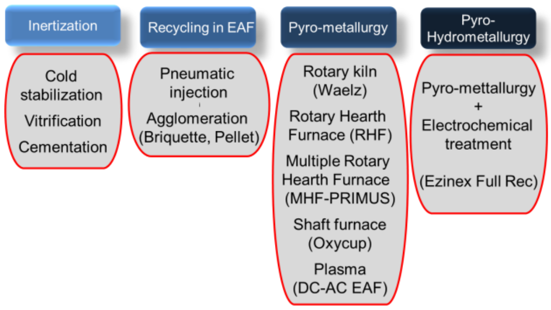


**Figure 14**: Dust treatment process

[7] European Union, Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC, Official Journal of the European Union, 30.12.2006, L 396/1.

[8] A. Braconi,Legislative constraints and future threats for by-products and waste, Circular Economy WorkshopBrussels, 10 November, 2016

[9] RFCS project Flexinject, RFSR-CT-2008-00001, EUR 25909, 2013

material which can and should be marketed and managed accordingly – i.e. it is a by-product –, whereas for dusts and sludges, legislative and sustainability drivers lead more towards technical and innovative solutions.

The most widely used pyro-metallurgical processes process is the Waelz Kiln already dating from 1910. The process retrieves only 60% of the zinc in the form of oxides while 40% remains in the slag that cannot be used anymore and has to be landfilled. Several new processes have been developed over the past years with the aim specifically to increase the recovery of zinc up to 94%.

*Re-use of residues and by-products of other industries in the steel plant*

Steel industry is also looking at residues from other industrial sectors as alternative carbon materials (ACM).

Examples are plastic residues as chemical feedstock for Coke oven where the coke quality allows the addition of 1-2% of plastics in the coal blend. Plastic residues are also injected in the BF: in Japan this technology is used since the mid-90s, in Europe Voestalpine Stahl GmbH has been using plastics as a reducing agent on its Linz BF A since 2006. Heavy fuel oil and coke have been replaced by up to 100.000 tons of outdated synthetic materials annually.

Rubber from tires, plastics, ASR and biomass residue have some application as slag foaming agent in the EAF. The RFCS projects RIMFOAM and GREENEAF involving a variety of steelmakers with different EAF sizes and types (AC/DC) will allow producing general guidelines for European Electric Steelmakers.

A factor restricting the utilization of residue from other industries is the cost of their collection and treatment. A reliable supply of consistent quantity and quality and at a suitable cost is required. For example, certain plastic qualities, used also in packaging and as containers, contain chlorine (from PVC waste) which is of great concern due to its corrosive effects. Consequently the chlorine needs to be removed from the plastic residue. A step in the right direction has been the recent UNI 10667-17 that regulate the blends of heterogeneous plastic from industrial residue and/or from postconsumer materials to be used from reducing process in iron and tell industry.

*Energy efficiency and new energy frontiers*

Even when it becomes leaner and moves towards circular economy, the steel sector can "green" its energy sources. Factory roofs can be covered by solar panels or wind turbines can be erected on the extended piece of lands on which steel mills are installed. However, steel mills based on renewable energy alone will probably never makes senses, because of the large energy needs of making steel, due to basic thermodynamically needs. However, if renewables are inter-mediated by an energy vector, electricity today and maybe hydrogen tomorrow, then the transition can be as high as the renewable content of the grid. Some of these topics are more extensively detailed in the Process section (Chapter 2.2.)

It should also be stressed the present energy system is built around steel. This has been true in the last century, it is true today and it will remain true in the future. The energy generation technologies based on renewables, due to the smaller scale with respect to traditional power plants, are several times more material intensive, including the steel among the required materials.

Hence, ESTEP supports the creation of the Industry Driven Initiative (IDI) of Energy Materials Industry Research Initiative (EMIRI) (www.emiri.eu).

As pointed out in the Energy section (Chapter 2.6.) , steel is also the almost exclusive material for the extensive grids of pipe, which will transport natural gas, fracking gas, shale oil, hydrogen and $CO_2$ from fields to urban-industrial consumption areas or to geostorage sites.

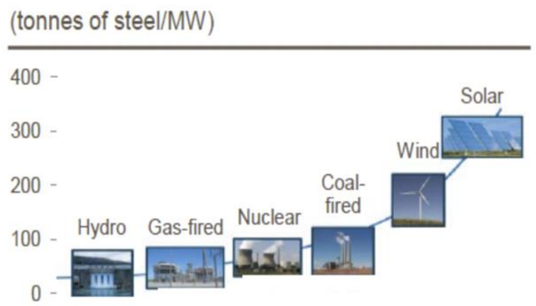


**Figure 15**: Renewables in steelmaking

## e) *Ecodesign of steel solutions, steel grades and steel processes*

The EU legislation on Eco-design and energy labelling is considered as an effective tool for improving the energy efficiency of products.

- The Eco-design Directive[10] sets minimum standards of performance for products, which results in poorly performing products being removed from the market whilst also driving innovation in the design and manufacture of new products to improve their performance.
- The Eco-labelling Directive[11] provides consumers with clear information on product performance to inform their buying decisions.

[10] Official Journal of the European Union, Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009, Framework for the setting of ecodesign requirements for energy-related products 31.10.2009, L 285/10-35.

[11] Official Journal of the European Union, Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010, The indication by labelling and standard product information of the consumption of energy and other resources by energy-related product, 18.6.2010, L 153/1-12.

In circular economy terms, the longer the first life use of a product is the better as there is a lesser need for new products. In principle this is the best approach to closing resource loops since any form of refurbishment, remanufacture, reprocessing or recycling necessarily requires an injection of additional resources and potentially a degrading of the product functionality or material value.

However, there are many factors that need to be considered such as before the benefits of extended product durability can be fully assessed, including:

- Practical limits on lifetimes from current manufacturing methods;
- Cost implications of changes to product materials, components and manufacturing to extend lifetime;
- Innovation rates that could make extended lifetime products obsolete and inefficient;
- Consumer buying habits and expectations of product performance for different types of product;
- Possible impacts of more durable products on their second life potential – e.g. any risk of reduced refurbishment potential;
- Availability and acceptance of appropriate standards, testing and compliance methods for enhanced durability.

These factors mean that there is more than just looking at the materials and environmental side of products: tools and processes for doing ecodesign need to be developed further, success stories have to be told and the deployment of that methodology organized, first at the interface between steel production and steel market and within the steel sector as well.

## *f) Steel and its synergies with nature*

The term "Biodiversity" derives from a contraction of "biological diversity" and commonly refers to a measure of the variety of organisms, which are present in different ecosystems. In particular, it can refer to genetic variation, ecosystem variation, or species variation within an area, biome, or planet. As the preservation biosphere integrity is currently recognized as a core objective for a sustainable development of the society, the meaning of the word "biodiversity" is no more exclusively associated to the preservation of endangered species, but mostly on the management of natural resources from a system's perspective. The system is the biosphere, assumed as an open system (ecosystem) with a special property called resilience, which is the skill to perpetrate itself under greatly changing conditions.

Within this context, the steel sector can contribute to the protection of, or increase in biodiversity, in order to secure available ecosystem services, such as water for example, and contribute to the stability/resilience of the system in which it operates[12]. On the other hand, biodiversity can represent for the steel industry not only a heritage to preserve, but also an opportunity.

In fact, some steel companies have already collaborated with local communities in order to achieve a sustainable use of forests as a source of livelihood, or they have been committed to programs aiming the conversion of mines and quarries into habitats for local wildlife: relevant examples of such cooperation can be found in Liberia, Canada, Brazil and Sweden[13] [14].

The importance of steel as a valuable and fundamental material in order to develop measures and systems for protection of biodiversity can be enhanced and promoted. Steel can be an ideal structural material to build boundaries between the biosphere and the anthroposphere or to build infrastructures for maintaining or restoring biodiversity, such as biodiversity corridors, which allow animal species to safely move through different geographic areas.

On the other hand, biodiversity offers an ecosystem´s perspective to industrial companies. The Millennium Ecosystem assessment[15] provided a methodological and compelling analysis of the Earth's ecosystems providing the humankind with essential and specific *Ecosystem services*. In the same document, in order to assess the natural capital represented by ecosystem services, an approach was proposed to monetize ecosystem services, i.e. to attribute a financial value to the benefits provided to people by the ecosystem services. In this light biodiversity can be considered an integral part of businesses, as it represents one of the boundary conditions within which the industry can operate. The connection to the economic sphere is realized through the exploitation of ecosystem services to integrate biodiversity issues into business practices and management.

An exemplar but not exhaustive list of topics, applications of methods within steel operations that affect biodiversity can be as follows:

- **Management of land surrounding the plant and landfills**: use of functional (agro) biodiversity in and around sites and landfills to the aim of performing phytoremediation[16], production of food and goods and overall biodiversity conservation. A positive impact is foreseen for such kind of actions also for the local community and the workers, as such

[12] Hanson C., Ranganathan J., Iceland C., and Finisdore J., The Corporate Ecosystem Services Review: version, 2012, 2, 1-48.

[13] Rio Tinto, URL: www. riotinto. com/documents/ReportsPublications/RTBidoversitystrategyfinal. pdf, 2008.

[14] Berg A., *Empowering the Steel Industry as a Stakeholder: Environmental Management and Communication through a Social-Ecological System Approach*, PhD thesis, 2013.

[15] Reid W.V., Mooney H., Cropper A., Capistrano D., Carpenter S., Chopra K., Dasgupta P., Dietz T., Duraiappah A., & Hassan R., *Millennium ecosystem assessment: ecosystems and human well-being: synthesis*, 2005.

[16] Batty L.C. & Dolan C., *Critical reviews in environmental science and technology*, 2013, 43(3), 217-259.

measures positively affect air, soil and water quality as well as the aesthetic of the plant.

- **Benefits of by-products for functional biodiversity**: increased use of by-products coming from iron and steelmaking processes to replace natural raw materials in order not only to increase their recycling but also to reduce the environmental impact and loss of biodiversity in the exploited areas (e.g. ferrous slags replacing natural aggregates, P-rich fractions of steelmaking slag used as fertilizing or liming agent in agriculture, steel slag used as effective adsorbent for the heavy metals in filters, BF dusts exploited for heavy metals ions removal from aqueous solutions).
- **Improvement of water effluents from plant through biodiversity management**: application of botanical bioremediation[17] to decontaminate soils, water and air, as a cost effective and safe technology. Investigation should also cover the viability of plant combustion to obtain energy[18] and recovery of metal from the ashes[19] [20], while in the case of forest species, the wood could be industrialized.
- **Aesthetics impact of the plant**: adoption of measures such as green roofs and walls, special night lights to the aim of improving sound insulation, reducing energy costs, extending the life of the roof, create, recreational spaces where workers can get in touch with nature, improve the industrial landscape color, attracting animals in the areas surrounding the plant.
- **Management of old mining sites**: application of phytoremediation but also recreation of agricultural land or natural habitats that can be colonized by species that have lost habitats elsewhere
- **Climate change adaptation and preservation of biodiversity**: exemplar application are re-composition of fragmented environments, that can give the possibility to animals and vegetables to migrate in response to climate changes and to the ecosystem to restore own structures and functions or $CO_2$ capture through reconstitution of forests, humid areas and other ecosystems that work as sink of carbon absorption.
- **Ecological remediation of industrial sites**: transformation of old industrial sites into different types of green areas with varying degrees of bio-diversity and for different purposes. This transformation always results in an increase in biodiversity and can furthermore contribute to solve common environmental problems such as attenuation of noise levels, decreased effects of dust emissions, by also providing a valuable recreation site for the personnel of the company, improving work environment and decreasing levels of stress.

The participatory approach is important for the research in this field, in order to include also evaluation of social impact and economic effects, by also improving their level of social acceptability. Therefore, the involvement of internal and external stakeholders, such as local administrative and municipal authorities and local communities, should be encouraged.

### *g) Global threats and future environmental demands*

In the past (roughly until the end of the nineties), the research was focused mostly on mitigation of the environmental risk at the specific site level and the environment has long been perceived as an externality in the economy. Current short term research activities are addressed toward the reduction of the environmental impact of the production cycle in both the surrounding areas and in general at a wider level. Global environmental issues are gaining strength, as they are becoming threats and grand challenges.


**Figure 16**: Foreseen dimension and time evolution of the SRA activities in the frame of sustainability

The ozone layer and climate change were the major global threats perceived until recently, but more issues are becoming global, like acidification, eutrophication of fresh and ocean waters and biodiversity (BES) issues. Projections of demands for the middle of the century show that the environment in general will be posting limits on various emissions, which will be as demanding as the ones for CO2 today (figure 17).

| Substances | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| GHG | 0% | 10% | 20% | 30% | 40% | 50% |
| VOC | 0% | 24% | 49% | 60% | 70% | 81% |
| $SO_x$ | 0% | 20% | 75% | 77% | 80% | 82% |
| $NH_3$ | 0% | 0% | 27% | 44% | 62% | 79% |
| PM | 0% | 0% | 50% | 50% | 50% | 50% |
| $NO_x$ | 0% | 26% | 53% | 64% | 74% | 85% |
| others | 0% | 10% | 20% | 30% | 40% | 50% |

**Figure 17**: Targets for major environmental emissions from 2000 to 2050

[17] Chaney R.L.,, Malik M., Li Y. M., Brown S. L., Brewer E. P., Angle J. S., and Baker A. J., Current opinion in Biotechnology, 1997, 8(3), 279-284.

[18] Dimitriou I. and Aronsson P., *UNASYLVA-FAO-*, 2005, **56**(2), 47.

[19] Pilon-Smits E., *Annu. Rev. Plant Biol.*, 2005, **56**, 15-39

[20] Yang X., Ye H., Long X., He B., He Z., Stoffella P., & Calvert D., *Journal of plant nutrition*, 2004

From a practical standpoint, this will also mean for steel demands on dust emissions, $NO_x$ and $SO_x$ for example, which are way beyond what is achieved or even achievable today. Therefore, this calls on deep research and development work to arrive in time at technological solutions, which are not simply waiting on the shelf today.

By 2050, according to the *OECD*[21], global water demand is projected to increase by some 55%, due to growing demand from manufacturing (+400%), thermal electricity generation (+140%) and domestic use (+130%). The growth population, the uneven water distribution around the world and the droughts put in evidence the importance of a rational water usage that goes from the optimization of the current water systems, following to recycle and reuse strategies and to find alternative water resources.

Further research efforts need to be devoted toward both technologies and novel practices supporting the improvement of the quality of water effluents, by limiting or even eliminating the consumptions of freshwater while improving internal recycling as well as recovery of energy and valuable raw materials from industrial wastewater. Being this issues common to many industrial sectors, especially those belonging to the category of Energy Intensive Industries, a synergic approach with other sectors will be of utmost importance and will allow a real progress toward sustainability of production processes. This is especially valid for the regions characterised by water scarcity as well as for densely populated areas, where large urban settlements and a number of economic activities jointly exploit land and water resources.

Water is essential for producing steel and consequently it could be considered as another raw material. Average water consumption and discharge per tonne of steel are close to each other, 28,4 and 25,4 m3/tonne respectively[22] In the steel industry, 75% of water is for cooling or heat transfer (Johnson, 2003). There are different water cooling strategies that may lead to water savings. For example, the extensive recirculation cooling systems reduces the total water intake to 2.4% of the requirement of the once-through systems (Initiatives U. F. (2002).

Finding and implementing cost-effective technologies that meet legislative discharge requirements and/or allow the reuse of effluents is a technical challenge faced by the steel industry.

### 2.1.3. Partners, disciplines, level of the innovation step, bottlenecks and risks

Sustainability needs to address the environmental dimension but it is also needs to consider the wider social and economic impacts in a global context. In addition, the circular economy calls for new business models in the light of increased (when reasonable) prolonged life-time, re-use and re-manufacturing.

Having this in mind this industrial program (WG Planet) calls on industries of the steel value chain, but also of the end-of-life and recycling community and of other industries and urban communities with which waste energy and residues can be traded and exchanged.

This means make include in the design cycle of the steel process disciplines like LCA and MFA, but also new methodologies like SAT and those being worked out in the SOVAMAT initiative, which are essential for future research and development areas assisting in the transition of the steel industry towards a complete circular economy:

- Material Input
  - High use of secondary materials
  - Retain functionality of alloying metals in ferrous scrap.
  - Investigate possibilities for alternatives to CRM as alloying components.
  - Investigate the use of residue of other industries for industrial symbiosis
- Eco-design
  - Assist/work with customer to make products having a longer life (such as steel property improvement/adaptation, improvement of corrosion protection/resistance) and/or are designed for disassembly, reuse and remanufacture (such as new designed steel products facilitating this requirement).
- Production
  - Development of alternative steel products to current ones with environmentally hazardous substances in production (chromium-6, cobalt, lead).
  - Development of new business strategies with customers including circular concepts such as products/materials ownership, remanufacture and service-based offers.
  - Increase of yield of steel production (e.g. lower need for internal recycling) in the steel industry.
- Consumption
  - Development of advanced steel grades to ensure (extended) long life in products.
  - High rate of reuse of water within the steel plant and zero waste release
  - Develop with customers tools and build databases as basis for LCAs and EPDs
- Waste recycling
  - Improve processes to avoid waste generation such as maintaining process liquids or water streams
  - Transform residue to new feedstock or (secondary) raw materials for other industries.

The main bottlenecks can be identified in the legal burden and complexes permitting that if not clear and uniform between all the European countries can be a strong

[21] OECD, *Environmental Outlook to 2050: The Consequences of Inaction*, 2012

[22] Worldsteel Association, Water Management in the Steel Industry, 2011

obstacle to economic viability of horizontal and vertical symbiosis in and between different industrial sectors and more in general to the circular economy development.

Moreover, the death rate (failure to secure capital investment) was enormous due to low return on investment and/or high operating costs of "environmental investment, thus:

- a system of subsidies would have had to be implemented, like it is done for renewable energy and many other examples;
- the transversal, through-process approach pursued as well as the quick integration of new technologies developed outside of the sector and cooperation with other economic players such as illustrated in Figure 18.


**Figure 18**: Cross-sectorial approach to foster by-products reuse

### 2.1.4. Stakeholders

- Steel industry
- Steel research centres
- Suppliers of iron ores and coals
- Equipment suppliers
- World Steel Association
- Other energy intensive industries (cement, pulp & paper, glass, chemicals, etc.)
- Non-ferrous metals producers
- Electricity producers
- Public authorities
- Recycling industry
- Universities
- Modelling laboratories for eco-design and LCA studies

## 2.2. Profit through innovation in production processes (Process)

### 2.2.1. Introduction

In a global world economy evolving continuously towards fiercer competition, the European Steel sector must continue to meet essential challenges: safe conditions at the working place, high standards of quality, steady renewal of the offer while applying highly productive, safe, clean, sustainable and cost-effective processes.

More specifically, attention is paid to promote key-enabling technologies and to develop new approaches with low capital expenditure and higher resource and energy efficiency along the value chain and the life cycle.

After the significant progress achieved by the European steel industry over the past 45 years with a decrease in energy consumption of more than 50%, more reduction is targeted, particularly in fossil energy intensity, by combining further process integration, introducing novel energy-saving processing routes, using alternative and renewable energy sources and implementing intelligent automation solutions.

Another major objective is the reduction in the consumption of high quality virgin or primary raw materials (including alloying elements) by improving global process yield and using more variable or diversified raw material including secondary (recycled) raw materials, by-products or land-filled waste.

Much investment has already been engaged in recent years by the steel industry to meet the objectives of the industrial program of this section. To go further, new R&D&I effort and technological development are needed.

### 2.2.2. Exploring solutions: the R&D&I approach

#### *a) Safety at the workplace: improvement through automation and robotics*

The first priority of steel producers is the objective of "zero accident". It is tackled by promoting the use of safer practices on the plant floor. The related managerial and organizational aspects are developed in the section People (chapter 2.7). Process improvements regarding safety concentrate on withdrawing human beings from dangerous zones (liquid metal and slag, toxic or asphyxiant gases, flames, hot slabs, fast moving steel strips, etc). Three main directions have to be further explored:

- promoting new, intelligent and remote analysis and on-line contact-free measurement systems with no manual intervention
- using of long-range wireless systems allowing the control cabinets and the data harvesting equipment to be located far from dangerous zones and with no need to maintain the transmission hardware placed in harsh environments
- customizing industrial robots (hardware and software) for use in steel mills

The scope of these applications can be very wide, covering all processing steps on continuous or discontinuous lines.

## b) New steel products: grades, coatings and manufacturing processes

Continuous developments in this area are required to keep European steel products in the forefront as performing, affordable, robust and attractive responses to end-user needs.

### *New alloys and steel grades*

New alloys and steel grades have to be developed to obtain extended life in products and/or improved properties in use. Among high performance materials, high strength steel grades (AHSS, UHSS) for transport and construction applications, high temperature carbon steels for supercritical boilers and demanding engine applications, or new alloys for energy-related applications in harsh environments (high/low temperatures, highly corrosive media) are examples of grades for which further advances are required by end-users. The concept of "smart steels" which integrate various functions in new steel grades to support new applications is also gaining interest, especially when considering internal properties such as magnetic, piezoelectric or conductivity properties. For light-weight applications (especially transport), the development of alloyed steel grades with lower density than carbon steels is also regarded as a complementary approach to the use of high strength grades. Beyond metallurgical research, work in the area of new steel grades should certainly include the development and demonstration of the associated technologies for large-scale production, from steelmaking to shaping, coating and joining with dissimilar materials

### *New coating formulations and new surface treatments*

New coating formulations and new surface treatments are required to obtain improved resistance or new functional properties of steel products, or to achieve significant reductions in cost or environmental impact. Developing alternative steel coatings to avoid environmentally hazardous substances as per the REACH directive, such as chromium-6, cobalt, lead or BPA (Bisphenol-A), is an on-going effort of the steel industry which has to be pushed further. Modified or innovative coating processes and technologies also have to be developed for advanced high strength steel grades, which exhibit reduced coatability. Beyond that, new tailored surface treatments also have to be developed to improve specific functional properties of steel products such as wear resistance, IR reflectivity, cleanability or self-healing properties. One of the paths to do so is through the industrialisation of advanced vapour deposition processes which have been successfully developed on small scale. These processes would allow significant steps forward in surface treatments in terms of coating thinness and cost or development of new coating strategies. Another concept of interest is the development of "smart coatings" which can integrate additional functions such as marking, information, identification or traceability along all the product life cycle.

### *New manufacturing processes*

New manufacturing processes can allow creating new steel structures with specific properties. The development of hybrid materials such as steel/refractory matrix or multi-laminar structures is one of the alternative ways to generate added value to steel. Developments in powder metallurgy are also of notable interest to create gradient or layered structures that can accommodate the harsh operating conditions of some niche applications or to obtain complex near-net shaped parts such as aeronautical components which currently would still involve a long process chain. Additive manufacturing is one of the most promising technologies that could spark these metal powder developments.

## c) Continued improvement of existing production routes

There are two main routes to produce steel: the Blast Furnace and Basic Oxygen Furnace (BF-BOF) route and the Electric Arc Furnace (EAF) route. They differ by the type of raw materials they use, mainly iron ore for the former and mainly recycled steel (scrap) for the latter. Installed plant capacity in the EAF route is significantly lower and the product mix does not usually include high quality flat carbon steel grades. In both routes, **knowledge sharing of best practices and dissemination of Best Available Techniques** (BATs) first have to be pursued to ensure continuous improvements regarding quality, costs, energy consumption and environmental impact. Process routes also have to be kept **flexible and multifunctional** regarding raw materials, production schedule and products.

Among the R&D&I topics that then have to be developed in both routes, the **recovery of waste heat** is certainly of first importance. For the BF-BOF route, the main stakes lay in the development of advanced, cost-effective, heat recovery processes for high temperature intermediate products: hot coke, sinter, slags, slabs and coils. In the EAF route, energy is mainly lost through cooling water and off-gas, which altogether contain about 40% of the total energy input to the EAF and 5-10% of the energy required by the complete production route.

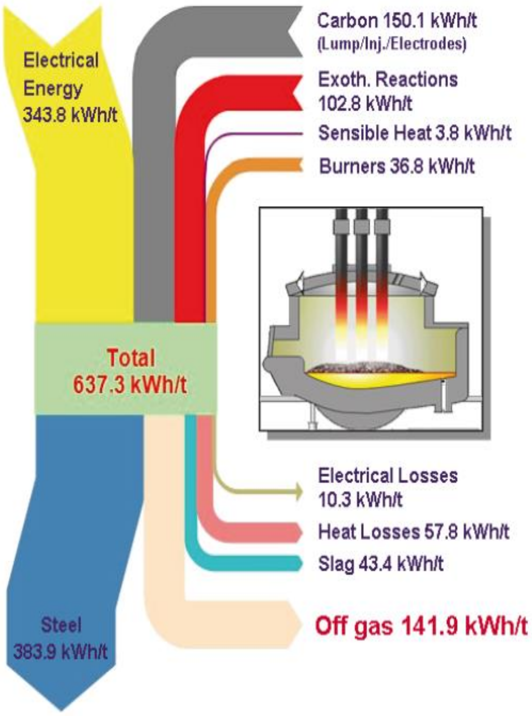


**Figure 19:** EAF Sankey diagram [A-P Hollands et al., METEC, Düsseldorf, 27 June – 1 July 2011]

For reducing cooling water losses, specific technological developments are required on shell and roof panels or to increase the tightness of furnace openings. For recovering the off-gas losses, developments have to include either new heat exchangers that can operate at high temperature, high dust concentration and in corrosive environment or fully satisfying scrap pre-heaters, i.e. which are efficient, can be used with many scrap grades and avoid dioxin formation due to de novo synthesis. In all cases, innovative technologies have to be adapted for heat valorisation at high, medium and low temperature, including ORC (Organic Rankin Cycles), low- and high-temperature heat pumps, temporary energy storage, etc.

Another common R&D&I topic for both production routes is the **optimization of operation using control models and expert or guiding systems** that help plant operators, with a focus on integrating successive production steps. This topic is detailed in the integrated intelligent manufacturing (I²M) section (chapter 2.7.). **Plant-wide Energy Management Systems** (EMS) also have to be developed for both routes to allow advanced energetic optimization, involving models of energy and exergy balance, standardized holistic approaches, etc. When appropriate, steel plants could also be included in an Industrial symbiosis approach, which can optimize energy flows of an entire industrial park where different industries share the same location.

Some specific improvement paths can additionally be mentioned. In the **BF-BOF route**, a specific goal is to improve the recovery of energetic plant gases, through the reduction or even the suppression of flares. When it comes to **casting, rolling and thermo-mechanical production steps**, in both routes, specific targets are to increase the hot charging of slabs in reheating furnaces and to extend near-net-shape casting technologies to a larger range of applications and to additional or new materials and alloys.

## d) Leaner use of raw materials

The leaner use of raw materials is another topic of common and significant importance for both production routes. Some of the following topics are more extensively detailed in the Planet section (chapter 2.1.).

Firstly, the **use of secondary iron** (scrap) has to be maximised. This requires scrap quality improvements through the development of new standards, collection and sorting practices (including more stringent quality monitoring systems), plus innovations in scrap pre-treatment processes to separately recover the metals contained in coatings and in hybrid materials (sandwich panels, etc). In the BF-BOF route, using more scrap would directly provide significant energy and GHG emission reductions. In the EAF route, using cleaner/better sorted scrap would allow the move to higher quality products. This move can also be achieved by using alternative iron sources such as Direct Reduced Iron (DRI) but DRI is largely imported in the EU from gas-rich countries, so full recycling of the available scrap must be achieved in the first place.

Secondly, process modifications allowing the **use of raw materials of lower quality** (especially regarding the ore and coal for the BF-BOF route) would increase flexibility and reduce production costs.

Thirdly, **yield improvements** are also mandatory in all steel production steps. Innovative technologies for efficiently recycling internal by-products and residues with a significant content in iron and carbon thus have to be pushed further. An additional contribution of the EU steel industry towards the leaner use of energetic raw materials that has to be emphasised and maximised is the **recycling of societal residues** such as plastics, used tyres, car fluff, etc., to partly substitute coal in EAF or even in the BF. Barriers to the adoptions of these materials are due to contamination or low quality, so cost-effective techniques are needed to improve their recyclability.

An additional topic has to be carefully investigated: the development of alloying strategies to **limit the use of critical raw materials** currently used for several steel grades, e.g. Niobium.

## e) Carbon-lean steelmaking and GHG emissions of the BF-BOF route

The steel industry is willing to actively contribute to the greenhouse gas emission reductions needed for keeping the global temperature rise this century well below 2 degrees Celsius as agreed at the COP21 in Paris.

To significantly reduce the GHG emissions of the BF-BOF route in the EU **in the medium and long term**, the more radical option is the progressive switch from carbon to alternative reducing agents such as green $H_2$ or electricity, provided that these energy vectors can be made available on sufficient scale and at competitive price, or the development of breakthrough technologies on the usage of $CO_2$ for the supply of chemical products. The development of respective solutions, their integration in a green power/hydrogen-based economy and their scale-up to the huge size of current steel plants has to be sparked and supported by public authorities.

**In the short and medium terms**, however, the blast furnace is a highly efficient reactor and carbon has to remain the main reducing agent for the production of virgin iron in Europe, in order to retain economically important energy-intensive industries and the associated employment. Many leverages of action can be used in that time frame, though, to make significant steps regarding $CO_2$ emissions reductions:

- The level of steel recycling, i.e. the use of scrap in integrated plants, has to be increased. As already mentioned, this can be achieved through better scrap sorting/preparation steps and by using modified steelmaking practices, but also by processing additional scrap in dedicated melting units.
- The use of pre-reduced material (with CH4) from the direct reduction process is also a tool to reduce Carbon demand in the BF process resulting in lower $CO_2$ emissions.
- The carbon load from the fraction of coal which is used for its heat content in ironmaking has to be reduced, either through further energy savings, or by partly switching to leaner carbon sources. One promising example of such switch is to replace part of the coal charged in coking ovens or injected in the blast furnace with torrefied or carbonised biomass. It must be mentioned that this option is also valid for the coal injected in the EAF production route.
- Steel producers have to make a better internal use of their energy-containing by-products (e.g. heat recovery from slags), notably steel plant gases which are for a large part combusted externally, not using the full potential of the gases. The internal recycling of these gases could be pushed further to reduce the consumption of fossil fuels. The calorific potential of these gases could first be exploited to replace the natural gas purchased for several furnace heating applications. Even their reducing potential (CO and $H_2$ contents) could be internally valorised e.g. by injection in the blast furnace to partly replace coke and/or coal. These applications, however, require some preparation steps of the gases (cleaning, compression, pre-heating and/or reforming) which have to be carefully optimised.
- The produced $CO_2$ has to be captured and trapped instead of liberated to the atmosphere. Today, the cost of the existing capture technologies and the lack of operating storage network make the CCS option unrealistic. The effective integration in steel plants of new and specific $CO_2$ separation techniques would contribute to reduce capture costs. Several options have already been proposed such as the recycling of fumes in BF hot stoves or some new, in-process, capture techniques, which are of first interest when the $CO_2$ stream can be of limited purity. The captured $CO_2$ can then be valorised in the chemical industry or for making building materials through mineralisation. Additional opportunities which combine better use of steel plant gases and $CO_2$ valorisation are also considered as very promising: the CO, $H_2$, $CO_2$ and even $N_2$ content of these gases can be turned directly in new products such as chemicals, fertilizers or fuels for the transport sector through either catalytic or biological processes, e.g. using algae or micro-bacteria (gas-to-power applications). Such developments are significantly widening through broad-based, cross-industrial cooperation.
- The integration in steel plants of dedicated $H_2$ production technologies, e.g. making use of some high-temperature waste heat streams, can also be of interest. This kind of low-cost $H_2$ can then be used in the steel plant, either for its calorific or reducing potential, or in many $CO_2$ valorisation processes.

For more than 15 years, the steel industry has demonstrated with the ULCOS programme its commitment to tackle climate change. The 4 ULCOS breakthrough routes (ULCOS-BF, HISARNA, ULCORED and ULCOWIN/ULCOLYSIS) are combining many of the mitigation paths mentioned above and are designed to reach very high $CO_2$ mitigation results (50 to 90%, the latter if CCS is available). The development and scale-up of these routes to the huge size of current steel plants has to be pursued.

It is in this regard that the large scale ultra-low carbon future steelmaking project, called **Big Scale** innovation initiative, is on track. In order to find a common way into low-carbon steelmaking, the EU steel producers are working on a proposal for a R&D framework to foster the resources for developing innovation for the reduction of CO2 emission during steel production. Further joint research & development activities to enhance new low-carbon steelmaking technologies within the EU is necessary to enable time- and cost -efficiency by means of complimentary share of technical knowhow with experts from different companies because a single company is not able to pursue the R&D activities on behalf of the EU steel industry alone by using only its own technical and financial resources. Moreover, the European Commission welcomes this initiative, which is contributing to drastically mitigate $CO_2$.

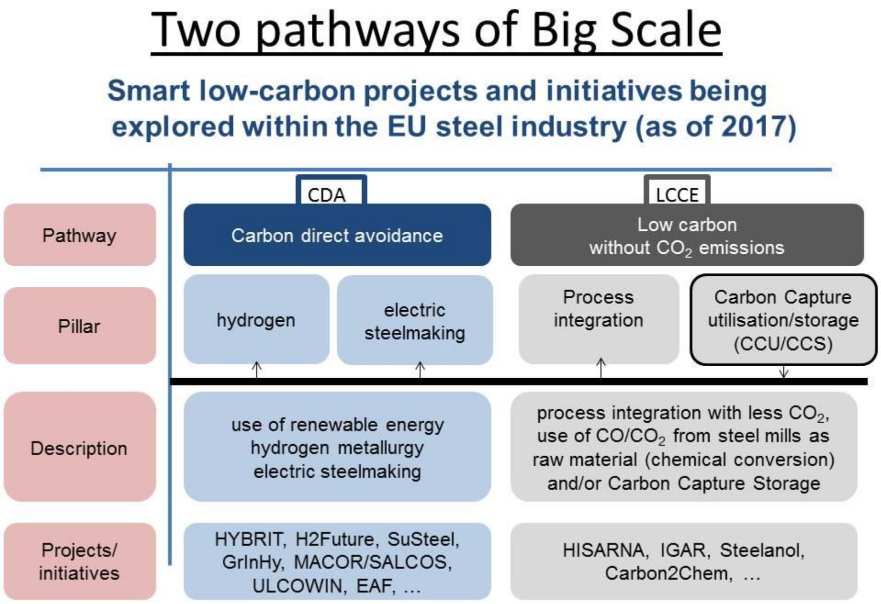


**Figure 20:** Two pathways in low-carbon projects (Big Scale)

As shown on figure 20, the steel companies driven solution can be clustered among two pathways, namely carbon direct avoidance (CDA) and smart clean carbon without $CO_2$ emissions. CDA is focussing on using hydrogen instead of carbon and (clean) electric energy to produce steel. In the second pathway, carbon based metallurgy is applied in a smart way without greenhouse gas (GHG) emissions. In case of process integration (PI), less carbon is necessary. GHG are avoided by carbon capture and storage (CCS) or by carbon capture and utilisation (CCU), process integration (PI), and carbon capture and utilisation (CCU). While the EU steel industry is creating own know-how on CCU, it relies on other partners in case of CCS. This Big Scale EU steel innovation initiative is coherent with the ETS innovation funds as well as the SET plan action 6 and action 9. The company activities contribute to all three activities. Transforming the steel sector to an ultra-low carbon industry is very challenging as the necessary financial means are not covered by growing markets, new products nor new customers. In order to implement the steel projects, reasonable preconditions have to be met like guarantees for clean energy supply at affordable cost, compliant way of cooperation between steel producers, and appropriate. EUROFER and ESTEP are working on a EU steel masterplan, which aligns all activities and preconditions on a timeline.

# 2.3. Integrated intelligent manufacturing (*Industry 4.0*)

## 2.3.1. Introduction

The road from the current status of industrial production in general and steel production in special to the vision of a Smart Factory passes the steps of vertical, horizontal and transversal integration. These integration concepts will work on a set of key enabling technologies (KET) which are mainly driven by new developments in the field of Information and Communication Techniques (ICT). All together this describes the integrated intelligent manufacturing (I²M) concept, which is explained in this chapter of the SRA.

In ESTEP, the term "integrated intelligent manufacturing" was created long before in Germany *Industrie 4.0* was launched. There is a very wide consistency between I²M and *Industrie 4.0*.

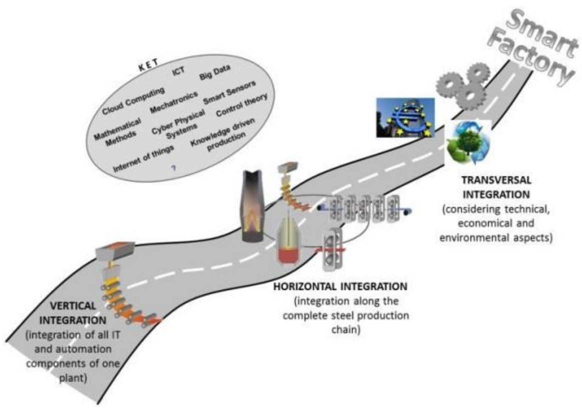


**Figure 21**: Roadmap integrated intelligent manufacturing

## 2.3.2. Needs and challenges

In order to maintain the leading role for Europe in the field of steel production, it must be both competitive and sustainable, forming an integral part of the green economy, today and in the long run. Customer and society oriented policies are part of the same global challenge to achieve profitable and sustainable business. In connection with these challenges, five top level needs will drive the future evolution of steel production: sustainability, quality, lead time, profitability and health & safety.

The I²M concepts are unifying in an interdependent manner three key concepts: vertical, horizontal and transversal Integration. This evolution is enabled by the rise of disruptive information and communication technologies (ICT) such as Big Data, Internet of Things, Cloud Technologies and Cyber Physical Systems (CPS). Vertical integration is the integration of all IT and automation components of a single plant or installation. Horizontal integration is integration along the complete steel product chain and lastly. Transversal integration addresses simultaneous optimization of technical, economic and environmental issues.

These concepts, steered by key enabling technologies, drive us towards the realization of the final goal of implementing the **Smart Steel Factory** which represents the *intelligent*, *flexible* and *dynamic* steel production of the future. Significant efforts are needed to exploit the aforementioned techniques and technologies by extensive connection and networking between the factories, companies and the society.

### 2.3.3. Themes and R&D requirements

Technological themes for development can be specified in relationship with the mentioned Top Level Needs that serve to settle specific R&D requirements to realize the smart steel factory. A matrix view among top level needs, themes and R&D requirements is presented. This matrix contains the following main components:

- **Customer Orientation:** Proactive connection between steel manufacturing and customer demand, in particular with premium customers, enables customer pull on orders, whilst managing stocks, etc., and delivers flexibility in planning and tailoring of products according to the customer processing capabilities and quality requirements.
- **Manufacturing supply chain:** The integration of the supply chain from steel processing up to end user applications requires transparent connection and dynamic product flow management through all the manufacturing stages, including yard control. Sharing of production plans in the supply chain enables autonomous Planning and Scheduling integrated with material and product logistics. Enhanced multi-physics and multi-scale simulation tools, based on fast computing networks, and rapid prototyping technologies for in-field testing and end user applications will shorten the time-to-market of new steel grades with superior surface and bulk characteristics strengthening the steel competitiveness.
- **Manufacturing Technology:** Cyber Physical Systems with adaptive, self-learning capabilities will enable through-process collaborative control for optimal quality with minimum resources. Simultaneously, product quality parameters will benefit from the through-process information and material micro-tracking obtained by advanced sensors with minimal human interventions. Virtual factory and real factory will run and be maintained in parallel for off line multi-objective optimization strategy design, fast tuning and deployment of results.

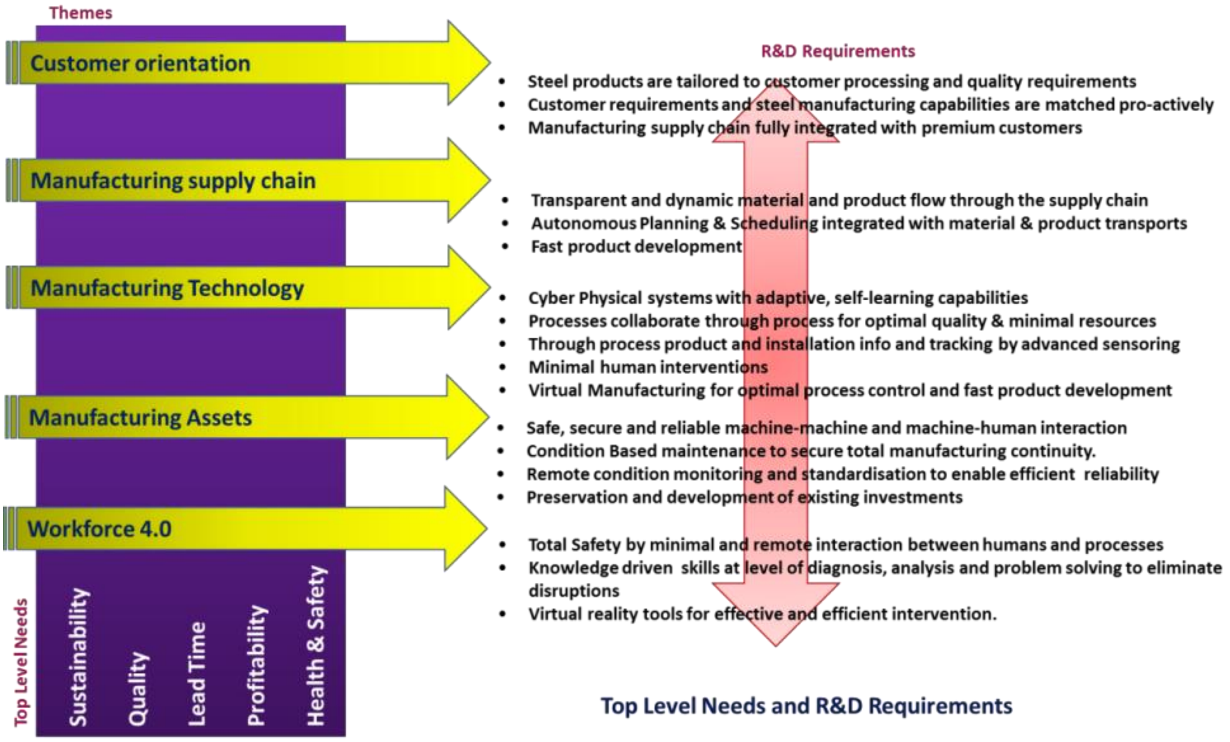


**Figure 22**: Top level needs, themes and R&D requirements

- **Manufacturing assets:** Equipment, machines and systems must ensure safe, secure and reliable cooperation among them (M2M) and with humans (H2M). New systems will be compatible with existing ones integrating and progressively replacing them in order to achieve maximum value from previous investments. In addition, new approaches and technology like remote condition monitoring and condition based maintenance will secure total manufacturing continuity and equipment availability. In connection, standardization will enable efficiency, reliability and transferability of new systems, equipment and models.
- **Workforce 4.0:** New technologies with extended connectivity and fast access to information will ask for novel workforce and working environments. Safety will benefit from the minimal and remote interactions in harsh environments by means of intelligent systems and robots, both autonomous and piloted by humans while local and global monitoring of plants and workplaces will guarantee health to workers and surrounding communities. Operator skills will be more oriented to maintaining manufacturing trajectory and correcting deviations rather than manual operations.

## 2.3.4. General concepts of I²M

### *a) Vertical integration*

In the frame of integrated intelligent manufacturing, the vertical integration means the integration of all IT and automation systems which are related to one plant and which are running on the different levels of the automation pyramid (see figure 23). The solution will therefore be based on Cyber Physical Systems (CPS), which can be considered as the next evolution step of process automation. The consequences of a deepened usage of CPS will be an increased decentralization and a significant de-hierarchy.

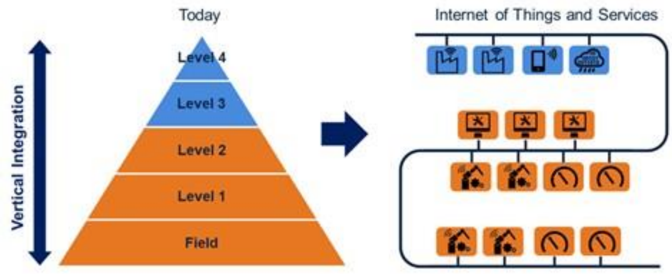


**Figure 23**: Vertical integration

### *b) Horizontal integration*

Along the complete chain of steel production a strong communication between all participating processes has to be guaranteed in future. This is not only true for neighboured plants but for all plants along the process chain. Additionally, a 100% material tracking including a full material genealogy taking into account all possible transformation of material (liquid to solid, cutting, welding, coiling, length changes, etc.) is necessary for a complete horizontal integration. Therefore, it has to be possible to identify all types of intermediate and final products and sensors or indicators are necessary to follow all possible material transformations.

Data coming from different process steps and different information levels (refer to point 2.3.4 a) vertical integration) have to be stored in such a way, that they are available at any time and from any location in the company. Horizontal integration is on the one hand the basis for the connection of automation solutions of neighboured plants but also necessary to realise quality control loops on a very high abstraction level, for e.g. based on suitable decision support tools.

### *c) Transversal integration*

Transversal integration means to take all decisions which have to be made during the long chain of steel production, the aspects of technical solution, economic benefit and environmental aspects need also to be taken into account at the same time. This is the only possible way to find the best solution for each decision-making process based on the overall strategy of the steel producing company. Some aspects are discussed to underline the need to look for such multi-criteria solutions

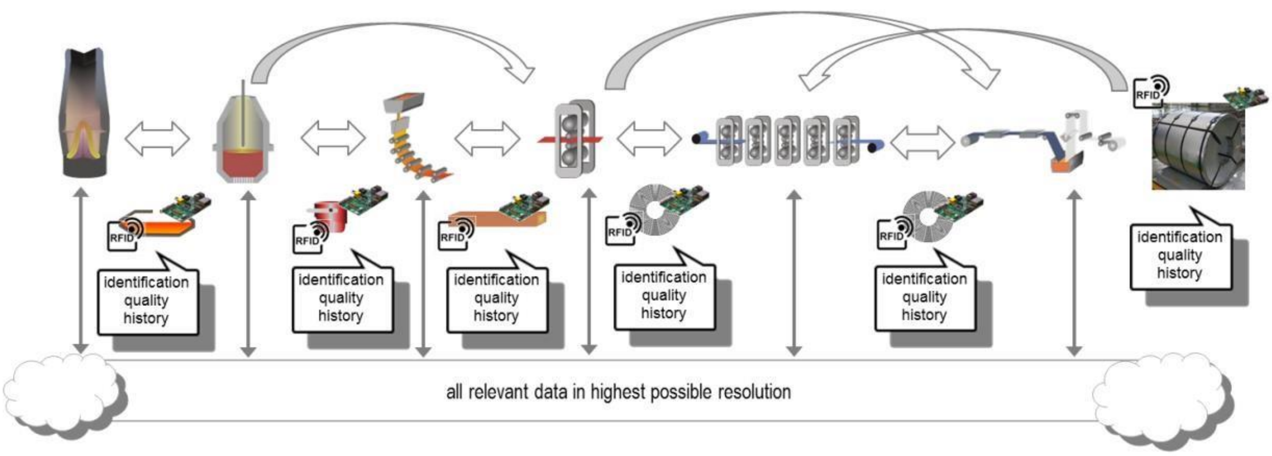


**Figure 24**: Horizontal integration

based on I²M technologies.

### 2.3.5. Future research needs

At the end of this chapter, the short, medium and long term research needs in the field of integrated intelligent manufacturing are presented on the basis of the previous described concepts and the key enabling technologies available today. The diagram where the industrial challenges are connected with the general R&D needs will be used. The table (figure 25) has a dynamic nature in the sense, that it will continuously be adapted and changed in the next years by the I²M working group depending on new upcoming key enabling technologies on one hand, and/or in the meantime solved or overcome tasks/problems on the other hand.

| Customer orientation | Timescale |
|---|---|
| **Steel products are tailored to customer processing and quality requirements** | |
| Smart Product Inventory | Medium |
| **Customer requirements and steel manufacturing capabilities are matched pro-actively** | |
| Automatic auction methods for product selection via Multi-Agent-Technology | Short |
| **Manufacturing supply chain fully integrated with premium customers** | |
| Cooperative systems for supply chain management (incl. monitoring and simulation) | Medium |
| **Manufacturing Supply Chain** | |
| **Transparent and dynamic material and product flow through the supply chain** | |
| Tracking, tracing, genealogy technologies for all flat and long products | Medium |
| Solutions to make all supply chain data available in real-time everywhere in the factory | Short |
| Supply chain monitoring and simulation | Medium |
| **Autonomous Planning & Scheduling integrated with material & product transports** | |
| Solutions for self-organised planning and scheduling based on software agent technology and taking reverse planning and maintenance aspect into account | Short |
| Coordination of process control of single processes with material scheduling tasks | Medium |
| **Fast product development** | |
| Integrated product-process modelling and simulation | Long |
| **Manufacturing Technology** | |
| **Cyber Physical systems with adaptive, self-learning capabilities** | |
| Integrated networks of sensors based on IoT Paradigm incl. auto-check capabilities | Medium |
| Extraction of knowledge from huge amounts of data by Big Data approaches (incl. data reliability improvement) and combination with experience knowledge from people | Medium |
| Self-learning based optimisation of real time process models | Short |
| VR tools for process simulation and management | Long |
| **Processes collaborate through-process for optimal quality & minimal resources** | |
| Through-process and model based predictive control (feedback, feed-forward) | Short |
| Integral optimisation of product quality parameters (surface, properties, geometry) based on through process and multi objective optimisation approaches | Medium |
| **Through-process product and installation info and tracking by advanced sensoring** | |
| Solutions to realise tracking and tracing of products based on sensors and CPS | Medium |
| Augmented Reality applied to product evolution detection and process supervision | Medium |
| **Minimal human interventions** | |
| Remote control of operations by robots and remotely controlled systems | Medium |
| Intelligent pulpit for integrated manufacturing control | Short |
| **Virtual Manufacturing for optimal process control and fast product development** | |
| Modelling for integrated vertical-horizontal-transversal process simulation | Long |
| **Manufacturing Assets** | |
| **Safe, secure and reliable machine-machine and human-machine interaction** | **Medium** |
| **Condition Based maintenance to secure total manufacturing continuity** | |
| Solutions for intelligent predictive maintenance based on combinations of 1st principle models and Big Data approaches incl. learning capabilities | Medium |
| **Remote condition monitoring and standardisation to enable efficient reliability** | **Short** |
| **Preservation and further development of existing investments** | **Long** |
| **Workforce 4.0** | |
| **Total Safety by minimal and remote interaction between humans and processes** | |
| Anti-collision, anti-crushing, access control and tracking systems | Short |
| Solutions for the use of autonomous vehicles for difficult/dangerous operations | Medium |
| **Knowledge driven skills at level of diagnosis, analysis and problem solving** | **Short** |
| **Virtual reality tools for effective and efficient intervention** | **Medium** |

**Figure 25**: Future research needs

## 2.4. Steel applications for transport

### 2.4.1. Introduction

The European steel sector constantly addresses the challenge of meeting customers' demands for a broad variety of ever more sophisticated high-performance materials. To meet these needs, direct partnerships between steel producers and their immediate customers are a strong requirement. Such collaborations, supported by academic research, are major features of new product development in the steel industry and an essential element in the promotion of steel use. In the framework of this Strategic Research Agenda, the transport, construction and energy sectors are regarded as priorities.

Optimal engineering and processing of advanced steel products is a challenge that must be addressed by improving computer-aided-engineering modelling and existing production technologies or by developing new processes or technologies in combination with adapted design.

### 2.4.2. Issues and challenges

Mobility is a basic requirement for people in modern industrial and knowledge-based societies. In the EU freedom of movement for both persons and goods is also a prerequisite of the European integration. Value creation and economic prosperity have only been made possible by the spatial mobility of people and goods.

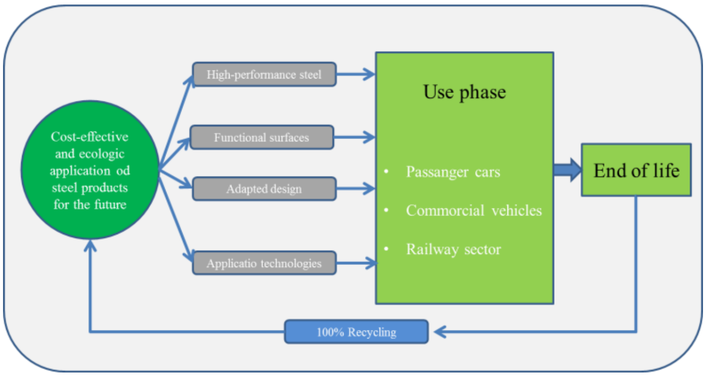


**Figure 26:** Appealing steel solutions for end users: cost-effective and ecologic application of steel products to meet society's needs.

Energy consumption in the traffic and transport sector is dominated by road (73%) and air transport (12%). Worldwide, the transport sector is responsible for about 20% of greenhouse gas (GHG) emissions. Energy efficiency of vehicles and alternative powertrains are at the heart of the Research and Innovation strategy of the transport sector. Light weighting of the vehicle structure can account for 8 to 10% of the CO2 emission reduction.. In addition to new powertrain technologies in combination with hybrid- or electric engines, new affordable lightweight concepts for passenger and goods transportation systems, new transport concepts and construction methods are required in order to be able to reduce greenhouse gas emissions despite increasing passenger and goods traffic.

The total 'Life Cycle Assessment' (LCA) of any product refers to the assessment of the environmental load during the complete lifetime of the product, from the raw material used for manufacturing, the emissions generated during the entire lifetime, and finally the disposal of the product. Steel is a very efficient material regarding GHG emissions while taking into account the whole life cycle, i.e. the production phase, the use phase and the end of life (the effective recycling).

Ancient practices took only into account the emissions arising from the fuel combusted by the engine, the so called 'tail-pipe emissions' or 'tank-to-wheel emissions'. In this case, the climate impact by the material production is not given any attention. However, as the drive-train gets more CO2-efficient by electrification or improved internal combustion engines, the significance of material production towards climate change will be higher. Therefore, to account for the environmental load of the complete life cycle, the following 3 phases should also be included: the fuel production phases (well-to-tank emissions), the material production phase for vehicle manufacturing and recycling.

Every year many thousands of people are killed in Europe in traffic accidents and more than 1.7 million people are injured. Road deaths are still the primary cause of mortality among the young. New strategies for maintaining mobility while mitigating the consequences of accidents will therefore be necessary in the future. In this context, the safety of passengers, drivers and pedestrians is increasingly becoming an important priority, as recommended by the EU Commission which targets a decrease by 60%. With its highest strength level, steel plays an important role in securing safety requirements of today and future trans-port systems.

### 2.4.3. Research and innovation areas of the transport sector

Work in close cooperation with the customers and all stakeholders of the supply chain is particularly important for the transport sector for proposing steel solutions meeting their requirements. The new solutions should use all technical progress: new metallurgy of steels, new functional coatings, new application technologies (forming, welding, joining, etc.) all included in an optimized design taking advantage of all these progresses. Mainly the automotive industry - as well as the whole transport industry in specific areas - is dedicated to respond to the mobility needs of individuals and those of society as a whole. The targets to be derived from these challenges are:

- Environmental sustainability related to
  - energy consumption
  - $CO_2$ emissions
  - resource efficiency

- dismantling
- recycling behaviour

- Circular economy
- Safety
- Reliability
- Cost effectiveness
- New powertrains or self-driving vehicles

Those societal challenges will be addressed collectively by working in close co-operation with all relevant stakeholders.

The steel industry and the automotive industry in the EU have to maintain their leadership in the world market. Simultaneous engineering and concurrent engineering are tools to meet the challenges of the world market for the targeted manufacturing of vehicles. The steel industry, with its expertise in production processes and tailoring of material properties, and the automotive sector, with its vision for the future development of vehicles, are well prepared for an EU joint action to achieve a quantitative leap in the construction of the car of the future, which would not be attainable through the partnership of individual steel and automotive companies. The EU steel and automotive industry can also benefit from the support of a dense network of academic research groups in EU working in the frame of metallurgy and mechanics, and more particularly on steels and steel solutions.

The automotive industry stimulates lightweight construction innovations. It is essential for the steel industry to exploit its material expertise through material development and component design for use in mass production and, in cooperation with the transport and especially the automotive sector, to achieve further improvements or totally new solutions for vehicle concepts. Multi material mixed structures need to be discussed and comparable, affordable steel solutions have to be offered.

The targeted development of a production and manufacturing chain using new high performance steels for lightweight constructions including new or modified forming and joining techniques and new coating processes will be a very ambitious R&I aim. The new hot forming steel grades with advanced corrosion protection coatings and new process technology approaches like tailored properties leading to weight reduced steel cars are good examples of the capability of the steel industry - And the development is still going on with the third generation of Advanced High Strength Steels dedicated to cold stamping which will also contribute to address the future safety and weight reduction challenges. The significant advantages of the new generation of Advanced High Strength Steels can be efficiently exploited only by new design principles and simulation methods in advanced engineering.

The R&D&I themes to be derived from these challenges are:

- Complex components from new high strength steel grades using innovative manufacturing methods
- Development of new surfaces for optimized forming behaviour and corrosion protection
- Development of optimized steel solutions for the cars of the future
- Transfer of the knowledge to the whole transport sector especially to the truck and train industry
- Enabling technologies for new advanced high strength steels like springback management or adapted joining techniques

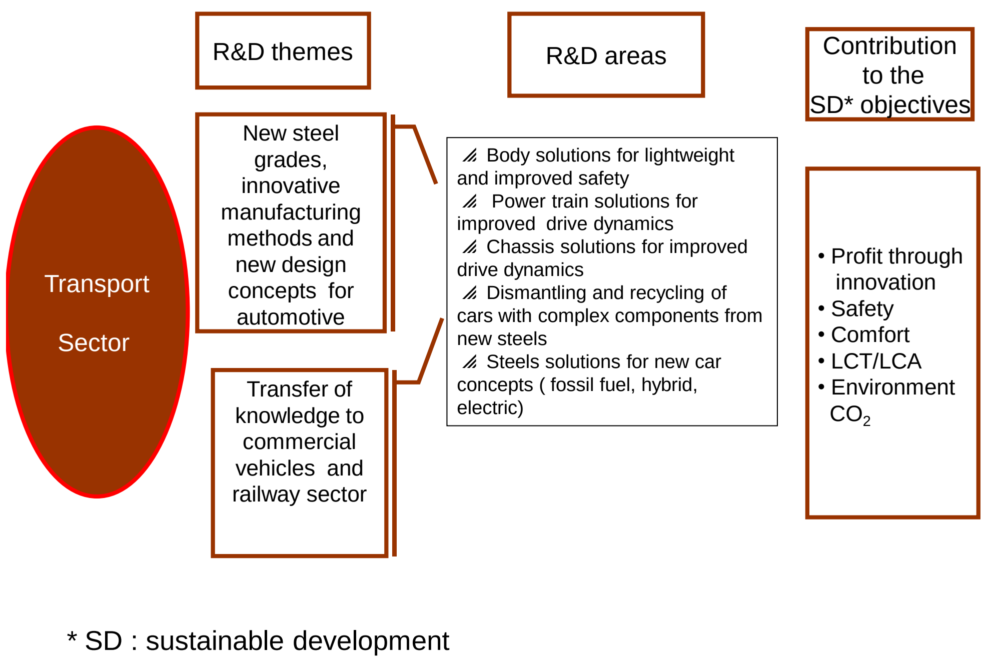


**Figure 27:** Appealing steel solutions for end users (transport sector): achieving the SD objectives through R&D

### 2.4.4. Socio-economic aspects of the automotive sector

The importance of the transport and especially the automotive sector for the EU economy is characterized by the following figures:

- There are more than 14 million new car registration units per year in EU (15) and more than 17 million new vehicle registration units per year (including commercial vehicles, coaches and buses);13.8 PC +1.5 LC
- The passenger car share represent an estimated turnover of about € 300 bn/year in the EU (15);
- The European vehicle park reached nearly 220 million units in 2003 of which passenger cars account for about 87%;
- 23% of cars in use in the EU are diesel powered against 16 % in Japan and nil in the US;
- The number of directly employed persons in the production of motor vehicles is about
- 1 050 000 and the total number including indirect employment is about 1 900 000.
- Taxes associated with the purchase and use of motor vehicles contribute over € 350 bn/year to the revenues of the EU Member States Governments

Steel has an important transversal role to play in enabling the technologies necessary to achieve the challenges faced by the automotive industry. The automotive sector program would facilitate the integrated approach – design, materials and processes – needed for further innovation and value addition in the automotive industry. Several aspects are covered:

- Ecological aspects. In an ecological comparison of the products, taking life cycles and the recycling ability of steel (LCA) into account car bodies, made e.g. with cold and hot forming high strength steels, tailored blanks and tailored tubes (closed profiles) with more than 20% saving in weight, can be far less detrimental to the environment than today's conventional bodies regarding the resource efficiency indicator 'Life Cycle Assessment' (LCA) and the "global warming potential" (GWP). Improving the drive train efficiency would bring a strong contribution to decrease CO2 emissions, eg by using efficient electrical steels for electric or hybrid vehicles machines.
- The implementation of innovative technologies has in the past contributed to reducing the impact of motor vehicles on the environment. To give a few examples: 100 of today's cars pro-duce the same amount of emissions as an average car built in the 1970s, the amount of local pollutants has been reduced 20-fold in the last 20 years, while vehicle noise levels have been reduced by 90% since 1970. Such progress should be pursued in the coming decades.
- Steel is a material easy to recycle (370 million tonnes per year)
- Societal aspect of increasing the integrated safety for all road users

### 2.4.5. Stakeholders

- Steel industry
- Steel research centres
- Transport sector
- Suppliers (surface treatments and chemical industry)
- Suppliers to the transport industry
- Universities & academic research centres

## 2.5. Construction and infrastructure sector

### 2.5.1. Introduction: context, ambition & foresight

The European construction industry supports the EU economy, by providing it with buildings and infra-structure that supports all other economic and social activities. It constitutes the largest single economic activity in Europe, contributing 8.8% of GDP, 28.7% of industrial employment and 6.5% of total employment (14.2 million people). Around 95% of the approximately 3 million construction companies are SMEs and in 2014 it was estimated that every €1 spent on construction output generates €2.84 in total economic activity. In use, buildings consume about 40% of global energy and are responsible for around one third of all greenhouse gas emissions. As such, a major goal in the EU is to promote green energy and encourage "smart infrastructure". Cities, and the buildings within them, are also subject to the pressures of increasing urbanisation, growing populations, climate change and, especially in the developed world, an ageing population. All these factors are driving change in the way that buildings are constructed and used and in the way that cities are developed and run.

Steel is one of the most important construction materials, competing with other materials but also opening up completely new possibilities. Figures from the World Steel Association indicate that construction continues to be the single largest market for steel, accounting for 52.2% or 838Mt globally. In Europe the mix is estimated at 40% or 42.5Mt. Many steel producers consider the construction sector to be among their largest single markets in terms of volume. To exploit the full potential of steel as a construction material, the development of new grades, building components and systems, composite structures, and construction technologies is needed. Safety and health are the main performance aspects of the built environment essential for the security and quality of life of occupants and other stakeholders.

The quality of built environment has a strong influence on the performance of individuals and organizations and on the well-being of society in general. However, the level of funding from European and national programs does neither properly reflect the significance of construction as an economic activity, nor the significance of the built environment as a fundamental contributor to the quality of life.

## 2.5.2. Issues and challenges

There is a wide range of pressures, expectations and drivers seeking to influence and shape the construction and infrastructure sectors. The most important issues and challenges are presented by market demands. There is a need for the industry to deliver increasingly innovative products at competitive prices within tight environmental regulatory targets.

The challenge for the industry is, simply, to find new ways or delivering new products with less resources and raw materials. Internally, the industry as a whole is not yet geared for a coherent response to these challenges. It remains highly fragmented and there is a need for much closer cooperation between leading suppliers and major construction companies. A key aspect of the steel industry strategic plan over the next 10 years is therefore to work more closely with customers seeking strategic alliances with research organizations and commercial companies. Strategic alliances with the EU construction sector would need to address the scientific, industrial and societal issues to meet the following global challenges:

- Impact of Climate Change
- Safety and health in manufacturing, construction and use of construction products
- Resource efficiency through improved recycling and reuse of construction material
- Life Cycle Thinking and Life Cycle Assessment for the construction sector
- Energy Efficient Buildings for new constructions and refurbishing of existing ones
- New EU directives and global challenges necessitating the tightening of regulations
- Resilience to and recovery from natural and accidental events like fire, earthquakes, flooding, and other accidental loadings
- Urbanization and other demographic changes
- Keeping pace, harnessing and facilitating information and communication technology integration with buildings and infrastructure and industry processes.
- Implementation of biomaterials and nanomaterials
- Integrating the supply chain and addressing the challenges of delivery
- Issues emerging from increasing partnership with customers.

Consideration of these factors leads to the definition of the following R&D areas grouped under three major R&D themes:

- High-performance
  - Clean and green
  - Resilience
  - Robustness
  - Adaptability
  - Integrity
  - Blast resistance
- Digital economy
  - Building information modelling
- Industrial/ Manufacturing 4.0
  - Energy-efficiency
  - Automation/Robotics
  - Modularisation
  - Additive manufacturing
  - Recycled materials
  - Design for reuse or flexible assembling
- High added-value solutions and products for building and construction
  - Energy integration
  - Energy storage/harvesting
  - Multi-functional envelope
  - Renovation/refurbishment
  - Structure for disaster relief
  - Structures to resist man-made hazards
  - Intelligent/interactive buildings
  - Effective use of HSS
  - Hybrid steel/composite or laminate
  - Infrastructure solution
  - Structures for clean energy
  - Intelligent infrastructural components

## 2.5.3. Research and Innovation areas: exploring solutions and turning them into opportunities for both business and the planet

### *a) High performance*

***Blast resistance/ Structures to resist manmade hazards Building Information Modelling (BIM)***

Buildings are conventionally designed to resist loads that are applied over timescales much greater than their natural period of resonance, and the response to such loading events is governed by the peak load. When structures are subjected, accidentally or intentionally, to loads which are introduced over much shorter time periods the response is governed by a combination of the peak load and the impulse (i.e. the integral of force with respect to time). Under such conditions of dynamic or impulsive loading, where the loading event imparts significant momentum to the structure, the ultimate effect on the structure depends on the ability of the structure to sustain the forces associated with subsequently bringing its own mass to rest. The strategies appropriate to the effective management of such loading cases differ from those associated with the management of slowly-applied environmental or service loads.

In the contemporary urban environment there may be concerns relating to the following sources of impulsive or dynamic loading:

- Accidental or deliberate collision of vehicles against the building
- Exposure of the building to airborne shock-waves arising from accidental explosions such as those that might arise from the ignition of leaking fuel gas
- Unintentional detonation in peacetime of military munitions that had remained undiscovered from earlier periods of conflict
- Deliberate malicious attack by terrorists or criminals armed with improvised explosive devices or with illicitly-obtained military munitions.

Various strategies are appropriate to the different scenarios. In the cases of vehicle collisions or criminal/terrorist attack, technical defences may take the form of deformable or rigid barriers around vulnerable parts of the building perimeter. In the case of accidental vehicle collisions such deformable barriers might be designed to not only protect the building but also to enhance the chances of survival of the vehicle occupants. In the case of defence against deliberate explosive attack an effective strategy might also involve a light-weight sacrificial barrier designed to trigger premature detonation of the warhead. Mitigation of the effects of accidental explosions would call for a more direct hardening of the building structure; the appropriate technical approach might then depend upon the relative probability of the different sources, as there are substantial qualitative differences between the airborne shock-waves arising from high explosives and from fuel gases.

### *Resilience / Robustness/ Adaptability/ Integrity/ Renovation/ Refurbishment*

It is essential that buildings and items of infrastructure possess the ability to adequately resist reasonably foreseeable structural loads (including self-weight) without fracture, excessive deflection or instability (such as overturning, buckling or transformation into a mechanism) and so remain capable of performing their intended functions throughout the duration of their designed life. This characteristic, which may be defined either at the level of individual structural components or at system level, is denoted by the term "structural integrity"

It is important for buildings and items of infrastructure to be able to absorb damage without suffering complete

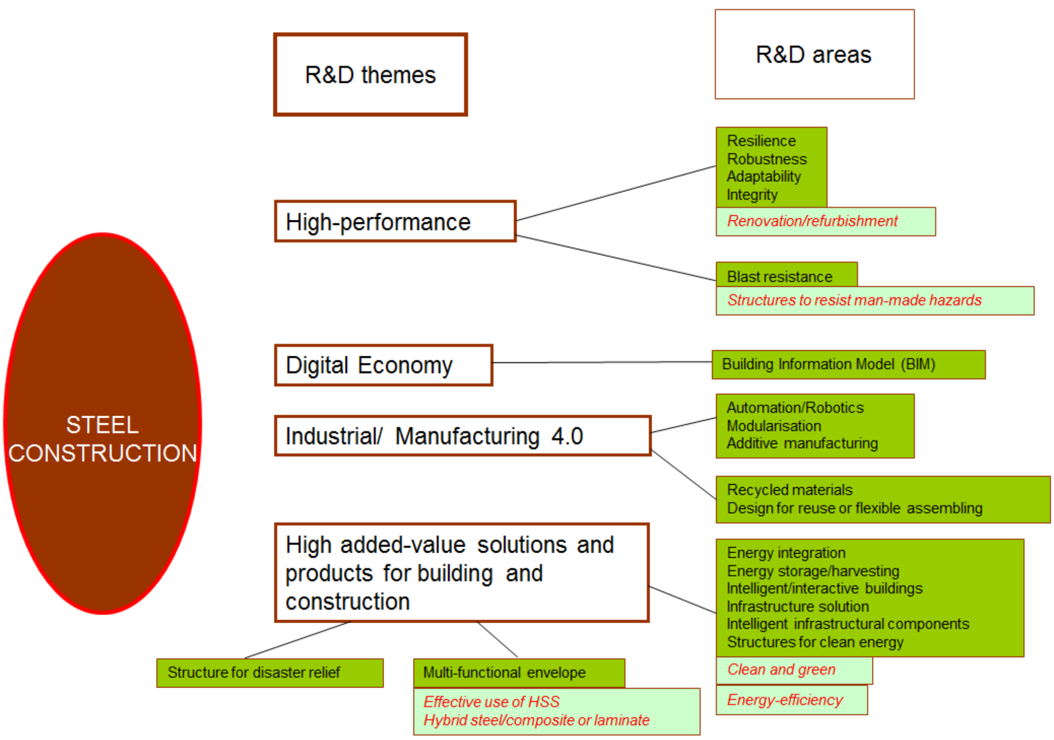


**Figure 28:** Appealing steel solutions for the construction and infrastructure sector

failure (a characteristic denoted by the term "resilience") and to withstand severe events (such as fire, explosions or impact) without a loss of function that would be disproportionate to the cause (a characteristic denoted by the term "robustness").

It is desirable for buildings and items of infrastructure to be adaptable, throughout their anticipated lives, to reasonable changes both in the demands placed upon them and in the levels of performance expected of them.

It can be foreseen that technological and societal changes will lead to challenges in terms of adaptability, while the an anticipated increase in the frequency and severity of extreme weather events as a consequence of climate change may pose challenges in terms of structural integrity, robustness and resilience.

## b) Digital economy

### *Building Information Modelling (BIM)*

Modern information technology is founded on the concept of the manipulation of data by algorithms. It is axiomatic that, for data to be manipulated by an algorithm, it must conform to some definite structure, i.e. a data model. Different data models can be created to represent the same information - to take a simple example, a position in 3-dimensional space could be represented in either a polar or a rectangular coordinate system. Where software has been designed to support the work of some particular engineering discipline, there is a natural tendency for the software authors to adopt a data model that corresponds closely to the perspective of that discipline. As different disciplines will thus tend to define different data models, this can lead to difficulties when these disciplines need to share data; quite apart from any superficial differences in data formatting (such as those commonly encountered when files are exchanged between different spreadsheet or word-processing packages), there is a more fundamental challenge in transferring the contents of one discipline's data model to the appropriate positions in another discipline's data model. This challenge may make it impractical to create a reliable automated system for the transfer of data between disciplines.

A number of problems can arise where human intervention or checking is required to ensure that data is correctly transferred from one data model to another:

- Data exchange is slow, expensive and liable to Error.
- At any moment in time, different disciplines may be working with inconsistent data as data has either been incorrectly transferred or where correctly transferred has not yet been updated to incorporate subsequent design changes.
- The costs, delays, and potential-errors associated with data exchange lead to different disciplines working sequentially where they might otherwise have been able to work in parallel.
- The need to check and re-check the validity of data leads to an additional burden in verifying compliance with contractual and/or regulatory requirements

In response to the challenges in effectively sharing data a number of industrial sectors have devoted considerable effort since the 1980s in developing Product Data Modelling (PDM) standards. A family of mature multi-industry standards has been implemented across sectors such as automotive, aerospace, shipbuilding and electronic hardware. The widely recognised conservatism and fragmentation in the building sector has, however, led to a perceived need for progress to follow a slightly different path to that taken in these other industries.

Building Information Modelling (BIM) has been defined as the process of designing, constructing, or operating a building or infrastructure asset using electronic object-oriented information.

BIM is a lifecycle information delivery process that employs BIM authoring software to create and compile information including graphical (2D, 3D, 4D, etc.), non-graphical data (e.g. technical specifications) and documentation (e.g. installation instruction, warranty documents, environmental declaration documents, etc.).

There is now an industry standard for defining project organisation's competence and delivery from a BIM. The levels are defined as:

- <u>Level 0:</u> Unmanaged CAD probably 2D with paper (or electronic paper) as the most likely data exchange mechanism.
- <u>Level 1:</u> Managed CAD in 2D or 3D format using published standards with collaboration tool providing a common data environment, possibly some standard data structures and formats. This is the level at which most organisations currently operate.
- <u>Level 2:</u> Managed 3D environment held in separate discipline BIM tools with attached data using published standards with collaboration tool providing a common data environment. Integration on the basis of proprietary interfaces or bespoke middleware.
- <u>Level 3:</u> Integrated BIM or single shared project model based on fully open process and data integration enabled by web services managed by a collaborative model server.

Standardisation and interoperability should enable lossless information exchange between information technology systems. It can be achieved by implementing common or complementary interfaces for information sharing or platform neutral file format specification format that interested vendors can implement. The currently implemented standard file format can be exported from and imported to all BIM platforms but the exchange is far from lossless and considerable effort could be required in verifying the information exchanged. This has so far hampered its use.

The potential benefits to construction product manufacturers of implementing BIM are expected to include:

- Timely response to RFI/RFP
- Opportunity to sell more products through existing contacts.
- Opportunity for cross selling of product lines.
- Easier identification of product improvement and NPD opportunities.
- Lower overall cost of managing product information.
- Ability to participate in BIM-enabled collaborative business models.
- Access to product data as input for optimisation (energy, cost, performance) tools.

The following barriers to effective implementation of BIM have been identified:

- Learning curve and lack of skilled personnel
- High cost to implementation
- Reluctance of other stakeholders (e.g. architect, engineer, contractor)
- Lack of collaborative work processes and modelling standards
- Lack of interoperability between industry software tools.
- Lack of or ambiguous legal/contractual frameworks and agreements.

The availability of product information in BIM environment is pivotal to the success and actualisation of BIM benefits (beyond design authoring and visualisation) hence uptake by product suppliers is critical. The most cited barriers by manufacturers/suppliers to the adoption of BIM technologies are:

- Lack of demand by clients
- Poor internal understanding of BIM

### c) *Industrial/ Manufacturing 4.0*

#### ***Automation/ Robotics/ Modularisation/ Additive manufacturing***

The term "advanced manufacturing" is usually taken to refer to production processes that embody the results of recently-completed scientific and technical research. In this context, the qualifier "advanced" applies to the manufacturing process rather than to the manufactured product. While the term is often regarded as synonymous with "high-value manufacturing", some commentators maintain the distinction that "high-value manufacturing" is a concept embracing innovation in manufacturing systems, supply chains and business models, and so may be based as much upon new business ideas as upon new scientific or technical ideas. The concepts are nevertheless closely linked, as developments in production processes may facilitate the implementation of new business models.

Drivers for growth in advanced manufacturing include trends in global manufacturing and overseas freight costs (leading to some re-focusing of manufacturing activity from Asia back towards Europe) and increased resource scarcity (leading to an emphasis on production processes and business models that minimise use of resources and/or extend the effective product lifetime).

Advanced manufacturing technologies may capitalise on developments in materials (providing products with new or improved properties), in novel manufacturing techniques (such as additive manufacturing) or in the enhanced productivity of established manufacturing processes (for example through opportunities to refine automation).

Additive manufacturing processes (sometimes referred to as "3D printing") create physical objects by building them up directly from a digital model. They are thus clearly distinct from "subtractive processes", such as the removal of material by machining or cutting, and from other processes such as fabrication (an additive process involving the assembly of parts subtracted from bulk products) and casting or forging (in which an intermediate physical object, such as a die, pattern or mould must first be created from the digital model). Various techniques are available, typically involving powders or jets of liquid material, to build up the product by depositing successive thin layers of material.

Within the construction sector, additive manufacturing processes may be exploited by:

- Direct printing of metallic objects (e.g. by selective laser fusion of metal powder)
- Printing of non-metallic patterns for metal-casting processes such as sand casting or investment ("lost-wax") casting
- Printing of non-metallic parts (e.g. concrete) in steel-framed structures.

The direct production of metallic objects entails a number of challenges. While the additive process removes some design constraints associated with established manufacturing processes, it also places its own restrictions on material properties (for example, in order to obtain material properties in a printed part comparable to those of a casting or forging it may be necessary to add a post-printing production step such as heat-treatment or to use a more expensive alloy composition). Furthermore, there may be concerns related to the adequate assurance that specified mechanical properties have been achieved. These challenges would be avoided if 3D printing were to be used indirectly through the production of, for example, patterns for casting processes, as it would then be possible to employ well-established standards for alloy compositions and product approval. A further advantage of this approach would be that high production rates might be achieved more easily than through direct printing of metallic parts.

One major attribute of additive manufacturing processes is that they may enable a business model known as "distributed manufacturing", in which digital models are downloaded to distributed multi-purpose factories where manufacturing operations take place. The potential advantages of such a system have been identified as:

- Reduced financial and environmental costs associated with freight transport, as products are manufactured close to their final destination
- Increased responsiveness to market demands, as product design changes can be implemented without disrupting a production line or supply chain
- More scope for innovation, as rapid prototyping and limited production runs are readily supported
- Improved life-cycle support for complex products, as replacement parts can be produced on-demand.

***Recycled materials/ Design for reuse or flexible assembling***

Traditionally, product life-cycles have been highly linear with a typical "make-use-dispose"-structure. More recently, there has been increased emphasis on the opportunity to extract value from resources at the end of the life-cycle; this has been particularly marked in the case of the capture of waste streams in sectors such as paper and glass. A "circular supply chain" is an advance upon this concept; it envisages that, as an integral part of the original product design, the material resources made available at the end of the product lifetime will be directed towards subsequent embodiment in some designated successor-product. By decoupling economic growth from resource consumption in this way, it is hoped that pressure on finite natural resources can be relieved; the significance of this can be judged from the European Commission's recent identification of twenty critical raw materials which have both high economic importance to the EU and high supply risk (including rare earth elements in modern technologies, less than 1% of which are currently recycled). It has been estimated by the World Economic Forum that by 2025 the circular economy could contribute as much as $1 trillion per annum to the global economy through reduced material use. The greatest potential benefits would be seen in economies such as Europe (through its reliance on imports) and industrial sectors such as construction (through its material-intensive attributes).

The EU Circular Economy Package published in December 2015 aims to enable the transition to a more circular economy through a range of measures aimed at increasing resource efficiency and minimising waste; in addition to EU Member States this package also applies to members of the European Economic Area.

Circular systems incorporate a range of activities that reduce the demand for material inputs, recover/reuse materials already in the system and extract the highest quality and value at each stage in the products' life cycle. For example, the useful life of a car can be extended through repair and maintenance; at the end of its useful life it can be disassembled, with serviceable components re-entering the supply chain as spare parts, before ultimate recovery of materials such as metals through scrapping.

A circular economy has implications for infrastructure to support product recovery, transport and reprocessing. These are particularly significant for the construction sector; while it has been estimated that over 86% of non-hazardous construction waste is currently recovered, much of the potential value is lost due to transport costs, challenges with multi-material product recovery and geographic mismatches between areas of supply and demand.

### *d) High added-value solutions and products for building and construction*

***Energy integration | Energy storage/harvesting | Intelligent/interactive buildings | Infrastructure solution | Intelligent infrastructural components | Structures for clean energy | Clean and green | Energy-efficiency***

Safe and efficient infrastructure is the foundation on which a modern economy is built. All around the world infrastructure systems are increasingly coming under strain due to trends such as urbanisation, continued globalisation, and the effects of climate change. Furthermore, while developing countries struggle to build new infrastructure, developed countries face a need to replace ageing infrastructure. It has been estimated that between now and 2030; a minimum of $50 trillion in infrastructure investment will be required to fuel global development.

The present day building stock accounts for some 40 percent of the energy consumed worldwide. In Europe, however, structures that were built prior to 1980 account for 95 percent of the energy used to provide buildings with heat, hot water, air conditioning, lighting, and ventilation.

The technological development of urban infrastructures has recently been classified into four well-defined stages.

*"Infrastructure 0"* is a basic brick-and-steel infrastructure characterised by simple road and rail tracks, lightly-serviced low-rise commercial buildings and "islands" of electrification (in which a supply is available only to small groups of users who generate their own electricity).

*"Infrastructure 1.0"* is characterised by semi-automated infrastructure in which railways have begun to be electrified (with some basic automation features), commercial buildings are constructed to modern standards (designed to incorporate services such as heating, lighting, air-conditioning, telecommunications, elevators, etc.) and where mono-directional power grids (in which generation is run in simple response to aggregate electrical demand) are ubiquitous.

*"Infrastructure 2.0"* features intelligent infrastructure, in which trains are largely driverless, buildings are fully automated and electrical power is provided via smart grids (in which continuous data exchange between generators

and consumers facilitates active load management, energy storage and despatch of generating assets).

*"Infrastructure 3.0"* describes a fully-integrated intelligent infrastructure in which integrated real-time optimisation and incident management takes place across all infrastructure domains. In one vision of such a paradigm, smart buildings and a smart grid cooperate seamlessly to optimise energy consumption while user-friendly traffic systems integrate all transport modes so that travellers can optimally plan their journeys using real-time information.

Disparate challenges are faced in the implementation of intelligent urban infrastructure. While developed economies may possess the resources to support the construction of state-of-the-art systems, they will be constrained by the need to introduce these in ways compatible with the uninterrupted operation of the legacy infrastructure. Conversely, in emerging economies there may be greater opportunities to start from new, while access to finance may be a restricting factor.

A detailed understanding of the energy performance characteristics and energy flows in urban areas is of crucial importance for the design and planning of smart energy systems.

Smart cities will require smart energy grids which are able to communicate with each other to balance thermal and electrical loads depending on supply and demand. Energy-efficient buildings will need to employ energy conservation measures and on-site renewables to reduce their energy demand and to operate as interactive elements of the urban energy system.

In the development of smart urban energy networks the large-scale integration of distributed renewable energy sources into existing energy grids presents some substantial challenges. In this context energy supply technologies such as heat pumps, solar thermal, photovoltaics, energy storage units, etc. will be significant. The development of smart integrated energy networks will require not only new components and systems, but also a better understanding of how to integrate distributed supply technologies into urban infrastructure in an efficient and cost-effective manner.

### *Multi-functional envelope | Effective use of HSS | Hybrid steel/composite or laminate*

A building envelope serves as a physical separator between the conditioned and unconditioned environments of a building. As such it is required to resist the transfer of air, water, heat, light and noise. It may also be required to resist and transfer structural loads and to satisfy other criteria such as internal or external aesthetic finish. The physical components of the envelope include the foundation, roof, walls, doors, windows and ceiling.

In many established forms of construction distinct elements and materials are intended to support each of the required functions.

In a multi-functional envelope individual elements perform more than one control function. At one extreme this can take the form of a single element or material addressing all enclosure control functions. More typically, however, a multi-functional envelope may comprise a number of elements each of which performs one primary function while contributing to one or more other control functions.

Multi-functionality clearly has the potential to offer economical, and potentially synergistic, benefits which may enable novel design and construction concepts. However, the challenges should not be underestimated; for example, it is well known that several building systems introduced in the mid-twentieth century subsequently experienced severe shortcomings in respect of their envelope control functions, as a result of deficiencies either in design or in management of build quality.

Many forms of construction feature the use of steel as a structural material and polymers as barrier elements of the envelope. By appropriate materials selection and joining methods it is possible to achieve a hybrid element in which the polymeric components perform not only their barrier function but also contribute towards the load bearing function by communicating shearing forces. In this way it is possible to enhance overall flexural stiffness and to stabilise thin steel elements against buckling, both of which offer routes towards the more effective use of the higher strength steels that have long been available.

### *Structure for disaster relief*

Major disruptions to civil society can arise from a number of sources. In addition to conflict-related issues (including the need to accommodate large civilian populations displaced by conflicts elsewhere), these sources include:

- Earthquake/tsunami
- Flooding
- Drought
- Famine
- Wildfire
- Hurricane/typhoon
- Major industrial accidents (e.g. widespread environmental contamination by chemical or radiological agents)

Fresh challenges are faced in the provision of relief efforts. In the case of weather-related catastrophes the results of global climate change will be an important driver. In the case of seismic disasters the physical threat may remain unchanged but its potential impact can be transformed as a region develops e.g. from a chiefly agricultural economy, with a large number of small population centres and unsophisticated infrastructure, to an industrialised economy with several major modern cities.

Facilities may be required to support affected populations over various timescales (e.g. overnight; several days; periods of weeks or months) which may determine the relevant priorities. Furthermore, these priorities may evolve over the duration of the relief effort (e.g. in the immediate aftermath of a disaster the main medical priority may be the treatment of traumatic injury, while within a matter of weeks an adequate level of maternity care and the effective provision of childhood vaccination may become increasingly significant health issues for the affected population).

Emergency structures and buildings may be needed to provide:

- Shelter (in a variety of formats including tents-and-blankets, dormitory-style cabins and family-unit household dwellings),
- Sanitation and water supply,
- Heating and lighting (e.g. distribution of portable propane gas appliances and arrangements for supply/re-charging of gas cylinders),
- Distribution, storage and preparation of food (e.g. field kitchens),
- Mortuaries and related facilities,
- Healthcare (including arrangements for the appropriate storage of medical supplies, e.g. refrigeration for vaccines and security stores for controlled drugs such as opiates),
- On-site maintenance and repair of basic mechanical equipment (including logistic management of spares),
- Childcare and education.

Modular construction techniques might offer particular advantages in disaster relief building systems. A common modular building envelope system might allow buildings to be deployed to sizes and ground-plans determined by on-site conditions while a compatible series of building services kits might allow completion of the buildings to suit different applications (e.g. one services kit might be used to complete the building as a clinic while another might allow it to be completed as an engineering workshop).

Different logistic management strategies may be appropriate to different scenarios. For instance, in seismic regions bespoke packages of equipment might be pre-positioned by the civil authorities in depots close to major centres of population, while relief of a major famine might entail the ad hoc coordination of multiple international supply streams across several modes of transport (e.g. marine freight, road haulage, commercial air cargo, military airlift) by a range of governmental and non-governmental organisations. Furthermore, individual packages might need to incorporate units with different storage characteristics: for example, a medical treatment package designed to be delivered to site as a single item might comprise a flat-pack building-and-equipment module with indefinitely long shelf-life, a stock of medical supplies (e.g. packs of sterilised surgical instruments and dressings) with a shelf-life of several years and a supply of pharmaceuticals with shelf-lives of possibly only a few months. Effective packaging (including suitable transit labels and compatible consignment-tracking technologies) and appropriate levels of modularisation are therefore important aspects of the specification of a disaster relief inventory.

### 2.5.4. Socio-Economic Aspects

Steel is one of the most important construction materials, competing with other materials but also opening up completely new possibilities. Almost half of the steel produced is used for construction purposes. New applications for steel can be found through the development of new grades, building components and systems, composite structures, and construction technologies.

Research themes are relevant in various fields including new buildings, renovation of old buildings, infrastructure, developing new materials, improving value chain, standardization, and dissemination of results.

Sustainable steel construction is based on competitive business that satisfies the needs of customers and societies. It captures economic and environmental goals along with social desirability. Steel-based construction with accurate and pre-fabricated components enables resource savings and waste reduction, and steel itself is an endless recyclable material.

***Steel and synergies with neighbouring communities***

Steel is a key component of any construction activities. In fact, in terms of construction, some structures and forms would not be possible without steel. Therefore, steel is linked naturally to various other construction projects. This also extends to research and innovation. As a platform, ESTEP has synergies and collaborates with various platforms and initiatives such as ECTP, E2B, Building UP, reFINE, etc.

### 2.5.5. Stakeholders

- Steel industries
- Suppliers
- Architects, designers
- Construction sector
- Raw material producers
- Steel Research Centres
- Universities
- Public authorities and communities

## 2.6. Steel products and applications for the energy sectors

### 2.6.1. Introduction

This work is part of the effort to keep the SRA of ESTEP updated, to prepare HORIZON 2020 and future research proposals on key strategic issues. More generally, it is meant to make sure that ESTEP is ready to face the challenges that lie ahead of it in a proactive and pioneering way. Energy sector is very important for the future of Europe as our society is willing to decrease GHG emissions resulting from power generation. This change will require huge efforts from many different actors and for very large investments. Materials used for the production, storage and transport of energy are very important elements to achieve the required performances at an affordable cost. The EMIRI proposal for a new PPP within Horizon 2020 (Energy Materials Industrial Research Initiative) is exactly for this purpose. In this general landscape, steel has a very important role to play. Working in collaboration with its customers, the European steel industry is ready to answer the challenge through innovative product and solutions.

## 2.6.2. Methodology

In order to better define the required steel applications to be developed, the energy industry has been subdivided in three main sectors:

- Energy Transportation (Oil & Gas, not standard fluids)
- Power generation and CCS
- Renewables (wind energy, Photovoltaic, CSP, Hydrogen, marine energy, others)

The time frame extends until 2030, as changing the energy system is a long-term endeavor. The approach of the working group has been to carry out a foresight analysis, trying to imagine how to bridge the present to the future.

In this context an ordered and rational set of research areas that could become populated by research proposals especially in the period up to 2020 has been proposed.

More specifically, the working group has proceeded as follows:

- picture the needs of Energy Industries up to 2030
- proceed, using a backcasting method, to draw the roadmap that bridges the gap between that future and today
- translate the needs in terms of R&D&I areas
- prioritize the areas in terms of time and funding instruments (HORIZON 2020, SET -Plan, RFCS, others).

## 2.6.3. Energy transportation: Oil & Gas, other less standard fluids

### *a) Exploration, production and transportation*

As the indigenous supplies for European oil & gas markets decline and Asian oil & gas markets continue to develop there is a growing need to exploit fossil fuel reserves that are increasingly farther from market, beyond the existing technology or in deeper waters off the continental shelves around the world. As new competitors have entered the field, Europe's central concern is to maintain its position and competitiveness in the future. This requires permanent innovation and continuous engagement in R&D&I. Many of the oil and gas companies and pipeline transportation companies have placed substantial funds into research and development. Any improvement in the design, materials or construction processes can yield extremely large cost savings.

Areas of particular interest include fracture control for demanding applications of higher strength steels fitness for purpose and defect assessment of Higher Grade/ Higher Pressure Pipeline (as grade ≥ X80, service pressure ≤ 15 MPa), pipeline operation in harsh environments such as corrosive and cryogenic conditions, improved loading systems for gas transportation by LNG/PNG and safe transportation of CO2, H2 and gas mixtures.

The aging of pipeline network is also a very important topic in Europe as well as the security of supply. The first wish is to extend life times of running systems. A better knowledge of the limits for these aged pipelines will create sooner or later the need for new pipelines.

As main R & D themes have been identified:

- Highly performing tubular materials and technical solutions for Oil & Gas wells and relevant infrastructures
- Steel pipes & components and technical solutions for High Productivity Energy Transportation

### *b) Highly performing tubular materials for oil & gas wells*

A step-wise decrease in cost and environmental impact of O&G wells should come in the future by the adoption of new design concepts for the well structure. The simplification of the "telescopic" casing structure toward an ideal mono-diameter casing is a goal which can be now realistically pursued, due to the availability of so-called "In-Situ Expansion" (ISE) technologies. This however calls for the availability of steel pipes with superior suitability in terms of deformability, mechanical and corrosion properties after expansion and a generally higher performance in terms of collapse resistance. Also the development of appropriate solutions for the joints is needed when ISE is applied. The reduction of the total weight of the casing structure through the use of ultra - high strength OCTG (Oil Country Tubular Goods) is a major issue. C-steel seamless pipes with yield strength of 980 MPa and higher are likely to be require d in the future. Additionally, reasonable sulfide stress corrosion cracking (SSCC) resistance in moderately aggressive environments will be necessary. In terms of line/OCTG pipe safety it is appropriate today to ask for smart pipe solutions, e.g. sensor equipped pipes. Cost effective laying and welding will be more and more important.

Support from the materials side is needed (needed material properties have to be provided). Same applies for new and improved welding methods (e.g. laser supported welding).

### *Flowlines & Risers*

The frontier of deep-water field which can be suitably exploited by current technologies has moved fast in the last decade. Challenges coming from ultra-deep waters of 2000 m and over, as well as from new concepts and technologies require the design of new or improved steel products (seamless and welded pipes, special forged components).

For subsea Flowlines, main future developments are related to laying in ultra-deep water and to increasingly severe operating conditions. Two specific requirements will be stressed in the near future: the deformability of pipe strings (including also the girth welded joint) and its fatigue resistance.

## *c) Steel pipes & components for high productivity energy transportation*

Politically, the issue of securing the energy supply to Europe is becoming of major concern. Alternative pipeline routes and increased gas supply by LNG and CNG (LNG: Liquefied Natural Gas, CNG: Compressed Natural Gas) can support this.

All involved modes of energy transport either by onshore pipelines as well as offshore trunk lines and by vessel (LNG and CNG) will require new or optimized steels as well as design, operation and production concepts to comply with operation at higher internal pressures, higher usage factors, severe loading conditions and an anticipated increased share of corrosive and multiphase gases. Complementary to this, safe transport of $CO_2$ from power plants and other emitters of $CO_2$ to storage areas will play an important role in the future.

$H_2$ in connection to wind energy is a more and more important topic. Energy storage in gas pipelines (max 10% $H_2$) may be the most practical solution to solve the "energy storage problem" Research in this area (transport of gas mixtures) is absolutely needed.

### *Onshore pipelines*

Steels with a high amount of deformability have to be developed as well as plastic design criteria to understand pipe and pipeline behaviour. A key issue for pipeline safety is the avoidance of corrosion and external damage, especially in thin-walled structures. More than 80% of all pipe-line failures can be devoted to corrosive attack or external interference.

Modelling will gain prime importance in development of new steels, pipe production, pipeline design, pipe laying and pipeline operation. Development and improvement of welding technologies will be also a main task as well as the determination of appropriate material and pipe properties, full scale testing and field validation.

From the construction and operation point of view, developments and improvements are needed in cooperation between steel and pipe producers, laying contractors and operation companies like:

- Advanced girth welding processes such as dual tandem, laser and/or hybrid laser.
- Development of optimized and, if possible, automated pipeline construction techniques (e.g. in-creasing offshore laying speed, tie-in equipment, pipeline crossing techniques
- Advances in the inspection, measurement, interpretation and repair of pipeline construction and operational damage
- Improvement of the long term behavior of pipe coatings in accordance with pipeline operation and cathodic protection methods

### *Offshore trunk lines*

Currently, 90% of the world's offshore structures with their related transmission pipelines are in shallow waters, less than 75 meters deep. However, an increasing number of transmission lines in deep (>400 m) and ultra-deep

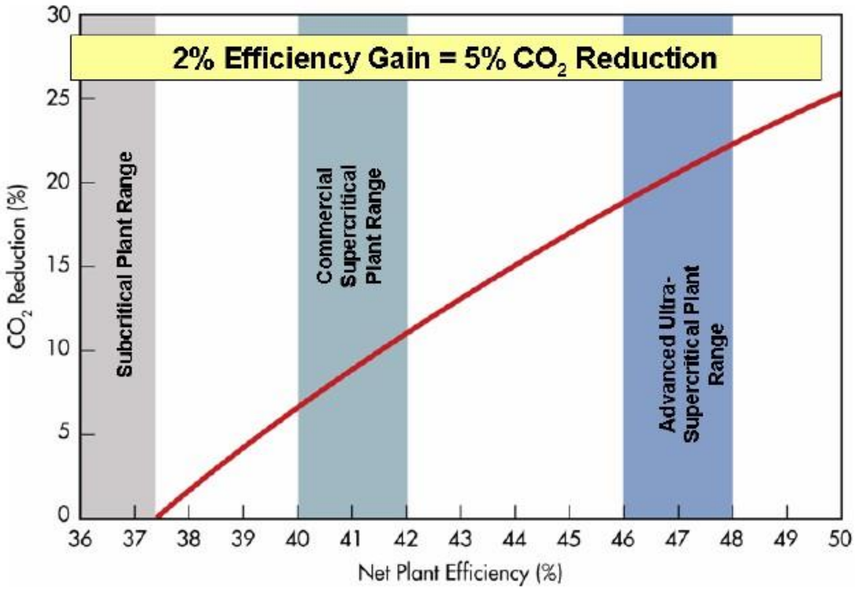




**Figure 29**: Efficiency improvement for advanced USC fossil power plant

(>1500 m) waters are to be expected. Key issues for offshore pipelines are the resistance against the extreme loading conditions (bending, tension, external pressure) during pipe laying and to allow a high speed of welding aiming at higher laying speeds, wall thicknesses and diameters, moreover their resistance to external damage can be a key point for shallow water pipelines. An excellent roundness of pipes is the basis for high speed joining as well as for collapse resistance.

***Liquefied natural gas (LNG)***

Liquefied natural gas (LNG) transportation represents an increasingly important part of the natural gas supply picture in the world For Europe, an increase in LNG supply could contribute to an improved security of gas supply. Current and future R&D&I activities are aiming at a new generation liquefaction, new and larger storage options and expandable LNG trains. Also the development of thermally insulated sub-sea LNG pipeline systems has to be anticipated. These would allow the loading and off-loading terminals to be located much further from shore with easier access by tankers. This technology presents a number of challenges including materials selection, highly stressed pipeline systems, thermal behavior of all components, operational monitoring and operational procedures and mitigation against contingency.

***Compressed Natural Gas (CNG)***

The Compressed Natural Gas transportation can be an interesting solution useful in some specific scenarios. Also this technology presents a number of challenges both in terms of strength/ductility of material, weight/ performance (in term of maximum pressure) of pressure vessel.

***Transportation of alternative gases***

- **Transportation of $CO_2$:** Carbon capture and storage technology (CCS) has the potential to reduce emissions from fossil fuel power stations up to 90%. CCS involves capturing the CO2 emitted from fossil fuels, transporting and storing it in secure spaces such as geological formations, including old oil and gas fields and aquifers under the seabed. CO2 will preferably be transported as a dense fluid. Offshore transportation can also be done by vessels making use of the CNG/PNG (compressed) technique.
- **Transportation of $H_2$:** The transport of hydrogen is the major component of a clean sustainable energy system in the longer term. Although there are currently more than 2000 km of hydrogen transmission pipelines in service in Europe and in the U.S., several technological issues need to be resolved and significant cost reductions are required for effective hydrogen pipeline transmission and distribution.
- **Transportation of aggressive gas mixtures:** Pipes are facing new challenges coming from new and/or more demanding material requirements, related to specific performances and applications when very aggressive gas mixtures (high $H_2S$, CO2, CO, pressure) have been transported in very hard conditions (high temperature, high pressure, high flow, hostile external environment). As an example, wells/fields in the North Sea, in the Kashagan field and/or Gulf of Mexico.

## 2.6.4. Power generation and CCS

Today's energy consumption for electricity production is composed by a mix of fossil sources (coal + natural gas + oil = 65%), nuclear power (17%), hydropower (16%) and renewable (solar+wind+renewables+geothermal+ waste= 2%). In the next 20 years, the fossil sources will still be the main fuel for the production of electricity in the world with an increase up to 72% of the total.

A large increase of electricity demand will come for China, India and the other emerging countries. Therefore several hundred power plants will be built in the main fossil fuelled. Also some new nuclear power plants are under construction, but for the strong increase of this technology the next plant generation is awaited. Therefore the nuclear seems will be reduced as percentage of the total energy supply in the near future. In the decade 2011-2020, the International Energy Agency (IEA) forecasts that the OECD (i.e. Europe plus the United States) will add 184 GW of new coal capacity, compared to 168 GW in China.

The development of the advanced USC fossil power plant with steam temperature up to > 700°C is urgently needed to reduce $CO_2$ emissions.

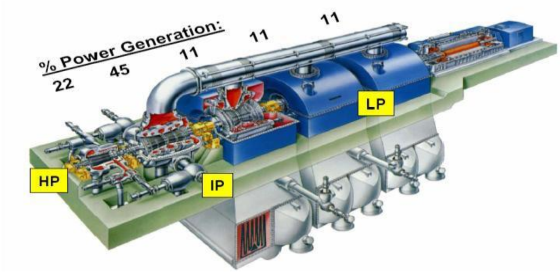


**Figure 30:** Steam turbine for power generation

***Nuclear***

Nuclear Energy contributes to the SET-Plan's objective to develop low carbon energy technology. In this framework, the SET-Plan aims to design and build over the next decade prototypes and demonstrators of fast neutron reactors, technologies for a more sustainable nuclear energy through better resources utilization and the reduction of potential impact of ultimate radioactive waste. On the other hand, the higher temperatures and irradiation levels as well as different coolants than Generation II/III reactors, foreseen for these systems, will require other materials to those used for Light Water

Reactors. In response to these needs the materials roadmap for nuclear fission proposes a research and development program on commercially available material (steel and Ni-alloys) for the prototypes and demonstrators; and advanced materials for the industrial scale systems. The focus is put on cladding application (Oxide Dispersion Strengthened -ODS- steels for liquid metal fast reactor) with the aim to improve high fuel burn-up capabilities and high temperature resistance; on coating technologies to enhance corrosion and erosion/wear resistance in liquid metal fast reactor. Based on the research results, projects to validate manufacturing routes of 9Cr steel heat exchanger, of fuel cladding tubes with ODS are also needed.

## 2.6.5. Renewables (Wind, PV, CSP, H2, Marine energy, others)

Globally, the energy sector emits 26 billion tonnes of CO2 each year and electricity production alone accounts for 41% of emissions. The International Energy Agency expects CO2 emissions in 2030 to have increased by 55% to reach more than 40 billion tonnes of CO2. The share of emissions coming from electricity production will increase to 44% in 2030, reaching 18 billion tonnes of CO2. Europe is going to be importing a growing share of its energy at unpredictable but most likely higher prices, from unstable regions, in competition with the rest of the world and at staggering environmental cost.

### *a) Wind*

At present, the largest turbines are designed for 6 MW and higher capacity (offshore) while much smaller units are locally applied in windy areas to generate the home supply electricity.

The European Wind Energy Technology Platform has a vision in which wind energy covers 12 -14% of the EU's electricity consumption by 2020, with a total installed capacity of 80 GW. By 2030, it sees this increasing to cover 25% of electricity consumption, with 300 GW of installed capacity. Satisfying our energy needs over the coming decades will be a big challenge. The economic future of Europe can be planned on the basis of known and predictable energy costs, derived from an indigenous wind energy source free from all the security-related, political, economic and environmental disadvantages associated with the current energy supply structure. Europe can go a long way towards an energy supply that is superior to the business-as-usual scenario, offering greater energy independence, lower energy costs, reduced fuel price risk, improved competitiveness and more technology exports. Over the coming 25 years, wind energy will play a major role in that development.

### *b) Photovoltaic*

The challenges of the photovoltaic sector is to further improve the competitiveness and ensure the sustainability of PV technology and to facilitate a self-sustaining large-scale penetration in both urban areas and free- field electricity production units, as well as its integration into the electricity grid. Materials are key enablers in all PV systems. There is a need to design and manufacture PV systems that are both efficient and low cost enough to meet specific grid parity targets within the next few years. The materials supply chain needs to be able to supply sufficient quantities of the required elements, and thus, cost effective recycling solutions should be developed along with standardized performance testing and reliability/ageing test protocols needs to be developed to provide confidence (and so bankability) for PV devices employing newly developed materials in a wide range of operating conditions (from Europe to Sunbelt environments).

To this end, the materials roadmap proposes a comprehensive research and development program on the optimization of materials usage through predictive modelling down to quantum devices at the nano-scale, the improvement of intrinsic performance and reduction in layer thickness of constituent materials for both inorganic and organic PV cells and modules.

The roadmap focuses also on materials for light management (anti-reflective, anti-soiling, anti-abrasion

FIG 4.1: **EWEA's three wind power scenarios (in GW)**

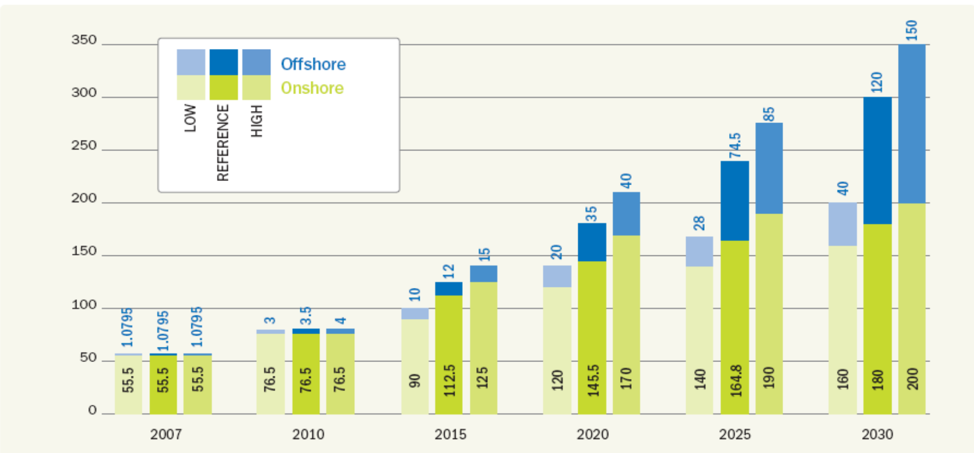


**Figure 31:** Offshore wind farms

coatings, light trapping/guidance, spectral conversion and optical concentrators' materials); the development of high throughput, low cost manufacturing processes for film/layer deposition/thin film (epitaxial) growth.

### c) Concentrated solar

The aim is to support the competitiveness and readiness for mass deployment of advanced concentrated solar power (CSP) plants, through scaling-up of the most promising technologies to pre-commercial or commercial level. Achieving these objectives will require large-scale CSP plants with better technical and environmental performance and lower costs with increasing power availability. This necessitates materials with higher performance than those of today.

Our materials roadmap proposes a comprehensive research and development program on low-cost, spectrally selective, high mechanically stable absorber materials suited also for higher temperatures; and the development of higher reflectance and/or specularity, cost competitive, sustainable reflector materials. The roadmap focuses as well on materials to allow for higher temperatures, better heat transfer; the development of more sustainable, reduced cost, corrosive-resistant structural materials such as steel and the development of storage materials (heat storage materials and materials for thermo-chemical storage) to increase the performance and extend the operating temperature up to 600°C. of heat exchangers also metal structures for central receivers as well as piping and tank structures are deeply needed.

### d) Fuel cells and $H_2$

The aim is to support the development and test, of cost competitive, high energy efficient fuel cell systems and sustainable hydrogen infrastructure technologies under real market conditions for transport and stationary applications. Achieving this goal will necessitate dramatic improvements in the economics, performance and reliability of fuel cells and hydrogen technologies. The need for new materials is overarching.

We focus on developing novel steel and composite materials with enhanced performances to obtain low-cost functional components for hydrogen transport and storage, coal gasification and thermo-chemical cycles technologies (improved chemical and mechanical properties); the development of low cost, reliable and corrosion resistant structural steels and composite structures also for pressurized and cryogenic hydrogen storage.

### e) Transportation of $H_2$ and $H_2$ mixtures

The transport of hydrogen is the major component of a clean sustainable energy system in the longer term. Although there are currently more than 2000 km of hydrogen transmission pipelines in service in Europe and in the U.S., several technological issues need to be resolved and significant cost reductions are required for effective hydrogen pipeline transmission and distribution. These issues include: a better fundamental understanding of hydrogen embrittlement and diffusion to enable the development of lower cost hydrogen resistant steels, or composites for hydrogen pipelines, improved welding or other joining techniques, improved coatings and seals. Grant applications are sought to develop advanced and novel approaches to significantly reduce the cost of new hydrogen pipelines (by as much as 50%) and/or technology to retrofit existing natural gas or petroleum pipelines for pure hydrogen transmission and distribution.

### f) Marine energy

Of all the large natural resources available for generating electricity, ocean energy is one of the last investigated for its potential. Although there are other marine energy sources — the thermal energy resulting from the large temperature differences between deep and cold ocean waters and sun-warmed surface waters, the chemical energy in ocean salinity gradients, and marine biomass, wave and kinetic stream energy are the most well-known.

There are two forms of tidal energy: potential (i.e., harnessing the potential energy changes associated with the tidal rise and fall of sea level) and kinetic (i.e., harnessing the kinetic energy associated with the motion of the tidal stream). There are three types of kinetic energy from water: tidal, ocean current, and river streams.

But how much marine energy is available? What is the amount of electrical capacity available and ex-tractable from two forms of marine energy: wave and kinetic stream?

Estimates of the total renewable energy available from the marine environment can be made by summing together the individual components available from the principal subdivisions of this energy source (Wave, Bio -mass, Ocean Thermal, Tidal, Subsea Current and Salinity Gradient). Estimated availability varies widely with researchers such as Isaacs and Seymour[23] posting estimates of between 1,000 and 10,000 GW. All estimates identify a highly significant energy source, even if only a limited percentage of the available energy can be recovered, either due to the remoteness of the source, transformation inefficiencies, or impact on marine ecosystems.

The technology to convert these resources to electricity has been deployed in demonstration projects, but remains the main challenge to see a large development of the Marine Energy. Commercial projects are expected in the next five to ten years. Given proper care in design, deployment, operation, and maintenance, ocean wave and kinetic stream energy could be two of the most environmentally benign electricity generation technologies yet developed.

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[23] Isaacs & Seymour, "The Ocean as a Power Resource", *Int. J. of Environmental Studies*, vol. 4(3), p201-205

Interest in wave and tidal stream energy has picked up over the last few years. Currently, many different device concepts compete for support and investment, and while some are more advanced than others, all are at early stages compared to other renewable and conventional generation systems. Optimal designs have yet to be converged upon. A few large-scale prototypes have been built and tested in real sea conditions, but no commercial wave and tidal stream projects have been completed to date.

Marine renewable energy has the potential to become competitive with other generation forms in future. In present market conditions, it is likely to be more expensive than other renewable and conventional generation systems until at least hundreds of megawatts capacity are installed. By way of comparison, this capacity is equivalent to several offshore wind farms at the scale currently being constructed.

Fast learning or a step-change cost reduction is needed to make offshore wave energy converters cost competitive for reasonable amounts of investment.

Considerable emphasis needs to be placed on cost reduction to ensure commercial viability for wave and tidal stream technologies. We need to accelerate the progress of technology development, through concept and detailed engineering design to bring substantial reductions in cost.

### 2.6.6. Stakeholders

- Steel industry
- Steel research centers
- Contractors
- Energy Equipment suppliers
- Oil and gas companies
- Electricity producers
- Public authorities
- Universities

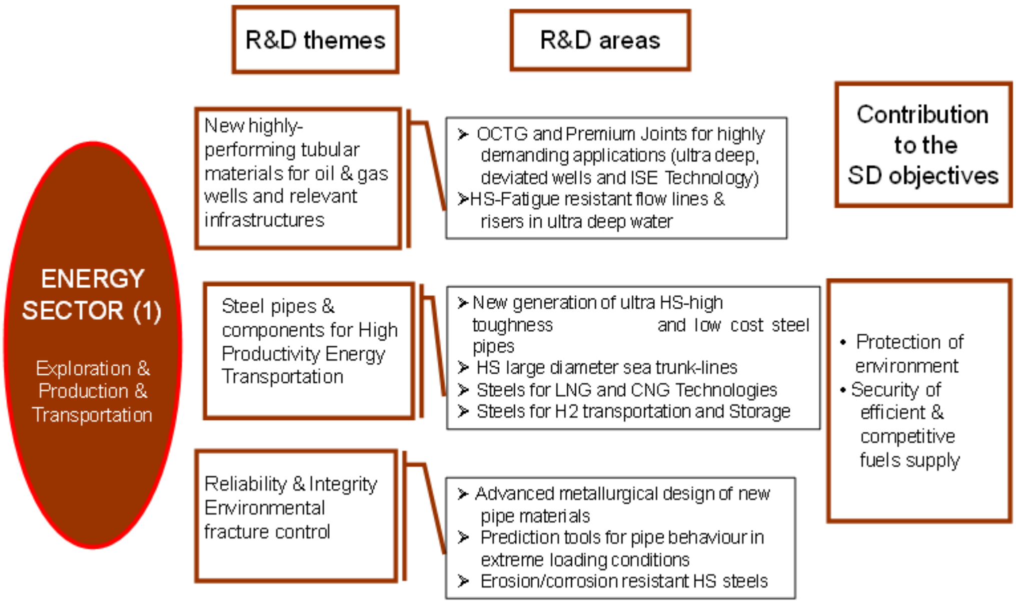
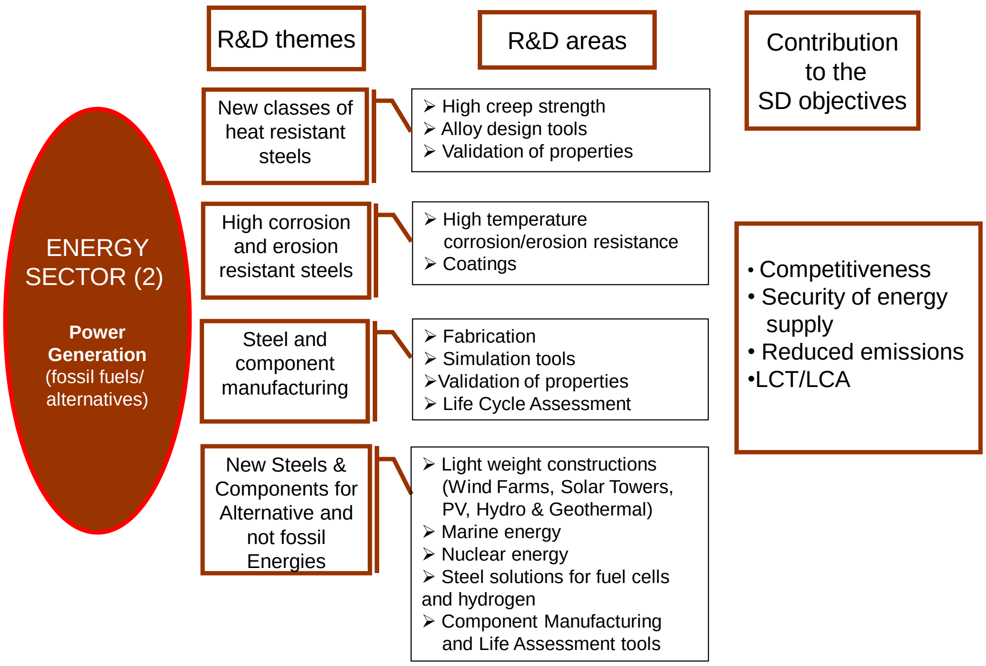



**Figure 32 - 33**: Steel applications for energy : R&D&I themes and areas



## 2.7. Attracting and securing qualified people to help meet the steel sector's ambition (People)

### 2.7.1. Introduction

From now until 2030, the world will undergo major changes, many of which will be brought about by the evolution of science and technology. The European steel industry will contribute its share with new processes and new products conceived to strengthen its competitiveness, answer evolving customer demands and to preserve the environment. Other changes will come from the increasing globalization of the world economy and the world steel market, which will induce continuing rationalization and concentration in the steel industry. Further changes will come from the evolution of society in a dynamic exchange with its own altered surroundings.

People, in the steel industry and in society in general, will be the drivers who make such changes happen, but they will also be those who will have to live through them, and may in some instances oppose them. This illustrates the key role of people in the success of the processes of change, as well as the need to prepare people to address constructively the changes ahead.

During this period the European steel industry will also be faced with an unprecedented and demanding situation. The population pyramid in most steel producing companies is such that more than 20% of its workforce will leave it during the next ten years, and close to 30% during the following ten years. Needless to say, this huge transformation will not only be quantitative, but will also have a crucial qualitative dimension. It represents, at the same time, a daunting challenge and a welcome opportunity.

The opportunity comes from the possibility to use this substantial transformation in the composition of the industry's workforce as an instrument of change.

The challenges lie in making sure that the education system will keep the capacity to supply the steel industry with the number of people and with the competencies it needs, while developing the steel industry's capacity to attract relatively scarce highly skilled people in a competitive labor market.

Requirements concerning labor organization and labor policy are increasing. The question about conditions of preservation and further development of innovation capacity at the level of organization of human work will become the central future issue of public innovation policy, where economic, technological and social innovations interact. One of the greatest current challenges of management is to organize effectively utilization of manpower dealing with core processes of interactive value creation and innovation. At the same time, in light of demographic change and apparent skilled worker shortage, the capacity of companies, to train, to recruit and to make qualified workers stay for a long period, is becoming a decisive success factor. In this context, it will become more important for companies to offer attractive workplaces. Issues of workplace quality will regain importance. The outcome of workplace innovation is to contribute to sustainable changes related to the economy, ecology and employability and to sustainable innovative capability of organizations and individuals.

The continuously improving record of the steel industry in the field of health and safety should also contribute to the attractiveness of the sector. The high priority given by the industry to its "zero accident" objective and the elimination of fatalities is a guarantee of further progress. Further, as reaching these objectives implies significant behavioural changes, improving health and safety at work also comes to be a potent agent of change management. In relation to health and safety and due to technological changes green skills, expertise and awareness have to be developed continuously. All these trends converge on and represent different facets of Talent Management. During the last thirty years, Talent Management has become the nexus of steel companies' competitive strategies, securing the coherence of their implementation and, more generally, seeking the optimization of one of their key assets. In-deed, human resources are the holders of a company's core competencies, which are one of the main sources of its competitive advantages.

Thus, it comes as no surprise that most steel companies, in a way or another, have been pursuing new organizational configurations tending to transform enterprises into "knowledge organizations", dealing also with the management of knowledge.

Talent Management also plays a key role in change management. In this capacity, it is instrumental in developing an industrial relations system supportive of innovation, improvement of job quality, and competitiveness, thanks to a constructive social dialogue.

In the end, an effective Talent Management is essential to the successful implementation of the steel sector's long term vision regarding profit, partners, the planet, and people

### 2.7.2. Research theme and implementation of actions

The main objective of attracting and securing qualified people to help meeting the steel sectors ambition will be operationalized by five research and development themes:

- Health and safety
- Innovation management
- Attracting and retaining qualified people
- Talent management

Within the topics health and safety, attracting and retaining qualified people as well as talent management a lot of activities were already carried out within ESTEP's WG People from a perspective of best practice exchange and first research activities. These themes will be further developed within research activities and the acquisition of projects, integrating innovation management (as an integrated approach combining technological innovation with a social innovation perspective) and management of knowledge as new priorities. Needless to say that the existing and future cooperation with the Social Dialogue Committee will be fed by these themes and its results as well.

### a) *Health and safety: Zero accidents still being the ambition*

The European steel industry has long been a pioneer in promoting and carrying out research to improve health and safety at work, mainly through the ECSC Social Affairs research programmes, which started in the early 1950s. The improvement of working conditions was in fact one of the most important objectives of the ECSC Treaty, and huge resources, amounting to approximately € 240 million, were dedicated to health and safety research until the programme lapsed in 1994. Subsequently, health and safety issues were only partly covered by ECSC Technical Research that ran to the end of the ECSC Treaty, and now, in the current Research Fund for Coal and Steel Research (RFCS) programme.

However, steel companies and organisations of the steel industry created specific methodologies and activities in the management of health and safety with the objective of reaching the "zero accident" target. All experts agree that in spite of the unquestionable progress that has been made, there are still too many accidents and health diseases occurring in the steel industry, even in the best cases. In order to foster breakthroughs, health and safety is and must be considered among the most important company objectives, with all hierarchical levels aware of its relevance and with adequate human and financial resources provided to achieve them. The most advanced steel companies in this field put health and safety at the top of the agenda of the periodic meetings of the board of directors, giving a clear signal to all the underlying layers down to the shop floor.

But working conditions are still changing rapidly, switching from physical to mental loading, and the consequences of new working conditions on workers should be investigated. The steel industry nowadays is characterised by a high internal risk potential due to the highly technology driven production process. The other way round, new technologies could take over harsh activities of the workers. Also the increasing number of subcontracting accumulates the operation risks because of the lower standards of risk management in most of these enterprises (estimated up to five time higher accident rates).

New safety concepts focus on technical and organisational, human and cultural factors. The acceptability and the achievement of these concepts could only reached by a risk sensitive workforce. Therefore awareness programmes and technologies have to be developed also than organisational models and risk decreasing tools and methods (simulation, monitoring, etc.), in line with the new paradigm of social innovation combining different perspectives in an overall approach (see e.g. the Horizon 2020 programme).

The long-term vision is the achievement of the zero accidents objective. This in turn calls for a multidisciplinary approach to prevent accidents and treat injuries, i.e. call for the integration of health and safety ergonomic, and even organizational aspects in research or research and development projects, as well as in designing new plants, production lines and products. WG People started with an exchange of good practice within the different companies engaged and went on to develop new research projects combining technological and behavioural development strategies supporting sustainable, fundamental and continuous improvement of performances towards a zero accident workplaces. This includes strengthening managers' understanding of their role and responsibility in health and safety and to provide managers with an overview of good practices and tools available within the company.

### b) *Innovation management: A comprehensive approach embedding technological innovation in a social innovation process*

Requirements concerning labour organisation and labour policy are increasing. The question about conditions of preservation and further development of innovation capacity at the level of organisation of human work will become the central future issue of innovation policy, where economic, technological and social innovations interact. Again, this will be done in line with the EU 2020 Strategy: "Creativity and innovation in general and social innovation in particular are essential factors for fostering sustainable growth, securing jobs and increasing competitive abilities, especially in the midst of the economic and financial markets crisis."[24]

Innovation management from a peoples´ perspective is different from a pure technological perspective like it is nowadays mainly discussed within the recent digital developments named "internet of things", industry 4.0 or the fourth industrial revolution. Every technological or economic innovation is also a social innovation because of the social adaption, implementation or refusal of these innovations. Therefore innovation management has to be seen as new strategies, concepts, ideas and organisational models to meet social needs of the employees. Within joint initiatives between ESTEP, companies and universities research (even from other industry sectors than the Steel

[24] Barroso 2009, Rapid Press Release, IP-09-81

Industry) innovation management will be fostered or initiated by the development of innovation :

- to create, develop and implement innovation in different fields like organisational development, work practices, collective intelligence, knowledge and change management
- to foster the ability to change practices taking into account constraints and opportunities, to lead change, to take into account new expectations from personnel and society
- to advance working conditions and to enable work place innovation.

Taking this approach serious the integration of technological innovation within social innovation processes (every technological innovation is a social innovation as well) a more intensive co-operation between WG People and the other working groups is intended.

### c) *Attracting and retaining qualified people: the ground for a competitive steel industry*

Due to the relevance of the steel industry for the industrial European added value and to ensure the ongoing competitiveness of a safer, cleaner and more technologically developed steel industry, a highly skilled workforce is required. In fact, highly skilled people are the vital resource for the industrial added value in Europe today and tomorrow.

For this very reason, it will be the sufficient supply of qualified and trained workforces which will decide the future success of businesses. Current and future social challenges like demographic change, an over aged workforce, skill shortages and others have to be proactively solved by the steel companies within competitiveness with other advanced manufacturing industries.

Therefore the steel industry is developing its capacity to attract, recruit and retain highly skilled workers in a competitive labour market. It will be people, independent of organisational or technical innovations, which will create innovation and success in the end. The challenge is :

- How to raise awareness of young people at an early stage and broadly enough in the vast amount of possibilities technology can mean to them?
- How to communicate the leading technologies of the European steel industry in order to attract talented young people to study metallurgy/materials science and engineering?
- How to tempt talented people to find their way into steel industry, and to stay to further develop technology, products and solutions for customers and customers' customers?

Actions to be implemented by WG People are:

- surveys to evaluate the attitudes of school pupils and students towards the steel industry
- concepts and activities to promote the image of the steel industry
- supporting resources and teaching for technical education (mathematics, physics, chemistry, design, technology and engineering).

### d) *Talent management: crucial for current and future innovation and competitiveness*

Talent management is one of the main current and approaching challenges for the competitiveness of the European steel industry in particular and the European economy in general. In line with the main European strategies[25], high qualification and competence of the workforce is seen as the prerequisite for the European industrial added value. In particular the steel industry of today, with its high-tech production processes, needs young talents to keep its European companies competitive by a continuous improvement of innovation in products and production (technologically, organisational, and environmental).

Of course, talent management is primarily a company's task and enormous activities and strategies already put in place by steel companies: events, fairs, target group specific and young potential programs, mentoring and management training programs, internship and trainee programs, systematic personnel development. Cooperation between steel companies and schools and universities seems quite normal nowadays. These activities are adjusted to short-term recruiting as well as to long-term retention and attractiveness.

The performance of talent management includes all phases of lifelong learning: it runs from informing and explaining pupils about technical professions in industry at (primary and secondary) schools over to students and graduates. The development of talents comprises systematic measures in personnel development and target group oriented training seminars and coaching for all workforce members.

Collaboration between companies, regional and local education, training institutions, job centres, vocational schools, "steel related" universities, and also primary and secondary schools, management and training academies as well as faculties and universities have to be developed further in a more reliable way. New kind of co-operations like dual study, pathways between higher education and vocational education have to be established between companies and educational systems and in between the different educational systems.

The results of the survey on Talent Management in the European Steel Industry conducted by WG People in 2015 is delivering the ground for further activities in the

[25] Particularly Europe 2020 strategy and its flagship initiative "An Agenda for New Skills and Jobs", Communication Paper on Integrated Industrial Policy putting competitiveness at centre stage

direction of targeted strategies to recruit, develop and retain talented people from every age. As well a comparative analysis of enterprise approaches as learning organisations will help to analyse the critical factors for success and constraints for future innovation and competitiveness.

### 2.7.3. Social responsibility and inclusive business

- Ensuring safe work conditions;
- Exchange of practices in view of the "zero accident" target;
- Close relationships with a network of top level universities taking initiatives to attract the best students in the steel industry; disseminate a steel culture;
- Support and development of training at European level;
- Fostering the interrelation of technological with social innovation as co-creation processes, integrating all the relevant stakeholders and dealing with social and environmental impact

### 2.7.4. Stakeholders

- Steel sector
- European universities dealing with steel developments
- Steel research centres
- Unions organisations
- Stakeholders in the European Steel Technology Platform

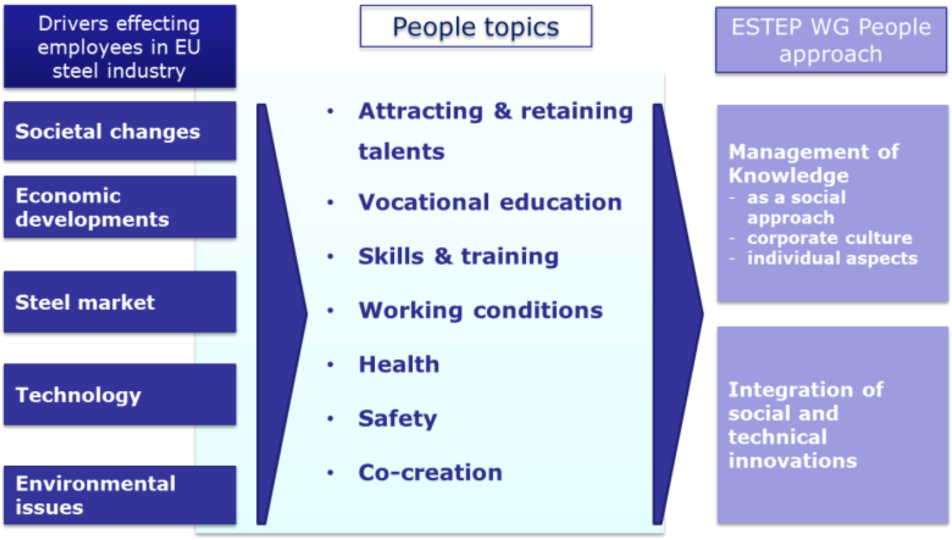



**Figure 34**: Attracting and securing qualified people to help meeting steel sector's ambition

# Part 3. Overall view of ESTEP's SRA and consistency with Horizon 2020

This new SRA offers a global vision of the innovation and R&D&I efforts that should help the steel sector and its value chain reach the objectives highlighted by ESTEP to retain a sustainable world leadership of the sector in the coming decade.

Priorities have been identified for the themes and R&D&I areas of the three industrial programs of ESTEP and of the 7 domains described in the previous chapters:

- Sustainable steel production
- Safe, cost-effective and lower capital intensive technologies
- Steel solutions for transports
- Steel solutions for construction and infrastructures
- Steel solution for energy
- Attracting and securing qualified people for the steel sector.
- Enabling the digitisation of the steel sector

Another important aspect of this program is to cover the whole chain of innovation, addressing basic and applied research, pre-industrialization and deployment. The activities of the research & innovation cycle can be represented by the Technology Readiness Levels (TRLs). This methodology has become recognized internationally and is being at industry level: the 9 TRL steps, from basic principles to market commercialization are shown in Figure18.
In the next chapter (4-Implementation), a deployment scheme will be proposed for the different R&D&I themes over the next decade, using TRL methodology.

Private funding from stakeholders as well as public funding from the EU, National and, possibly, Regional institutions will be necessary to implement the 3 industrial programs and a transversal one.

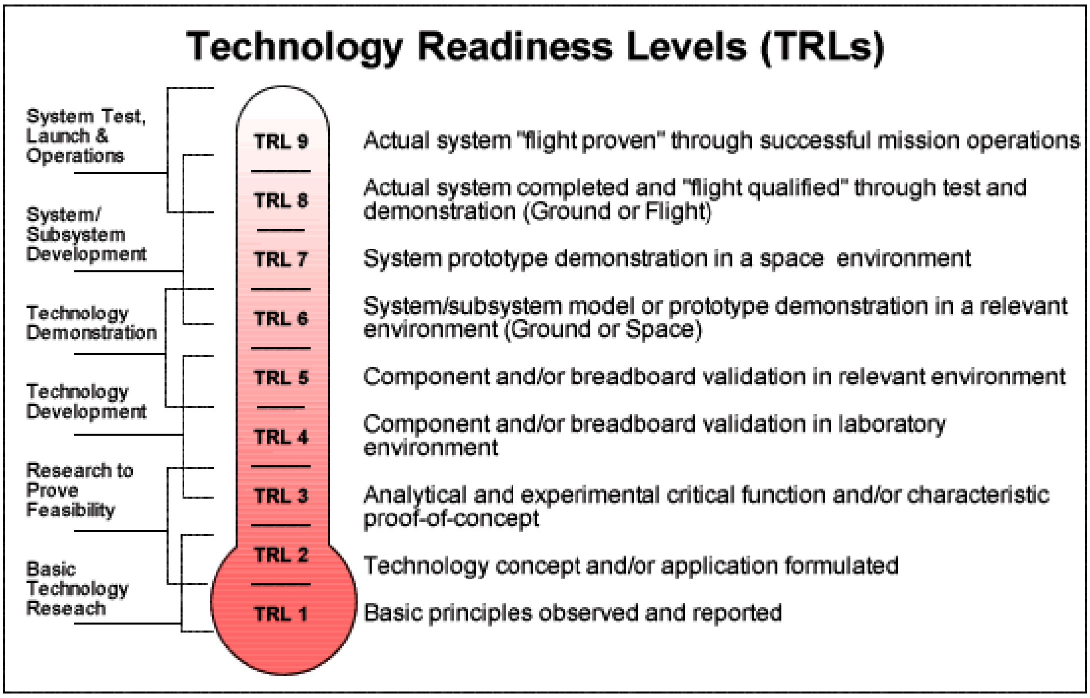



**Figure 35:** TRLs describing the whole chain of innovation

## 3.1. Horizon 2020

The new Research & Innovation roadmap proposed by the European Commission[26] has been carefully analyzed by the ESTEP Working Groups, and this revised agenda already includes the topics which are relevant to the steel sector.

Within Horizon 2020, the implementation would follow 3 key priorities:

- Excellent science
- Industrial leadership
- Societal challenges

For *Excellent Science,* one of the challenges for the steel sector is to attract talented young researchers and to offer better career prospects within our industry. Another objective is for ESTEP to work closely with Universities and engineering high schools for developing the different domains of European science in order to meet challenges of the steel industry of the future.

For *Industrial Leadership,* the proposals of the EC to enhance the KETs (Key Enabling Technologies) are welcomed by ESTEP. In particular, the 2 items "advanced materials" and "advanced processing and manufacturing" are developed in the present revised roadmap.

For *Societal Challenges,* the most relevant items for the steel sector are "secure, clean and efficient energy", "Smart, green, and integrated transport", "climate action, resource efficiency and raw materials" and "inclusive and innovative societies".

Horizon 2020 also marks a new start and a new ambition for R&D&I with a clear need to identify strategic targets and expected impacts. It is a new way of working, putting everyone together to promote not only research, but also innovation, in order to make the link with market expectations. In this context, the European Technology Platforms have a key role to play. We have to create the bridge from science and knowledge to users and customers, transforming results into industrial reality.

This implementation of this SRA should take place between 2014 and 2020 for both Horizon 2020 and the Research Fund for Coal and Steel (RFCS) activities.

The Research Fund for Coal and Steel program should refer to the SRA in formulating the annual priorities, looking for a significant number of projects in line with the SRA and these priorities.

ESTEP has been involved already in the preparation of Horizon 2020, especially within the Public Private Partnerships, the Key Enabling Technologies, and some of the European innovation Partnerships (EIP) such as Raw Materials, Water Resource and Key Enabling Technologies.

## 3.2. Public Private Partnerships

At the end of 2008, the onset of the economic crisis, the European Union launched its Economic Recovery Plan, based on the need to reinforce Europe's competitiveness through innovation. Three Public Private Partnerships (PPP) were created: Factories of the Future (FoF), Energy Efficient Building (E2B) and the European Green Cars Initiative now called the European Green Vehicles Initiative (EGVI). The steel sector decided to participate to these three research PPPs.
Building on the experience of the PPPs under the European economic recovery plan, the European commission considered that within Horizon 2020 " there will be greater scope for establishing such Partnerships without recourse to new legislatives procedures". That is why through cross-sectorial contacts with other ETPs and associations, ESTEP strongly contributed to the creation of SPIRE as a new PPP in H2020.
Several of ESTEP' stakeholders are involved in these PPPs, as partners in H2020 calls. ESTEP is in favour of pursuing these contractual PPPs within the successor of Horizon 2020 (Fp9): the themes and some areas developed in chapter 2 are well in line with FoF, EGVI, E2B, and SPIRE. This is also true for EMIRI, which is well recognised even without being a contractual PPP.

- **FoF**, Factories of the Future. The new 2020 roadmap identifies significant impact for the whole value chain of production, with increased value added by advanced processing and manufacturing. The environmental impact makes reference to the reduction of energy consumption, of waste generation as well as the consumption of materials, well in line with themes and areas of chapter 2. The most relevant domains of Research & Innovation proposed by FoF are: processing novel materials, advanced joining technologies, material efficient manufacturing, product life cycle management for advanced materials, adaptive and smart manufacturing systems, intelligent maintenance systems, energy monitoring and customer-focused manufacturing. The challenge for the steel sector lies in the focus of FoF on discrete manufacturing rather than continuous production.
- **EGVI**, European Green Vehicles Initiative. The objective of this PPP in Horizon 2020 is "energy efficiency of vehicles and alternative powertrains", including electrification, hybridization, advanced Internal Combustion Engines and adaptation to alternative fuels. The roadmap proposes the development of technologies at all product layers from modules to systems and vehicles. Chapter 2 of this SRA is well in line with the domains "modules" and "systems" of the EGVI roadmap. The development of resources, like new steel

[26] European Commission (2011), 808 final – Horizon 2020: The Framework programme for Research and Innovation. COM (2011), 809 final - Establishing Horizon 2020. COM (2011), 810 final - Changing down the rules for participation and dissemination in Horizon 2020. COM (2011), 811 final - Establishing the specific programme implementing Horizon 2020.

products, is not directly in the scope, but the integration of resources for the definition of modules and systems is covered. The application of new materials leading to the weight reduction of a module is given as an example.

- **E2B**, Energy Efficient Building. The roadmap aims at developing R&D&I activities covering the components of the value chain of production. Some of them are fully relevant to chapter 2, promoting steel- based solutions for construction: structural parts where material processing innovation will allow further reducing $CO_2$ embodied footprint of the structural components over the life cycle of new buildings, building envelopes reducing heating/cooling demands by a smart use of renewable energies, construction processes combining pre-manufacturing of critical components and self-inspection/automation of construction, end-of-life optimization in view of recycling/reusing demolition waste.
- **SPIRE,** Sustainable Process Industries through Resource and Energy Efficiency. The steel sector is one of the main European process industries producing structural materials and ESTEP is one of the founding members of this initiative, well in-line with the chapter 2 of the ESTEP roadmap.
- **EMIRI**, Energy Materials Industrial Research Initiatives. The purpose is to develop materials solutions for the production of energy, both for conventional means of production (fossil fuel, nuclear) and for renewable energy (wind turbines, photovoltaics, concentrated solar, etc.) ESTEP is a partner in the project, well in-line with chapter 2.

## 3.3. European Innovation Partnerships

The **European Innovation Partnerships** (EIPs) have been proposed by the European Commission as part the flagship initiative Innovation Union, communicated at the end of 2010. ESTEP has been involved in several EIPs, which will help coordinate with Horizon 2020 over the period 2013-2020.

- **The Raw Materials Initiative**, dealing with the issues of sustainable supply of raw materials. ESTEP is active within work package 1, Developing New Innovative Technologies and Solutions for Sustainable Raw Materials Supply, especially in the area of "secondary" raw materials providing innovation for the valorisation of waste and by-products. ESTEP also participates to work package 2, Substitution of Critical Materials, providing inputs for steel alloying elements.
- **The Water Resource Initiative**, dealing with the sustainable use of water in the industry. ESTEP has worked closely with the Water Technology Platform (WssTP) in order to identify new topics of R&D&I for a better use of water in the steel industry (chapters 2.1. and 2.2.).
- **Key Enabling Technologies** (KETs). ESTEP is active for two KETS: Advanced Materials (steel is of course an advanced material) and Advanced Manufacturing and Processing. For this last KET, it is important to notice that our SPIRE initiative is well in-line with what was proposed in the HORIZON 2020 communication for increasing the competitiveness of process industries by drastically improving resource and energy efficiencies.

## 3.4. Other initiatives

The **SET-Plan**, Strategic Energy Technology Plan, adopted by the European Union in 2008, aims at establishing an energy technology policy for Europe over the next 20 years. The implementation of the SET-Plan started with the establishment of the European industrial Initiatives (EIIs), aiming at the rapid development of key energy technologies at European level for the production of renewable and conventional energy. ESTEP participated actively to the preparation of the materials roadmap of the SET-Plan, proposing innovative material solution for energy production and energy efficient buildings[27] . The Chapter 2 of ESTEP's SRA is well in line with this material roadmap.


The SET-Plan includes also initiatives for the "energy intensive industries" like chemicals, cement, metal, which have since been renamed process industries. In 2016, the implementation started by a public consultation. Action 6 (energy efficiency for industry) and action 9 (carbon capture storage/use) are of high relevance for the steel sector. ESTEP/EUROFER are contributing to these working groups of the SET-Plan. In action 6 two sectors are given a priority: steel and chemistry.

The **Strategic Transport Technology Plan** (STTP), adopted by the European Union in 2011, sets ambitious objectives for reducing Europe's dependence on imported oil, improving the environment, reducing accidents and sharply cutting greenhouse-gas emissions. In 2012, a Research & Innovation approach was proposed for this STTP[28], identifying three main areas for R&D&I:

- Clean, efficient, safe, smart transport means
- Infrastructure & and smart systems

[27] SEC (2011) 1609 Final- Materials Roadmap Low Carbon Energy Technology.

[28] European Commission (2012), 501 final – Research and Innovation for Europe's future mobility developing a European Transport Technology strategy.

- Transport services and operations for passengers and freight

With regard to means of transport, the development of clean and safe vehicles proposes the R&D&I areas of the Green Vehicles PPP initiatives. Trains and vessels are also in the scope. The plan includes development in components, materials and enabling technologies where steel has a role to play (cf. chapter 2). The Joint Technology Initiative (JTI) Shift2Rail is also contributing to these objectives, with having an ESTEP member working in it.

**The Alliance for Materials, A4M**. The driver for this A4M collaboration is to ensure a value-chain coverage in the frame of Materials R&D for improving the speed of implementation of innovation within Horizon 2020. Created in 2011, and initiated by EuMaT, the European Technology Platform for Advanced Engineering Materials and Technologies, A4M gathers six ETPs with a strong materials agenda in their respective strategies: EuMaT, Suschem (the chemicals platform), Manufuture (the platform on manufacturing), FTC (the platform for textiles), ESTEP and SMR (the platform on mineral resources). Materials R&D are by definition a crosscutting and enabling technology area that affects every industrial sector. This value-chain coverage is essential for the steel applications and ESTEP is active within A4M for contributing to this coordination need along the value-chain of production.

**The flagship initiative "an agenda for new skills and jobs"**. When defining the Europe 2020 strategy in 2010, the European Commission was putting forward flagship initiatives, and one of them is targeting new skills and jobs.[29] Our ESTEP transversal group for attracting and securing qualified people takes into account this challenge for new skills and jobs in the steel industry, especially when proposing cooperation in education and training involving universities and social partners.

[29] COM (2008) 868 final - New skills for new jobs - Anticipating and matching labour market and skills needs.

# Glossary

| | |
|---|---|
| A4M | Alliance for Materials |
| AHSS | Advanced High Strength Steel |
| AUST SS | High strength Austenitic Stainless Steels |
| BAU | Business As Usual |
| BF | Blast Furnace |
| BH | Bake Hardening steel |
| BOF | Basic Oxygen Furnace |
| CAD | Computer-Aided Design |
| CAM | Computer-Aided Manufacturing |
| CCS | Carbon Capture and Storage |
| CIP | Competitiveness and Innovation Programme |
| CMn | Carbon Manages Steel |
| CNG | Compressed Natural Gas |
| CP | Complex Phase steel |
| CSP | Concentrate Solar Power plant |
| CSR | Corporate Social Responsibility |
| DP | Dual Phase steel |
| DRI | Direct Reduced Iron |
| EAF | Electric Arc Furnace |
| E2B | Energy Efficient Building |
| ECTP | European Construction Technology Platform |
| EED | Energy Efficiency Directive |
| EGVI | European Green Vehicle Initiative |
| EII | European Industrial Initiative |
| EIP | European Innovation Partnership |
| EIT | European Institute of Technology |
| EMIRI | Energy Materials Industrial Research Initiative |
| EMS | Energy Management System |
| ESTEP | European Steel Technology Platform |
| ETP | European Technology Platform |
| ETS | Emissions Trading Scheme |
| EuMaT | European technology platform for advanced engineering Materials and Technologies |
| EWEA | European Wind Energy Association |
| FoF | Factories of the Future |
| FP6 | 6th Framework Programme (2000-2006) |
| FP7 | 7th Framework Programme (2007-2013) |
| GDP | Gross Domestic Product |
| Gen 3 HSHF | Third Generation High Strength, High Formability Steel |
| GHG | Green House Gases |
| HSLA | High Strength Low Alloy steel |
| HSS | High Strength Steel |
| I2M | Integrated Intelligent Manufacturing |
| IED | Industrial Emissions Directive |
| IF | Interstitial free steel |
| JRC | Joint Research Centre |
| JTI | Joint Technology Initiative |
| IF-HS | Interstitial Free High Strength |
| IPPC | Integrated Pollution Prevention and Control |
| KET | Key Enabling Technology |
| LCA | Life Cycle Assessment |
| LCC | Life Cycle Costing |
| L-IP | Light Induced Plasticity steels |
| LCT | Life Cycle Thinking |
| LNG | Liquefied Natural Gas |
| Manufuture | European technology platform for Manufacturing |
| MART | Martensitic Steel |
| MFA | Material Flow Analysis |
| Mild | Mild steel |
| NER-300 | New Entrant Reserve of CO2 emissions rights (300 million tons allowances) |
| OCTG | Oil Country Tubular Goods |
| OECD | Organization for Economic Co-operation and Development |
| ORC | Organic Rankin Cycle |
| PHS | Press Hardened Steel (hot stamping) |
| PPP | Public Private Partnership |
| REACH | Registration, Evaluation, Authorization, and restriction of Chemical substances |
| reFINE | research for Future Infrastructure Networks in Europe |
| R&D&I | Research & Development & Innovation |

| | |
|---|---|
| RFCS | Research Fund for Coal and Steel |
| RTD | Research Technology Development |
| SET-Plan | Strategic Energy Technology Plan |
| SF | Stretch Flangeable steel |
| SMR | Sustainable Minerals Resources ETP |
| SPIRE | Sustainable Process Industry through Resource and Energy efficiency |
| SRA | Strategic Research Agenda |
| SSC | Sulfur Stress Corrosion |
| STTP | Strategic Transport Technology Plan |
| Suschem | European technology platform for chemicals |
| TGR | Top Gas Recycling |
| TRIP | Transformation Induced Plasticity steel |
| TWIP | Twinning Induced Plasticity steel |
| ULCOS | Ultra Low CO2 Steel making |
| USC | Ultra Super Critic power plant |
| VD | Vacuum Degassing |
| VOD | Vacuum Oxygen Decarburization |
| WG | Working Group |

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