Research Fund for Coal and Steel

A summary of the findings of
the Steel Research Technical Groups - 2023

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Compiled by Anastasios Tsakalidis, Spyridon Merkourakis, Andreas Jenet and Sebastiano Fumero

European Commission

European Research Executive Agency (REA)
Unit B.1 — Future Low Emission Industries

E-mail: REA-RFCS@ec.europa.eu

European Commission
B-1049 Brussels

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This synthesis is based on reports provided following the annual meetings of the steel research techical groups (TGAs) that support the Research Fund for Coal and Steel: TGA1 – Iron- and steelmaking; TGA2 – Downstream steel processing; TGA3 – Conception of steel products; TGA4 – Steel applications and solutions for existing and new markets; and TGA5 – Steel factories – smart and human. The synthesis would not have been possible without the input of the members of these groups.

Summary

The Research Fund for Coal and Steel has made significant contributions to the European Green Deal and contributes through its steel-related research and innovation projects to the Clean Steel Partnership, the EU's new industrial strategy and the sustainable Europe investment plan. The fund's portfolio of projects addresses key areas such as decarbonisation, process control and waste management, covering various aspects of the steel industry, including iron- and steelmaking, downstream steel processing, the conception of steel products, steel applications and solutions, and steel factories – smart and human. The project portfolio contributes to several key performance indicators of the Clean Steel Partnership, including decreasing scope 1 and 2 emissions, decreasing specific energy consumption, and reusing and recycling solid residues.

This report summarises the key outcomes and recommendations of five expert meetings of the steel research technical groups in 2023. It highlights the potential for collaboration and synergies among the portfolio of steel-related projects, and also with EU-funded initiatives of the Clean Steel Partnership, Horizon Europe and others.

The report also provides recommendations for future calls, including an additional focus on additive manufacturing, prolonging the service life of and reuse of steel from industrial assets, the primary energy sector, and incorporating artificial intelligence and predictive simulation models in innovative steel products. It recommends the inclusion of key performance indicators to measure the impact of systems and solutions developed in a final assessment. The report concludes that the fund's portfolio is well positioned to contribute to the European Green Deal objectives and the Clean Steel Partnership key performance indicators, with opportunities for further development and implementation.

1. Introduction

The Research Fund for Coal and Steel (RFCS) is a multiannual European Union (EU) research programme distinct from Horizon Europe, an EU framework programme for research. According to its legal basis, the RFCS seeks to provide support for collaborative research in the coal and steel sectors. It is consistent with the scientific, technological and political objectives of the EU, complementing activities carried out in the EU Member States and within the EU's existing research programmes, in particular its framework programmes for research.

During the 2021–2027 programming period, the RFCS is linked to the objectives of the European Green Deal (EGD) ([1]), which aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy, where there are no net greenhouse gas (GHG) emissions in 2050 and economic growth is decoupled from resource use. Other policy priorities include the Clean Steel Partnership (CSP), the new industrial strategy for Europe ([2]), the Just Transition Mechanism ([3]) and the sustainable Europe investment plan ([4]).

The RFCS plays a crucial role in supporting the EU's ambitious climate and industrial policies, including the EGD, the new industrial strategy for Europe, the Just Transition Mechanism and the sustainable Europe investment plan. In the steel sector, the RFCS supports research and innovation projects that aim to reduce GHG emissions, improve energy efficiency and develop low-carbon steel production technologies. With a significant budget of approximately EUR 568 million for 2021–2027, the RFCS is funding a diverse range of steel-related projects, including those focused on hydrogen-based steel production, carbon capture and storage and advanced steel recycling technologies.

The RFCS is also working in close cooperation with the CSP, a European Commission initiative that aims to accelerate the transition to low-carbon steel production in Europe. By supporting research and innovation projects that align with the CSP's objectives, the RFCS is helping to bridge the gap between research and industry, and to bring low-carbon steel technologies to market. The RFCS portfolio of projects related to steel comprises around 50–70 projects annually, with a focus on supporting the development of breakthrough technologies and innovative solutions that could help the European steel industry to decarbonise and remain competitive. By supporting the CSP and other EU initiatives, the RFCS is contributing to the development of a sustainable and climate-neutral European steel industry that is capable of overcoming the challenges of the future.

The fund supports three main types of actions: research projects, accompanying measures, and pilot and demonstration projects. Actions related to research projects fund research and innovation projects that develop new technologies. Accompanying measures support complementary activities, such as the dissemination and exploitation of results, training and networking. Actions associated with pilot and demonstration projects fund projects that showcase the feasibility and scalability of new technologies.

([1]) https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

([2]) https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en (as updated by Commission communication – Updating the 2020 new industrial strategy: Building a stronger single market for Europe's recovery (COM(2021) 350 final)).

([3]) https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en.

([4]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0021.

The RFCS is implemented by the European Research Executive Agency. This implementation is supported by **technical groups (TGs)**, composed of technical experts appointed by the European Research Executive Agency to monitor research projects and the dissemination and exploitation of research results, and provide feedback to policymakers. There are five steel research technical groups (TGAs), namely **TGA1 – Iron- and steelmaking**; **TGA2 – Downstream steel processing**; **TGA3 – Conception of steel products**; **TGA4 – Steel applications and solutions for existing and new markets**; and **TGA5 – Steel factories – smart and human**. One meeting takes place annually per TG, at which selected RFCS projects are presented by their coordinators.

Table 1: TG meeting schedule for 2023

TG	Date of meeting	Place of meeting
TGA1	4–5 October 2023	Barcelona, Spain
TGA2	17 October 2023	Online
TGA3	5 July 2023	Lisbon, Portugal
TGA4	21–22 November 2023	Leoben, Austria
TGA5	17–18 July 2023	Pisa, Italy

This report synthesises the final reports of the five TG meetings of 2023 and aims to highlight their most important outcomes. These include various findings related to the status of projects and their potential impact on the steel industry's performance (e.g. synergies, competitiveness) and regarding EU policies (e.g. the EGD). Moreover, recommendations are provided for further developing and implementing a policy framework for research and innovation through the RFCS.

2. An overview of the technical group meeting outcomes

2.1. Projects' contributions to the European Green Deal

An assessment of the findings of the five TG meetings showed that the RFCS portfolio of steel-related projects is in line with the EGD objectives.

2.1.1. Iron- and steelmaking (TGA1)

The TGA1 portfolio contributes to the objectives of the EGD by covering mainly the decarbonisation of steel production, the improvement of process control, and waste management. It also addresses the treatment of waste and the recovery of valuable secondary raw materials, including slag, inside and outside the steel plant; pollution control and the protection of the environment in and around the steel plant; and, lastly, new steel grades used to facilitate green mobility (through vehicle weight reduction) or to produce green energy.

2.1.2. Downstream steel processing (TGA2)

The TGA2 portfolio provides good coverage of the RFCS's objectives. The projects aim to achieve a balance between economic constraints and EGD goals, focusing on downstream steel processing and the fields of process optimisation, sensors, modelling, process integration, maintenance, energy efficiency and cross-sectoral activities.

2.1.3. Conception of steel products (TGA3)

The TGA3 portfolio supports the EGD with the aim of increasing the use of electricity produced from renewables, and the use of electrical steels to improve magnetic steel performance, which, together with machine design, greatly influences the efficiency (e.g. e-mobility) of electric motors. The projects also promote the development of predictive simulation models of microstructures, mechanical properties and production processes. These models will be used in future to drive the production of materials (product line management) or to develop digital twins of the press forming process. Furthermore, this portfolio of projects contributes to the standardisation of testing and evaluation methods.

2.1.4. Steel applications and solutions for existing and new markets (TGA4)

The TGA4 portfolio contributes directly or indirectly to the RFCS's objectives as well as those of the EGD, with projects contributing to green (i.e. carbon-neutral) steelmaking and aiming to increase resource efficiency in the construction and automotive sectors. However, the effective reduction of carbon emissions, energy consumption and other environmental impacts, as well as the conservation of resources, is still moderate.

2.1.5. Steel factories – smart and human (TGA5)

In the TGA5 portfolio, digitalisation is currently a component of most projects, including those focused on environmental issues and those targeting the improvement of workers' health and safety. The latter mainly aim to promote the use of artificial intelligence (AI) and robotics to relieve operators from cumbersome, risky or repetitive operations (including big data analysis) while preserving their central role in decision-making, according to the demands of the steel sector.

2.2. Benefits for industry and for society

The assessment of the current RFCS portfolio of projects has shown that all TGs can have benefits for the EU steel sector but also for European society, both directly and indirectly.

2.2.1. Iron- and steelmaking (TGA1)

The TGA1 portfolio supports the overall sustainability of the European steel industry (e.g. economic, environmental and social sustainability), boosting the competitiveness of the sector in two ways.

- Through improving resource and energy efficiency or processes in steelmaking. With regard to the steel industry, most of the ongoing projects are focused on improving resource and energy efficiency or processes. By doing so, if successful and industrially implemented, the projects can effectively reduce costs and/or increase productivity.
    - The MinSiDeg project aims to minimise sinter degradation in transport and storage and improve sinter quality.
    - The COACH project aims to feed waste material from iron- and steelmaking into blast furnaces (10 % of the total burden) in the form of cold-bonded, cement-free, self-reducing agglomerates. This brings expected coke savings of at least 30 kg/t hot metal and reduces sinter consumption.
    - The ECOSLAG project aims to facilitate the hot recycling of internal ladle furnace slag in electric arc furnaces (EAFs). Partial lime substitution and landfilling avoidance will induce savings of between EUR 0.8 million and EUR 3.0 million per year, plus energy savings in EAFs.
- Through new decarbonisation pathways. The complementarity of various projects focused on different decarbonisation pathways can realistically support the transition of the steel sector to climate neutrality.
    - In the DevH2forEAF project, a new modern multifuel hydrogen / natural gas oxygen burner, developed for EAF application, can work with up to 100 % hydrogen.
    - The H2transBF2030 project investigates new opportunities to decrease carbon dioxide (CO_2) emissions from blast furnace ironmaking, exploiting the CO_2 mitigation potential of the injection of hydrogen-containing gases in combination with direct reduced iron to the blast furnace. This will enable a significant reduction in CO_2 emissions at an early stage of new decarbonisation processes.

Although jobs and skills are not the focus of the TG, the portfolio contributes globally to increasing the competitiveness of the steel sector and, therefore, to maintaining the related workforce, providing the skills needed for the implementation of the new technologies.

2.2.2. Downstream steel processing (TGA2)

Several projects of the TGA2 deal with the implementation of digital tools leading to process optimisation and automation, which reduces costs, creates new skills in the EU and leads to more cost-effective production, indirectly reducing GHG emissions. Other projects aim to decrease energy consumption during reheating and prepare for the increased use of hydrogen. These projects lead to a direct reduction in GHG emissions and increase energy efficiency. Several projects also create new skills in the European steel industry (e.g. by investigating new in-line sensing concepts or novel process steps). Most projects also contribute to increasing safety in the workplace.

The benefits of the TGA2 portfolio of projects for the industry can be summarised as follows:

- process optimisation,
- increased product quality,
- operational cost savings,

- increased production flexibility,
- increased global competitiveness of the EU steel industry,
  - increased profitability and resilience of the European steel industry,
  - facilitation of machine-assisted decision-making.

The effects of the TGA2 portfolio of projects on society are characterised by:

- reduced dependence on fossil fuels,
- job creation,
- provision of long-term employment opportunities.

A significant reduction in GHG emissions can be expected as a result of the four projects linked to the optimisation of the reheating process (HYDREAMS, FULLH2REHEAT, MODIPLANT, BURNER 4.0) through switching to hydrogen/electrical energy and optimising burner design, but also because of another project (ReduHeatLoss), which optimises process conditions to reduce energy losses during hot rolling. Moreover, the dissemination project DissHEAT has other significant outcomes in terms of reducing energy consumption.

Benefits more linked to innovation, new advanced processes or measurement techniques result from the CentriClean, AUSSENS, RollProf and FlexGap projects. Their aim is to also improve the quality of final products and reduce quality-related downgrading or scrap.

2.2.3. Conception of steel products (TGA3)

The TGA3 projects support the energy transition and climate change mitigation, for instance through the development of lighter steels/components or hydrogen-compatible steels (e.g. for hydrogen production and storage). They also aim to develop more durable and tailored steel products that will decrease maintenance costs while improving safety and structures. Examples are as follows:

- a project contributing to the development of improved austenitic stainless steels for liquid gas storage applications, supporting the use of hydrogen as a new energy source (AUSTRONG);
- projects promoting energy efficiency and the reduction of CO_2 emissions (e.g. STeELS-EM, Si-Shift) and increased attention and efforts on recyclability and circular economy concepts (e.g. ALCOAT, COOPHS);
- projects dedicated to novel advanced high-strength steels (AHSS) with higher strength-to-mass ratio, contributing to the reduction of GHG emissions through enabling the building of lightweight structures (e.g. for transport, such as the iNiTiAl (aerospace), DELIGHTED and LIGHTFORGE (automotive) projects).

Moreover, the findings of some TGA3 projects can be used to develop a roadmap for future European standardisation in defining and preventing hydrogen embrittlement. This will have a direct effect on increasing safety, through facilitating the procurement of safe automotive parts (e.g. cost-efficient lightweight solutions), and on the development of new applications to accompany renewable energy production (e.g. offshore components), as for example in the Dynaustab, HYDRO-REAL, Crystal and AtHyCor projects.

Digital solutions based on the application of advanced modelling and simulation will lead to the optimisation of steelmaking and finishing processes and improved efficiency of material and process development (e.g. HYDRO-REAL, vForm-xSteels and MiPRE).

2.2.4. Steel applications and solutions for existing and new markets (TGA4)

TGA4 projects contribute to enhancing the EU's competitiveness, aiming to:

— facilitate the supply of high-quality products for the automotive sector (e.g. FATECO, Stir4Steel), and recently for hybrid and fully electric vehicles, prolonging their in-service life (e.g. TOPGEAR);

— promote the creation of new AHSS grades to manufacture complex geometries and thus stimulate the progressive application of steel-based lightweight solutions, with the potential to foster innovation in product design, create new jobs and develop skills aligned with sustainable industrial practices (e.g. CuttingEdge4.0);

— utilise new cutting and punching technology for sheets made of high-strength steels from the AHSS group – for example, a new coating on a cutting tool has increased its lifespan by 60 %;

— promote higher safety demands and the use of lighter-weight materials to reduce the emission of GHGs in the automotive sector;

— combine methods to reduce the energy used during fabrication, improving environmental sustainability and providing a safer workplace (e.g. LASTTS).

The InCSEB project is at the interface between the steel and construction sectors. The outputs of the project are likely to have direct impacts on society. The five innovative steel envelope systems investigated in the project aim to reduce the carbon content of buildings by incorporating waste wood fibres as infill material.

The DREAMERS project aims to deliver final design solutions providing enhanced seismic safety and sustainability for the steel construction sector, compared with other construction materials.

The WINDUCTION project will benefit wind turbine manufacturers by reducing GHG emissions, increasing energy efficiency and, thus, potentially achieving cost reductions. The time to market of the gears will be also reduced, as the induction heating process is quicker than the current carburising one. The benefits for steelmakers will come from the use of new grades of steel, which will help in maintaining the competitiveness of the sector.

Projects such as CONSTRUCTADD will enhance the EU's competitiveness and create new types of jobs in the construction sector (e.g. metal printers and robot operators), and will empower engineers and architects with new digital skills.

2.2.5. Steel factories – smart and human (TGA5)

The TGA5 portfolio provides benefits regarding the overall sustainability of the European steel industry (e.g. economic, environmental and social sustainability), thus supporting the competitiveness of the sector.

All TGA5 projects directly or indirectly contribute to achieving the CSP's specific objective 6 – strengthening the global competitiveness of the EU steel industry – and more precisely to achieving the operational objectives 'establishing the EU steel industry as a leader in low-carbon steel and ensuring standardisation and global market uptake of successful technologies developed in the EU', 'fostering R&D collaboration between EU companies and science in the clean steel value chains' and 'upskilling steel workforce'.

One cluster of projects (DynReAct, OMA, InTEGrated, SmartLadle, STEELAR, DeepQuality, TWINGHY) contributes to:

— increasing productivity and yield;
— enhancing the flexibility and reliability of production processes;
— improving and stabilising the quality of products;
— improving resource efficiency;
— decreasing energy consumption, waste and GHG emissions;
— reducing the use of fossil and non-renewable fuels;
— reducing production costs.

A second cluster of projects (ControlInSteel, AutoSurveillance, RoboInspect, SMARTER, iSlag, EnerMIND) contributes to:

— improving and optimising production processes;
— enhancing the stability and reliability of production processes;
— reducing production costs;
— improving energy and resource efficiency;
— implementing alternative energy sources;
— reducing CO_2 emissions;
— conserving resources;
— securing raw materials;
— reducing waste and landfill material;
— improving the health and safety of workers in steelworks;
— improving workforce management;
— upskilling the workforce.

In addition, the TGA5 projects benefit EU citizens by improving working conditions and creating a safer working environment, by developing new labour skills and competencies, and by preserving the environment around steel plants.

2.3. Potential of high-technology-readiness-level projects to be scaled up and enter production

2.3.1. Iron- and steelmaking (TGA1)

In most TGA1 projects, steel companies are the key players and their plants are used to test the technologies investigated. In some cases, the results are readily implemented in the plants at the end of the projects and quickly transferred to other plants of the participating companies.

On average, the time for the industrial scale-up of TGA1 projects or entry into production of their outputs can be:

— 1–3 years for pilot and demonstration projects, or even for some research projects within the scope of a given consortium;

— 3–5 years for research projects.

A good practice is to include in the consortium a plant supplier or a measurement/information technology supplier. Furthermore, having on board an original equipment manufacturer, which can include the technology in its portfolio and sell it to steelmakers, facilitates industrial implementation (e.g. in the ECOSLAG project, the slag dry granulation process is already being industrialised).

2.3.2. Downstream steel processing (TGA2)

Most projects in the TGA2 portfolio are focused on producing outputs with a high technology readiness level (TRL) with pilot/demonstration tests in the operational environment. The high-TRL project portfolio can be divided into two groups, based on the development of sensors or components aimed at improving processes and product quality and reducing CO_2 emissions in heating systems. The difference is in the time frame of the implementation of resulting measures: the development and implementation of sensors, as in the case of the AUSSENS project, can be achieved in a relatively short time (i.e. less than one year). Other technologies (e.g. new robust burners and heating devices) and process hardware, as in the projects SmartCool and RollProf, must be integrated in current technologies (mechanically, technically, safety-wise, etc.), which takes a couple of years. In this respect, the uptake of technologies for process optimisation in the TGA2 portfolio is likely to occur in a short period (1–5 years), considering that the steel industry is rather conservative.

2.3.3. Conception of steel products (TGA3)

In TGA3, the projects dedicated to building knowledge and new methodologies apply to products that are already commercial and therefore at TRL9. The results will be used in real production in around 2–4 years.

The same estimation (i.e. 2–4 years) applies to projects developing advanced modelling and simulation tools for the optimisation of steel microstructure design and steel performance in forming processes or during use.

Other projects are dedicated to the development of new grades of steel or new coatings and will reach TRL5 or TRL6 by the end of the project. The time needed for products to reach TRL8 and TRL9 and enter production is approximately 5–10 years. In general, when end users and steelmakers have been involved in the consortium at an early stage of the project, the technology tends to enter production more rapidly.

2.3.4. Steel applications and solutions for existing and new markets (TGA4)

The high-TRL projects of the TGA4 portfolio will require 1–3 years to reach the market depending on the status of each project and the technology, whereas lower-TRL projects will require several years of research. For example, the time to market for the technology in the FATECO project (focusing on the improvement of the fatigue performance of automotive components through innovative ecofriendly finishing operations) is quite short. Stir4Steel is already programming the design and manufacturing of demonstrators and, thus, the implementation of technology at the industrial scale could be undertaken soon. The technology developed through the CuttingEdge4.0 project can be at a high TRL, between TRL8 and TRL9, and may therefore take only 1–2 years to be implemented at that scale.

The technology of the FIRST-WIRE project is at TRL4 and will require several years of research, as each type of rope investigated in the project may be subject to different standards and tests, affecting the certification timeline.

For the FISHWALL project, the scaling up of the proposed solution also depends on its future incorporation in the European standards EN 1999-1-2 and EN 15254-5. Moreover, the LASTTS project relies on the findings of a recently concluded project involving new connections / connection designs to be incorporated into the Eurocodes. A medium- to long-term timeline (5–15 years) is therefore needed. National standards may require a shorter implementation period, of less than five years.

2.3.5. Steel factories – smart and human (TGA5)

Regarding TGA5, the technologies of projects need, on average:

— 1–3 years for industrial scale-up or to enter production within the scope of the consortium;

— 3–5 years for deployment outside the consortium and to reach the market.

Some results may become available even earlier, especially for pilot and demonstration projects. However, for others, especially those dealing with robotic solutions, the risk arises that some outcomes are outdated by the time the projects are finished, due to the very rapid development of the market in this context. Therefore, the optimal duration of these types of projects should be considered at the proposal evaluation stage.

The targeted and current TRL of the solutions and systems developed is not always clear in the presentations provided by the coordinators.

2.4. Collaboration potential and synergies

2.4.1. Iron- and steelmaking (TGA1)

The TGA1 portfolio analysis shows a high potential for collaboration and synergies within and outside the TG portfolio.

Regarding circularity and industrial symbiosis, the following examples can be highlighted for potential collaboration through the Processes4Planet Research Association ([5]):

— the COACH project on waste management of by-products too rich in zinc for internal recycling or on the knowledge acquired about new binders and agglomeration techniques;

— the ECOSLAG project on converting slag as a by-product, which could be useful for the whole steel sector and for the cement or construction sectors.

Regarding hydrogen, the results can be disseminated to other projects funded by both the RFCS and Horizon Europe to create more meaningful results. Some examples are as follows.

— With regard to production versus use, potential synergies are conceivable within the RFCS portfolio, between the projects ProSynteg and H2transBF2030, or within the Horizon Europe project MaxH2DR.

([5]) https://www.aspire2050.eu/.

— Regarding the DevH2forEAF project, the impact of hydrogen burners (e.g. on refractories ([6])), is a good example of a topic that could be further investigated by other TGs.

— With regard to hydrogen transport, storage and feeding (i.e. safety and regulatory issues), the exchange of best practices could be quite profitable in some European or national programmes (e.g. the 'Strategic projects for economic recovery and transformation' ([7]) programme on renewable hydrogen in Spain and projects of the Belgian Hydrogen Council ([8])).

ProSynteg could be suitable for collaboration on the topic of carbon capture, utilisation and storage (CCUS) ([9]).

Regarding biomass and other alternative carbon sources, the effective exchange of results achieved in the projects TACOS, COACH and OnlyPlastic, and future results of BioReSteel and BioRECAST, could be beneficial for the whole industry, including within European or national research and development programmes (e.g. 'Agglomerates for next generation lignin-united steelmaking', funded by the Swedish state).

2.4.2. Downstream steel processing (TGA2)

In the TGA2 portfolio, four areas were identified as potential topics for cooperation, since a significant number of projects were related to them. The following projects could benefit from synergising dissemination activities.

— **Sensor development and application.** HYDREAMS, RollProf, BURNER 4.0, RealTimeCastSupport, OPTILOCALHT, MODIPLANT, HatFlat, FlexGap and AUSSENS.

— **Numerical modelling.** HYDREAMS (computational fluid dynamics (CFD) / combustion), PROTEUS-RS (finite element method), FULLH2REHEAT (combustion), BURNER 4.0 (CFD/combustion), CentriClean (CFD), RealTimeCastSupport (CFD), OPTILOCALHT (CFD) and FlexGap (finite element method).

— **Heating, temperature control and energy.** ReduHeatLoss, SmartCool, PROTEUS-RS, FULLH2REHEAT, RealTimeCastSupport, OPTILOCALHT and MODIPLANT, with a potential link to Swedish Energy Agency (Energimyndigheten) calls.

— **Digitalisation.** BURNER 4.0, RealTimeCastSupport and OPTILOCALHT, with a potential link to Vinnova (Sweden's innovation agency) calls.

In relation to the area of heating, temperature control and energy, hydrogen-related topics can be combined into hydrogen-cluster topics. as in the case of the projects BURNER 4.0, HYDREAMS, FULLH2REHEAT and MODIPLANT. This can also apply to other hydrogen-related projects from other TGs or funding programmes.

Several projects deal with digital models of various aspects of production processes ('digital twins') and in-line process sensing. These projects may therefore benefit from

([6]) https://resource-sip.se/projekt/agglomerat-for-nasta-generation-genom-effektivt-inforande-av-lignin-under-staltillverkning-angelus/?en.

([7]) https://espanadigital.gob.es/en/measure/perte-strategic-projects-economic-recovery-and-transformation.

([8]) https://h2.belgianhydrogencouncil.be/.

([9]) https://www.ccusnetwork.eu/.

collaboration on IT-related aspects to prevent duplication of efforts (there may also be relevant projects in other TGs).

2.4.3. Conception of steel products (TGA3)

In the TGA3 portfolio, there is potential for collaboration between RFCS projects, which can be organised into common research areas:

- hydrogen embrittlement (e.g. HELIX, Crystal, HYDRO-REAL, AtHyCor, FEATHER),
- coated and corrosion-resistant steels (e.g. BIOFIRE, ALCOAT, iNiTiAl),
- advanced steels (e.g. Dynaustab, DELIGHTED, MARTBAIN, AUSTRONG, OPTIDAMATOL, STeELS-EM, LIGHTFORGE, COOPHS, Si-Shift, NanoWinTur),
- digitalisation of steel design and forming (e.g. vForm-xSteels, MiPRE),
- additive manufacturing (e.g. SuPreAM, NewAIMS).

The potential for collaboration with other EU/national funded programmes is high and not fully exploited, notably in the field of energy transition. It would make sense to explore ways to increase links with funded programmes in the renewable energy sector.

Similarly, since the hydrogen economy is expected to be key for energy production in the future, all projects dealing with hydrogen embrittlement, hydrogen storage and the use of hydrogen-containing gases have collaboration potential.

2.4.4. Steel applications and solutions for existing and new markets (TGA4)

In the TGA4 portfolio, there is generally high collaboration potential across the projects, as the areas covered are in many cases complementary or overlapping, especially in the following areas:

- the automotive sector (e.g. new manufacturing routes and new-generation gears for hybrid electric vehicles in the projects FATECO, TOPGEAR, WINDUCTION) and wind gears;
- high-strength steel manufacturing, promoting the use of high-strength steels in the automotive industry (e.g. Stir4Steel, STEEL S4 EV, IntellCutProcess);
- mooring solutions for high-capacity offshore wind turbines (e.g. FIRST-WIRE and WINDUCTION).

CONSTRUCTADD shows that additive manufacturing is a topic with increasing popularity in the construction sector. Potential collaboration is envisaged with the projects IAMFat and NewAIMS. It is noted that relevant projects are not only in the construction sector, but also in the automotive sector.

InCSEB has the potential to collaborate with any demonstration project related to structural frames (e.g. DREAMERS) to evaluate the influence of non-structural elements on seismic resistance.

DREAMERS already exploits findings from the design and testing of beam-to-column connections equipped with friction dampers that were produced during the completed Freedam and Freedam Plus RFCS projects.

2.4.5. Steel factories – smart and human (TGA5)

The TGA5 portfolio analysis showed that there is a high potential for collaboration and synergies inside and outside the TG portfolio. In particular, the TGA5 projects could build up synergies with projects/clusters from RFCS (Big Ticket Steel) and Horizon Europe (CSP), and the Process4Planet ([10]) partnership.

Exemplary projects that can cooperate and form synergies with other EU-funded projects (RFCS and Horizon Europe's CSP) are:

— TWINGHY, which can be connected to the EU-funded projects HyInHeat, DevH2forEAF and DissHEAT;

— SMARTER, which is connected to the Horizon Europe CSP project MAXH2DR;

— DeepQuality, which can be connected to the RFCS project SurfConInspect (started in July 2023).

2.5. Research gaps and future research areas

2.5.1. Iron- and steelmaking (TGA1)

In the TGA1 portfolio, several areas have been identified as needing further investigation.

— **Scrap** ([11])**.** There are currently no scrap projects in TGA1; to further increase scrap recycling rates while maintaining high basic oxygen furnace / EAF performance and EU steel quality standards, further research is needed on scrap, in relation to (i) collection and treatment technologies to minimise tramp elements, (ii) improved (a.o. sensor-based) characterisation (a.o. percentage of non-ferrous metals, and inert and organic materials) linked to advanced basic oxygen furnace / EAF process control tools, and (iii) up-to-date knowledge on the link between the new 'tramp elements landscape' and steel product quality (link to other TGs).

— **CCUS.** There are no projects in the portfolio about capturing CO_2 or conditioning carbon monoxide- or CO_2-containing process gases, although CCUS topics are increasingly considered a key element of the long-term transition to carbon neutrality.

— **Hydrogen and EAFs.** The impact of hydrogen burner flames on processes, products, refractories, among others, should be better understood in EAFs (deeper scientific knowledge is needed). Hydrogen for ferrous oxide reduction inside EAFs could also be a relevant topic, in addition to natural gas replacement.

2.5.2. Downstream steel processing (TGA2)

In TGA2, the project portfolio is focused heavily on rolling, heating and coating operations, whereas casting activities are only covered in two projects. Breakthrough technologies and cutting-edge innovation are missing from the project portfolio. This is a consequence of the risks inherent to breakthrough technologies, and of the difficulty in properly justifying the benefits to the environment or in terms of energy, since these are considered secondary targets to process development in casting and rolling. Therefore, it is strongly

([10]) https://www.aspire2050.eu/p4planet/p4planet-sria-2050.

([11]) Horizon Europe projects with high TRLs are funded (Caesar, Purescrap, Hiyield).

recommended that the need to clearly link, and justify contributions to, the EGD targets, with the outcomes/impacts of the projects continues to be communicated.

The focus of TGA2 projects is the hydro- and electrification of processes – heating, heat treatment and finishing – and the development and introduction of energy-efficient technologies (drives, pumps, etc.).

The shortening of process lines – in strip or long-product direct casting, or near net shape casting – might have a relaunch. This was a trendy topic in the 1990s and could be revived in the context of CO_2 emission reduction by minimising heat loss due to product reheating and the reduction of rolling phases.

Furthermore, there is a demand for developing or improving steels for specific applications.

— **Steel products for harsh environments.** With regard to offshore and deep-sea engineering, owing to the increased amount of catastrophic natural phenomena, the physical and chemical resistance of steel materials within constructions should increase. These resilience and safety aspects are becoming much more important.

— **Steel powders.** This is still a niche market; however, the utilisation of steel powders in the printing process, among other processes, may enable new markets to form where conventional manufacturing may fail. This could involve topology optimisation (e.g. reduction of casting marks and scatter marks) or simply repair.

— **Steel passport (digital).** The reuse of materials and products as well as their recyclability relates to the history of the materials. Tracking materials data may enable the formation of much cheaper circular value chains. These data should include corrosion and fatigue, as main causes of failure and end of service life.

Another gap in the portfolio is the absence of a unique impact measure (e.g. key performance indicator (KPI) of tonnes of CO_2 avoided per tonne of hot rolled steel) in terms of alignment with the decarbonisation and energy transition goals set out by Council Decision (EU) 2021/1094, the CSP, the Just Transition Fund and the Innovation Fund.

2.5.3. Conception of steel products (TGA3)

In TGA3, the portfolio is generally well in line with the RFCS objectives. Nevertheless, several areas are proposed to be reinforced or launched in the future.

— advanced steel solutions (steel substrates and coatings) to support the development of new energy sources (hydrogen, nuclear, wind) and electric mobility;

— increased effort and portfolio enlargement towards the decarbonisation of steel manufacturing, and recyclability and sustainability;

— enhancement of the development of digital solutions through the development of metallurgical models combined with the extensive use of process data;

— attention to certification of new materials and products – as this is currently missing, early collaboration with certification bodies is strongly advised.

2.5.4. Steel applications and solutions for existing and new markets (TGA4)

Most of the projects in TGA4 are focused on buildings and automotive products. It would be interesting to focus on the application of steel and steel products in the energy sector, which is quite relevant to achieving decarbonisation in the EU. In this respect, it would also be interesting to investigate the use of steel in green-energy-related technologies and industrial plants, where there could be challenging operating conditions (e.g. service environment, pressure, temperature) and there could be room for advanced steel grades and products characterised by higher performance and reliability.

Considering the EU digital transformation (e.g. the Digital Decade roadmap), the RFCS may consider funding projects that incorporate digital tools/technologies, from machine learning to building information modelling / extended reality / virtual reality, to develop cleaner steel materials through optimised production processes, enabling circularity in the use of steel in the built environment (materials and information flows, components/connections that enable use over multiple life cycles, tools for evaluating the residual life of existing steel elements/connections, among others).

The circular economy is a key aspect of the steel sector, as steel structures have a unique potential to be reused in the future. However, although some projects have already addressed this issue (e.g. REUSteel and PROGRESS), there are still no clear answers on how to cope with reused steel (e.g. dismantlability of steel structures, assessment of the condition of structural steel members, assessment of the reliability of existing structures, certification issues, responsibility for end-of-life products).

Furthermore, business models are required to boost the market of reused steel products, including the storage of structural components before re-entrance into the market. In addition, the extension of the service life of steel structures, the durability of steel structures and design for adaptability, among others, are important topics in the circular economy that require further research.

In line with the EGD and CSP, with regard to TGA4, the RFCS may consider funding projects addressing steel composites with bio-based materials, for example steel–timber composites / hybrid systems, due to their enhanced environmental sustainability (lower carbon content) and circularity (potential for disassembly at the end of life, reuse and repurpose, design for/from disassembly).

2.5.5. Steel factories – smart and human (TGA5)

In TGA5, most projects now rely on AI, machine learning and deep learning approaches, which in turn require large amounts of high-quality data. These data must often be extensive and of good quality to enable the proper development and deployment of solutions as well as transferability. Moreover, the launch of technologies for sharing data and automatically controlling processes has introduced the issue of cybersecurity in various sectors, and this problem will be of the utmost importance in the coming years, including for the steel sector. Therefore, potential topics for the TG portfolio could involve trustful and secure data sharing, as well as the AI-based assessment of data quality and data governance.

Additionally, it would be useful to support the more intensive application of deep learning for quality monitoring, but also the more intensive adoption of explainable AI and green AI approaches, to reduce data (and related computational resource and energy) demand for implementing deep learning. In this aspect, it is also important to support and develop predictive models based on data analysis and AI, and the further development of digital twins and intelligent IT tools supporting data analysis and the control of production processes. It is important that these tools are dedicated to production solutions and are created in close cooperation with production plants, as the tools should respond to the plants' needs.

Moreover, currently not all RFCS projects assess their environmental impact. The application of AI to global process efficiency (from the point of view of saving energy, raw materials and costs) is very valuable for highly-energy-intensive industries, and a holistic approach that can link all the steps in the production process is encouraged.

Addressing the issue of digital culture, updating the skills of workers for the adaptation of new technologies, lifelong learning and the capitalisation of knowledge for the proper sustainability of expertise are of the utmost importance to enable the digital, green and circular transformation of steel production, in accordance with the EGD. Therefore, promoting the conduct of projects in these areas and encouraging projects to include training aspects in their final stage to ensure full acceptance of the innovation by workers is important for the European steel industry and complies with the EGD's key elements.

Overall, more emphasis should be put directly on projects devoted to near-zero-carbon steel processes.

2.6. Contribution to the key performance indicators of the Clean Steel Partnership

As a general observation, all projects in the RFCS portfolio contribute to a certain extent to the KPIs of the CSP ([12]).

2.6.1. Iron- and steelmaking (TGA1)

Regarding TGA1, all projects contribute to the KPIs of the CSP.

It should be noted that impacts quanitified at the EU level were not sufficiently put forward in most reports or presentations given by coordinators during the TGA1 meeting. The section on the expected impact of each RFCS project should be periodically updated taking into account the effective results of its implementation (i.e. not just gains per tonne of steel, but rather the potential for deployment at the EU level and the estimated global impact within a specific number of years).

2.6.2. Downstream steel processing (TGA2)

With regard to the CSP, the TGA2 portfolio contributes mainly to the following KPIs:

— decreasing scope 1 and 2 emissions at the demonstration scale (within specific objective 1 'Enabling steel production through carbon direct avoidance').

— decreasing specific energy consumption (within specific objective 3 'Developing technologies to improve energy and resource efficiency').

— reusing and recycling solid residues (within specific objective 4 'Increasing recycling of scrap and residues to support a circular economy model in the EU').

— increasing the percentage of high-TRL projects (within specific objective 5 'Demonstrating clean steel technologies').

([12]) https://www.estep.eu/assets/Publications/2024-CSP-SRIA.pdf.

2.6.3. Conception of steel products (TGA3)

The TGA3 portfolio clearly contributes to the KPIs of the CSP. CO_2 emission reduction is addressed in almost all projects in the portfolio, accompanying climate change mitigation. This can be achieved through savings during steel production, and the use of new high-strength steel grades (resulting in energy savings during production, and the reduction of fuel consumption), steels with better electrical properties for electric engines, coatings and surface treatments prolonging service life, simulation tools reducing the number of trials during production and experiments in research, etc.

Concerning specific objective 1 of the CSP, increaseing the use of renewable energies in Europe will promote the development of the hydrogen economy. Concerning specific objective 3, technologies should be developed to reduce the energy required to produce steel and therefore the use of energy per tonne of steel. Concerning specific objective 4, there should be more support for the increased use of scraps in steel production routes.

2.6.4. Steel applications and solutions for existing and new markets (TGA4)

Regarding TGA4, the portfolio contributes to the following specific objectives of the CSP.

— **Specific objective 3.** Developing deployable technologies to improve energy and resource efficiency (through smart carbon usage and process integration).

— **Specific objective 5.** Demonstrating clean steel breakthrough technologies contributing to climate-neutral steelmaking.

— **Specific objective 6.** Strengthening the global competitiveness of the EU steel industry in line with the EU industrial strategy for steel.

The projects in the TGA portfolio also align with at least one of the objectives of the Innovation Fund, which will support projects involving highly innovative technologies, processes or products that have a significant potential to reduce GHG emissions.

2.6.5. Steel factories – smart and human (TGA5)

The TGA5 projects demonstrate convincing contributions to the CSP’s operational objectives and KPIs. However, for many projects their alignment with the CSP would be clearer and more evident if KPIs practically measuring the impact of the developed systems and solutions (e.g. estimated savings of CO_2 emissions, energy and primary raw materials) were included in the final assessment provided by the consortia, which is not necessarily consistent with the KPIs included in the CSP’s strategic research and innovation agenda (as for some topics this can be a very difficult and speculative exercise, outside the scope of the RFCS), but is at least in line with them.

2.7. Competitiveness

The RFCS projects can be beneficial for the EU both industrially and socially, aiming to increase energy efficiency, reduce GHG emissions, lower production costs by optimising the design of processes and reduce the wastage of resources. Moreover, employment and the development of workforce skills also provide a competitive advantage.

2.7.1. Iron- and steelmaking (TGA1)

The TGA1 projects can be beneficial in three ways.

They are beneficial to the following aspects of the regulatory framework.

- **Industry standards.** To ensure the industrial uptake of hydrogen-using processes, the EU must define related industrial safety standards.
- **The environment.** The projects can enable the legislative de-risking of the new investments, for examply by organising events/platforms for innovators, EU environmental specialists and policymakers to facilitate a sound and common ground for the discussion of EU environmental policy (clarifying and harmonising the path towards future regulations).
- **The circular economy.** The projects can help in developing circular solutions, such as slag valorisation, in other industrial sectors, which is complicated by the presence of different national waste regulatory frameworks in the EU.

They promote access to green energy.

- There is a high interest in biomass and alternative carbon sources (e.g. plastics), but many questions remain about availability, variability, legal status and logistics (and possible competition for access among all energy-intensive industries and the energy sector). This could be clarified by an independent EU analysis.
- The production, storage and transport of green electricity and hydrogen at a competitive cost and in sufficient amounts will be crucial (and could present a barrier) for many projects.
- Alignment is needed between different European industry and energy roadmaps (e.g. CSP versus repowerEU).
- Public authorities must play a more important role as enablers, ensuring that the required green electricity, hydrogen or biomass will become available and that infrastructure will be built to meet the demand.

Regarding education and upskilling, to quickly make progress in the different decarbonisation pathways, an adequate workforce is needed (in terms of skills and staffing). There is a lack of skilled human resources and interest of students, which poses a significant challenge. It could be useful to have dedicated dissemination actions to attract talent to the sector.

2.7.2. Downstream steel processing (TGA2)

For TGA2, all the developments achieved can contribute to the competitiveness of the steel production sector in the EU. Nevertheless, of particular concern is the fact that the number of patents / new products is very low in relation to the number of projects presented (only two patents, for the projects BURNER 4.0 (EP3749896B1) and MODIPLANT (EP2676093)).

This can be interpreted as a reflection of the incremental innovation achieved through the projects, but also possibly of the fact that patent applications are not filed during the project running time, as they are registered in advance before the project starts (this applies especially in the case of pilot and demonstration projects). It should be noted that in TGA2, which lacks the development of breakthrough technologies, the focus is mainly on the implementation of existing technologies in well-established processes.

2.7.3. Conception of steel products (TGA3)

An important feature of the TGA3 portfolio is the promotion of the collaboration between companies and technical centres or universities, being the core of most partnerships in the projects. Such cooperation leads to new, innovative solutions. This approach is essential to keep the EU steel industry internationally competitive (as per CSP specific objective 6).

Most projects declare benefits such as energy efficiency, reducing CO_2 emissions, reducing costs, increasing the EU's competitiveness, designing new processes and/or products, improving and optimising processes/products, creating high-quality jobs and having a favourable impact on employment.

However, the TGA3 portfolio supports the building of capacities of renewable energies, with a chance to increase the EU's sectoral competitiveness (e.g. by creating relevant know-how and intellectual property).

2.7.4. Steel applications and solutions for existing and new markets (TGA4)

The TGA4 portfolio contributes in terms of technological advances to producing high-quality products, prolonging their in-service life, increasing their strength and reducing their weight, while reducing the carbon footprint of the manufacturing process. These developments have the potential to foster innovation in product design, create new jobs, and develop skills aligned with sustainable industrial practices. The results of the projects are likely to maintain or increase the EU's sectoral competitiveness, for example by achieving economic benefits due to connection fabrication costs being reduced by almost 50 % depending on the configuration.

Regarding the automotive sector, the production of high-quality parts, prolonging their in-service life, and new AHSS grades to manufacture complex geometries and thus stimulate the progressive application of steel-based lightweight solutions enhances competitiveness with non-EU producers.

In the construction sector, there are various benefits, for example shortening the construction time on-site and reducing the amount of manual labour through increased automation and prefabrication, or in the production of mooring lines used in offshore conditions and in the production of lines used in suspension bridges, thus reducing the carbon footprint of the line manufacturing process.

In addition, the energy sector is affected by extension (e.g. products with high-strength properties compared with traditional ones create the opportunity for the development of wind platforms with higher capacities).

The benefits for steelmakers will come from the use of new steel grades, which will help in maintaining the competitiveness of the sector. At the same time, the adoption of these new technologies will boost the sector's competitiveness, especially compared with low-wage countries, through the provision of more advanced solutions.

2.7.5. Steel factories – smart and human (TGA5)

All TGA5 projects have direct or indirect contributions to the competitiveness of the EU's steel industry, and more precisely to the operational objectives of the strategic research and innovation agenda 'establishing the EU steel industry as a leader in low-carbon steel and ensuring standardisation and global market uptake of successful technologies developed in the EU', 'fostering R&D collaboration between EU companies and science in the clean steel value chains' and 'upskilling steel workforce'.

The TGA5 projects can benefit the EU steel industry in terms of competitiveness by modernising steel production and manufacturing chains, and by enabling the more efficient use of energy and resources. The contribution of the portfolio to increasing competitiveness is achieved through the reduction of scraps and energy use, and the improvement of the maintenance process.

As far as the EU's competitiveness is concerned, if cost minimisation is not the main driver of innovation in the steel sector, there is a risk of reducing competitiveness in the market if achieving green production costs more. Therefore, suitable measures should be considered to ensure a level playing field (e.g. to impose a carbon footprint analysis to steel products coming from outside EU / carbon border adjustment tax).

3. Conclusion and ways forward

The results provided by the five TGs allow an assessment of the state of play in the field, the identification of gaps in research efforts and proposals for the way forward for individual projects and for research in the sector as a whole. The TGs, in their meeting reports, provide recommendations that span from the introduction of novel techniques to quality improvement, resource savings and safety-related issues.

With regard to TGA1, the annual RFCS calls should continue to focus on process improvements, aiming to improve resource and energy efficiency, productivity, predictive maintenance, the quality of intermediate products, supply chain management and water management. TGA1 recommends that all these topics should make use of the most advanced digitalisation tools available on the market. Particular attention should be given to new (more dynamic) process control methods to cope with lower-grade and more variable input materials/fuels (e.g. recycled by-products, plastics) or to adjust production to short-term fluctuations in energy supply and price.

The success of our future steel industry will rely on environmental issues only partially covered for now by RFCS projects. Some examples are:

- the impact of hydrogen burners, plasma torches, plastic injection in EAF, among other things, on pollutant emissions (e.g. nitrogen oxides, dioxins);
- appropriate technologies needed to further reduce air and water pollution associated with (new) steel and iron production;
- the more widespread use of life-cycle analysis to quantify the environmental impact of different production methods and materials.

In TGA2, there are further barriers slowing down or limiting the introduction of promising new technologies after technical feasibility is achieved. For projects aimed at introducing hydrogen into heating systems, the challenge is not technological but economic. To date, the costs of using green hydrogen are too high compared with current natural gas pricing, making it barely usable in the steel industry, considering the current and future expected availability of renewable electricity. Currently, switching to hydrogen as an energy source is not economically viable, although it could be in the future if a renewable energy transition is performed successfully. In addition, the status and future potential of this energy source vary greatly across various European countries (see data provided by the

International Renewable Energy Agency ([13])). Furthermore, the direct replacement of intensive usage of electricity is limited and strongly connected to the transformation in the energy sector.

The upscaling of surface technologies very much depends on the quality of relevant products and their 'green' readiness. Barriers to upscaling will be the expense and to some extent the expected transformation in the energy sector.

Areas currently underrepresented should be further supported in future calls through the introduction of RFCS call priorities. Future projects should focus on the process steps of casting and finishing, on process line shortening, on yield and on the implementation of a digital product pass ('steel passport'). Support measures must be formulated individually for the forthcoming RFCS calls, and the introduction of these measures should have a limited lifetime'.

Regarding TGA3, several areas are proposed to be reinforced or launched. Most projects declare benefits in terms of improving energy efficiency, reducing CO_2 emissions, reducing costs, increasing the EU's competitiveness, designing new processes and/or products, improving and optimising processes/products, creating high-quality jobs and having a favourable impact on employment. To ensure that KPIs are specific, measurable, assignable, realistic and time bound, it could be interesting to propose in the slideshow template for project leaders a list of KPIs and a selection of those most relevant to the projects or a quantitative indicator with a value of between 1 and 5 (or 1 and 3). The TG members could then summarise this information, identify gaps and make recommendations if needed. The projects in the portfolio could indicate the TRL level increase expected by the end of the project.

Some of the projects in the TGA4 portfolio are open to adopting technologies that can be considered innovative in the steel industry, such as AI and additive manufacturing. This openness is interesting and could contribute to the modernisation of the sector.

In the steel construction industry, three emerging topics are gaining importance and are recommended for future TG portfolios.

— **Steel reuse.** Reusing old steel elements is becoming a key strategy to reduce GHG emissions, aligning with sustainable and circular economy practices by minimising waste and conserving resources.

— **Exploiting AI.** Future RFCS calls should focus more on incorporating AI in creating innovative steel products.

— **Additive manufacturing.** This emerging field should be a focus of the RFCS, as currently the topic is not readily funded by the industry due to its medium–high risk (with potential medium–high gain).

Moreover, the following areas are missing from the actual portfolio, and should be investigated in the future:

— primary energy sector;

— prolonging the service life of industrial assets;

— predictive simulation models of materials' behaviour for life prediction and life extension.

According to TGA5, it would be beneficial to encourage all consortia to provide a clear quantified estimate of the practical benefits (e.g. savings of CO_2 emissions, energy,

([13]) https://www.irena.org/Data.

materials and costs – in this order of priority) for all the systems and solutions developed. The dissemination of this quantitative data must also be strengthened outside the steel sector, following the approach taken in the dissemination project ControlInSteel.

Projects exploiting AI and machine learning tools and technology rely on the availability of data. Therefore, a broader overview of data already collected in previous projects could be useful.

3.1. Future perspective

In a nutshell, the RFCS portfolio works towards very important developments in the steel sector, focusing on research into enhanced solutions for the design and construction of steel structures. However, it lacks a holistic understanding of the entire value chain of steel products, from design to construction and the end of life of steel structures (lack of life-cycle assessment and life-cycle thinking).

Therefore, more attention needs to be given to certification, traceability and recycling, with the aim of achieving effective circularity in the steel sector and making use of / integrating digital technologies relevant to the sector. Furthermore, in line with the CSP, decarbonisation efforts in the steel industry need to be stepped up and integrated in a coherent framework through a renewed research and innovation strategy.

Annex

Table 2: List of RFCS project acronyms and titles

Acronym	Project Number	TG	Title
ALCOAT	RFCS-2022-101112544	TGA3	recycled aluminium alloy coatings with chemically tailored electrochemical potential for safe protection of steel structures
AtHyCor	RFCS-2020-101034041	TGA3	modelling of hydrogen activity from atmospheric corrosion in ultra-high strength steels for light structure application
AUSSENS	RFCS-2019-899391	TGA2	Phase transformation measurement for mechanical properties control and assessment
AUSTRONG	RFCS-2020-101034012	TGA3	Development of new high strength austenitic stainless steels for large lightweight storage applications
AutoSurveillance	RFCS-2018-847202	TGA5	Automatic surveillance of hot rolling area against intentional attacks and faults
BIOFIRE	RFCS-2018-847229	TGA3	Advanced coated steels for new demanding biomass firing environment having a high recycling behaviour and an improved service life
BioRECAST	RFCS-2022-101112601	TGA1	Biobased residues conversion to advanced fuels for sustainable steel production
BioReSteel	RFCS-2022-101112383	TGA1	Valorization of wet biomass residues for sustainable steel production with efficient nutrient recycling
Blemab	RFCS-2019-899263	TGA1	Blast furnace stack density estimation through on-line muons absorption measurements

BURNER 4.0	RFCS-2018-847237	TGA2	Development of a new burner concept: Industry 4.0 technologies applied to the best available combustion system for the steel industry
CentriClean	RFCS-2018-847341	TGA2	Metallic coating bath cleaning by centrifugation
COACH	RFCS-2019-899318	TGA1	Cold-bonded agglomerates for blast furnace ironmaking with chemically engineered binders
CONSTRUCTADD	RFCS-2021-101057957	TGA4	Resource-efficient steel construction using additive manufacturing
ControlInSteel	RFCS-2019-899208	TGA5	Dissemination and valorisation of RFCS-results in the field of ‘advanced automation and control solutions in downstream steel processes’ and development of a strategic vision for future research
COOPHS	RFCS-2022-101112485	TGA3	low co2 imprint on press hardened steels
Crystal	RFCS-2019-899406	TGA3	Control of risk for hydrogen embrittlement in steels for automotive applications
CuttingEdge4.0	RFCS-2018-847213	TGA4	Facing edge-cracking in AHSS: towards zero-defect manufacturing through novel material characterization and data driven analytics for process monitoring
DeepQuality	RFCS-2020-101034037	TGA5	Use of robust deep learning methods for the automatic quality assessment of steel products
DELIGHTED	RFCS-2019-899332	TGA3	Design of lightweight steels for industrial applications
DevH2forEAF	RFCS-2020-101034081	TGA1	Developing and enabling H_2 burner utilization to produce liquid steel in EAF
DissHEAT	RFCS-2021-101057930	TGA2	Dissemination of the heating technology research results for emission minimization and process optimization towards todays fossil-free heating agenda

DREAMERS	RFCS-2020-101034015	TGA4	Design research, implementation and monitoring of emerging technologies for a new generation of resilient steel buildings
Dynaustab	RFCS-2019-899482	TGA3	Austenite stability under dynamic loading
DynReAct	RFCS-2018-847203	TGA5	Refinement of production scheduling through dynamic product routing, considering real-time plant monitoring and optimal reaction strategies
ECOSLAG	RFCS-2017-800762	TGA1	Eco-friendly steelmaking slag solidification with energy recovery to produce a high quality slag product for a sustainable recycling
EnerMIND	RFCS-2019-899345	TGA5	Energy management in the era of Industry 4.0
FATECO	RFCS-2019-847284	TGA4	Improvement of the fatigue performance of automotive components through innovative ecofriendly finishing operations
FEATHER	RFCS-2022-101112471	TGA3	Steel for next generation H_2 cylinders
FIRST-WIRE	RFCS-2019-899299	TGA4	Fiber reinforced steel wires for high performance lightweight ropes and cables operating in demanding scenarios
FISHWALL	RFCS-2020-101034083	TGA4	Fire and seismic performances of hybrid fire walls in case of single-storey industrial and commercial steel buildings
FlexGap	RFCS-2017-800672	TGA2	Industrial demonstration of novel adaptive flat bearing with adjustable thickness for flexible gap control in rolling mills
FULLH2REHEAT	RFCS-2022-CSP-101099132	TGA2	Demonstrator of industrial transformation with hydrogen for HAV long products rolling mills
H2transBF2030	RFCS-2021-101057790	TGA1	Minimisation of CO_2 emissions from the BF by hydrogen containing injectants and use of DRI/HBI during transition to new ironmaking processes until 2030

HatFlat	RFCS-2020-101033991	TGA2	Holistic assistance for cross-process analysis and prediction of strip and plate flatness
HELIX	RFCS-2021-101057239	TGA3	Hydrogen embrittlement resistant new steel links solutions for off-shore wind turbines
HYDREAMS	RFCS-2022-CSP-101098480	TGA2	Clean hydrogen and digital tools for reheating and heat treatment for steel
Hydropick	RFCS-2018-847256	TGA1	Analysis and control of hydrogen content during steelmaking
HYDRO-REAL	RFCS-2019-899335	TGA3	Hydrogen interaction with retained austenite under static and cyclic loading conditions
IAMFat	RFCS-2022-101112614	TGA4	Intelligent additive manufacturing for improving fatigue strength of welded connections
InCSEB	RFCS-2020-101033984	TGA4	Innovative ultra-low carbon building steel envelop systems with bio-based insulation
Indiwater	RFCS-2020-101034072	TGA1	Independent industrial water supply by digitalization, simulation and innovative treatment technologies
iNiTiAl	RFCS-2018-847165	TGA3	Advanced implementation of novel corrosion resistant maraging steels with improved process robustness via tuned intermetallic nano-precipitation
InTEGrated	RFCS-2019-899248	TGA5	Development of innovative TEG systems optimized for energy harvesting from EAF off-gas cooling water and radiative waste heat sources designed to be cost-effectively integrated within steel plants
IntellCutProcess	RFCS-2019-899331	TGA4	Optimisation of cutting processes using intelligent cutting tools
iSlag	RFCS-2019-899164	TGA5	Optimising slag reuse and recycling in electric steelmaking at optimum metallurgical performance through on-line characterization devices and intelligent decision support systems

LASTTS	RFCS-2020-101034038	TGA4	Laser cutting technology for tubular structures
LIGHTFORGE	RFCS-2022-101112392	TGA3	sustainable forging steels for automotive lightweighting
MARTBAIN	RFCS-2019-899251	TGA3	Innovative martensite-bainite microstructures to provide industrially viable solutions to the need for high performance steel grades
MinSiDeg	RFCS-2018-847285	TGA1	Minimise sinter degradation between sinter plant and blast furnace exploiting embedded real-time analytics
MiPRE	RFCS-2019-899268	TGA3	Advanced metallurgical and micromechanical modelling to deploy the microstructural tailoring potential of press hardening
MODIPLANT	RFCS-2022-CSP-101099118	TGA2	Modular hybrId technology in the steel plant production
NanoWinTur	RFCS-2022-101112398	TGA3	Nanostructured surface layer of gear steel for wind turbines
NewAIMS	RFCS-2022-101112371	TGA3	New approach to additive manufacturing of microstructurally optimized steels
OMA	RFCS-2018-847296	TGA5	Online microstructure analytics
OnlyPlastic	RFCS-2019-899415	TGA1	EAF working with polymers derived from plastic residue in substitution of fossil fuel
OPTIDAMATOL	RFCS-2020-101034039	TGA3	Optimisation of high damage tolerance at very high strengths by the quenching and partitioning process
OPTILOCALHT	RFCS-2018-847269	TGA2	Optimisation of local heat transfer in the CC mould for casting challenging and innovative steel grades

PlasmaPilot	RFCS-2019-899223	TGA1	Flexible ladle preheating procedures using plasma heated refractory
PROGRESS	RFCS-2016 747847	TGA4	Provisions for greater reuse of steel structures
ProSynteg	RFCS-2021-101057965	TGA1	Production of hot hydrogen-rich syngas in integrated plants for efficient injection in the blast furnace and CO_2 mitigation
PROTEUS-RS	RFCS-2019-899455	TGA2	Long product quality optimisation through enhancement and utilisation of residual stress minimising process strategies
RealTimeCastSupport	RFCS-2018-847334	TGA2	Embedded real-time analysis of continuous casting for machine-supported quality optimisation
ReduHeatLoss	RFCS-2019-899290	TGA2	Reduction of heat losses during hot rolling of long products
REUSteel	RFCS-2018-839227	TGA4	Dissemination of results of the european projects dealing with reuse and recycling of by-products in the steel sector
RoboInspect	RFCS-2019-899252	TGA5	Mobile robots for inspection of steel plants
RollProf	RFCS-2019-882678	TGA2	On-line and real time meaurement of roll profile in hot and cold rolling mills
Sinbyose	RFCS-2018-847319	TGA1	Sintering with high by-products recycling rate and environmental optimization by selective preparation
Si-Shift	RFCS-2022-101112518	TGA3	High-performant non-oriented electrical steels with a silicon content beyond today's limits: new materials for an electrified future
SmartCool	RFCS-2021-101057274	TGA2	Smart controlled actuator to homogenize the temperature of the transfer bar

SMARTER	RFCS-2020-101034060	TGA5	Steam and gas networks revamping for the steelworks of the future
SmartLadle	RFCS-2020-101034017	TGA5	Smart consideration of actual ladle status monitored by novel sensors for secondary metallurgy process parameters and ladle maintenance strategies
STeELS-EM	RFCS-2020-101034063	TGA3	STabilized ELectrical Steels for Electric Mobility
STEEL S4 EV	RFCS-2017-800726	TGA4	Steel solutions for safe and smart structures of electric vehicles
STEELAR	RFCS-2020-101033790	TGA5	Steel components assessment using a novel non-destructive residual stress ultrasonic technology
Stir4Steel	RFCS-2020-101034068	TGA4	Friction stir welding for improving joinability of high-performance steels for automotive components to boost green road mobility
SuPreAM	RFCS-2022-101112346	TGA3	Predictive simulation of finishing operations in steel additive manufacturing for optimal surface integrity
TACOS	RFCS-2018-847322	TGA1	Towards a zero CO_2 sintering
TOPGEAR	RFCS-2020-101033989	TGA4	Gears with top in-service performance developed for hybrid and electric vehicles
TWINGHY	RFCS-2022-CSP-101099158	TGA5	Digital twins for green hydrogen transition in steel industry
vForm-xSteels	RFCS-2019-888153	TGA3	toward virtual forming and design: thermomechanical characterization of advanced high strength steels through full-field measurements and a single designed test
WINDUCTION	RFCS-2020-101034069	TGA4	Eco-design of an alternative production route for planet gears of wind turbine gearboxes

NB: BF, blast furnace; CC, continuous casting; DRI, direct reduced iron; H_2, hydrogen; HAV, high added value; HBI, hot briquetted iron. TEG, thermoelectric generator;

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Abbreviations

AHSS	advanced high-strength steels
AI	artificial intelligence
CCUS	carbon capture, utilisation and storage
CFD	computational fluid dynamics
CSP	Clean Steel Partnership
EAF	electric arc furnace
EGD	European Green Deal
EU	European Union
GHG	greenhouse gas
KPI	key performance indicator
R&D	research and development
RFCS	Research Fund for Coal and Steel
TG	technical group
TGA	steel research technical group
TRL	technology readiness level

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