European Commission

Research Fund FOR COAL & STEEL

Monitoring and Assessment Report (2011-2017)

Research and Innovation

Research Fund for Coal and Steel –Monitoring & Assessment Report (2011-2017)

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EUROPEAN COMMISSION

Research Fund for Coal and Steel

Monitoring and Assessment Report

(2011-2017)

2020

Directorate-General for Research and Innovation
Research Fund for Coal and Steel

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Abbreviations

AHSS	Advanced high strength steels
AM	Accompanying measure
CAG	Coal Advisory Group
COSCO	Coal and Steel Committee
DG RTD	Directorate-General for Research and Innovation
EAF	Electric arc furnace
EC	European Commission
ECSC	European Community for Coal and Steel, expired in 2002
ERA	European Research Area
ESTEP	European Steel Technology Platform
FE-Code	Finite elements code
FP	Framework programme of the European Union for research, technological development and demonstration activities
HLG	High Level Group of Expert for the RFCS Monitoring and Assessment 2011-2017
IPR	Intellectual property rights
LCA	Life cycle assessment
Legal basis	Council Decision n°2008/376/EC of 29 April 2008 on the adoption of the Research Programme of the Research Fund for Coal and Steel and on the multiannual technical guidelines for this programme, published in the Official Journal of the European Union on 20 May 2008, OJ L 130/7, replacing Council Decision 2003/76/EC of 1 February 2003, OJ L 29/28
Pilot & Demo	Pilot and demonstration project
RFCS programme	Research programme of the research fund for coal and steel
RFCS	Research Fund for coal and steel
R&I	Research and innovation
SAG	Steel Advisory Group
SEN	Submerged entry nozzle
SQ	Short questionnaire used in the monitoring exercise
TG	Technical Groups, there are 3 TGC and 9 TGS
TGC#	Technical Groups Coal (no. #)
TGS#	Technical Groups Steel (no. #)
UHSS	Ultra high strength steels
ULC	Ultra low carbon
VET	Vocational education and training

FOREWORD

This second report on the seven-year monitoring and assessment of the RFCS programme, covering 2011-2017, comes at a moment of transition: both for the European Union institutions entering a new programming cycle, and for people in the EU demanding the European Union to take action and lead the way on climate change. In this context, the EU will need to invest in innovation and research, redesign its economy and update its industrial policy. In such a period of transformation, turning towards our common European history is fundamental, if we want to forge a common, prosperous and sustainable future.

Seventy years ago, on 9 May 1950, the French Foreign Minister Robert Schuman proposed the creation of a European Coal and Steel Community (ECSC). The ECSC, formally established by the Treaty of Paris in 1951, became the first supranational European institution through which the European Union as we know today ultimately unfolded. The ECSC arose as a bedrock of peace, prosperity and welfare thanks to the development of production across Europe. This industrial solidarity wiped out the possibility of wars between countries that are now members of today's European Union.

In 2002, when the Treaty of Paris expired, Member States agreed to devote the ECSC's assets exclusively to research in the sectors related to the coal and steel industry, creating the Research Fund for Coal and Steel (RFCS). As in 1951, the European Member States renewed their choice for solidarity. Since then, the RFCS programme has been supporting research and innovation for the European industrial base.

Today, the European Union faces the greatest challenge and opportunity of its times: becoming the world's first climate-neutral continent. As stated by the European Commission President, Ms Ursula von der Leyen, the European Union will only be able to achieve this objective by following the European way of action, involving unity, solidarity, justice, sustainability, equality and ambition.

By following this path, the European Union will continue to be an industrial economy while remaining at the forefront of international efforts to fight climate change, leading in the provision of a circular economy and clean technologies, and supporting the decarbonisation of energy-intensive industries. Indeed, we Europeans have set the bar high.

The new EU research and innovation programme, Horizon Europe, with a proposed €100 billion budget, will be the biggest ever programme of its kind, running from 2021 to 2027 with a new level of ambition to boost the scientific, economic and societal impact of EU research and innovation investment. The programme will, amongst other, support strong public-private partnerships to tackle climate change and increase competitiveness of our economy. A major shift towards green and circular industry is expected especially in Europe's traditional coal and steel sectors. As a result, the ambition of Horizon Europe will be matched with a renewed RFCS and Innovation Fund which are expected to find and scale up solutions to further decrease the greenhouse gas emissions in these sectors and enable sustainable use of energy and resources. Moreover, this ambitious transition will leave nobody behind. The Cohesion Funds will support European regions, especially rural areas, while a Just Transition Fund will assist the most affected regions. The support of the private sector will be crucial to achieve this transition.

This report, carried out by the appointed Expert Group for the Monitoring and Assessment of the RFCS Programme as set out in the RFCS legal basis, encompasses the analysis and quantification of the benefits triggered by the RFCS programme as well as its development over the period analysed.

It sheds light on the progress achieved by the RFCS programme as well as on the next challenges and research trends upon which the programme may focus in the coming years. Our common goal is to continue protecting our natural environment, improving people's health and wellbeing and strengthening European industrial competitiveness, for the benefit of all people in Europe.

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EXECUTIVE SUMMARY

In September 2018, the European Commission established the **High-Level Group of Experts** (HLG) comprising one chair, two steel rapporteurs and one coal rapporteur, as well as six additional experts assigned to carry out the **monitoring and assessment exercise of the Research Fund for coal and steel (RFCS) programme** covering 2011–2017. The RFCS monitoring and assessment is based on the Terms of Reference drafted according to the legal basis of the research programme of the RFCS (Council Decision n° 2008/376/EC, Article 38) and was endorsed by the Coal and Steel Advisory Groups and the Coal and Steel Committee. The monitoring and assessment report relies on information from the (i) Commission's statistical data, (ii) the inputs of technical groups chairs with respect to a qualitative evaluation and (iii) the insights from the project coordinators of dedicated RFCS projects for a quantitative assessment. Overall, this report analyses about one third of the projects funded from 2011 to 2017. Furthermore, the preliminary results and achievements of the RFCS monitoring and assessment were presented and validated by around 100 stakeholders during the European conference — *Steel and Coal: A New Perspective. Research and Innovation in Action*[1] — held on 28 March 2019.

The purpose of the monitoring and assessment exercise was to review the RFCS programme between 2011 and 2017 and its multiannual technical guidelines. The main objectives of this exercise were to analyse how the programme functions, draw up recommendations for the programme's future and assess the expected benefits of the programme. The work of the HLG comprises a qualitative monitoring and a quantitative assessment of the RFCS programme, aiming to analyse and evaluate the current achievements and expected impacts. The HLG reviewed the RFCS programme in line with the criteria of the European Commission's Better Regulation Guidelines[2], drawing up recommendations on improving how the programme is managed and operated. In addition, the HLG recommended an update of the RFCS technical objectives for coal and steel in its legal basis (Council Decision 2008/376/EC).

The monitoring and assessment exercise covered a total of 293 projects (54 for coal and 239 for steel) which were completed or launched during 2011-2017. About one third of these projects were selected for a more detailed assessment.

The **introduction** outlines the roots and historical background of the RFCS, its structure, its legal architecture and institutional setting as well as its relation to other EU programmes.

Facts and figures of the RFCS-projects

Chapter 1 presents and analyses the programme's **facts and figures** for 2011-2017. It harnesses data on, among other things, i) the development of the RFCS budget and the success rate for coal and steel proposals, and ii) the type of activity and the proposed distribution per technical group (TG). This chapter is complemented by an overview of the coal and steel industry and concludes with an analysis of the existing and future synergies within the RFCS programme and other EU policies in the fields of innovation, industry and trade which can lead to the EU achieving its goal of a climate neutral economy by 2050.

Monitoring and qualitative evaluation

The scope of Chapter 2 is to monitor the technological achievements attained by RFCS projects since 2011 and the benefits they provided as well as to identify possible future challenges for research in the coal and steel sectors. Chapter 2 elaborated on the inputs brought forward by the 12 TGs for coal (3) and steel (9), which stressed the relevance of the RFCS programme for the coal and steel communities, pointing out the achievements that led to multiple benefits for the participants, the sector and society.

According to the monitoring and qualitative evaluation, projects carried out for the **coal sector** contributed to the sustainable development and to the improvement of the sector's

[1] "*Steel and Coal: A New Perspective. Research in Action*", March 28, 2019. Available online: https://ec.europa.eu/info/publications/steel-and-coal-new-perspective_en

[2] European Commission, *Better Regulation: guidelines and toolbox:* https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox_en

competitiveness[3], in line with the RFCS research objectives. Projects' achievements mainly focused on high-capacity coal operation and coal production performance, improving health and safety in mines, minimising the impact of operations and post-mining activities on the environment. The development of clean and efficient coal technologies, including carbon capture utilisation (CCU) and carbon capture and storage (CCS), brought significant results, which were implemented to lower the industry's carbon footprint. In addition, possibilities for the unconventional use of coal were investigated. Projects also helped to improve the efficiency of existing power and coking plants, leading to reduced emissions from coal use.

For the **steel sector**, one of the biggest challenges has been to drastically decrease the carbon footprint. Therefore, the focus of several research activities, in order to pave the way for future applications, has been (i) the development of alternative carbon carriers originating from renewable sources, and (ii) new breakthrough processes for iron ore reduction and smelting. For operations in steel production, increased productivity, energy efficiency and cost efficiency — together with an improved steel quality — have been studied. Achievements in the field of product development were the design and testing of new improved steel grades for the mobility and construction markets and the development of design methodologies for innovative steel-based systems for both industrial and construction applications, benefiting both the sector and society. The race towards lightweight solutions, leading to the lower carbon footprint from the use of steels, has been supported by several projects, improving the position of steel against other competing materials. A considerable improvement in the control of factory-wide processes and measurement equipments contributed to a better knowledge of process parameters and product properties and was one more step towards the digitalisation of the steel industry.

Quantitative assessment of the RFCS projects

Chapter 3 takes stock of information provided by ongoing RFCS accompanying measures[4] and by selected project coordinators. Thirty-nine projects went through an in-depth assessment concerning their benefits for the sector and society. The quantitative assessment was based on a survey analysing the expected aims and the outcomes of the projects during 2011-2017. The project coordinators were asked to evaluate the research achievements and benefits based on a questionnaire referring to the five criteria of the European Commission's Better Regulation Guidelines: relevance, effectiveness, efficiency, coherence and EU added-value.

For both the coal and steel sector, the respondents highlighted that the projects are clearly and factually aligned with the RFCS research objectives[5]. The advancements made towards attaining the specific objectives of RFCS have been confirmed as 'excellent' or 'good' and major improvements in the state of the art[6] has been reported for most of the projects analysed. Moreover, the achievement of the individual project objectives and the expected benefits outlined in the Technical Annex of the Grant Agreement are evaluated as 'very positive'. Specifically, the scientific and technological success of completed coal and steel projects is rated at 80% or higher. Concerning budget allocation, the surveyed project coordinators for both coal and steel considered that their budget is generally well balanced, utilised in a timely manner, in line with the original estimates and reasonable considering the project results.

All **coal projects** analysed responded very positively with regard to the RFCS projects' flexibility to adapt to new scientific and socio-economic developments. No project was deemed to have made poor progress. Furthermore, the responses highlighted clear benefits from carrying out the RFCS projects at EU level. Besides the value of knowledge creation, dissemination of the results (up to 91% of the projects assessed) and effective mobilisation of resources (55%), the strategic importance borne by the RFCS projects for the European coal regions has also been highlighted.

The **steel projects** have also been deemed a success in terms of economic and social aspects. Projects achieved their specific objectives, sometimes even going beyond the expectations set out

[3] Council Decision 2008/376/EC.
[4] CoalTech2051 for coal; LowCarbonFuture and GRISPE PLUS for steel.
[5] Council Decision 2008/376/EC. The objectives for the coal sector are: (i) improving the competitive position of EU coal, (ii) health and safety in mines, (iii) efficient protection of the environment and (iv) improvement in the use of coal as a clean energy source. The objectives for the steel sector are: (i) new and improved steelmaking and finishing techniques, (ii) RTD and the use of steel, (iii) conservation of resources and (iv) improvement of working conditions.
[6] The 'state-of-the-art' can be defined as the existing and most developed level of technology.

in the grant agreement. All projects show consistency with TG objectives and several projects (65%) show synergies with at least another or several TGS. Moreover, benefits are visible at beneficiary level, EU level (about 80% of projects are deemed strategically important) and at sector level. Finally, the projects attained further relevant benefits such as the increase of knowledge, a positive economic impact, and advantages for the environment and resources.

HLG recommendations – the future of RFCS

The results of the monitoring and assessment exercise confirm that the RFCS programme and its achievements are of great value and are highly relevant for the competitiveness and advancement of the European coal and steel sector. The research activity carried out during 2011-2017 brought significant and concrete benefits to the European coal and steel sectors, the whole economy and EU society at large. However, it also becomes evident that, in order to achieve the EU's ambitious goals towards a competitive, prosperous and climate neutral economy by 2050[7], there are still several challenges to overcome. Some of the major future challenges for the European coal and steel industry have been identified by the TG chairs, such as:

- the decrease of greenhouse gas emissions;
- the sustainable use of energy and resources; and
- the development of new competitive high-performance products and processes.

In Chapter 4, the HLG formulates its own views and recommendations having considered the inputs from the TG chairs, assessments of projects carried out by project coordinators, and the insights gained from the involvement and contribution of stakeholders during the above-mentioned conference on coal and steel in March 2019.

From a **cost-benefit** viewpoint, the HLG concluded that the programme's monetary benefits (€1 funded by RFCS provides €3 for the beneficiaries and €1 spent by the beneficiaries on research and innovation (R&I) supported by the RFCS generates about €5 – calculated in the previous monitoring & assessment exercise) - are still valid for the present period.

On a technical level, the **coal** sector is supporting climate change/protection initiatives and coal regions in transition[8] by exploring innovative solutions. The HLG recommends targeted R&I support to deploy technologies with a global impact to shape decarbonisation methods and support coal regions in transition. The key future research trends for the coal sector include (i) carbon capture usage and storage (CCUS), (ii) the alternative use of coal mine infrastructure to support renewables as well as clean coal technologies by means of deploying supercritical and ultra-supercritical coal-fired power plants and (iii) energy storage. In addition, the HLG recommends addressing the need to valorise coal products for non-energy uses in terms of coal gasification, integrated hydrogen production and coal as a resource for critical raw materials. Moreover, the HLG states that a prosperous, modern, competitive and climate neutral economy could be achieved by means of:

- fostering digitalisation and digital transformation in mining; and
- supporting European technological leadership through ongoing efforts in improving:
    - automation and performance efficiency;
    - safety;
    - health and environmental protection; and
    - land rehabilitation and ecological restoration.

Furthermore, the HLG suggests that discussion among stakeholders be fostered in order to maintain and disseminate knowledge on European coal technologies.

The **steel** sector, in agreement with the EU decarbonisation strategy[9], is promoting the reduction of CO_2 emissions and the development of tools to respond to climate change, together with the increase of resource efficiency of processes and products. New breakthrough technologies are required to produce carbon lean steel. The HLG recommends that RFCS support be strengthened

[7] COM(2018)773.
[8] For more information on the coal regions in transition, see : https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/EU-coal-regions/coal-regions-transition
[9] COM (2018) 773.

for the industrial implementation of improved technologies such as CCS or CCU as well as for processes that achieve carbon direct avoidance (CDA) like hydrogen or electricity-based steelmaking.

The RFCS programme should address the sustainable development of new high-performance products and solutions for safe and improved applications and demanding markets (e.g. automotive, construction, renewable energy markets), which has become a high-priority objective, achievable by controlling the whole manufacturing process. The rational use of energy sources, and the recovery and reuse of the waste energy and heat of intermediate products should be considered. This will enable energy efficiency to be improved along the whole production chain. The RFCS should support the circular economy approach, involving the use of low-quality reused materials and scrap, waste heat and secondary raw materials for producing high-quality products. In this context, the development and application of life cycle thinking[10] tools is recommended. In addition, it is critical that the steel industry enter into the era of digitalisation and Industry 4.0 to solve future technological, environmental as well as competitive challenges. The RFCS should support the required steps to ensure that existing steel plants are compliant with Industry 4.0. In order to drive and ensure the success of all these activities, **cross-cutting themes** in the field of (i) education and training; (ii) social awareness; (iii) attractiveness of workplaces and the sector; and (iv) international cooperation, as well as an increased innovation capacity in terms of intellectual property rights (IPR) management and exploitation, are indispensable.

Regarding the future challenges and changes mentioned above, improving people`s working conditions (safety and health) and upskilling of the work force (i.e. highly skilled people will be required to meet future challenges) are major 'social' challenges for the coal and steel sectors.

Last but not least, the cost effectiveness in processes and end products is a permanent cross-cutting challenge that is very important for the competitiveness and sustainability of Europe's coal and steel industry. More specifically for steel, the RFCS projects will contribute to developing future cost efficiency production and to the quality of the steel products and solutions, strengthening the position of the European steel industry in the competition with non-European producers and other materials.

Furthermore, in order for the coal and steel sectors to achieve the ambitious goals they are faced with, the HLG has made the following recommendations:

- maintain the annual RFCS call for proposal with a budget of at least €40 million for research in coal and steel related sectors, in accordance with Protocol 37[11] to the Treaty on the European Union;
- support breakthrough technologies in the steel sector as well as emblematic projects in the coal sector in line with Protocol 37, the implementation of RFCS programme and with the EU priorities of deep decarbonisation towards a carbon-neutral economy by 2050;
- steer the synergies and sequencing between the RFCS programme, the next EU Framework programme for Research and Innovation (Horizon Europe), the Innovation Fund and Structural Funds, among others;
- update and amend the RFCS legal basis, to more closely match the new challenges that the coal and steel sectors will face in the future; the RFCS research objectives for coal and steel especially need an update (as advised by the HLG at paragraph 4.5).

[10] Life Cycle Thinking (LCT) refers to the need of assessing burden of products adopting a holistic perspective, from raw material extraction to end of life. To make LCT operational, several methodologies exist, namely: Life cycle assessment (LCA), Life cycle costing (LCC), social life cycle assessment (sLCA) and other methodologies designed for a supply chain approach (e.g. material flow accounting, MFA).

[11] Protocol (n° 37) on the financial consequences of the expiry of the ECSC treaty and on the research fund for coal and steel. *OJ C 115, 9.5.2008, p. 327–328.*

INTRODUCTION AND CONTEXT

The history of the RFCS programme

The Treaty establishing the European Coal and Steel Community (ECSC) was signed in Paris on 18 April 1951 by Belgium, Germany, France, Italy, Luxembourg and the Netherlands. It was in existence for 50 years and, having entered into force on 23 July 1952, expired on 23 July 2002. Historically, the ECSC was the practical follow-up to the Schuman declaration[12] of 9 May 1950, which proposed placing Franco-German production of coal and steel under a common high authority as part of an organisation in which other European countries could participate.

The ECSC Treaty created a framework for arranging the production and distribution arrangements for coal and steel and set up an autonomous institutional system to manage it. Although its remit was limited to these two branches of industry, the ECSC had a crucial impact on major economic and political developments in Europe for almost 50 years. The ECSC was financed by (i) levies that most coal and steel producers had to pay based on their production and (ii) the contributions of the countries that joined the EU later on. These resources constitute the major part of the assets generated.

From its onset, notwithstanding a big decline in demand for coal and steel in the post-war period, which could have plunged Western Europe into a dangerous economic recession, the ECSC functioned smoothly by striking the right balance between production and distribution of resources. Again, in the 1970s and 1980s, when the coal and steel industry underwent deep crisis, the ECSC was able to marshal an organised response, which enabled the necessary industrial restructuring and conversion to be carried out, while particular emphasis was placed on protecting workers' rights, in keeping with the European social model.

First and foremost, however, it is in political terms that the ECSC's innovative impact can be measured. The ECSC launched an original process based on the principle of shared destiny and a long-term vision. Composed, structured cooperation between partners won out over ill-tempered and sometimes violent confrontation between competitors. The ECSC was a precursor to today's European Union, consisting of an autonomous regulatory system run by independent institutions vested with the power and authority needed to make the system work. Within that framework, the ECSC contributed significantly to the peace, stability, prosperity and solidarity that we enjoy in the EU today.

The ECSC also initiated five decades of successful collaborative research and technical development in the coal and steel industry, sustaining the competitiveness of these sectors and improving health and safety at the workplace. Since then, researchers became more and more accustomed to cooperating in a growing European spirit. The related research programme advanced by the ECSC Treaty, the first European research network, led to major achievements, including:

- the development of the ECSC working towards common objectives;
- the implementation of collaborative projects at EU level;
- the harnessing of effective synergies for modernising the coal and steel industry and meeting global challenges;
- the development of high-level research centres in the field of coal and steel;
- the strengthening of the European position in a competitive global environment.

Structure and legal bases of the RFCS

The ECSC Treaty expired on 23 July 2002 and all assets and liabilities of the ECSC, as they existed, were transferred to the European Community on 24 July 2002. The Nice European Council decided to annex to the Treaty of Nice Protocol 37 on the financial consequences of the expiry of the ECSC Treaty and on the creation and management of the RFCS. Protocol No 37 agrees that the net worth of ECSC assets and liabilities is to be considered as an asset earmarked for research in the sectors

[12] The Schuman Declaration – 9 May 1950. Available online at https://europa.eu/european-union/about-eu/symbols/europe-day/schuman-declaration_en

associated with the coal and steel industries. The revenue from these assets is to be used exclusively for research in these sectors.

On 1 February 2003[13] the Council laid down the measures necessary for implementing Protocol 37, annexed to the Treaty on the functioning of the European Union, on the financial consequences of the expiry of the ECSC Treaty and on the RFCS. The European Commission is responsible for winding-up the financial operations of the ECSC that were still in progress when the ECSC Treaty expired. It is also responsible for managing the assets in such a way as to ensure their long-term profitability. The objective in managing the available assets must be to obtain the highest possible yield that is securely attainable.

The Decision of 1 February 2003 further stipulates that the net revenue from investing the available assets constitutes revenue in the EU's budget and that this revenue be used to finance, in the sectors associated with the coal and steel industries, research projects that are not covered by the EU framework programmes for research. This revenue funds the RFCS programme and is managed by the Commission in line with the legal structure outlined in Figure 1.

The average annual budget for funding between 2011-2017 was €50 million; 27.2% allocated for coal and 72.8% for steel.

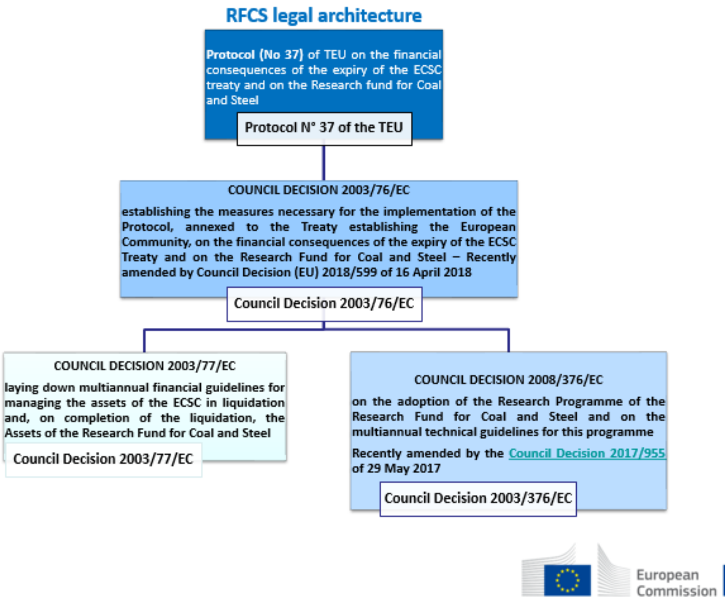
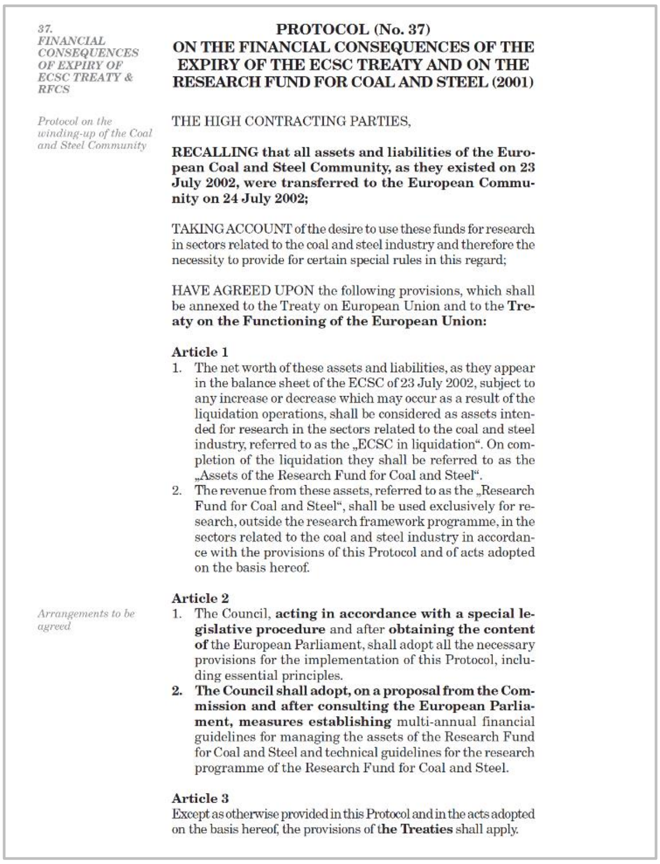


Figure 1 RFCS legal structure
Source: European Commission

Protocol No 37 of the Treaty on the European Union (Fig. 2) on the financial consequences of the expiry of the ECSC treaty and on the RFCS is annexed to the EU Treaty and is primary law.

[13] OJ L29, 05.02.2003, p. 22.



37. FINANCIAL CONSEQUENCES OF EXPIRY OF ECSC TREATY & RFCS

PROTOCOL (No. 37)
ON THE FINANCIAL CONSEQUENCES OF THE EXPIRY OF THE ECSC TREATY AND ON THE RESEARCH FUND FOR COAL AND STEEL (2001)

Protocol on the winding-up of the Coal and Steel Community

THE HIGH CONTRACTING PARTIES,

RECALLING that all assets and liabilities of the European Coal and Steel Community, as they existed on 23 July 2002, were transferred to the European Community on 24 July 2002;

TAKING ACCOUNT of the desire to use these funds for research in sectors related to the coal and steel industry and therefore the necessity to provide for certain special rules in this regard;

HAVE AGREED UPON the following provisions, which shall be annexed to the Treaty on European Union and to the **Treaty on the Functioning of the European Union:**

Article 1

1. The net worth of these assets and liabilities, as they appear in the balance sheet of the ECSC of 23 July 2002, subject to any increase or decrease which may occur as a result of the liquidation operations, shall be considered as assets intended for research in the sectors related to the coal and steel industry, referred to as the „ECSC in liquidation". On completion of the liquidation they shall be referred to as the „Assets of the Research Fund for Coal and Steel".
2. The revenue from these assets, referred to as the „Research Fund for Coal and Steel", shall be used exclusively for research, outside the research framework programme, in the sectors related to the coal and steel industry in accordance with the provisions of this Protocol and of acts adopted on the basis hereof.

Article 2

Arrangements to be agreed

1. The Council, **acting in accordance with a special legislative procedure** and after **obtaining the content of** the European Parliament, shall adopt all the necessary provisions for the implementation of this Protocol, including essential principles.
2. **The Council shall adopt, on a proposal from the Commission and after consulting the European Parliament, measures establishing** multi-annual financial guidelines for managing the assets of the Research Fund for Coal and Steel and technical guidelines for the research programme of the Research Fund for Coal and Steel.

Article 3

Except as otherwise provided in this Protocol and in the acts adopted on the basis hereof, the provisions of **the Treaties** shall apply.

Figure 2 Protocol 37 of the EU Treaty
Source: European Commission

Revisions of the RFCS legal bases

Two revisions of secondary legislation related to the RFCS were prepared and adopted. These revisions aimed to:

1. get additional funding and increase the revenues generated by the assets of the ECSC in liquidation to maintain an annual budget of €40 million;
2. align the RFCS with measures implemented under the EU framework programme for research and innovation, i.e. Horizon 2020.

The revenues assigned to fund research projects under the RFCS are falling at a substantial rate, leading to a situation whereby the critical level of funding for organising an annual call for proposals may not be reached. This decreasing rate is due to the condition of financial markets followed by quantitative-easing-policy led by the European Central Bank combined with the security principle governing the management of the assets of the European Coal and Steel Community in liquidation (ECSC i.L.).

The RFCS programme's budget[14] decreased from around €46 million based on 2015 ECSC i.L. revenues to around €27 million in 2018 based on 2016 ECSC i.L. revenues. This amount is expected to be even lower for 2019 (between €14m and €18m).

[14] Council Decision 2003/76/EC of 1 February 2003 establishing the measures necessary for the implementation of the Protocol, annexed to the Treaty establishing the European Community, on the financial consequences of the expiry of the ECSC Treaty and on the Research Fund for Coal and Steel, Article 4, *OJ L 29, 5.2.2003, p. 22–24.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32003D0076

1. *Maintaining an annual budget of €40 million*

- *Council Decision 2003/76/EC[15] establishing the measures necessary for the implementation of the Protocol, annexed to the Treaty establishing the European Community, on the financial consequences of the expiry of the ECSC Treaty and on the Research Fund for Coal and Steel - Recently amended by Council Decision (EU) 2018/599 of 16 April 2018.*

  This recent revision is a bridging solution that would maintain for a certain period an acceptable level of funding for coal and steel research projects while awaiting change in monetary policy and an increase of asset returns on public bonds markets. It aims to recycle unused appropriations for the research programme of the RFCS and, in particular, the amounts corresponding to cancellations of commitments made under this programme. The revision authorised the recycling of all the decommitments (including the amounts recovered) made under the RFCS research programme since 2003, which were returned to the assets of the ECSC i.L. This could possibly result in €52 million in complementary funding for the RFCS research programme.

- *Council Decision 2003/77/EC[16] laying down multiannual financial guidelines for managing the assets of the ECSC in liquidation and, on completion of the liquidation, the assets of the Research Fund for Coal and Steel amended by Council Decision 2008/750/EC[17]- Soon to be amended.*

  The Commission is willing to revise Decision 2003/77/EC, in order to make the ECSC portfolio more resilient by enlarging the scope for investing in other asset classes and using other investment techniques to shield the portfolio from being exclusively dependent on fixed income securities. This proposal would suggest enlarging the financial guidelines to broaden the eligible range of available assets/instruments and possible combinations of risk exposures (e.g. interest and credit risk or even some limited equities market risk). New investment opportunities will allow the portfolio to be managed more efficiently (in terms of diversification and risk-return trade-off) and deliver higher expected returns over the long term. The European Commission will propose that Council Decision 2003/77/EC be modified to explicitly provide for an annual budget of €40 million to support research projects in the coal and steel sectors. This payment should be covered by the net revenue on investments and the application of the smoothing mechanism[18]; if these fall short of the target annual payment, they will be supplemented by the withdrawal of assets from the fund.

2. *Alignment with Horizon 2020 rules*

- *Council Decision 2008/376/EC on the adoption of the Research Programme of the Research Fund for Coal and Steel and on the multiannual technical guidelines for this programme. Recently amended by the Council Decision 2017/955 of 29 May 2017.*

  To ensure a coherent framework for participation in both the RFCS programme and Horizon 2020[19], certain rules for participating in the RFCS programme needed to be aligned with those applicable under Horizon 2020. The rules on the tasks and composition of the advisory groups and of the technical groups, notably the rules on the nature of the experts whom the Commission appointed, had to be revised to ensure increased transparency as well as compliance and consistency with the framework for Commission expert groups. This revision also contributed, in as far as was possible, to a balanced representation of relevant areas of expertise and areas of interest, as well as to an optimal gender balance. It was deemed appropriate to consider simpler funding rules to help SMEs to participate in the RFCS programme and to permit the use of 'unit costs' to calculate eligible staff costs for SME owners and other people not receiving a salary.

[15] OJ L 29, 5.2.2003, p. 22–24. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32003D0076
[16] OJ L 29, 5.2.2003, p. 25–27. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32003D0077
[17] OJ L 255, 23.9.2008, p. 28–30. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32008D0750
[18] According to Council Decision 2003/76/EC of 01.02.2003, OJ L 29, 5.2.2003, p. 22, namely Article 5.2.
[19] Horizon 2020 as well as future EU Framework Programme for Research and Innovation.

Institutional setting and implementation of the RFCS programme

The RFCS supports EU collaborative projects related to the coal and steel industry. This means that the RFCS contributes to sustainable development; efficient, clean and safe production; protection of the environment; conservation of resources and energy; health and safety aspects as well as to improving the working conditions.

The Commission manages the RFCS programme with the support of several bodies (see Fig. 3). These bodies usually meet once a year.

- The *Coal and Steel Committee (COSCO*) is composed of representatives from the Member States. Main decisions concern the final approval of the management of the RFCS programme and especially of the selected projects to be funded*.*
- The *Coal and Steel Advisory Groups* (*CAG* and *SAG*) are independent technical advisory groups. The Commission appoints the members to serve in a personal capacity. They are active in the coal or steel area and aware of the industrial priorities. The Commission ensures a broad and balanced composition regarding expertise, geographical representation and gender. Main consultations concern all aspects of the RFCS programme's overall development, its objectives and priorities, the evaluation of proposals, the documentation and manuals and the technical groups.
- Three coal and nine steel *technical groups* (TGC# and TGS#) advise the Commission on monitoring of the projects and on defining priorities of the research programme (Table 1). The members are appointed by the Commission. They must come from entities related to the coal and steel industries, including research institutes and user industries and must be highly experienced. They review the technical implementation reports and the final reports.

COAL AND STEEL TECHNICAL GROUPS STRUCTURE (2011-2017)

TGC1	Coal mining operations, mine infrastructure and management, unconventional use of coal deposits
TGC2	Coal preparation, conversion and upgrading
TGC3	Coal combustion, clean and efficient coal technologies, CO_2 capture
TGS1	Ore agglomeration and iron making
TGS2	Steelmaking processes
TGS3	Casting, reheating and direct rolling
TGS4	Hot and cold rolling processes
TGS5	Finishing and coating
TGS6	Physical metallurgy and design of new generic steel grades
TGS7	Steel products and applications for automobiles, packaging and home appliances
TGS8	Steel products and applications for building, construction and industry
TGS9	Factory-wide control, social and environmental issues

Table 1 The 12 coal and steel technical groups (TGC – TGS)
Source: European Commission

As proposed by the Commission, discussed at CAG and SAG and endorsed by the 20th COSCO on 19 December 2018, the TGs are restructured into a total of seven coal and steel technical groups: two TGs for coal and five TGs for steel. This new configuration (Table 2) was published in the RFCS Information Package 2019 and will be implemented for the first time in 2020.

COAL AND STEEL TECHNICAL GROUPS STRUCTURE (FROM RFCS INFO PACK 2019)

TGK1	Post-mining issues, safe and productive coal mining operations
TGK2	Environmental, technical and economic issues related to coal treatment and use
TGA1	Iron- and steelmaking
TGA2	Downstream steel processing
TGA3	Conception of steel products
TGA4	Steel applications and solutions for existing and new markets
TGA5	Steel factories - smart and human

Table 2 The new 7 coal and steel Technical Groups (TGK – TGA)
Source: European Commission

The objectives of the research programme in the period under review, according to Council Decision 2008/376/EC are:

For ***coal***:

- improving the competitive position of EU coal;
- health and safety in mines;
- efficient protection of the environment and improvement in the use of coal as a clean energy source;
- management of external dependence on energy supply.

For ***steel***:

- new and improved steelmaking and finishing techniques;
- RTD and the utilisation of steel;
- conservation of resources and improvement of working conditions.

In Chapter 4 of this report, the HLG recommends the RFCS programme's objectives be updated so they can better address the current challenges faced by the coal and steel sectors. The RFCS research objectives can be modified through comitology[20] (Council Decision 2008/376/EC, Art. 41 (c)).

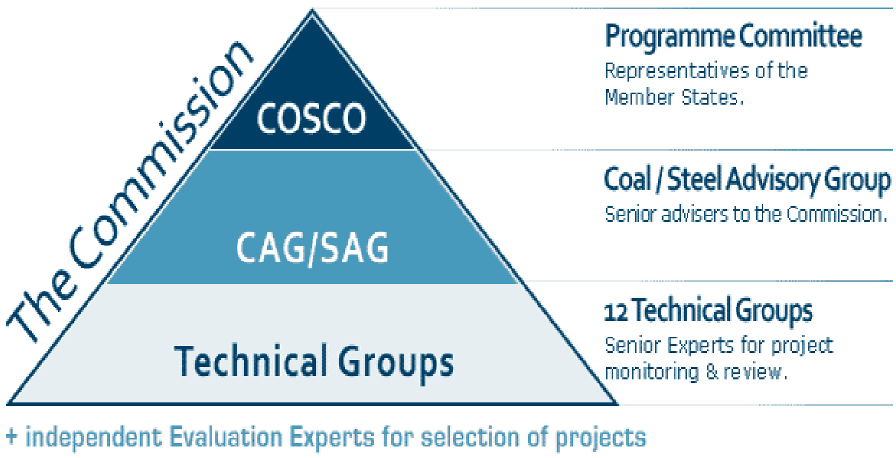


Figure 3 Management scheme of the RFCS programme
Source: European Commission

[20] 'Comitology' refers to the way the Commission exercises, with the aid of committees, the implementing powers conferred upon it by the legislators. These committees are composed of representatives of the Member States. Council Decision 2008/376/EC provides for implementing powers on the Commission to adopt measures for the implementation of the legal instruments of the European Union.

The RFCS programme supports the following activities:

1. *Research projects* are intended to cover investigative or experimental work in order to acquire further knowledge on how to attain specific practical objectives such as creating or developing products, improving or developing production processes and developing services.
2. *Pilot projects* are characterised by the construction, operation and development of an installation or a significant part of an installation on an appropriate scale. They use suitably large components to examine the potential for putting theoretical or laboratory results into practice and/or increasing the reliability of the technical and economic data needed for progress to the demonstration stage, and in certain cases, the industrial and/or commercial stage.
3. *Demonstration projects* are characterised by the construction and/or operation of an industrial-scale installation or a significant part of an industrial-scale installation. Their aim is to bring together all the technical and economic data needed for industrial and/or commercial use of the technology at minimum risk.
4. *Accompanying measures* aim to promote the use of knowledge gained and the organisation of dedicated workshops or conferences in connection with projects or priorities of the research programme.

Furthermore, the legal basis of the RFCS, Council Decision 2008/376/EC[21], allows the Commission to provide support and preparatory measures to ensure the research programme is managed soundly and effectively, e.g. the evaluation of proposals or monitoring and assessment exercises.

According to this Decision, 'any undertaking, public body, research organisation or higher or secondary education establishment, or other legal entity, including natural persons', that are established within a Member State may participate in the research programme and apply for financial assistance, provided that they intend to carry out an RTD activity or can substantially contribute to such an activity. The same types of entity that are established in a candidate country can also participate without receiving any financial contribution under the programme, unless otherwise provided under the relevant European Agreements and their additional Protocols, and in the decisions of the various association councils. In addition, any such entity established in a third country is entitled to participate without receiving any financial contribution under the programme, provided that such participation is in the EU's interest.

The RFCS programme is based on cost-sharing RTD grant agreements. The total public funding must conform to the applicable rules on State aid.

The maximum RFCS co-funding is:

- 60% for research projects;
- 50% for pilot and demonstration projects;
- 100% for accompanying measures.

Eligible costs of the programme are:

- staff costs comprising scientific, postgraduate or technical staff and manual workers directly employed by the beneficiary[22] and devoted to the project;
- costs for purchasing or hiring of equipment needed;
- operating costs, e.g. for raw materials, consumables, energy, transportation, rental or alteration of equipment, analysis and tests, assistance from third parties or protection of knowledge.
- indirect costs, which are defined as flat rate amounting to 35% of the eligible staff costs and are to cover all other project expenses e.g. overhead costs and travel and subsistence costs.

Calculations methods are detailed in the RFCS information package. At the end of a project, all costs must be certified by means of an external auditor's certificate.

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[21] OJ L 130, 20.5.2008, p. 7–17. Available online*:* http://data.europa.eu/eli/dec/2008/376/oj

[22] The beneficiaries are the signatory of a grant agreement. The beneficiary may be represented by a project coordinator in the case of multi-beneficiary grant. A participant or applicant may not necessarily become a beneficiary of an EU grant.

An open call for proposals for the programme is published with a submission date set around 15 September of each year.

The submitted proposals must comply with the programme rules and the stipulations laid down in the information package. Each proposal must include a detailed description of the proposed project and contain full information on objectives, partnerships, including the precise role of each partner, management structure, anticipated results and expected applications. An assessment of anticipated industrial, economic, social and environmental benefits is also requested. The proposed total cost and its breakdown must be realistic and effective including a favourable cost/benefit ratio. Since 2011, there has been an electronic submission process. There are only a few conditions for admissibility and eligibility spelled out in the programme's information package. No limits are set for project budgets or project duration.

The Commission reviews submitted proposals to check their eligibility, with independent experts evaluating the eligible proposals in the last quarter of the year, first remotely and then during consensus meetings in Brussels. Each proposal is evaluated by at least three experts who must find a consensus. Based on this evaluation, the Commission draws-up two ranking lists for the coal and the steel proposals, which are presented to the relevant Advisory Group (CAG or SAG) and finally to COSCO for endorsement, at its annual meeting[23].

After the Commission delivers its final decision, a grant agreement is signed for the projects awarded funding with a targeted starting date, usually on 1 July of the year following the submission. On average, each research project receives funding of €1-1.5 million, comprises 6-7 partners, and runs for 36 months. Some pilot/demonstration projects are awarded significantly higher funds, while accompanying measures are relatively smaller.

During an RFCS project, the beneficiary must submit several reports to the Commission and the technical groups describing the technical progress achieved and the financial situation. Until 2015, according to the RFCS guidelines for technical reporting, published in the yearly information package, the beneficiary had to produce an annual report every calendar year covering the progress of the respective project. Since 2015, annual reports have no longer been requested. Instead, the beneficiary must submit a mid-term technical report (called a periodic report since 2015) on the accumulated results and a final report on the whole project, including an assessment of the project's operation and impact, must be provided by the beneficiary. Both reports must be accompanied by financial statements.

The research results are distributed by means of presentations to the technical groups, and publication of final reports of all projects funded until 2015 in the EU Publication Office as well as by other publications. Other forms of distribution and dissemination, such as scientific publications in international journals, websites, workshops and conferences, are encouraged.

[23] See Council Decision (EU) 2017/955 of 29 May 2017 amending Decision 2008/376/EC on the adoption of the Research Programme of the Research Fund for Coal and Steel and on the multiannual technical guidelines for this Programme.

1. RFCS FACTS AND FIGURES, SYNERGIES WITH EU POLICIES

1.1. RFCS programme management

The European Commission manages the research programme of the RFCS following the yearly timeline described in Figure 4 below.

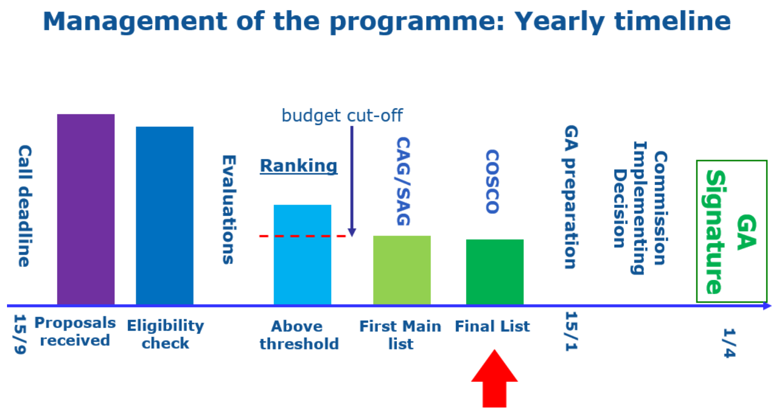

Figure 4 Management of the RFCS programme
Source: European Commission

Annual budget of the RFCS programme

During the period under consideration (2011 – 2017[24]) the cumulated total budget of the RFCS programme approved by COSCO was €352 million, leading to an average yearly budget of approximately €50 million (Table 3). There was a reduction in the yearly available funds ranging from €60 million in 2011 to €42 million in 2017, depending on the actual decreasing interest rates of the ECSC assets in liquidation.

Year	Coal	Steel	Total
2011	€ 16.572.892,00	€ 44.356.858,00	€ 60.929.750,00
2012	€ 15.902.446,00	€ 42.562.429,00	€ 58.464.875,00
2013	€ 14.071.240,00	€ 37.661.260,00	€ 51.732.500,00
2014	€ 13.155.620,00	€ 35.201.630,00	€ 48.366.250,00
2015	€ 12.266.803,00	€ 34.725.600,00	€ 47.700.000,00
2016	€ 11.723.200,00	€ 31.376.800,00	€ 43.100.000,00
2017	€ 11.451.200,00	€ 30.648.800,00	€ 42.100.000,00

Table 3 The RFCS budget 2011-2017
Source: European Commission

[24] The period under assessment considers the project proposals submitted in 2010 and funded in 2011.

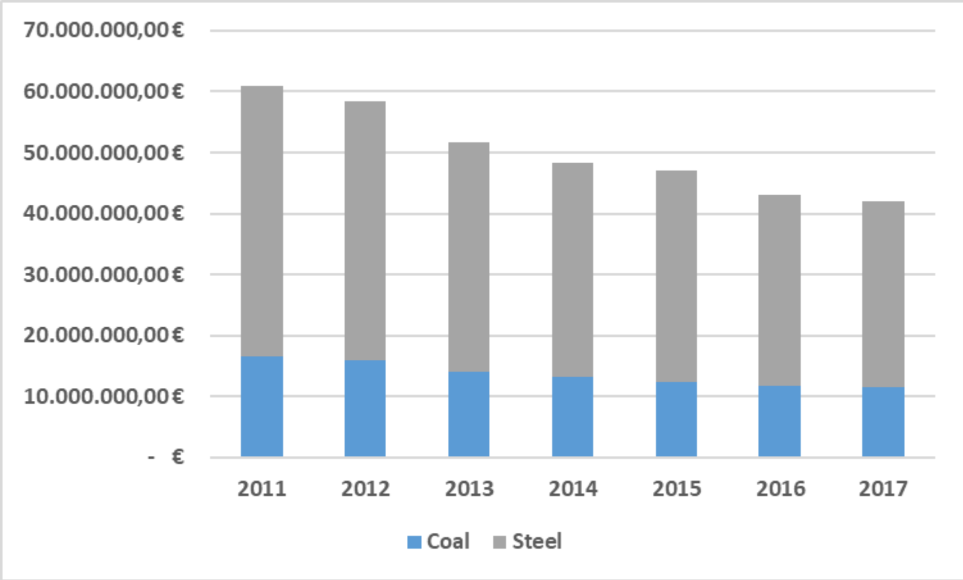

Figure 5 RFCS budget for coal and steel (2011 – 2017)[25]
Source: European Commission

The European Commission has undertaken different steps to limit the rapid decrease of funds: as mentioned above, Council Decision 2003/76/EC was amended so unspent resources in previous RFCS projects could be used. This amendment will guarantee a €40 million call for proposals per year until 2020 (Table 4).

Year	**Budget**
2011	60 929 750 €
2012	58 464 875 €
2013	51 732 500 €
2014	48.366.250 €
2015	47.700.000 €
2016	43.100.000 €
2017	42.100.000 €
2018	27.400.000 €
2019 (estimation)	22.000.000
2020 (estimation)	18.000.000

Revision of 2003/76/EC for using decommitments and unused revenues to get EUR 40 m per year

Table 4 Revision of Council Decision 2003/76/EC
Source: European Commission

Regarding the average funding for a project among the 12 technical groups of the RFCS programme (2011-2017), for coal the higher average funding is attributed to (i) coal mining

[25] Minor differences in the distribution of budget may be due to the ranking lists being financed until funds are available.

operations, mine infrastructure and management, unconventional use of coal deposits (TGC1) and (ii) coal combustion, clean and efficient coal technologies, and CO_2 capture (TGC3). For steel, about 60 % of the RFCS funds are related to the production processes of the steel works (TGS 1, 2, 3, 4, 5 and 9). The remaining funds (40%) support the development and utilisation of steel in the major application sectors, such as automobiles, packaging, home appliances, building, construction and industry (TGS 6, 7 and 8).

Proposals received from 2011 to 2017[26]

The RFCS programme received a total of 1,320 proposals (248 for coal and 1,072 for steel) in the period under assessment (Table 5). On average, the Commission received 190 proposals per year, with a steady increase from 2011 to 2014, followed by a drop in 2015. After 2015, there was a relatively consistent combined number of submitted proposals of around 200 proposals per year.

Year	Coal	Steel	Total
2011	22	123	145
2012	24	134	158
2013	37	164	201
2014	40	187	227
2015	37	156	193
2016	43	153	196
2017	45	155	200
Total	**248**	**1072**	**1320**

Table 5 RFCS proposals received (2011 – 2017)
Source: European Commission

Table 6 shows the proposals received by the coal technical groups. Starting from 2011, there was a constant increase in the submitted proposals for coal. Whereas TGC1 and TGC3 received a consistent number of proposals per year (with at least an average of 10 per year), it appears that TGC2 received fewer proposals. This is because the majority of coal project proposals tend to focus on coal mining operation, mine infrastructure and management, and unconventional use of coal deposits (TGC1), and on coal combustion, clean and efficient coal technologies, and CO_2 capture (TGC3) rather than on coal preparation, conversion and upgrading (TGC2).

Year	TGC1	TGC2	TGC3	Coal
2011	7	4	11	22
2012	14	5	5	24
2013	21	6	10	37
2014	21	4	15	40
2015	22	4	11	37
2016	23	4	16	43
2017	6	11	28	45
Total	**114**	**38**	**96**	**248**

Table 6 RFCS proposals submitted per TGC (2011 – 2017)
Source: European Commission

[26] For each year, we consider the proposal received in year N-1 and financed in year N. For instance, the proposals showed in Table 1.10 for the year 2011 refer to the RFCS Call for Proposals 2010 (Information Package 2010).

The following table (Tab. 7) shows the proposals received by the steel technical groups. There was a significant increase in the number of proposals from 2011 until 2014. There was a slight drop in 2015, followed by a relatively consistent number of submissions until 2017. TGS8 on steel products and applications received the highest number of submitted proposals - 379 - followed by TGS9 on factory-wide control, social and environmental issues and TGS6 on physical metallurgy and design of new steel grades. It should be considered that TGS9 covers a broad field of technical transversal topics which may attract a wide number of submissions. TGS1 on ore agglomeration and ironmaking received the lowest number of proposals (45 between 2011 and 2017).

Year	TGS1	TGS2	TGS3	TGS4	TGS5	TGS6	TGS7	TGS8	TGS9	Steel
2011	6	8	10	12	9	13	10	38	17	123
2012	7	15	9	8	9	11	10	44	21	134
2013	6	18	8	13	10	20	9	62	18	164
2014	5	19	10	13	17	21	15	62	25	187
2015	8	11	5	15	12	16	10	56	23	156
2016	6	14	6	15	8	14	9	60	21	153
2017	7	8	10	15	10	11	12	57	25	155
Total	**45**	**93**	**58**	**91**	**75**	**106**	**75**	**379**	**150**	**1,072**

Table 7 RFCS proposals submitted per TGS (2011-2017)
Source: European Commission

Table 8 shows the proposals submitted sorted by type of activity under the coal and steel topics of the RFCS programme[27]. For both coal and steel, the majority of submitted proposals concerned research projects, respectively 233 proposals for coal and 972 for steel. There were 14 pilot and demonstration project proposals for coal and 63 for steel. Furthermore, accompanying measures were quite well represented for steel (37 proposals), whereas only 1 proposal was submitted for coal. Since 2016, there has been a remarkable increase in the number of submitted accompanying measures.

Year	Research	Pilot & Demo	AM	Coal	Research	Pilot & Demo	AM	Steel
2011	20	2		22	114	6	3	123
2012	22	2		24	126	6	2	134
2013	32	5		37	148	13	3	164
2014	37	3		40	168	16	3	187
2015	37			37	146	6	4	156
2016	41	1	1	43	136	7	10	153
2017	44	1		45	134	9	12	155
Total	**233**	**14**	**1**	**248**	**972**	**63**	**37**	**1,072**

Table 8 Coal and steel project proposals by activities (2011-2017)
Source: European Commission

Concerning country participation, Table 9 depicts the participation for the top 10 EU Member States under RFCS-coal call for proposals. Table 9 also represents the other 18 EU countries, which are displayed using two different thresholds. Participation is defined as the act of involvement of a legal entity in a project. A legal entity may participate in multiple projects.

[27] Pilot and demonstration Project (Pilot & Demo); research project (Research); accompanying measures (AM).

Regarding the participation of legal entities in coal proposals, Poland has the highest participation rate, followed by Germany, Spain, the United Kingdom and France. The two last columns on the right show the participation rate of legal entities for all the other EU Member States, by using two different thresholds.

COAL		EU member states										
Year	BE	CZ	DE	EL	ES	FR	IT	PL	RO	UK	Other Countries	Other Countries
2011	1	7	45	5	23	23	7	28		16	AT, FI, HR, NL, PT, SE, SI	BG, CY, DK, EE, HU, IE, LT, LU, LV, MT, SK
2012		5	31	12	27	14	2	37	1	23		
2013	2	6	42	17	41	19	12	46	23	26		
2014	7	10	28	23	60	12	13	59	5	30		
2015	8	15	38	21	38	20	12	80	8	35		
2016	9	21	48	18	34	22	19	90	5	35		
2017	7	22	47	18	32	21	22	91	5	38		
Total	**34**	**86**	**279**	**114**	**255**	**131**	**87**	**431**	**47**	**203**	**From 28 to 10 Proposals**	**< 10 Proposals**

Table 9 Legal entities' participation in coal proposals by EU Member States
Source: European Commission

Table 10 below presents the top 10 EU Member States that participate under steel. Legal entities from Germany have submitted the highest number of proposals followed by Italy, Spain, Sweden and France. Again, apart from the top 10 participants, the two last columns on the right also display all the participation rates for legal entities from other EU countries participation by using two different thresholds.

STEEL	EU member states											
Year	BE	DE	EL	ES	FR	IT	NL	PT	SE	UK	Other countries	Other countries
2011	60	189	16	76	45	102	40	15	57	36	AT, CZ, FI, LU, PL	BG, CY, DK, EE, HR, HU, IE, LT, LV, MT, RO, SI, SK
2012	46	177	13	99	52	121	21	18	66	51		
2013	57	204	22	116	82	163	26	40	67	56		
2014	55	243	24	143	78	210	23	55	84	58		
2015	70	205	28	125	55	167	26	50	75	39		
2016	74	170	36	126	61	162	34	36	56	51		
2017	64	162	34	123	74	194	33	38	62	53		
Total	**426**	**1350**	**173**	**808**	**447**	**1119**	**203**	**252**	**467**	**344**	**From 172 to 80 Proposals**	**< 80 Proposals**

Table 10 Legal entities' participation in steel proposals by EU Member States
Source: European Commission

Projects financed from 2011 to 2017

In the period under consideration, the RFCS programme financed 293 proposals in total (54 proposals for coal and 239 for steel) (Table 11).

An average of 42 projects per year have been funded, with a slight decline from 2014 due to a decrease in the available funding.

Year	Coal	Coal success rate	Steel	Steel success rate	Total
2011	5	23%	40	33%	45
2012	7	29%	43	31%	50
2013	11	30%	34	21%	45
2014	9	23%	31	17%	40
2015	7	19%	30	19%	37
2016	7	16%	31	20%	38
2017	8	18%	30	19%	38
Total	**54**	**22%**	**239**	**22%**	**293**

Table 11 Proposals financed (2011-2017)
Source: European Commission

On average, the overall success rate of the proposals submitted is around 22%. Higher success rates close to 30% were observed in 2011, 2012 and 2013. In 2014, the success rate fell, but in 2016 – 2017 it stabilised at around 17% for coal and 20% for steel.

Among the TGs for coal, TGC1 on coal mining, mine infrastructure and coal deposit has the highest number of financed proposals, followed by TGC3 and TGC2 (Table 12).

Year	TGC1	TGC2	TGC3	Coal
2011	1	1	3	5
2012	4	1	2	7
2013	5	3	3	11
2014	5	1	3	9
2015	5	2		7
2016	1	3	3	7
2017	5	1	2	8
Total	**26**	**12**	**16**	54

Table 12 Proposals financed by TGC
Source: European Commission

Concerning the TGs for steel, TGS8 on steel products and applications had the highest number of financed proposals, followed by TGS9 and TGS6 (Table 13).

TGS1 on ore agglomeration and ironmaking has the lowest number of financed proposals, albeit with a high amount of funding per proposal. However, while TGS8 on steel products and application had the largest number of financed proposals, projects under this category had a relatively lower average amount of funding due to the academic component of the TG and to the smaller size of projects.

Year	TGS1	TGS2	TGS3	TGS4	TGS5	TGS6	TGS7	TGS8	TGS9	Steel
2011	3	1	4	4	4	2	6	11	5	40
2012	4	2	5	2	2	4	3	15	6	43
2013	1	2	2	3	1	4	2	11	8	34
2014	1	7	1	3	2	5	2	5	5	31
2015	2	3		4	3	3	4	6	5	30
2016	2	3	1	2	2	7	1	10	3	31
2017	2	2	3	2	2	3	3	12	1	30
Total	**15**	**20**	**16**	**20**	**16**	**28**	**21**	**70**	**33**	239

Table 13 Proposals financed by TGS
Source: European Commission

Table 14 shows the proposals financed by the type of activity under the coal and steel part of the RFCS programme. Research proposals account for the highest number of financed proposals, 49 for coal and 209 for steel in 2011-2017. Pilot and demonstration presents 4 financed proposals for coal and 15 steel. Furthermore, 1 accompanying measure has been recommended for funding under coal and 14 under steel.

Year	Pilot & Demo	Research	AM	Coal	Pilot & Demo	Research	AM	Steel
2011	2	3		5	2	36	2	40
2012	1	6		7	1	41	1	43
2013	1	10		11	3	30	1	34
2014		9		9	3	25	3	31
2015		7		7	1	29		30
2016		6	1	7	4	24	3	31
2017		8		8	1	25	4	30
Total	**4**	**49**	**1**	54	**15**	**210**	**14**	239

Table 14 Proposals financed by type of activity
Source: European Commission

Research projects are by far the most funded activity (nearly 90 %). The Pilot & demonstration projects and accompanying measures have a share of about 5% each. Accompanying measures are mainly carried out in the steel part for dissemination and recommendation of technical guidance applicable to the use of steel in buildings, construction and industry. The success rate of the research and pilot & demonstration proposals are quite similar, whereas the accompanying measures proposals have a significantly higher success rate, above 35%.

The yearly distribution of funded proposals per activity (accompanying measures, pilot and demonstration projects and research projects) is presented in Table 15.

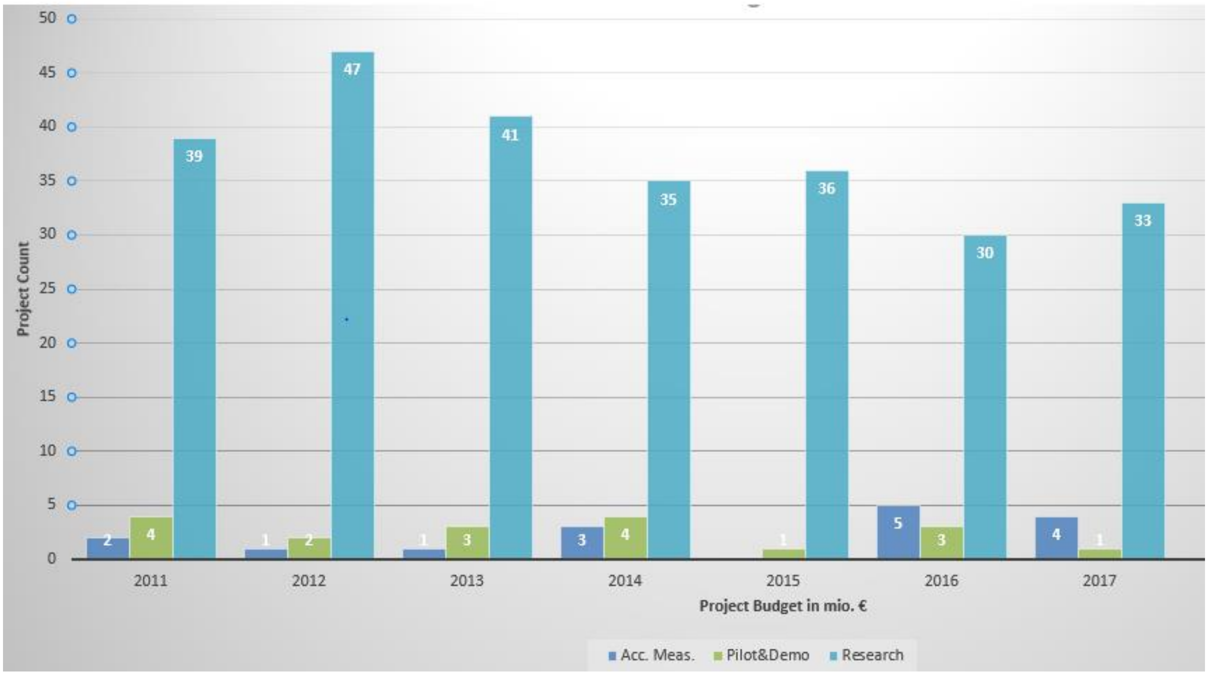

Figure 6 Project distribution by type of activity
Source: European Commission

The average allocation of funds to the different activities is 91% for research, 8% for pilot and demonstration and 1% for accompanying measures. The significant share of funds allocated to research and pilot/demonstration projects - as compared to other R&D programmes - denotes the industrial orientation of the RFCS programme.

In terms of the participation of legal entities from different countries in proposals financed under coal (Table 15), Poland has the highest rate, followed by Germany and Spain.

Coal	**EU member states**											
Year	**AT**	**CZ**	**DE**	**EL**	**ES**	**FR**	**IT**	**PL**	**RO**	**SI**	**UK**	**Other countries**
2011	-	2	9	1	3	2	3	8	-	1	3	BE, BG, CY, DK, EE, FI, HR, HU, IE, LT, LU, LV, MT, NL, PT, SE, SK
2012	4	1	12	1	9	3	1	8	1	-	6	
2013	-	1	16	3	14	5	5	12	-	1	9	
2014	2	1	7	3	12	2		16	3	1	6	
2015	1	3	6	4	8	5		12	4	1	7	
2016	1	3	8	3	6	3	3	6	-		8	
2017	-	5	9	4	7	4	1	23	-	4	4	
Total	**8**	**16**	**67**	**19**	**59**	**24**	**13**	**85**	**8**	**8**	**43**	**< 7**

Table 15 Legal entities' participation in financed projects under coal - by EU Member State
Source: European Commission

In terms of participation of entities from different countries in projects financed under steel (Table 17), Germany has the highest number of participations in financed projects, followed by Italy, Spain, Sweden, the United Kingdom and France.

Steel	EU member states												
Year	**AT**	**BE**	**DE**	**ES**	**FI**	**FR**	**IT**	**NL**	**PT**	**SE**	**UK**	**Other countries**	**Other countries**
2011	13	21	58	18	7	15	27	19	8	25	11	EL, LU	BG, CY, CZ, DK, EE, HR, HU, IE, LT, LV, MT, PL, RO, SI, SK
2012	6	18	61	34	7	15	22	4	3	33	24		
2013	4	17	44	27	5	22	36	6	3	14	14		
2014	5	15	54	20	4	13	42	6	4	18	12		
2015	8	16	45	17	2	7	24	10	6	21	9		
2016	3	15	55	21	7	6	26	5	9	9	12		
2017	2	14	43	21	12	16	26	8	8	16	14		
Total	**41**	**116**	**360**	**158**	**44**	**94**	**203**	**58**	**41**	**136**	**96**	**From 40 to 20**	**< 19**

Table 16 Legal entities' participation in financed projects under steel – by EU Member State
Source: European Commission

As discussed earlier, participation in the RFCS programme is possible for companies, public bodies, research institutes or other legal entities that are established in a Member State or a Candidate Country or based on individual projects also from non-EU countries. Funding is restricted to participants from Member States. Approximately half of the participants (Fig. 7) are categorised as research institutes. One of the positive effects of the ECSC and the RFCS programme has been the development of EU research institutes strongly committed to the coal and steel industry. The half of the participants consist of industry partners (mainly coal and steel producers or fossil power plants) and universities. This distribution of partners reflects their capability and willingness to participate in the programme (in terms of necessary personnel, equipment and qualification) to conduct research on the production and use of coal and steel.

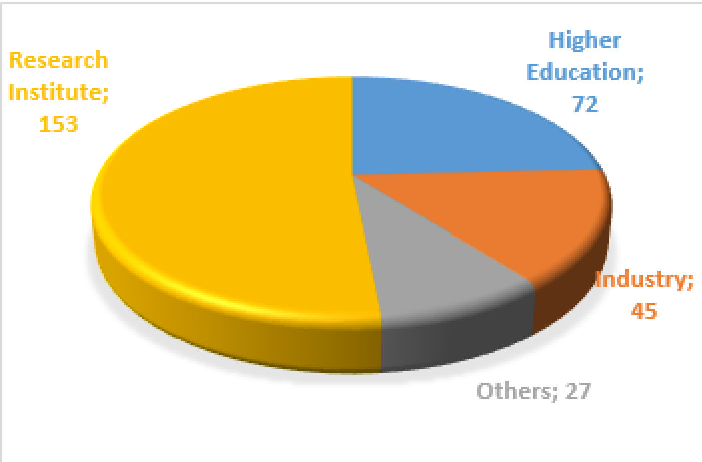

Figure 7 Beneficiaries of the RFCS programme by type of participants
Source: European Commission

1.2. Coal and steel industries

EU Coal industry

Coal still plays a crucial role in energy supply in the EU, despite a decline in some Member States (Figure 8).

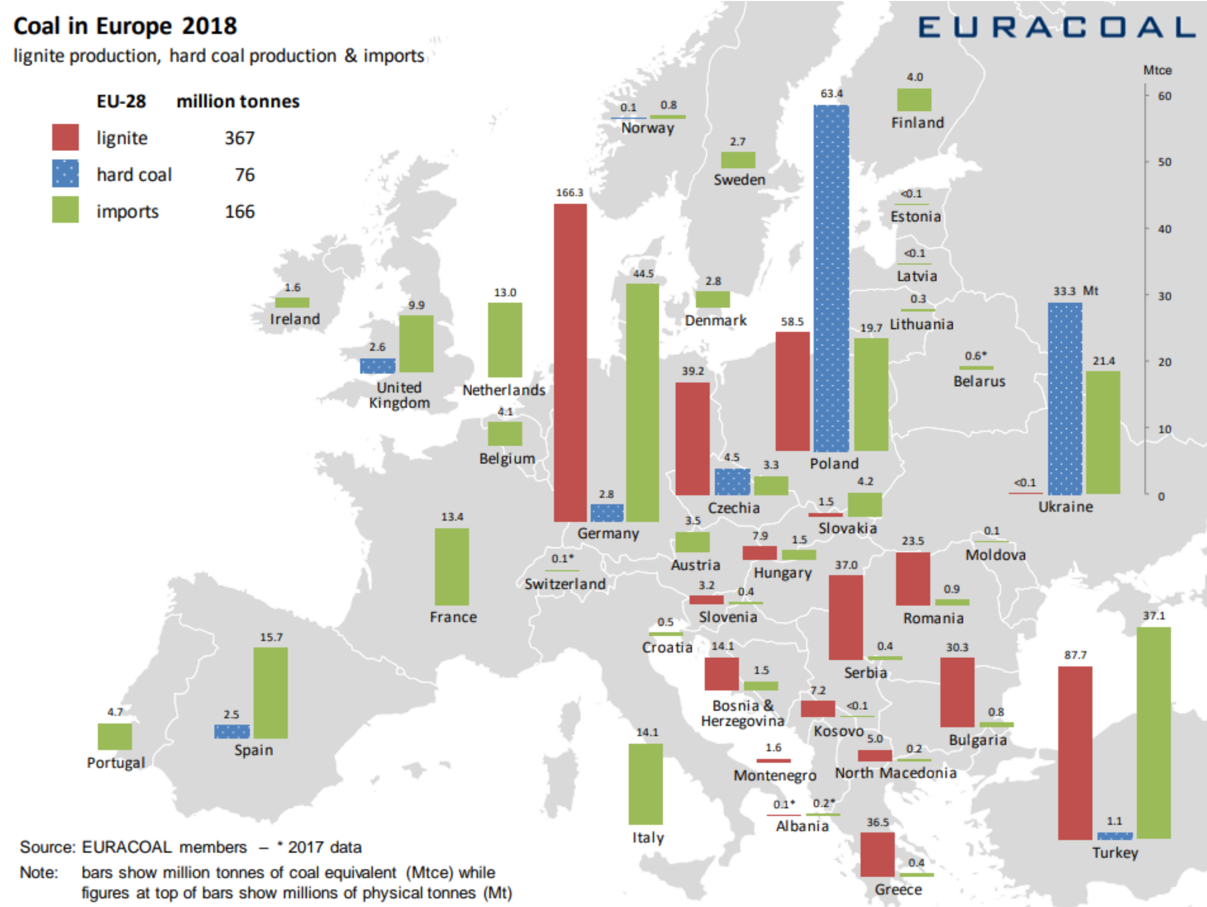

Figure 8 Coal production in Europe in 2018
Source: Euracoal

Nowadays, 40% of world electricity production comes from coal. In the EU, coal is mined in 41 regions spread over 12 countries. Most of the hard coal[28] and brown coal[29] is used for power production. In 2018, an estimated 127 million tonnes of hard coal was delivered to the main producers of electricity and heat in the EU-28. EU consumption of hard coal saw a 4% decline last year to 226 million tonnes, according to the latest EUROSTAT figures[30]. The production of hard coal in the EU has been falling year on year. In 2018, production stood at 74 million tonnes, 6% below the level in 2017 and 80% less than the 368 million tonnes in 1990.

The coal sector provides 240,000 jobs: 180,000 in the mining of coal and lignite and 60,000 in coal and lignite-fired power plants. Coal contributes to a quarter of electricity production in the EU and it is a major fuel for several industrial processes, including steel and cement production. Within the

[28] Anthracite, or hard coal, has the highest carbon content, the fewest impurities, and the highest energy density of all types of coal.
[29] Lignite, or brown coal, is considered the lowest rank of coal due to its relatively low heat content. It has a carbon content around 60–70 percent. It is mined all around the world and used almost exclusively as a fuel for steam-electric power generation.
[30] See EUROSTAT figures and statistics explained: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Coal_production_and_consumption_statistics#Consumption_and_production_of_hard_coal

EU, Poland has the highest employment in coal mining (100,000), followed by Germany (25,000), Czechia (18,000), Romania (15,000) and Bulgaria (12,000)[31].

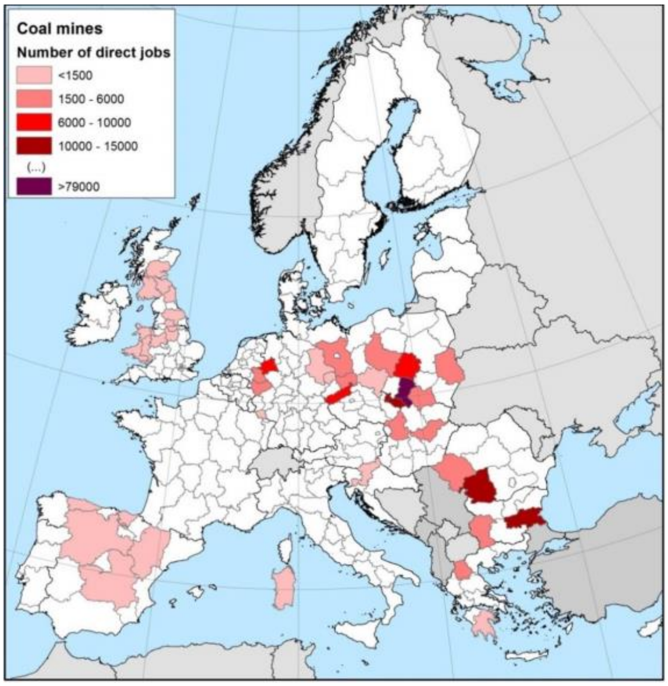

Figure 9 Number of jobs in coal mines in NUTS 2 regions (2017)
Source: European Commission

In 2017, production of hard coal fell by 6.5 million tonnes, from 87.2 million tonnes to 80.7 million (-7.5%), despite rising prices. In contrast, the EU's overall production of lignite grew by 3.0%, reaching 382.6 million tonnes, with notable increases in Romania and Greece. Much of the fall in hard coal production was replaced by coal imports, which rose 5.8 million tonnes to 173.1 million tonnes (+3.5%) in 2017. Poland still produces significant coal amounts, whereas Germany closed its last two remaining hard coal mines in 2018.

The EU energy system is becoming greener and more efficient. The EU is advancing industrial decarbonisation and is looking at cost-efficient ways to make its economy climate-neutral[32] and less energy intensive.

Producing green energy will be challenging, as it requires radical changes to EU power, heating and cooling industry as well as to transport. However, the EU's commitment to a clean energy transition is irreversible and non-negotiable. The Commission's Roadmap postulates a reduction in greenhouse gas emissions of 80 to 95% by 2050. Its low-carbon economy roadmap suggests two main milestones: a 40% reduction in emissions by 2030 and 60% by 2040. All sectors need to contribute to the low-carbon transition, which is considered both feasible and affordable. Coal transition is a significant challenge and has three dimensions:

- economic, where a regional economy has to modernise and transform from a coal industry that is no longer competitive to other sectors;
- societal, where social change is needed for job restructuring in places where heavy industry is often strongly embedded in the local identity; and
- environmental, meaning a strong impact of energy transformation on climate change.

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[31] European Commission, JRC Science for Policy Report, *EU coal regions. Opportunities and challenges ahead – Study*, 2018. Available online: https://publications.europa.eu/s/mkNa
[32] COM(2018)773

Due to this new approach, the EU regions relying on coal mining and specialised in coal-based energy and industry will be the most affected. Currently, there are up to 52 regions in Europe that are facing these challenges to various extents (mostly Bulgaria, Czechia, Germany, Greece, Poland, Romania, Slovakia and Spain). However, Europe's old industrial regions are the best example to prove that, even if the whole process could be difficult and very challenging, a successful transformation is possible, for example, the German Ruhr region. The required transition towards renewable energy sources entails many stakeholders, such as SMEs and industry, start-ups, research organisations and universities, NGOs, public sector and government, to closely cooperate. What is more, new policies, local practices and regulations need to be introduced. Research and innovation is particularly important in this case. A number of initiatives were organised to boost the clean energy transition focusing on social fairness, new skills and financing for the real economy. In December 2017, the European Commission launched a Platform on Coal Regions in Transition to help coal mining regions to identify, develop and implement projects that could help them in the economic and technological transformation, and to enable multi-stakeholder discussion on the policy framework and regulations (this could be done, for example, through *smart specialisation*). Currently[33], the Commission is trying to involve regions where coal mining is the main source of economic activity and employment. The Commission will also focus on regions where the economic activity and employment mostly relies on carbon-intensive industries. Within the Platform, country teams have been established – for Greece, Poland, Romania and Slovakia while Czech Republic and Spain will be involved in the future. The Commission has been clear all along that this is a transition for all Europeans.

In order to bolster cooperation, two working groups have been formed:

- the Post Coal Economy and Structural Transformation (DG ENER and DG RTD, REGIO, CLIMA, JRC…)
- the Eco-Innovation and Advanced Coal Technologies (DG RTD and DG ENER, REGIO, CLIMA, JRC…)

The Platform on Coal Regions in Transition promotes networking and exchange of good practices between regions, national authorities, societal and business stakeholders, and innovation and financing experts in the framework of the platform of advanced coal technologies. It also identifies the best ways to seize the opportunities of the transition. The Coal Regions in Transition Platform delivers tailor-made assistance to 13 pilot regions in 7 Member States.

As part of the industrial modernisation of European regions, the Commission supports smart specialisation, an innovative approach characterised by identifying strategic areas for intervention based on the analysis of both the strengths and potential of a region's economy to develop its own competitive advantages. The Smart Specialisation Platform (S3P)[34] helps Member States and regions to develop, implement and review their research and innovation strategy for smart specialisation (RIS3) strategies. These include a focus on (i) identifying niche areas of competitive strength, (ii) solving major societal challenges bringing in a demand-driven dimension, (iii) innovation partnerships emphasising greater coordination between different societal stakeholders and (iv) aligning resources and strategies between private and public players of differing governance levels.

[33] As of 2017.
[34] Smart Specialisation Platform (S3P): http://s3platform.jrc.ec.europa.eu/

Figure 10 Coal- and carbon-intensive regions
Source: European Commission

EU Steel industry

Steel is the basic material for many industrial value chains within the EU-28. There are steel production sites in nearly all EU Member States. Major producers are Germany, Italy, France, Spain and Poland (Figure 11). Between 2011 and 2017, the EU steel sector produced an average of 170 million tonnes of steel per year.

Crude steel production per country: EU

All qualities • in '000 metric tonnes

EU COUNTRIES IN DESCENDING ORDER OF CRUDE STEEL PRODUCTION TABLE • 2018

SOURCE: EUROFER

		2018	% shares 2018
1	GERMANY	42,435	25.3%
2	ITALY	24,532	14.6%
3	FRANCE	15,385	9.2%
4	SPAIN	14,299	8.5%
5	POLAND	10,167	6.1%
6	BELGIUM	7,980	4.8%
7	UNITED KINGDOM	7,268	4.3%
8	AUSTRIA	6,885	4.1%
9	NETHERLANDS	6,813	4.1%
10	SLOVAKIA	4,947	3%
11	CZECH REPUBLIC	4,938	3%
12	SWEDEN	4,632	2.8%
13	FINLAND	4,146	2.5%
14	ROMANIA	3,550	2.1%
15	LUXEMBOURG	2,228	1.3%
16	HUNGARY	1,989	1.2%
17	GREECE	1,467	0.9%
18	SLOVENIA	692	0.4%
19	BULGARIA	666	0.4%
20	CROATIA	136	0.1%
21	OTHERS	2,215	1.3%
	TOTAL	167,370	100%

EU COUNTRIES SHOWN BY RELATIVE SIZE OF CRUDE STEEL PRODUCTION MAP • 2018

SOURCE: EUROFER

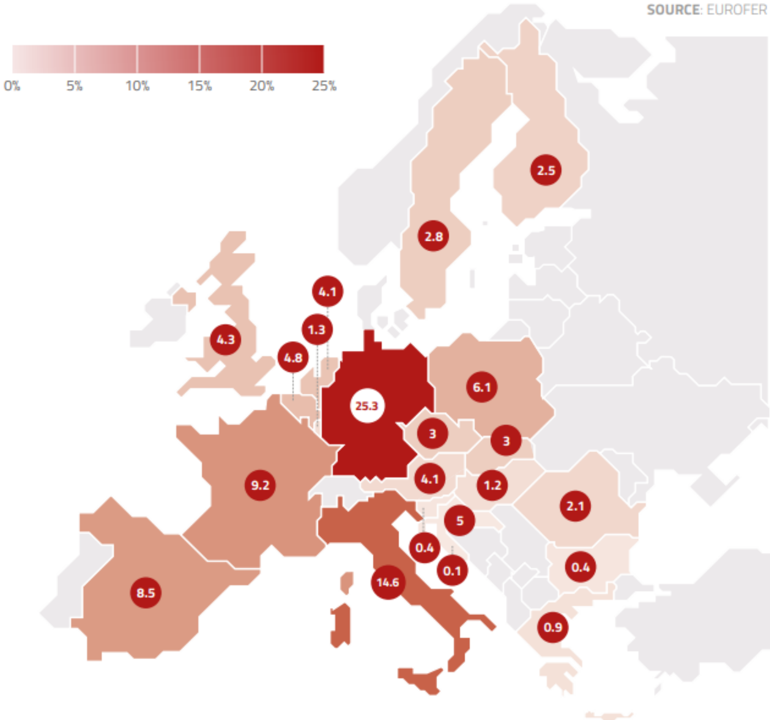

Figure 11 Crude steel production per country in the EU in 2018
Source: Eurofer

About 75% of total EU steel production is yielded in the blast furnace from iron ore and about 25% via the electric arc furnace route from scrap (Figure 12).

EU crude steel production: by process

All qualities ▪ in '000 metric tonnes

EU CRUDE STEEL OUTPUT BY PRODUCTION ROUTE

TABLE, CHART ▪ 2009 – 2018

SOURCE: EUROFER

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	% shares 2018
Basic Oxygen Furnace and other	78,239	101,790	102,371	98,316	100,106	103,024	100,577	97,642	99,925	97,588	75.1%
Electric	61,106	70,995	75,204	70,266	66,069	66,074	65,519	64,351	68,497	69,781	24.9%
Total Crude Steel	**139,344**	**172,785**	**177,576**	**168,583**	**166,175**	**169,098**	**166,096**	**161,993**	**168,422**	**167,370**	**100%**

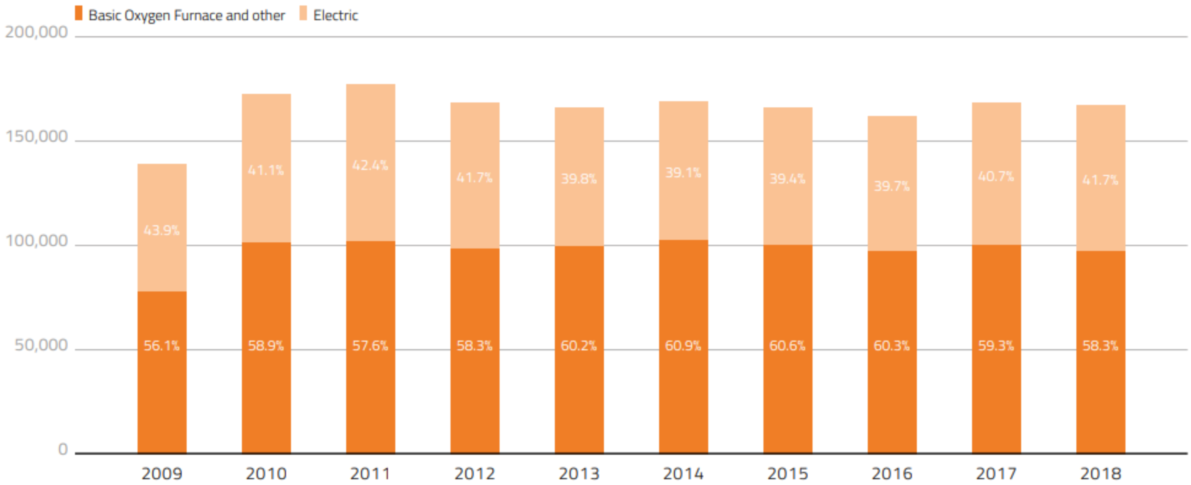

Figure 12 EU Crude steel output by production route (2009-2018)
Source: Eurofer

In 2018, the three sectors identified as major consumers of steel are the construction, automotive and mechanical engineering sectors (Figure 13).

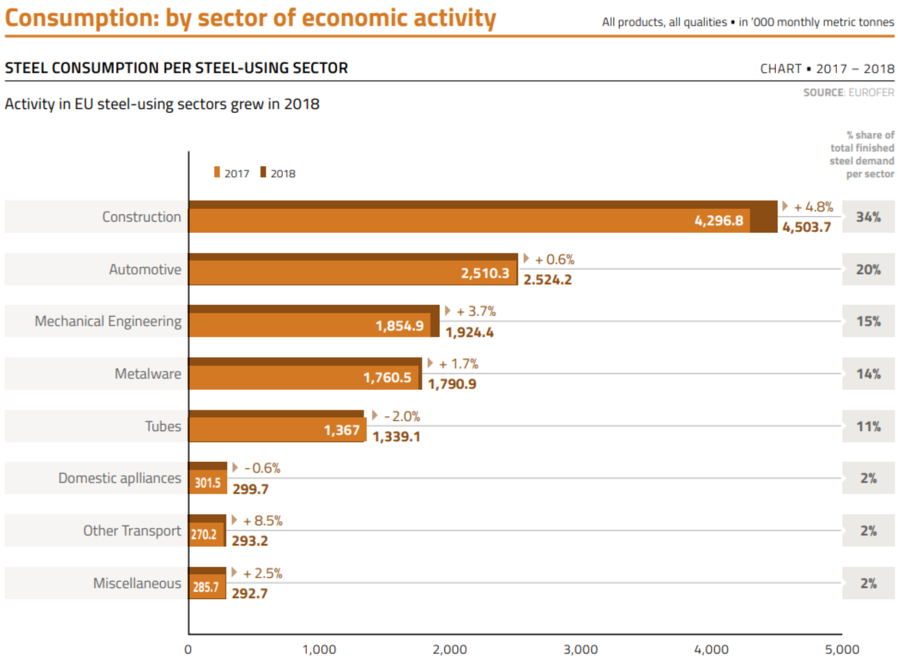

Figure 13 Steel consumption per steel-using sector in 2018
Source: Eurofer

The steel industry directly employs around 320,000 workers across 23 Member States (Fig. 13). However, it contributes to the employment of 2.6 million workers overall across the EU-28[35].

[35] The EU steel industry supports nearly 2.6 million jobs classified as Direct (320.000), Indirect (1.570.000) and Induced (701.000) jobs. Source: Eurofer, 2018. Available online: http://www.eurofer.be/News%26Events/PublicationsLinksList/201907-SteelFigures.pdf

Direct employment in the EU steel industry: by country

Employment by absolute numbers

EMPLOYMENT PER COUNTRY IN DESCENDING ORDER TABLE • 2018

SOURCE: EUROFER

		2018	% shares 2018
1	GERMANY	84,230	25.55%
2	ITALY	33,356	10.12%
3	POLAND	24,100	7.31%
4	ROMANIA	22,490	6.82%
5	FRANCE	21,900	6.64%
6	CZECH REPUBLIC	17,800	5.40%
7	SPAIN	17,352	5.26%
8	UNITED KINGDOM	15,811	4.80%
9	SWEDEN	15,700	4.76%
10	AUSTRIA	15,688	4.76%
11	BELGIUM	11,290	3.42%
12	SLOVAKIA	10,730	3.25%
13	NETHERLANDS	9,552	2.90%
14	FINLAND	8,124	2.46%
15	HUNGARY	5,707	1.73%
16	LUXEMBOURG	4,360	1.32%
17	SLOVENIA	4,236	1.29%
18	BULGARIA	4,150	1.26%
19	GREECE	1,455	0.44%
20	PORTUGAL	1,000	0.30%
21	DENMARK	418	0.13%
22	CROATIA	190	0.06%
23	ESTONIA	9	0.00%
	TOTAL	**329,648**	**100%**

EMPLOYMENT IN STEEL PER 100,000 PEOPLE MAP • 2018

SOURCE: EUROFER

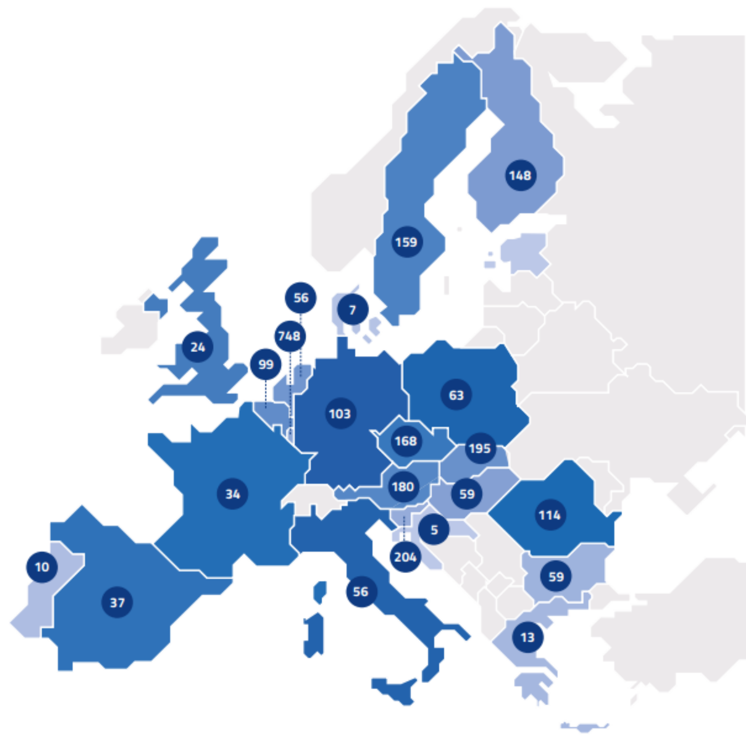

Figure 14 Direct employment in EU steel industry by country in 2017
Source: Eurofer

An Oxford Economics Study[36] found that the direct impact of the European steel industry was €21 billion in terms of the gross value added measure of output (GVA) in 2017. This amount is essentially the sum of its total employment costs and gross profits. However, the total GVA contribution, including direct, indirect and induced GVA (such as supply chain and staff spending), is significantly higher, amounting to €128 billion (Table 17).

The indirect impact (€71.4 billion of the total GVA) is spread across goods and services providers in a wide range of industries. The induced impact, which is spread across a range of more consumer-oriented sectors, accounts to €35 billion. The indirect and induced benefits are spread across national boundaries and they may also support EU countries where the steel industry has not a significant presence.

[36] Oxford Economics, *The impact of the European steel industry on the EU economy,* May 2018.

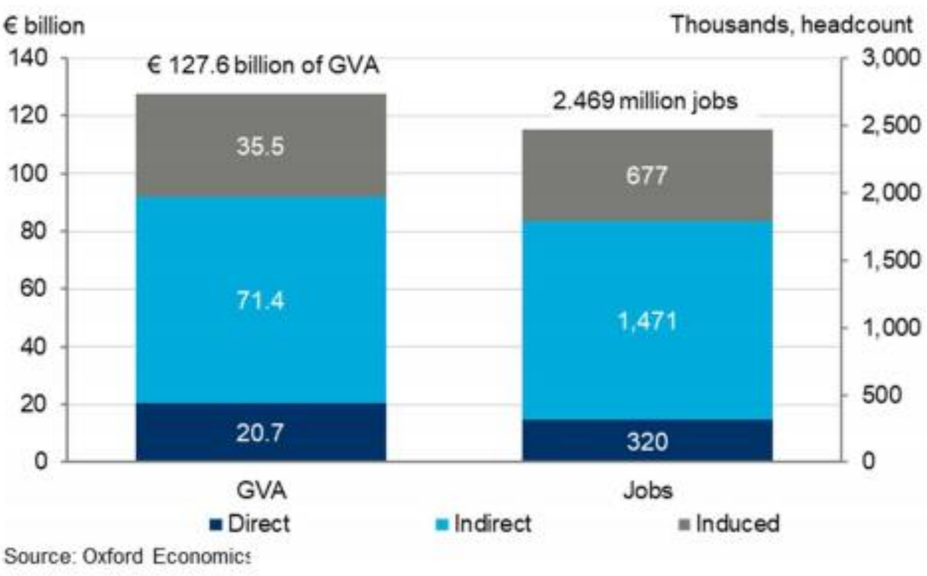

Table 17 Added value and related jobs of the EU steel
Source: Eurostat; Oxford Economics

1.3. Synergies with EU policies

Alignment of RFCS with Horizon 2020

Although it is outside of the EU Framework programme for Research and Innovation[37], the revision of Council Decision 2008/376/EC aligned the RFCS with Horizon 2020 (2014-2021) concerning rules on experts, selection criteria and IT systems.

Horizon 2020 itself supports research in steel, coal and energy intensive industries under two pillars.

1. The 'Industrial Leadership' pillar supports activities related to key enabling technologies, space, access to risk finance and SME specific innovation measures.
2. The 'Societal Challenge' pillar deals with energy topics on energy intensive industry with a focus on enabling near-zero CO_2 emissions from fossil fuel power plants and carbon intensive industries. It also supports research, demonstration, innovation and market-uptake activities across different low-carbon energy sectors, notably in the core priorities identified in the Energy Union strategy (renewable energy, smart energy systems, energy efficiency, and CCU and CCS).

Horizon 2020 endorses the *Sustainable Process Industry through Resource and Energy Efficiency* (SPIRE), a contractual public-private partnership focused on innovation in resource and energy efficiency and enabled by the process industries (cement, ceramics, chemicals, engineering, minerals and ore, non-ferrous metals, steel and water). The SPIRE initiative aims to improve resource and energy efficiency through developing breakthrough technologies. SPIRE also benefited from inputs and insights from the European Steel Technology Platform.

Innovation policy

The EU has an historic opportunity to regain innovation leadership[38] as large parts of the economy are being reinvented, creating opportunities for innovation. The EU will seize this opportunity by encouraging new synergies among EU policies and sequencing among programmes.

The EU research programme for coal and steel endeavours to develop successful synergies with EU policies and programmes to foster innovation that addresses EU policies in environmental protection and climate change, energy efficiency, the circular economy, trade competitiveness and workers' safety. An efficient sequencing of funds as well as pilot & demonstration projects are also essential for the market uptake of research.

Overall, the family of EU research programmes assists the design, update, implementation and enforcement of EU policies. It also supports Member States in effectively implementing key plans and strategies required under EU legislation. Furthermore, EU research programmes provide knowledge for policy making.

When it comes to the coal and steel industry — the industrial roots of the EU — the contribution of research programmes mainly focuses on the following areas:

1. social innovation;
2. contribution to circular economy through increasing the use of steel scrap as a secondary raw material;
3. compliance to the emission-trading scheme (ETS) for the competitiveness of the steel industry (Innovation Fund);
4. development of new steel products;
5. modernisation of the coal sector, including extracting technologies;
6. support to innovation and new technologies (e.g. CCS and CCU) that can help the coal and steel sector to remain competitive and adapt to the new realities of climate change;
7. promotion of energy, material and cost efficiency.

[37] Protocol 37 of the TEU.
[38] European Commission, DG RTD, Directorate B - Open Innovation and Open Science Unit B.3 - SMEs, Financial instruments and State Aid, *Funding - Awareness - Scale - Talent (FAST).*

Several Commission communications[39] mention the RFCS in connection with the growing need for research, innovation and deployment to advance EU industry in a circular and climate neutral economy. These communications highlight a clear path towards developing a competitive, resource-efficient and prosperous economy, supporting energy intensive industries to reduce emissions.

In 2016[40], the Commission announced measures to strengthen the EU's defence against unfair trade practices, and to guarantee the competitiveness and sustainability of energy-intensive industries, as steel. Since the long-term competitiveness of energy-intensive industries depends on the development of breakthrough technologies, the EU chose to invest in solutions and technologies, with €315 billion from the European Fund for Strategic Investments (EFSI) (which already supported the modernisation of a steel factory), EU Structural and Investment Funds and Horizon 2020.

The Commission Communication 'A renewed industrial policy strategy'[41], adopted in September 2017, stresses the need to facilitate investment and embrace changes brought on by digitisation and the transition to a low-carbon and more circular economy. EFSI helps to close the investment gap by sustaining the development of smart, sustainable and innovative industry, through its support for strategic projects across the continent. The Important Projects of Common European Interest (IPCEI) is an initiative designed for joint, well-coordinated efforts and investments by public authorities and industries from several Member States.

Transitioning to a climate-neutral economy

In December 2019, the European Commission adopted 'The European Green Deal'[42] Communication setting the framework to transform the EU into the first climate-neutral continent by 2050. The EU Green Deal is an ambitious package of measures that should enable European businesses to benefit from sustainable green transition. It tackles climate and environmental-related changes while developing a modern, resource-efficient and competitive economy, in the framework of the United Nation's 2030 Agenda and the sustainable development goals[43]. The European Green Deal Communication also stresses the Commission's interest to 'support clean steel breakthrough technologies leading to a zero-carbon steel making process by 2030 and (…) to explore whether part of the funding being liquidated under the European Coal and Steel Community can be used'[44]. Synergies of funds with the EU Emissions Trading System Innovation Fund will also be engineered in order to help the deployment of such large-scale innovative projects.

Moreover, the Communication 'European Green Deal Investment Plan. Sustainable Europe Investment Plan', presented on 14 January 2020, committed the Commission to 'propose a revision of the Regulations on the Research Fund for Coal and Steel in order to enable the use of a portion of the European Steel and Coal Community assets in liquidation. This will help with maintaining the annual research programme of at least EUR 40 million as well as to enable the funding of large clean steelmaking R&I breakthrough projects. Research activities in the coal sector will focus on regions in transition in line with the principles of the Just Transition Mechanism'[45].

Already in November 2018, Europe confirmed its commitment to lead in global climate action, presenting a strategic long-term roadmap that can lead to net-zero greenhouse gas (GHG) emissions being achieved by 2050. The strategy adopted by the Commission outlines a vision of the economic and societal transformations required, engaging all sectors of the economy and society, to achieve the transition to net-zero GHG emissions by 2050.

[39] European Commission Communication, *Steel: Preserving sustainable jobs and growth in Europe*, 16/03/2016; Commission Communication, *Investing in a smart, innovative and sustainable Industry. A renewed EU Industrial Policy Strategy*, 13/09/2017, COM(2017)479; Commission Communication, *A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*, 28/11/2018, COM(2018)773.
[40] COM(2016)155
[41] European Commission, State of the Union 2017, Industrial Policy Strategy. https://ec.europa.eu/growth/content/state-union-2017-%E2%80%93-industrial-policy-strategy-investing-smart-innovative-and-sustainable_en
[42] COM(2019) 640.
[43] https://sustainabledevelopment.un.org/post2015/transformingourworld
[44] COM(2019) 640, pp. 8, 9.
[45] COM(2020) 21, p. 18.

This transition will require increases in the use of electricity (from renewable sources of energy) to fully decarbonise Europe's energy supply.

Achieving energy efficiency in Europe is key for energy intensive industries (such as the steel industry), considering that energy costs are one of the main drivers of their competitiveness. The steel industry estimates that energy costs represent up to 40% of total operational costs depending on the segment of the value chain. The strategic energy technology plan[46] (SET-Plan) aims precisely to accelerate the transformation of the EU's energy system, bringing promising new zero-emissions energy technologies to market.

In addition, the Cohesion Fund allocates €63.4 billion towards (i) activities for trans-European transport networks, (ii) supporting infrastructure projects under the Connecting Europe Facility and (iii) for projects benefiting the environment (energy efficiency, use of renewable energy, developing rail transport, supporting the combination of different forms of transport, strengthening public transport, etc.).

Several research projects were carried out under the RFCS in the steel sector providing solutions for process optimisation and new production processes to decrease energy consumption and, therefore, to reduce carbon emissions. The potential to combine these initiatives with CCS or CCU has been looked into (i.e. chemical conversion of CO_2 using CO_2 as a raw material). An emerging research interest is carbon avoidance – such as hydrogen use or replacing coal/cokes for steelmaking. The RFCS Technical Groups on 'Coal combustion, clean and efficient coal technologies, CO_2 capture' (TGC3) and 'Steelmaking processes' (TGS2) and 'Ore agglomeration and Ironmaking' (TGS1) promoted and developed projects dealing with technologies and studies that enable coal to have lower CO_2 emissions. Chapter 2 and 3 present insights on the outcome of RFCS-funded projects.

All these technological progresses require people who are skilled and able to adapt, and who can drive and support change. The Blueprint for Sectoral Cooperation on Skills[47], part of the New Skills Agenda, addresses skills gaps that may prevent promising industries from growing. The Blueprint is a platform for strategic cooperation between key stakeholders (such as business, trade unions, research, education and training institutions, public authorities) in a given economic sector. The aims of the Blueprint in the steel sector are: (i) to assess the current situation regarding the workforce and address critical aspects (knowledge transfer, skills shortage, recruitment, etc.); (ii) assess the situation of the national vocational education and training (VET) systems; and (iii) improve the steel sector's image.

[46] DG RTD, DG ENER, Joint Research Centre, *The SET-Plan*, 2017.
[47] European Commission, DG Employment, Social Affairs and Inclusion, Blueprint for Sectoral Cooperation on Skills, 2017.

2. MONITORING AND QUALITATIVE EVALUATION

The information provided in this chapter is based on the input from the TG chairs representing the three TGs for coal and the nine TGs for steel.

2.1 Technological achievements of the RFCS projects

The following sections outline the achievements, first of projects related to coal, and then those to steel.

2.1.1 TGC1 - Coal mining operation, mine infrastructure and management, unconventional use of coal deposits

The scope of TGC1's work covers modern techniques for surveying deposits, and integrated mine planning for highly efficient, largely automated excavation and mining technologies. Mining technologies encompass the geological characteristics of EU hard coal and lignite deposits, appropriate support technologies and transport systems as well as power supply services, communication and information, transmission, monitoring and process control, health and safety in mines, including gas control, ventilation and air conditioning, and occupational health and safety. TGC1 also tackles the reduction of GHG emissions from coal production, the return to the mine of mining waste (fly ash, desulphurisation waste, other forms of waste), the rehabilitation of waste heaps and the industrial use of residues from coal production and consumption, the management of environmental risks (including the protection of water tables, the purification of mine drainage water and the protection of surface installations from short- and long-term effects of subsidence), CO_2 geological storage, and the upgrading of coal deposits including coal bed methane, underground coal gasification, and others.

During the period 2011-2017, 20 TGC1 projects, 7 of which are still ongoing, were reviewed. A few projects cover more than one aspect of the scope of TGC1's work. For clarity, below is a subset of the projects that fall under the main scope of the TGC's work.

<table>
<tr><th></th><th>Projects</th></tr>
<tr><td>Integrated mine planning</td><td>3</td></tr>
<tr><td>Highly efficient, largely automated excavation and mining technologies</td><td>2</td></tr>
<tr><td>Appropriate support technologies</td><td>2</td></tr>
<tr><td>Transport systems</td><td>1</td></tr>
<tr><td>Power supply services, communication and information, transmission, monitoring and process control</td><td>4</td></tr>
<tr><td>Health and safety in mines, gas control, ventilation and air conditioning, occupational health and safety</td><td rowspan="3">4</td></tr>
<tr><td>Rehabilitation of waste heaps and the industrial use of residues from coal production and consumption</td></tr>
<tr><td>Management of environmental risks, including the protection of water tables and the purification of mine drainage water, as well as the protection of surface installations from the effects of short and long term subsidence</td></tr>
<tr><td>Upgrading of coal deposits, including coal bed methane, underground coal gasification and others</td><td>4</td></tr>
<tr><td>TOTAL</td><td>20</td></tr>
</table>

Table 18 Main technological challenges for TGC1 and number of projects

The main achievements are presented in the following paragraphs.

Integrated mine planning

By changing the process management in open pit mines from periodical to a near continuous process, better process performance is expected in terms of coal recovery and financial measures. For this reason, a stochastic approach was taken, quantifying the uncertainty of process-influencing factors, in order to develop an innovative and integrated framework for real-time process reconciliation and optimisation in large open pit coal mines along the whole value chain (RTRO-Coal).

Modern technologies for monitoring slopes in open pit mines have been deployed, tested and evaluated against physical and numerical models. Based on these results, a reliability-based risk evaluation method was developed, to optimise design and support decision-making (RFCS co-funded project SLOPES).

Highly efficient, largely automated excavation and mining technologies

European coal mining is extending to deeper levels, featuring a higher coal seam methane content and, as a result, much higher methane emissions in production districts. The increased release of methane observed is not only a serious safety risk. It is also a problem for coal production, as it limits the advance rates of both headings and longwalls. Innovative gas control and drainage techniques have therefore been developed, taking different borehole stimulation techniques into account (GasDrain).

Conditions in newly opened and existing lignite mines are increasingly difficult. This is mainly due to the occurrence of inclusions and geological structures with excessive mining resistance, resulting in large dynamic and impulse loads. To reduce breakdowns and failure rates, novel ways of reducing the size of dynamic loads and the sensitivity of excavators on pulse load have been developed (BEWEXMIN).

Mine automation has significantly improved thanks to the development of power supply services, ICT, transmission, monitoring and process control. Some of these are described in detail below.

Appropriate support technologies

To better control highly stressed ground, a support management system for gateroads below 1,000m has been developed. Laboratory tests, numerical modelling and underground field trials (AMSSTED) have shown that the system also functions for face salvages and other wide openings.

An online shield support monitoring system, for monitoring roof condition in real time, as well as a longwall mining conditions prediction system, for predicting roof falls hazards and generating information about indispensable corrective measures, are being developed. These systems aim to prevent adverse phenomena associated with roof behaviour, such as roof falls to the longwall face or lack of roof fall beyond the shield support leading to local dynamic loads (PRASS III).

Transport systems

The last two decades have seen the rapid development of auxiliary transport systems in European mines, associated with longer transport routes for staff and material. This has reduced effective shift working time and given rise to new challenges. The INESI project is developing and testing transport systems adapted for increased speed. It also analyses low energy consumption ventilation systems for underground transport routes. Increasing the shift working time at the face, while enhancing safety by fitting both people and equipment/material with tracking systems in dangerous environments, is a focal point. A fully automated system for identifying human presence on underground conveyors and optimising processes, with people and equipment tracking, is also being developed.

Power supply services, ICT, transmission, monitoring and process control

The development of a novel approach to mine power engineering, involving smart grid systems, tools for operating central network devices, as well as different sensor technologies, has brought about significant progress in mine automation aimed at increasing efficiency and safety. Information-based incident response systems are also being developed.

Energy consumption is a major cost component of all mining operations. A novel approach to mine power engineering, using smart grid systems, together with boreholes to provide direct power connections from the surface, has been developed and implemented (M-SmartGRID).

New ICT developments for process optimisation have been integrated into and demonstrated in five European underground mines. Tools for operating central network devices (e.g. staff information and communication, material logistics) and remote maintenance have been put in place. New and existing wired and wireless components and systems have also been integrated (OPTI-MINE).

For the safety of mine staff in harsh underground environments, mining equipment must be accurately positioned. A prototype for a diverse redundant collision avoidance system with three different sensor technologies (an electromagnetic observation unit, a sound-based localisation system, and radar) has been developed and demonstrated on a road header (FEATureFACE).

For rapid data acquisition and information provision in case of a mining incident, two resilient and novel communication methods that are independent of fixed networks (one operating through rock, the other using a readily deployable cable) are being developed. These methods make it possible to develop other technologies such as environmental sensors, small unmanned vehicles and highly efficient drilling technologies (INDIRES).

Health and safety in mines, gas control, ventilation and air conditioning, occupational health and safety

Significant progress has been made in improving health and safety in underground coal mines, with regard to mine ventilation, dust control, monitoring, assessment, prevention and mitigation of rock bursts and gas outbursts, as well as the prevention and mitigation of methane explosions, the inspection of mine areas affected by catastrophic events, and the development of mine rescue equipment.

Advanced tools to improve the control of ventilation networks and methane emissions in underground coal mines have been developed. The tools aim to improve workers' safety by better controlling methane emissions and climatic conditions and optimising the ventilation airflow, while reducing energy and maintenance costs. Thanks to these tools, new monitoring and control system concepts, such as novel sensing devices, advanced methods for the dynamic regulation of airflow (ventilation on demand), and fast-sealing systems for use in emergencies have been developed (AVENTO).

Despite international efforts to limit workers' exposure to it, coal mine dust continues to affect the health of thousands of miners across Europe. Modern assessment tools and devices to improve risk evaluation, control dust and protect workers, particularly from the fine particulate fraction (PM2.5) (ROCD) have therefore been developed.

A new air pressure monitoring system for predicting and mitigating methane explosions, including system controls and numerical models of methane explosions, has been developed and tested on a large scale (EXPRO).

New prevention techniques, based on the use of large-diameter boreholes with alternative stress and gas pressure relief techniques, are being developed to improve the monitoring, assessment, prevention and mitigation of rock burst and gas outburst hazards in coal mines. The coupling of near-real-time processing of field-monitored micro seismic data with artificial neural networks and fractal dimension data, are being developed (MAPROC).

A virtual teleportation system (TeleRescuer) has been developed to inspect underground areas of a coal mine that have been closed due to a catastrophic event without human presence. The system includes an unmanned vehicle equipped with different sensors, a communication system and a simulator for training and remote control purposes.

Several rescue devices have been developed and enhanced to improve the safety, work comfort and effectiveness of rescue teams. Among these are a rescue conveyor, a rescue support device, an air conditioning system, an experimental low energy rescue tunnelling device, and a system for monitoring physiological and local climatic parameters (INREQ).

Rehabilitation of waste heaps and the industrial use of residues from coal production and consumption

For the industrial use of residues from coal production and consumption, while at the same time reducing the risks associated with acid mine drainage (AMD), a way of co-processing AMD-generating coal production wastes is being developed as a cheap source of leaching solution (lixiviant) to recover metals from electronic wastes. The new flow-sheet will remove the AMD-generating potential of coal wastes, ensuring their long-term environmental stability while expanding avenues for their safe reuse. It will also make it possible to selectively recover base metals from waste PCBs, while concentrating precious, critical and rare earths into enriched substrates (CERES).

Management of environmental risks, including the protection of water tables and the purification of mine drainage water, as well as the protection of surface installation against the effects of subsidence in the short and long term

Managing environmental risks during and after mine closure is a multi-hazard and multi-risk process requiring the integration of interrelated environmental processes and a combination of their effects. For this reason, several projects focused on assessing and monitoring flooded shafts, mitigating environmental risks associated with mine drainage water, and developing mine closure plans.

For the long-term stability assessment and monitoring of flooded shafts, inspection tools for measuring water quality and gas production have been developed. Devices for carrying out macroscopic inspection and/or monitoring the water level rebound dynamics have also been installed (STAMS).

Mine water often includes heavy metals, metalloids, heavy salinity loads, suspended solids and radionuclides. Innovative ways of mitigating the environmental risks of mine water discharge have been developed. They relate to several aspects, such as: identifying substances of concern in mine waters based on local conditions, long-term forecasting, risk assessment and EU Water Framework Directive objectives; developing innovative, cost-effective and sustainable passive and active treatment technologies; identifying forward-looking technical possibilities of mine water reuse and metals recovery, as well as innovative management of mine drainage water and treatment (MANAGER).

A planning tool that makes for a logical, gradual approach to mine closure is being developed, taking account of all the necessary investigations (MERIDA). The advantage of this planning tool is that it can be progressively refined during the post-closure period, to deal with all relevant environmental risks.

Upgrading of coal deposits, including coal bed methane, underground coal gasification and other means

RFCS projects have been implemented in areas such as underground coal gasification (UCG), the use of flooded coal mines as a source of thermal energy, the upgrading of methane in the ventilation emissions of working shafts, and the emissions from abandoned mines.

Given how important it is to assess the risks associated with UCG in operating mines and areas of high vulnerability, a control system and risk assessment method has been developed. The system is based on data relating to rock mass, temperature, groundwater and air monitoring during and after UCG trials (COGAR).

Large-scale gasification tests have been conducted in artificial coal seams under atmospheric and high pressure (35 bar) regimes; UCG-related contaminants have been analysed and laboratory tests of drill samples carried out. The aim of all these tests was to evaluate the feasibility of UCG in shallow lignite seams, taking into account geological, technical and environmental aspects. The data obtained made it possible to identify suitable process operation and monitoring techniques. A numerical modelling of the impact of UCG operations on surrounding earth layers and rocks has also been carried out. In addition, a risk assessment procedure for UCG operations, assessing the future feasibility of UCG field implementation, has been developed. The procedure can also be transferred to other geo-energy activities such as (enhanced) coal bed methane (COAL2GAS).

To facilitate wider use of thermal energy from mine water for both heating and cooling purposes, new technical tools have been developed and tested on pilot implementations. Economic and management models for efficient energy extraction and distribution have also been developed, and technical, legal, managerial and cost-benefit analysis of various types of decentralised and centralised heat pump systems (LoCAL) carried out.

Methane emissions with low concentrations caused by ventilation emissions of active (VAM) and abandoned (AMM) mine sites are a potential source of energy and chemicals. Current developments therefore focus on evaluating concentrations and flow rates, the design of separation processes and chemical reactors, for methane combustion or for transforming methane into useful chemicals, such as hydrogen or methanol (METHENERGY PLUS).

The main technical and technological achievements of the RFCS projects implemented during the period 2011-2017 are summarised below.

1. Mine automation and integrated mine planning:

   - novel approaches to mine power engineering involving smart grid systems;
   - tools for operating central network devices;
   - new sensor technologies to identify the location of equipment in the longwall and the spatial characteristics of its geometry;
   - tools for identifying the presence of humans on underground conveyors and tracking people and equipment;
   - an inspection robot for coal mines that have been closed due to a catastrophic event;
   - new gas control and drainage techniques.

2. Lignite coal mining and reclamation practices:

   - risk evaluation methods based on monitoring and modelling results in order to optimise design and support decisions in open pit lignite mines;
   - tools to reduce the failure rate of bucket wheel excavators;
   - new methods of stochastic mine system simulation and decision support methods for short- and long-term mine planning under uncertain mining conditions;
   - an understanding of the long-term behaviour of lignite mine waste materials, as well as stability and ground movements in heaps and on reclaimed ground.

3. Mine health and safety:

   - research into rock mass behaviour and rock burst prediction; improvements in responding to and preventing emergencies, with appropriate monitoring and mitigation techniques for mine ventilation and dust control; development of a support management system for highly stressed gateroads.

   All of the above has greatly improved health and safety in mines, making working conditions for staff better, as well as protecting the surrounding environment and local communities.

4. Upgrading coal deposits:

   - underground coal gasification (UCG);
   - using flooded coal mines as a source of thermal energy;
   - upgrading methane in the ventilation emissions of working shafts and emissions from abandoned mines;
   - UCG pilots.

   - Besides the pilots, considerable theoretical work has also been done on UCG, but public concerns have made industry wary of taking it up, requiring more research.

5. Post-mining activities and the management of environmental risks:

   - tackling of problems related to:
   - mine closure, mine drainage water treatment, the stability of abandoned and flooded shafts, subsidence and slope stability

2.1.2 TGC2 - Coal preparation, conversion and upgrading

The scope of TGC2 covers coal beneficiation, cokemaking, coal-derived carbon materials, coal gasification (hydrogen, syngas, synthetic natural gas), including chemical aspects and process-related aspects of UCG, coal liquefaction and environmental issues associated with coal upgrading processes.

During the period 2011-2017, the TGC2 reviewed 22 projects listed under each of the TG scope topics outlined in the table below.

	Projects
Cokemaking	9
Underground coal gasification (UCG)	2
Coal gasification (hydrogen, syngas, synthetic natural gas)	4
Preparation and processing of coal-derived products for carbon materials	6
Coal liquefaction	1
TOTAL	22

Table 19 Main technological challenges in TGC2 and number of projects reviewed

The main achievements are set out below.

Cokemaking

The coal carbonisation process can be optimised by using fuel in coking coal blends. New methods for ascertaining metallurgical coke quality have been tested on the reactive/inert ratio of coal blends. An innovative monitoring, control and optimisation system for preparing coking blends has been designed and implemented, and its feasibility demonstrated at full scale (RATIO-COAL).

Emissions have been reduced, while maximising the energy efficiency of coke oven heating, using intelligent diagnostics and individual wall heating control. A new understanding of combustion characteristics under irregular conditions, caused by through-wall leakage, combustion inefficiency and regenerator malfunctioning, has been developed using plant trials, physical modelling and analysis. The resulting information and data have enabled the development of a data-based real-time system for detecting and identifying heating faults at an early stage. A regenerator inspection robot, supplied with guidelines to be able to identify combustion problems, has been developed and used in real coke oven conditions as part of a complete evaluation of combustion efficiency. An individual wall heating control system has been designed and implemented to counteract the effects of heating faults, with no detrimental effect on nitrogen oxide emissions or heat distribution (ECOCARB).

Alternative materials in coking coal blends have been used to deliver technological solutions increasing oven charge bulk density for European plants. This has been achieved through an integrated series of trials supported by process development and mathematical modelling to evaluate charge pre-treatment/densification methods (DENSICHARGE). Coal swelling pressure is one of the major causes of coke oven degradation. Coupling of pressure development in the oven chamber and thermo-mechanical behaviour analysis of heating walls made it possible to quantify the effect of swelling pressure on oven wall degradation (SPRITCO). Wall pressure is another one of the major causes of coke oven degradation. However, it is impossible to directly measure it. On the other hand, internal gas pressure is easy to measure. It is possible to increase the service life of coke plants by controlling internal gas pressure in industrial ovens. RFCS co-funded projects looked at parameters influencing internal gas pressure measurements in stamp and gravity charging, in order to identify correlations between internal gas pressure measured at pilot and industrial scales. The results will make it possible to draw up guidelines for European coke plants on how to better monitor internal gas pressure, and to determine limit values for safe operation (BINGO).

The cokemaking industry generates large amounts of contaminated wastewater, containing substances classified as priority hazardous substances according to the EU Water Framework Directive. It is therefore crucial to treat and manage such wastewater appropriately, to protect the aquatic systems they are often discharged into. This is why it is so important to assess the characteristics of coke oven wastewater, its treatment and utilisation fall. Analytical procedures have been tested, a range of wastewater treatment methods have been adapted and developed, and water recovery using clean technologies has been looked into (INNOWATREAT).

The exposure of coal to mild weathering decreases the thermoplastic capability of coking coals. This modifies coal behaviour during the coking process, affecting the structure and properties of coke. An understanding of the mechanisms of coal oxidation has been developed by systematically studying a wide range of weathered and oxidised coals and blends including waste plastics and biomass fractions. This technology is used for the introduction of alternative raw materials that can reverse the detrimental effects of coal weathering (COWEST). A novel methodology, using biomass in coking blends, combined with hydrous pyrolysis, has been developed. The potential of this methodology has been maximised by using alternative raw materials in the coke oven charge. A major benefit of the methodology has been to increase the coke production of existing oven plants, resulting in fewer coal imports outside the EU (ALTERAMA).

Projects assessing monitoring systems for coke batteries have provided insights into monitoring systems for coke battery wall heating and leaks. This has an impact on the life span of the batteries and on emission control (NOEMI).

Underground coal gasification (UCG)

Thanks to the UCG projects funded, significant progress has been made in relation to outputs and technical knowledge with added societal value. The scientific investigations, experiments and large-scale on- and off-site pilots have provided new insights and know-how, as well as monitoring and environmental assessment. The investigations also evaluated public acceptance, concluding that in certain circumstances social constraints can impede the industrial implementation of UCG. An underground trial was carried out in a test mine environment using a two borehole system and reactive barriers. The most serious environmental concerns related to UCG were investigated, including contamination of underground aquifers and potential leakage of poisonous and explosive gases into the surrounding strata. The work focused on finding practical ways of preventing potential leakage using reactive barriers. A complex system of telemetric environmental monitoring was built and tested. Technical and ecological risk assessment was also carried out (HUGE2).

On the basis of the understanding developed in earlier projects, deep methane rich coal deposits are being evaluated for the production of coalbed methane and coupling with UCG. Enhanced coalbed methane (CBM) recovery, coupled with subsequent UCG at high pressure and CO_2 storage, are also being studied. A radical and holistic approach is being developed, to optimise the coupling of CBM-UCG processes, using high-pressure gasification tests and advanced numerical simulations (MEGA PLUS).

Coal gasification (hydrogen, syngas, synthetic natural gas)

Thanks to coal gasification projects producing syngas, using a heatpipe reformer including CO_2 capture, significant progress has been made in relation to process integration and know-how. Optimisation has been achieved using a variety of catalysts, with the technology developed using small-to-medium scale pilot plants within a model of distributed energy. It offers the opportunity for further investigation using clean lignite deposits, such as those from the German Rheinish area, as well as lignite deposits in Europe (Poland, Bulgaria, Romania and Greece). It could be used in combination with low-rank clean fuels, as an abundant alternative in several countries (CO_2freeSNG). The CO_2freeSNG2.0 project focused on the complete process chain demonstration of the innovative process design the previous project developed. The new process consists of substantially simplified gas cleaning, based on carbonate scrubbing. It makes it possible to simultaneously remove CO_2, sulphur and tar components by means of a single pressurised water/ carbonate scrubbing process, making the process much more efficient than state-of-the-art systems.

High temperature Winkler (HTW) gasification technology results in valuable products, such as Fischer-Tropsch-fuels or methanol, from lignite and a variety of types of waste including plastics and bio-waste. An innovative acid gas removal stage can reduce the costs of cleaing syngas for the subsequent synthesis step. With the use of adequate models whose pilots have been validated, it is being scaled up to industrial implementation (LIG2LIQ).

The need to efficiently convert/upgrade coal and renewable fuels and to drastically reduce CO_2 emissions requires research into improving technologies for converting solid fuels to energy. Fluidised bed and entrained flow gasification processes have been considered, because of their flexibility and effectiveness in thermally converting different feedstock (FECUNDUS).

Preparation and processing of coal-derived products for carbon materials

Thanks to projects related to the preparation and processing of coal-derived products for carbon materials, significant progress has been made in this area. Coal-derived products are used to prepare tailored carbon materials and precursors of graphene oxides. The results are mostly laboratory-derived, with some bench-scale exceptions (COALPHENES, SUPERCOAL).

Electrochemical studies have shown the advantage of activated carbon fibres over activated particulates when used as electrodes in supercapacitors. The information obtained was used to define the processing conditions of pitches for producing carbon fibres. Porous materials, including nitrogen- and cobalt-doped activated carbon fibres, were prepared using physical and chemical activation procedures, from a selection of stabilised and carbonised anthracene oil-based powders and fibres. Their textural properties and surface chemistry were evaluated in order to determine their possible applications. The materials proved to be highly efficient as selective adsorbents of gases (i.e. CO_2) and water contaminants (i.e. phenol) (EUROFIBRES).

Carbonaceous by-products are upgraded in an intelligent, integrated way through hydrogen-intensified synthesis processes. Advanced process control and operational strategies, at component, site and system level, have been used to minimise operational costs. Agent-based modelling of the complete process chain evaluated opportunities for reducing coal-based CO_2 emissions in steel works and the benefits for the electric grid in the context of new emerging volatile markets (I3UPGRADE).

Novel porous carbon materials for energy and environmental applications using low-value coal-derived liquids as the carbon precursor have been developed, with involvement from both ends of the value chain (coal tar distillers and porous carbon manufacturers) (PROMOTEE).

Coal liquefaction

Research has been done on the environmental performance of direct coal liquefaction (DCL) developing technologies suitable for co-processing a variety of wastes, including plastics, tyres and bio-wastes, which can thermally decompose into effective solvents. The research identified and implemented improvements for existing catalysts to optimally co-process heavy coal liquids and petroleum fractions. This flexible approach enables plants to operate on a relatively small scale and provide intermediate heavy oil products suitable for further processing in existing oil refinery operations. It also minimises CO_2 emissions from co-processing a range of bio-wastes (DIRPRIMCOAL).

2.1.3 TGC3 – Coal combustion, clean and efficient coal technologies, CO_2 capture

The scope of TGC3 covers clean and efficient coal combustion, integration of the coal chain from mining to the final product (electricity, heat, hydrogen, coke), a carbon management strategy, a reduction of the environmental impact of installations using EU coal, lignite and oil shale, a reduction in emissions from coal utilisation, clean and efficient coal technologies, CO_2 capture, the co-combustion of coal with solid waste or biomass, zero emissions and highly efficient power generation, combined heat and power (CHP) from coal, and the contribution of coal to global energy security.

During the period 2011-2018, the TGC3 reviewed 22 projects under the four scopes outlined in Table 21.

	Projects
Clean and efficient coal technologies	5
CO_2 capture	11
Reduction in emissions from coal utilisation	5
Co-combustion of coal with solid waste or biomass	1
TOTAL	22

Table 20 Main technological challenges in TGC3 and number of projects

The main achievements are set out below.

Clean and efficient coal technologies

TGC3 projects have brought about significant progress in the area of power plant applications. In particular, state-of-the-art power plant efficiency, for subcritical (40%) and supercritical (45%) steam cycles, have both been improved and tested. Components for reaching ultra-super steam cycles (700 °C, 300 Bar) have been studied on an industrial pilot scale. The results of the pilots made for 50 % cycle efficiency (NIBALO725).

Coal power plants need to be able to operate flexibly, with load changes and partial load operation, due to the increasing amount of renewable energy. A pilot highly load-flexible plant concept, and a pilot system using energy storage based on $CaO/CaCO_3$, have been studied. Data on load changes and energy storage were used to validate dynamic system and reactor models in order to scale up efficient and flexible calcium looping systems (FLEXICAL).

A scaling-up methodology and simulation tools have been used in pulverised-coal flameless oxidation (PC-FLOX) burners in utility plants. The simulation tools developed have been integrated into commercial software codes (FLOX-COAL-II).

New and innovative retrofitting concepts for lignite pre-drying and pre-dried lignite co-firing have been developed on the basis of an existing lignite power plant to increase flexibility and improve operational and environmental performance. This was done by designing specific concepts for retrofit cases for pre-dried lignite application in green-field plants (DRYLIG).

Scientific and technological work focused on making the 700°C technology ready for deployment in coal-fired power plants. A PF-fired hyper supercritical (HSC) plant, also known as an advanced ultra-supercritical (A-USC) power plant, is able to reach 50-55% net (LHV) efficiency, thereby decreasing the power plant's CO_2 emissions. However, HSC plant development entails high technical and commercial risks. This has led to the design, building and operation of a full-scale 1000MW demonstration plant, giving EU companies a head start in these new markets (DP700-PHASE 1).

CO_2 capture

Post-combustion CO_2 processes have been developed and tested on an industrial pilot scale. CO_2 was removed from flue gases, oxy-firing combustion and chemical looping combustion using oxygen carriers. The trials involved combining biomass-fired power plants with CO_2 capture using post-capture, an oxy route and a chemical looping route (CARINA, CAL-MOD, ASC2, ECLAIR, ACCLAIM, RECaL).

The development of advanced process layout and boiler design strategies makes plants more efficient and reduces the costs of maintaining oxyfuel power stations. Material-related limitations on the boiler performance of CO_2-lean, oxyfuel-operated power plants determine the usability of advanced and conventional boiler materials (OXYCORR).

Coal ash is disposed of, or used in different ways, depending on the type of by-product, the processes at the plant and the regulations the plant has to follow. Power plants may dispose of it in surface impoundments or in landfills. Considering that coal combustion emits a great amount of

CO_2, the resulting fly ash can be used as a material for on-site CO_2 capture and storage (CCS). Laboratory scale studies of mineral carbonation of coal fly ash for CO_2 sequestration are developed (COALBYPRO). The capture of CO_2 in zeolites has also been studied.

In addition, directly electrochemically converting coal to electricity might significantly increase efficiency, with consequent reductions in CO_2 emissions and sequestration possibilities. Direct carbon fuel cells (DCFC) could exceed commercial molten carbonate fuel cell performance levels. Coal DCFC application has been further developed on lab scale by increasing its application, improving cell design, seeking new active and conductive structure and surface-promoted catalysts, tackling the issue of durability, investigating sources of coal, and optimising coal processing (DCFC).

Large-scale coal-fired power stations can reduce their carbon intensity in the short term by implementing or increasing energy- and cost-efficient biomass co-combustion in conventional air-fired systems. Sorbent injection systems can be installed relatively cheaply in existing or newly built power plants, to back up or replace existing gas cleaning systems that cannot cope with increasingly flexible plant operation. In oxy-fuel combustion, reducing SOx, HCl and Hg with sorbents has great potential to reduce energy emissions and costs and make it possible to minimise problems arising from corrosion by those species in hot and cold parts of the power plant, and problems of corrosion that affect CO2 processing and transportation facilities (BIOXYSORB).

A pilot energy-efficient process based on a CO_2 capture post-combustion calcium looping system has been developed for and tested on coal-based power plants. Capital cost and energy consumption have been shown to be reduced significantly due to lower calciner, ASU and O_2 and fuel requirements, thereby improving the competitiveness of the system (CAO_2).

Reduction in emissions from coal utilisation

Projects investigated aspects that included lowering load, changing load, improving flexibility and using a variety of coals/lignite blends. This involved several projects focusing on lignite drying and the co-firing of coal and biomass. The main outcome was the development of smart control systems with new sensors, minimising the fouling and corrosion of heat exchangers, while increasing plant availability (CERUBIS).

The introduction of more severe emission control regulations and increased co-firing has led to the development of projects covering gas-related emissions (NOx, SOx, heavy metals, trace species such as dioxines) and solid wastes for possible reuse in a circular economy approach. As a result of poor combustion, high emissions of CO or NOx may emanate from the burner. In order to co-fire higher concentrations of biomass, a system was required that could provide warnings for these conditions. Advanced signal processing was applied based on joint time-frequency methods, and an artificial neural network was used to identify characteristics that could be related to operational parameters such as local air/fuel ratio, NOx emissions, and flame stability. The system developed has been successfully tested on a pilot scale (500 kWt), and on a full-scale power plant (burner 20 MWt), where its ability to monitor and optimise combustion for a variety of unseen coal/biomass blends was demonstrated. It has also been shown how the system could be used to balance out air/fuel supply to multi-burner applications, and detect potential flame-out conditions (SMARTBURN). The effect of modified selective catalytic reduction technology on downstream air pollution control devices, such as flue gas desulphuristion systems, has been studied. A 3D computational fluid dynamics model has also been used, to improve the modelling of the selective catalytic reactor system (DEVCAT).

Apart from process development, technology components and testing, other key achievements are related to knowledge acquisition (science and technology), risk reduction, for example damage from power plant materials cracking (CRAMUFAT24), and scaling up technology using modelling (computational fluid dynamics and physical modelling) (FLEXFLORES).

Co-combustion of coal with solid waste or biomass

The emerging trend in favour of using renewable energy sources has led to a greater proportion of biomass being used in solid fuel-fired power plants. Research into the co-firing of high amounts of chlorine-rich biomasses at high steam temperatures has demonstrated success in using coal and its ash as a protective agent. Coal and its inorganic constituents, such as sulphur and alumina-silicates, can prevent the formation of alkali chlorides and consequently chlorine-rich deposits. Two online corrosion sensors have been developed and used, in combination with online techniques for measuring gaseous and solid phase composition, to monitor corrosion. Both sensors were tested under aggressive conditions. Modelling has deepened the understanding of corrosion attack and its mechanisms. As a result, strategies have been developed for setting up fuel blends and strengthening the position of solid fuel-fired boilers, particularly the position of coal, since it enables the use of low-grade biomass in highly efficient combustion systems (ONCORD).

The following sections give an account of the work of steel project TGs.

2.1.4 TGS1 - ORE AGGLOMERATION AND IRONMAKING

The scope of TGS1 covers the agglomeration of iron ores, cokemaking, blast furnace and ironmaking processes and new reduction processes, as well as related instrumentation, modelling, maintenance and environmental issues. During the period 2011-2017, the TGS1 reviewed 16 projects, 3 on sintering, 8 on blast furnace processes, 4 on new reduction processes and 1 on hot stoves and cokemaking. No project looked at the pelletising and direct reduced iron (DRI) production processes. The projects reviewed have been broken down into five categories:

- CO_2 reduction in ironmaking
- sinter plant process control and sinter quality
- blast furnace process control and instrumentation
- pulverised coal and alternative carbon injection into blast furnaces
- putting alternative carbon sources into blast furnaces and coke plants.

The projects' main achievements are set out below.

CO_2 reduction in ironmaking

Four projects were directly related to the continuation of the ULCOS Programme, of which the aim is to operate with low CO_2 emissions.

Top gas recycling in blast furnaces (ULCOS TGRBF) has been further tested and optimised at the experimental blast furnace in Luleå. The trials have confirmed that it is possible to operate the process and the gas separation plant in a closed loop at a carbon consumption decrease of 25%. The research results also make it possible to select the best process and technology options for an industrial-sized demonstration unit.

The test at an industrial blast furnace of the top gas recycling operation mode by injecting hot reducing gas into the shaft (IDEOGAS) was not successful. This is because the burner technology planned to be used to produce the reducing gas by partial oxidation of natural gas did not work. The project then developed the oxygen tuyere technology for the blast furnace. The jointly developed oxygen tuyere passed the technological test.

Breakthrough technologies to drastically reduce CO_2 emissions have been requested. One of these, HIsarna, is a new ironmaking concept that directly uses fine coals and fine ores without any preparation. The trials, with specifically designed and engineered experiments, carried out in the HIsarna experimental plant in IJmuiden, have demonstrated that the process works effectively (HISARNA B&C). It has reached a TRL (technological readiness level) of 7 (prototype system). A scaled-up analysis, with the aim of setting up a demonstration plant (TRL8), has also been done.

A breakthrough technology to produce steel without any direct CO_2 emissions has been studied, involving the use of electricity to directly decompose iron oxide into metal and oxygen (IERO) by electrolysis of iron ores. The project focused on understanding the physics and chemistry of the electrochemical phenomena in order to propose what the scale of an industrial individual cell should be. It demonstrated a very high level of CO_2 mitigation.

Sinter plant process control and sinter quality

There is a general trend towards decreasing the quality of iron ores. To improve sinter quality and ensure its competitiveness and sustainability, the European steel industry must use such ores in sinter plants, while maintaining the quality of the sinter. The challenge is all the greater, since recycled materials are also incorporated into the sintering mix. Advanced control of all preparation phases is needed for the optimal use of challenging input materials (INSIMI). New techniques have been developed to characterise the material. Operational and technological solutions, such as intensive mixing/granulation technology, have been developed to optimise sinter strand performances. An optical sizing system has been implemented for in-plant monitoring of sinter mix homogeneity, balling efficiency and granule resistance. The control of all stages of the sintering process has been significantly improved by the development of new measurement and control techniques, leading to a clear improvement in fuel utilisation (TOSICO). A new blending support tool has been developed that makes it possible to estimate in advance the sinter properties and quality on the basis of the characteristics of the sinter mix. A new monitoring and advisory system for sinter charging control, based on innovative sensors which measure sinter bed height and other operational parameters, has been developed. Most sinter plants use permeability bars to increase productivity. A single set of well-coordinated operational trials at several plants was carried out and analysed, using measurements and innovative models, to fully understand the influence of permeability bars on the local sinter processes (OPTIPER).

Blast furnace process control and instrumentation

The optimisation and durability of blast furnace hot stoves and tuyeres, as well as smooth casthouse operation, are among the prerequisites for improved plant availability.

Practical measures for extending tuyere life have been studied (EXTUL). A detailed analysis of the initial state of tuyere damage has been done at a big and a small blast furnace. The damage shows similarities for both furnaces, such as unstable operation, low permeability and non-uniform gas and liquid flow, resulting in locally high heat load, causing big furnaces to react much more sensitively.

An innovative approach has been developed to optimising blast furnace tapping practices (SUSTAINTAP), combining the direct measurement of liquid level and the characterisation of drainage systems. The measurements of circumferential strain in the furnace shell, using strain gauges, have been found to be capable of determining the levels of liquid metal and slag in the hearth. A deadman dynamics indicator has been developed to evaluate the deadman position, floating or sitting on the hearth bottom.

Some older European ironmaking plants often experience problems with hot stove performance and operation. Different optimisation techniques to make operation more efficient and stable have been analysed (oxygen enrichment, preheating of fuel/air, automated stove control), and general guidelines established for the characterisation and optimisation of hot stoves (OPTISTOVE).

Pulverised coal and alternative carbon injection into blast furnaces

The injection of hydrocarbon carriers into blast furnaces through the tuyeres to minimise coke consumption is state of the art in blast furnace operation. However, in case of changing operating conditions or limited availability of adequate coal types, the challenge is to reduce coke consumption by injecting greater amounts of conventional pulverised coals or new carbon products, such as biomass or pet coke (IMPCO). The suitability of alternative carbon materials (e.g. plastics, dusts, sludge) for blast furnace injection has also been assessed (FLEXINJECT). Two injection layouts for blast furnace application were compared and the additions to a pulverised coal injection system were evaluated.

> The selection of appropriate coals or coal blends for high pulverised coal injection rates remains critical. Correlations can be established between coal characteristics, raceway conditions and overall blast furnace parameters, including the impact of the burden column on melting, smelting and permeability (CHARFOCO).

Putting alternative carbon sources into blast furnaces or coke plants

The practice of putting carbon briquettes into blast furnaces has been studied, to reduce metallurgical coke consumption (INNOCARB). The cold bonded briquettes were produced from alternative carbon agglomerates (coke breeze, coke dust, anthracite, pet coke, charcoal, etc.) usually not usable in blast furnaces. In an operational trial, 12% coke was replaced with carbon briquettes at a constant production rate.

Consistent blast furnace operation must also be maintained, using low-cost raw materials, usually of lower quality. Operational trials tested ferrous fines and nut coke charging correlated with coal injection rates (CONSISTENT BF).

The selection of alternative carbon sources for coke making and the production of coke that meets the quality requirements for stable blast furnace operation helps reduce the costs of hot metal production, with similar or lower carbon input and CO_2 emissions. The link has been established between alternative raw materials for coke making, blast furnace coke properties and blast furnace behaviour (FLEXCOKE).

2.1.5 TGS2 - STEELMAKING PROCESSES

The scope of TGS2 covers electric arc furnace (EAF) and basic oxygen steelmaking (BOS) processes, the recycling of steel scrap, secondary metallurgy techniques and the physico-chemical metallurgy of liquid steel and slags, as well as the related instrumentation, modelling, maintenance and environmental issues.

During the period 2011-2017, the TGS2 reviewed 27 projects: 5 on EAFs, 2 on BOS, 6 on scrap recycling, 10 on secondary metallurgy, 1 on steel slag, and 3 on the control of the whole liquid steel production chain. In addition, 2 accompanying measures projects have been implemented to disseminate the results of the projects on EAFs and secondary metallurgy.

The main technological achievements in the TGS2 are:

- the use of recycling, waste and biomass materials in EAFs
- the enhanced use of scrap materials in EAF steelmaking by means of scrap cleaning, charge mix optimisation and process control
- the improved control of the basic oxygen furnace (BOF) process
- the processing of steel slags to enable their enhanced use in construction applications
- the application of imaging systems for monitoring and controlling secondary metallurgy processes
- the improved performance of ladle refractories and stirring plugs
- the process control of the complete production chain of liquid EAF steelmaking

Use of recycling, waste and biomass materials in EAFs

In modern EAFs, more than 40 % of energy originates from chemical sources derived from fossil fuels. There are different approaches to replacing fossil fuels or other input materials containing carbon in EAFs. The feasibility of replacing fossil coal with char from biomass has been demonstrated for charging and injection to promote foaming. Moreover, the use of syngas produced by biomass pyrolysis has been simulated and shown to lead to a decrease in EAF efficiency (GREENEAF, GREENEAF2).

The substitution of carbon and oxygen with industrial and/or municipal waste (e.g. automotive shredder residue, rubber tyres, plastics, biomass waste and by-products, EAF dust and mill scale) has been assessed with respect to slag foaming purposes (RIMFOAM). Methods for putting or injecting the waste into EAFs have been developed to maintain and improve the flexibility of the industry. Material tests and pilot trials have shown that the liquid steel quality can be preserved and the environmental footprint kept low.

Enhanced use of scrap materials in EAF steelmaking by means of scrap cleaning, charge mix optimisation and process control

Recycling of coated scrap is currently limited by the formation of problematic by-products in EAFs. A process for preheating and surface-cleaning scrap has been developed to improve the recyclability of coated scrap. The coatings are removed in the gas phase and collected in recovery systems designed specifically for that purpose, making it possible to recover valuable metals (PROTECT).

The volatility of the scrap quality-to-price ratio requires maximum flexibility in relation to the charge of the variable materials mix, considering the quality of steel required and the need to minimise production costs and the environmental impact. To determine the scrap mix for a given quality and quantity of steel, while minimising the cost and energy consumption, an advanced control system has been developed to manage and improve EAF operations. The metallic yield of each scrap type can be calculated with reasonable accuracy (FLEXCHARGE). The improvement in charge practices and process management, and the optimisation of the definition of scrap mix, also have to be accompanied by the optimisation of operating practices and process performance (OPTISCRAPMANGE). The production of higher quality steel, greater flexibility in the use of lower value materials and a reduction in the cost of charged materials can be achieved by using an adapted multi-criteria monitoring and control approach involving performance indicators.

Changing scrap properties, in terms of scrap composition, yield and energy demand, requires a heat-individual control of chemical energy input into the EAF for best results in energy consumption and metallic yield. To reach these targets, a dynamic control for chemical energy input using burners and oxygen injectors adapted to actual scrap mix has been developed, for optimal furnace practice regarding scrap charging, steel bath level and slag amount (ADAPTEAF).

Improved control of the BOF process

Control of slag foaming in the BOF process has always been problematic. With increased pressure on process yields and productivity, combined with increased demands for accurate control of refining, it is important to develop a process control tool that can consistently achieve optimum performance in relation to slopping control and refining in the BOF process. A process control system that proactively controls slag formation in the BOF has been developed and new relationships for slag foaming behaviour and rheology derived (BATHFOAM). It has been shown that it is possible to predict slopping in the converter using information from dynamic systems combined with static process data.

The end-point control of the BOF converter process is generally based on the results of a static charge calculation, the observation of the decarburisation behaviour based on off-gas data and an in-blow measurement for steel temperature and oxygen content. These measurements do not provide direct information on dephosphorisation behaviour and the final P value. This means that, quite often, a reblow due to high P content is required. As part of the project, a comprehensive dynamic process model for the BOF process, which can be used for online monitoring and control of the process behaviour, with the focus on dephosphorisation, has been developed and implemented (BOFDEPHOS).

Processing of steel slags for enhanced use in construction applications

Processed slag can be used as building material if certain quality criteria are met. Slag quality is defined by its mechanical properties and environmental behaviour. Its quality, and the possibilities of using it, can be improved by immobilising the leachable substances and recycling washing/cooling water from slag treatment, with the elimination of leachable components. For this purpose, new techniques have been developed to immobilise the critical elements and separate remaining leachable substances from the washing/cooling water, for resource-efficient use of steelmaking slags (SLACON).

Application of imaging systems for monitoring and controlling secondary metallurgy processes

The optimisation of ladle stirring is an important step in improving the energy efficiency of the process, steel metallurgy and the cleanness of the product. With camera-based monitoring of the ladle treatment, it is possible to differentiate between steel and slag at equal temperatures to avoid steel losses during deslagging. Camera monitoring and image analysis make it possible to adapt the gas flow rate for soft stirring, to avoid reoxidation at open eyes and determine the actual stirring efficiency. This helps improve the melting of alloying additions on the bath surface (STIMPROVE). Gas stirring efficiency during ladle metallurgy can be quantified using (ONDECO). Imaging and vibration measurement systems are also used to monitor actual stirring, compare it to ideal treatment according to stirring policies, and advise correct stirring accordingly. This improves energy efficiency by shortening treatment time, reducing the amount of stirring gas used and diminishing the temperature loss from melting steel (DYNSTIR). Deslagging and slag conditioning can also be improved by CCD and IR monitoring of deslagging (OPTDESLAG).

Improved performance of ladle refractories and stirring plugs

Ladle refractory wear is an important concern for steelmakers, not only on account of the material cost, but also on account of its effect on plant productivity and safety. By developing model-based soft sensors and doing thermo-mechanical FEM-studies[48], improvements in ladle refractory life, ladle capacity and security could be achieved (LADLIFE).

In order to improve the performance of purging processes and avoid non-purging events, a purging plug monitoring system based on continuous online temperature measurements in the plug has been developed (PLUGWATCH). These measurements have shown that it is possible to monitor and predict plug availability and performance as well as plug wear, making steel production trouble-free.

The heat stored in the refractory lining of the steelmaking ladles has a major impact on the steel temperature in the ladle, from tapping to casting, which cannot be measured continuously. Innovative temperature measurements to monitor the thermal state of steelmaking ladles have been developed to provide online information for accompanying thermal models, calculating the actual total ladle heat content (LADTHERM). This is a new input parameter for ladle thermal state monitoring systems, steel temperature prediction models and advisory systems for best ladle practices, for optimum use of the thermal energy stored in ladle lining.

Process control for the complete production chain of liquid EAF steelmaking

Dynamic process models for EAF treatment and vacuum degassing, as well as regression- and data-based models for all aggregates of the electric steelmaking process route, have been developed and combined into a through process control strategy to support a reliable, simultaneous achievement of the requested liquid steel quality. The combination with suitable optimisation tools has led to optimal solutions for the production of the investigated steel grades with regard to quality, costs and productivity. The focus has been on the carbon and nitrogen content of liquid steel (LOWCNEAF), as well as sulphur and hydrogen and melt temperature (TOTPTLIS). The control systems have been put in place at five electrical steelmaking plants with different process routes and aggregates for various steel products.

2.1.6 TGS3 - CASTING

The scope of TGS3 covers the continuous casting and near-net shape casting techniques for flat and long products, and the physics and chemistry of solidification and ingot casting, as well as the related instrumentation, modelling, maintenance and environmental issues.

During the period 2011-2017, the TGS3 reviewed 12 completed or ongoing projects. The related exploitation and dissemination activities, made mandatory in project submissions in the last few years, were strongly encouraged.

The general outcomes can be summarised as follows:

- use of advanced and dedicated process engineering measurement and modelling tools (especially in the last 5 years);
- improved knowledge of solidification and the occurrence of defects;
- increased quality, productivity and yield.

Use of advanced and dedicated process engineering measurement and modelling tools

One of the main outcomes in this area is the integration of modelling, measures and plant data. Online process engineering measures can be supported by a broad range of techniques. For example, an innovative induction tomography system has been developed for the metal

[48] Finite element method studies.

solidification process in order to provide a real-time and reliable measurement of shell thickness during solidification, and the value of the metallurgical length, for better control of the process (SHELL-THICK).

An online monitoring system and numerical models enable the identification of defects and support decision making in relation to formulating guidelines that improve the quality of as-cast products. A regression database for defect prevention has been developed using these models, to assist operators and enhance process control (SUPPORT-CAST).

Ti-stabilised ULC steels are important due to their positive properties, but they are also problematic with regard to the occurrence of clogging. The application of plant trials, numerical computations and clogging simulator trials has led to a better understanding of the mechanisms that contribute to clogging, leading to improved steel qualities and an increased yield resulting from a lower risk of SEN clogging (TICLOGG).

Improved knowledge of solidification and the occurrence of defects

In order to improve product quality and process stability, innovative methods for solidification control of liquid steel in the mould have been developed (INNOSOLID), with great care taken to control the heat transfer at the meniscus and the mould corner. An additional outcome was an online model for primary cooling control.

Within the scope of the SHELL-THICK project, a tool for the online and non-destructive detection of different surface defects and potential failure in the process has been implemented. This will introduce a step change in understanding the solidification process, with significant benefits in terms of quality, safety, productivity and costs.

Increased quality, productivity and yield

European steelmakers aiming to produce high quality steel grades for demanding applications are affected by quality issues linked to the mould powders used in continuous casting. A novel concept in relation to mould flux behaviour offers a potential breakthrough in increasing the quality, cleanness, productivity and competitiveness of continuously cast steels. Suitable flux compositions have been designed, and the benefits of non-Newtonian mould fluxes for the continuous casting of advanced steel grades investigated (NNEWFLUX). Using these fluxes, the right viscosity required for each part of the mould can be achieved.

2.1.7 TGS4 - HOT AND COLD ROLLING PROCESSES

The scope of TGS4 covers reheating furnaces and hot and cold rolling and thermal treatments, as well as the related instrumentation, modelling, maintenance and environmental issues. In the period 2011-2017, the TGS4 reviewed 38 projects. Although focused on rolling in general (hot, cold, flats and longs), the projects are not evenly distributed across all those areas. Only five projects related to rolling longs were reviewed. This probably reflects the fact that the European steel industry is concentrating more and more on strip steel. Another reason is that the longs rolling business has reached a stage thought to require less research. The same goes for the plate mills. In this period, there were no projects related specifically to plate rolling. Hot rolling also has more research potential compared to cold rolling (65% vs 35%).

Looking at the subjects investigated, a few categories stand out.

- Rolling-related research on both hot and cold rolling mills and a few projects on long rolling.
- Instrumentation, modelling and control: in this area new measurement equipment is being investigated that was possible to integrate into a control loop.
- Lubrication during rolling.
- A recent area of interest relates to scale/oxide. This area is becoming increasingly more important because of the new steel grades that are being produced, with different behaviours in the hot mill, leading to surface defects if not properly counteracted.
- Reheating furnaces: the number of TGS4 projects is limited, but before 2015 this topic fell under TGS3, under whose auspices several reheating projects have been implemented.

Rolls

In the reporting period, 9 projects were carried out in this area, where there is quite an active community proposing projects. In recent years project consortia have brought together roll suppliers, roll users and inspection equipment suppliers.

This has led to the development of new, more wear- and incident-resistant roll grades by roll suppliers, for the roughing and finishing stands in hot mills.

Roll users have gained a lot of insight into how to use the rolls in the various conditions. Cracking mechanisms, the formation of protection oxide layers, and roll degradation mechanisms have been studied in order to see how to make roll cooling systems more efficient so that the roll could last longer. Different rolling schedules have been designed, with the possibility of selecting better adapted roll qualities for the different stands and circumstances. All this has increased the value in the use of the roll fleet, not by buying the cheapest rolls, but by buying and using the best rolls given the circumstances.

Through these projects, the supplier of NDT equipment has developed equipment that can better determine roll degradation and failures in the roll shop, improving roll grinding practices by making sure a damaged roll is spotted in the roll shop, not causing problems in the mill.

A few projects focused on coating roll or treating the roll surface to increase the life of the roll. This has not yet led to significant breakthroughs, although promising results were obtained by surface treatments as a replacement for chrome plating of the (work) rolls. There is more work to do in this area.

Instrumentation, modelling and control

About 10 projects focused the development of measurement systems and it was possible to integrate the result into control loops.

Mill chatter in cold and hot rolling has been studied, resulting in a good understanding of where to place (wireless) sensors on the mill stands in order to detect mill chatter early on. Chatter can be caused by the rolling process and prevented by slowing down the (cold) mill. Another cause can be degradation issue in the gearboxes, roll chock etc. The work done in this area has resulted in a system that is also able to detect early phases of mechanical damage in the rotating part of the mills stands so that preventive measures can be taken, an example of predictive maintenance.

Before the reporting period a prototype of a roll mark detection system was developed. In the reporting period a pilot and demo project was done, to go from the prototype to a commercially available roll mark detection system for cold mills. This is a significant development, because it replaces the labour-intensive manual inspection of roll mark imprints on the strip with an automated inspection. This equipment is expected to be on the market soon.

A significant area of interest is the measuring of mechanical properties in the hot mills during the rolling process. Various technologies can be used to determine these properties, one of which is to measure the magnetic properties, a technique that was studied in the TGS9-run product uniformity control project. In TGS4 laser ultra-sound technology is being developed in two consecutive projects. Although promising, the work is not yet complete, but this is to be expected, given how difficult it is to measure mechanical properties in steel rolling.

Lubrication during rolling

This focused on the development of reliable lubrication during hot rolling. The projects have shown how to design a properly functioning hot rolling lubrication application and how best to combine this with work roll cooling. The lubrication application performs best without entry cooling on. This can best be done by installing the high turbulence roll cooling (HTRC) developed in the RFCS framework before 2011. When this is installed, entry cooling is not required. In a few mills, the lubrication application has been installed successfully and the combination with HTRC cooling is gradually taking shape in Europe.

Trials have also been done on finding oil-free lubricants. Despite a few promising trials, this work has not yet succeeded in finding viable alternatives. One reason for this is that the environmental consequences are not clear yet.

Scale/oxide-related

Scale formed during the hot rolling process is inevitable. There are two reasons for controlling the formation of scale. One is yield loss, with yield loss as a result of scale formation mainly taking place in the reheat furnace. The other is surface defects. If not properly removed before rolling, scale will be rolled in on the surface, causing defects. In the case of the finishing mill, it is becoming increasingly important to control the scale layer. With the new AHSS steel grades containing aluminium and silicon, the problem of scale has become much more complex, making it crucial to bring about improvements in this area for new products.

The projects in this area have involved work on steel coating in order to protect steel from oxygen, to lessen yield loss. Various coatings and ways of applying them have been tested. Despite the fact that coatings do not have detrimental effects on furnace refractories, but do slow down the oxidation process, the technology did not take off in the mills. At this stage, the business case is not good enough to justify it.

The other purpose of coating is to reduce decarburisation. Its importance, especially for long products, has led to the implementation of this technology.

In the mill itself, descaling is an important part of the process, to prevent surface problems. Many descaling trials have been done, testing both the nozzles and other parameters of the descaling setup. This has led to the drawing up of design rules for descalers that can easily be used by the European steel industry.

The projects in this area have also contributed to a much deeper understanding of the mechanisms behind the formation of scale, both in the reheat furnace and the mill, and of how to control the scale layers in order to prevent surface defects. This knowledge is being put to use in multiple mills, reducing the surface problem caused by scale formation. This has greatly improved the quality of steel. However, because of the continuous development of new steel grades (AHSS, UHSS) with more alloying elements (such as greater aluminium and silicone contents) that change the behaviour of oxidation, vigilance is required, because the new AHSS steel grades are prone to highly undesirable surface defects.

Reheating furnaces

An extensive investigation into fuelling the reheating furnace with blast furnace (BF) gas has proved that it is possible to construct a 100% BF gas-fuelled reheating furnace. A design for such a burner configuration has been made and tested in a lab-scale environment and an industrial reheating furnace, for use in future furnace setups. A complete retrofitting guideline has been produced and published for general use.

2.1.8 TGS5 - FINISHING AND COATING

The main topics TGS5 analysed are heat treatment technologies, finishing and coating technologies, including the development of new/improved processes, surface characterisation and corrosion properties, instrumentation and sensor control, modelling, and related maintenance and environmental issues.

During the selected period, 17 new RFCS projects were started: 2 in the ‘pilot and demonstration’ category, 2 in the ‘pilot’ category, and the remaining 13 RFCS research projects with clearly defined objectives.

The main project topics fall into the following categories:

- the development of predictive models for steel products
- better finishing and coating processes
- monitoring systems for product quality control
- new applications.

Development of predictive models for steel products

Five projects, two of them ongoing, related to the development of predictive models for steel products. The development of predictive models is the most useful tool available for improving the industrial process and directly analysing the impact on the final products, for instance in terms of corrosion.

From a material point of view, although there is widespread knowledge of the relationship between the microstructure of dual-phase steels and the resulting mechanical properties, it is difficult to determine and quantify many parameters influencing the microstructure during the process. The changes in the microstructure cannot be traced in industrial lines and are difficult to investigate on a lab scale, making recourse to numerical models the most promising avenue to explore. In this context, the VADPSHEET project developed a physically based model for a continuous annealing/galvanising process able to identify the quantitative effects of chemical composition and thermal cycle on the microstructure of dual-phase sheets.

The corrosion process of zinc-based galvanised steel is well known, but economic and environmental reasons lead to the progressive adoption of aluminium-based coatings (e.g. with a lower zinc content), whose behaviour has not been studied in as much detail and whose durability is mainly assessed in extensive and expensive long-term lab and outdoor campaigns. Numerically simulating the process can significantly improve times and costs. The ATCORAS project studied and calibrated modelling tools able to represent the effects of corrosion on steels protected by aluminium-based alloys, structurally integrated into lifetime macroscopic prediction tools, making it possible to understand the effects of corrosion phenomena on steel samples coated with aluminium, zinc, or magnesium alloys in different atmospheric situations. The numerical model describing the effects of coating microstructure on the development of coated steel structures, with time-emphasising zinc-aluminium and zinc-aluminium-magnesium systems, validated by accelerated and field corrosion tests – developed in the MIROCORR project – has favoured the development of the market for new generations of metallic coatings with superior long-term corrosion stability and lower coating thickness.

The presence of flatness defects and the resulting generation of residual stresses is another relevant topic, mainly affecting thin strips of high-strength steels. There is a need to control the flatness by introducing an automatic set-up control, replacing the operator's experience. The multi-physics process model, developed in the ICONTENS project, for different leveller types, to estimate residual stresses and flatness using intelligent sensors, has made it possible to achieve a better knowledge of material behaviour under cyclic loading conditions, of online controlling of the different leveller types, and of parameters and effects on steel products.

Residual surface stresses strongly affect the abrasion resistance of the steel material: the steel microstructure and its mechanical response to impact affect the abrasion resistance, not usually accounted for in the conventional design criteria, where only the material hardness is considered. The enhanced numerical model developed in the INMARS project relates the surface state (i.e. topography, composition and structure) to the level of residual surface stresses, the microstructure and the resulting abrasion resistance.

Better finishing and coating processes

Six projects, three of them ongoing, related to the development of better finishing and coating processes.

There is a lack of knowledge about the effects of embrittlement, crack initiation and growth in direct press-hardening of steel protected with zinc-based coatings, strongly affecting the quality of the resulting product. The analysis of the reasons for crack formation (after or before heat treatment), the study of the damage mechanism (including determining the parameters with the most impact, analysing the changes undergone by the coatings during heat treatment, microstructural and mechanical properties, etc.) and its propagation are fundamental to developing strategies for crack reduction or damage prevention. The ZINCOBOR project has studied these problems in depth, making it possible to develop strategies for producing safer components, thereby preventing problems and deterioration.

The efficiency of pickling line is another relevant aspect, analysed in depth due to its relevance, especially for stainless steel, where the quality of the surface is crucial for customers. Together with the required high process flexibility, the fast adjustment of defined concentrations in industrial mixed-acid pickling baths is needed for high-quality products and high plant productivity. Since available mixed-acid concentration analysis techniques do not guarantee the fulfilment of these requirements, the MACO-PILOT project looked at the optimisation of innovative online concentration measuring techniques for the set-up, long-term reliability and modernisation of existing mixed-acid pickling plants, to improve the whole process and working conditions in the plants. An innovative electrolytic pickling process based on alternating current (AC), developed at lab scale for carbon and stainless steels, is a real pickling process breakthrough, because it reduces the pickling time, lowers the environmental impact and increases the surface quality. The ACE-PICK pilot project has installed an AC pickling section on an annealing and pickling line, taking the whole process to full industrial scale.

Reducing the cost of production is another relevant aspect, related to the increase in the galvanising line speed. One project (High-speed Galvanising) analyses how to overcome the limits of high-line speed (for example, developing new bearings with a low-maintenance profile, improving dedrossing operations connected to surface defects, etc.), to increase coating quality and be able to determine possible alternative metallic baths.

The NOSTICKROLLS research project looked at extending the service life of furnace rolls working in continuous annealing and galvanising lines, reducing maintenance costs and increasing productivity by lengthening the furnace’s time-to-maintenance, getting higher quality steel strips in terms of surface defects due to wear, and the build-up of oxides from steel products, picked up by the roll surface. The biggest pick-up formation problems have made it necessary to improve strip running speed and/or annealing temperature, to determine which steel products are of use to the automotive sector.

The Efficient-ELO project studied the development of new energy- and resource-efficient processes for electro-galvanising steel strips, by increasing electrolyte conductivity and using zinc-containing dross from hot-dip galvanising as raw material, and proposing to improve the conductivity of the electrolyte solution by increasing the temperature or developing new formulations. Besides, the protective properties of the galvanising layers can be enhanced by using alloying zinc with aluminium or aluminium and magnesium: the thickness of the ZnAl and ZnAlMg layers can be reduced, keeping the same total corrosion protection as a thicker Zn layer, with economic and environmental benefits. A project (BOLT ZnAlMg) has been developed on this in relation to offshore applications, analysing the influence of processing and alloying parameters on the microstructure of the galvanising layer and its corrosion performance, and studying the coatability of the newly developed galvanised coatings.

Monitoring systems for product quality control

The market is demanding higher quality products, mainly in terms of stricter material property tolerances and surface appearance. Two of the most important features that shall be accurately controlled are residual stresses and surface waviness (partially connected).

One ongoing project (ORSC) is devoted to the development of a new residual-stress-based control system that combines inline measurements with accurate modelling approaches, later directly validated at an industrial plant. The project will facilitate material property-related homogenisation, resulting in noticeably higher product quality that meets market requirements, for European steel producers.

Mastering waviness is becoming a major issue for making high-quality coated steel. If the waviness of a steel sheet is above defined limits, steel users will not accept the annealed and galvanised product, since it is potentially connected to lower quality and downgrading in the later processing steps, notably the finishing and painting operations. Online measurements are mandatory, to fully evaluate the surface quality all along the coil and control the production parameters. To this end, sensors studied in the WAVISURF project have been tested at industrial level, resulting in guidelines on reaching the waviness target defined by the customers and collecting data needed for the implementation and commercialisation of a commercial industrial sensor.

New applications

The STEELPV project proposes using rough structural steel as direct substrates for photovoltaic (PV) devices. It looked at three steel grades – stainless steel different from solar grade one, galvanised/aluminised cold-rolled low-carbon steel and bare cold-rolled low-carbon steel – analysing the industrial implementation feasibility of the PV systems.

Another project (DUPLEXWASTE) has analysed the efficiency of the application of lean duplex stainless steels to urban and industrial wastewater treatment, considering the effects of corrosion through laboratory and in-field exposure and applying a life cycle cost assessment. This has led to the development of guidelines for material selection in urban and industrial wastewater units, and expanded the market.

2.1.9 TGS6 - PHYSICAL METALLURGY AND DESIGN OF NEW GENERIC STEEL GRADES

The scope of TGS6 covers the development of steels with improved properties at low and high temperatures, the development of new steels for demanding applications, precipitation, recrystallisation, microstructure, texture and ageing properties, predictive simulation models for microstructures and mechanical properties, magnetic properties, and the standardisation of testing and evaluation methods.

During the period 2011-2017, TGS6 committee reviewed over 30 projects.

The projects can be categorised as follows:

- development of new generic steels
- study of in-service product properties, modelling and a deeper understanding of metallurgy
- metallurgy and process controls in production lines
- breakthrough developments (new metallurgy and production routes).

Development of new generic steels

The main objectives are the development of new advanced high strength steel grades, especially for the automotive sector.

The quenching and partitioning (Q&P) process, with improved strength, ductility and strain hardening, has been studied in detail. It paves the way for developing steel microstructures based on the exceptionally advantageous combination of austenitic and martensitic phases on an industrial scale. The industrial applicability of the process has been improved in terms of compositions, treatments and properties, such as the ability to be zinc-coated, and weldability, to develop a controlled and reproducible production process for these materials.

A new high-temperature Q&P treatment has been studied, in which austenite is stabilised both by carbon diffusion and the diffusion of substitutional alloying elements. This innovative idea opens up an unprecedented approach to producing martensite-austenite microstructures, which is expected to lead to a new third-generation advanced high-strength steel family with enhanced formability.

A novel method for making extremely strong and inexpensive nanocrystalline steels, without using severe deformation, rapid heat treatment or mechanical processing, has been developed by the formation of nanostructured bainite at very low temperatures (200-300ºC). It makes for an extremely fine microstructure, consisting of thin plates of ferrite (40-60 nm) and retained austenite (15-30%). This new generation of steels, referred to as nanobainitic steels, are potentially one of the most significant discoveries in steel metallurgy over the past 10 years, with an almost unique potential to optimise both toughness and wear resistance at a reasonable cost.

Submicron ultrafine grain (UFG) long steel products (ferrite-cementite microstructures in medium- and high-carbon steels) have been produced, with high strength and adequate ductility, for automotive and mechanical applications. They can be further processed by cold forming or direct machining.

Extensive study has been done on new complex phase low-carbon microalloyed steels, obtained by optimising chemistry and thermo-mechanical processing, i.e. hot rolling and cooling, to simultaneously obtain refined microstructures and several types of precipitate nanoparticles. The previously unexplored synergies between niobium, molybdenum, vanadium and titanium on precipitation before, during and after phase transformation from austenite during hot rolling and cooling, have been studied. The project has resulted in new product concepts, optimised with regard to processing parameter windows, making for robust mechanical properties, i.e. static and fatigue strength, bendability, hole expandability and toughness.

The study of in-service product properties, modelling and a deeper understanding of metallurgy

The complex effect of boron in steels has been taken into account in existing models (recrystallisation, precipitation and transformation). The use of the models has improved the consistency of properties in boron-treated ultra-high strength plate, and the applicability of boron additions for producing advanced multiphase cold-rolled and annealed strip with high strength, formability, wear resistance and weldability at a reduced cost.

A methodology has been developed for predicting the performance of high quality stainless steel after forming and finishing treatments. Performance prediction is used as the basis for linking end-customer requirements to steel production conditions. This methodology has been tested on three types of steel and routings: 1) martensitic stainless steel and heat treatment; 2) austenitic stainless steel and nitrocarburising; 3) precipitation hardening stainless steel and precipitation hardening and simultaneous nitrocarburising.

New products have been developed based on strip processes: press-hardened steels, low-temperature tempered, quenched and partitioned and hot-rolled directly quenched steels. These products have introduced new in-use properties in ultra-high strength steels: press formability, delayed fracture resistance and wear resistance. Current metallurgical approaches describing martensite transformation, tempering reactions, microstructure development and properties overlook key issues, such as the role of prior austenite state and heterogeneous carbon distributions across lath structures. Developing a common approach to low-carbon martensite characterisation, the study has integrated new fundamental knowledge into a workbench of product design tools, validating its industrial application to modern martensitic steels.

Modelling issues related to the production of AHSS have been extensively studied. These steels are increasingly used in the automotive industry, but their forming behaviour is problematic. An extremely fast crystal plasticity code has been used to derive macroscopically observable anisotropic plastic properties from complex 3D artificial multiphase microstructures. This has been directly combined with efficient multi-scale code, resulting in very numerically efficient state-of-the-art models for dual-phase steel forming processes. The resultant multi-scale material model has been demonstrated for use in realistic microstructures in an industrial FE-Code, to predict product properties after the forming of a large automotive part.

Metallurgy and process controls in production lines

The properties of AHSS/UHSS after roll forming, when the tensile strength level increases over 1000MPa as cold-rolled sheet has been optimised thanks to the definitions of well adjusted processing parameters, processing routes (continuous annealing lines (gas or water-quenching)) and hot dip galvanising.

Carbide-free nanobainitic microstructures are made up of 40-60nm-thick bainite laths with retained austenite. Unprecedented combinations of strength and ductility have been achieved, and very encouraging results obtained in terms of fatigue resistance. To fully realise the potential of these microstructures in industrial applications, a better understanding of the relationship between process and microstructure on the one hand, and microstructure and in-service properties on the other, has been arrived at.

Breakthrough developments (metallurgy and production routes)

A new steel grade with enhanced mechanical properties has been made by adding ceramic nanoparticles to molten microalloyed steel. The innovation is a feasible addition technique to disperse nanoparticles into the melt. Ceramic nanoparticles give steels high-temperature strengthening, making them more easily applicable to use in the energy sector.

Hot stamping has received much attention as a way of producing automotive ultra-high-strength parts. The manufacturing of final hot-stamped parts with enhanced elongation, maintaining the current tensile strength requirements, has been studied. To do this, new microstructures have been produced after the hot-stamping process, mainly martensite/austenite combinations, based on the new Q&P heat treatment applied just after component hot forming.

2.1.10 TGS7 - STEEL PRODUCTS AND APPLICATIONS FOR AUTOMOBILES, PACKAGING AND HOME APPLIANCES

TGS7, whose focus is on steel products and applications for automobiles, packaging and home appliances, covers the technologies relating to forming, cutting, welding and joining steel and other materials, the design of assembled structures to facilitate the recovery of steel scrap and its reconversion into usable steels for recycling, the prolongation of the service life of steel products, the development of steel-containing composites and sandwich structures, and the standardisation of testing and evaluation methods.

The TGS7 projects during the period 2011-2017 brought several notable technical and technological achievements to the fore in the following areas:

- the joining and forming of high-strength steels
- the development of new simulation methods
- the improvement of processing capabilities for advanced steels
- the development of advanced testing methods and creation of new standards.

Joining and forming high-strength steels

These technologies help the end-consumer to use high-strength steels, especially in demanding applications such as road vehicles and mobile machines.

One of the most promising technologies is adhesive joining, an alternative to welding in construction and the automotive application of steel products. It is particularly useful in the case of the low thickness of components made of high-strength steels. However, adhesive joints of galvanised steel sheets, especially in corrosive environments, are not yet durable enough. The results of laboratory tests and studies of the adhesion and de-adhesion mechanisms of galvanised and zinc magnesium alloy-coated steel, have provided a better understanding of these mechanisms, and models describing the corrosion behaviour of adhesive joints have been developed. These models provide a theoretical background for the development of new adhesive joints with improved interfacial properties. New surface treatments (prior to the bonding process), to improve adhesion, have also been proposed.

Some automotive joined components may be affected simultaneously by corrosion and fatigue. The investigations of spot-welded and adhesive-bonded joints have provided a better understanding of fatigue-corrosion damage processes.

Bringing advanced high-strength steels to the automotive industry is quite a challenge. The final results of the related project have not been published yet, but the proposal was quite ambitious. It was aimed at supporting the introduction of twinning-induced plasticity (TWIP) steels into vehicle manufacturing by providing reliable technologies for joining TWIP steels to conventional steels and lightweight materials. The investigations have focused on low-heat and mechanical joining technologies such as clinching, tack-setting, flow-drill screwing, rivet element welding and friction element welding.

Development of new simulation methods

The development of new simulation methods has been a major part of several projects, focused on steel applicability and the safety of steel structures.

After joining, forming is the next biggest challenge connected to the introduction of advanced high-strength steel sheets to the automotive industry. Problems occur when stretching and bending are combined in the forming process. To improve the reliability of using AHSS in industrial stamping applications, numerical models for forming operations have been developed. A new way of indicating the forming limits of AHSS sheets in combined stretching and bending processes has also been developed. New and more accurate failure models and advanced shell formulations increase significantly the simulation capability of AHSS.

Another advanced candidate material for the production of lightweight automobile components are TWIP steels. To introduce a new steel grade like TWIP steel for large-scale industrial applications, a thorough validation of the material's behaviour, with usable material laws implementable in commercial finite element codes, must be available. This is because numerical simulations are used all along the production process of body parts, from the design of forming dies to the prediction of in-service performance, to the prediction of passenger safety in crash simulations. As a result of the work carried out, a material model has been developed, that identify the main characteristics of TWIP-steels, and implemented in the form of two commercial finite element software packages. A detailed experimental test program has been used to analyse different aspects of material behaviour on a microscopic and macroscopic level, such as the evolution of twins, stress-dependent hardening or the Bauschinger effect. These analyses have given a valuable insight into forming behaviour and a better general understanding of the material in question. The results have been used to validate the TWIP4EU model. As a prototype, a backrest side member of a seat frame was chosen and successfully produced.

In-service fatigue conditions of mechanical components range from less than 1 Hz to several kHz load frequency. Fatigue testing can be carried out in a similar range of frequencies, but higher frequencies are usually preferable in order to reduce testing time. This means that testing and in-service load frequencies do not often match. Nevertheless, the use of high frequency testing is inevitable, and it is increasingly used to acquire knowledge needed for design components of high to very high fatigue life lengths. High frequency loading, combined with plastic deformation at the fatigue crack tip, produces a local increase in temperature, causing on-site mechanical steel properties to change sharply. The generation of very long fatigue life materials data and the clarification of conditions at the crack tip is very important for real component fatigue life and fatigue testing validity. To increase the applicability of high frequency tests, a theoretical model of the relationship between microstructure and fatigue properties has been developed. The model also focused on the thermal history of advancing fatigue crack tip under high frequency load, making it possible to better understand the temperature effect at high frequency fatigue.

Processing capabilities for advanced and improved steels

For economic and environmental reasons and to meet the requirements of the new demanding steel applications and enable the processing of new advanced steel grades, manufacturing processes need to be further developed.

Steel hydroformed tubular components with tailor-made properties, used in automotive exhaust systems, make it possible to incrementally improve component functionality performance and reduce the weight of parts. However, expensive combination of manufacturing processes, low automation and long manufacturing times greatly hamper current technologies. An innovative process has been proposed, based on a combination of tube flow forming and hydroforming. The flow-forming process makes it possible to obtain the tailor-made tube with the required variable thickness, before hydroforming it to be in line with the final geometry of a component. This reduces the number of manufacturing process stages, eliminates welding operations, reduces the final weight of parts and makes the whole process more homogenous (due to the elimination of welds). On two car parts selected as demonstrators, it has been proved that the proposed process can be used. The demonstrators exhibit a weight reduction of 8-9% compared with the original parts. A drawback, identified during the experiments, is that flow forming exhausts the plasticity of the material to the extent that an annealing process needs to be applied before hydroforming. This requires more work, to find a solution, or a detailed cost analysis before each implementation.

Press-hardened components used as automotive structural body parts, due to their exceptional mechanical strength and consequential reduced weight, increase passenger safety and reduce vehicle CO_2 footprint. However, the cost and energy efficiency of hot-stamping processes is still far from satisfactory. This means that long manufacturing cycle times, and costly heating and cooling, continue to hamper matters. To decrease the cost and environmental impact of the press-hardening process, two new steel grades with lowered Ac3 temperatures have been designed. Both grades – when compared with the reference grade 22MnB5 – significantly reduce gas consumption and, consequently CO_2 emissions (20%) during furnace heating. They have been shown to be acceptable and comparable to the final mechanical and technological properties of the reference grade and an automotive company is considering using them.

Several other RFCS activities in the reporting period related to the area under discussion, such as the development of safer and more competitive road restraint systems using high-performance (higher strength) steels, or the development of a press-hardening process for a new type of steel with a tensile strength of 2000 Mpa, designed for lightweight car components. The final reports have not been published yet, so the activities cannot be discussed in terms of what they achieved. Nonetheless, their objectives seemed to be important enough to mention them here.

Development of advanced testing methods

Advanced materials and products require advanced testing methods that can proof their ability for further processing as well as their suitability for final applications. Several projects focused on these areas and valuable new testing and numerical analysis techniques have been developed.

The machining cost of an automotive part can be significant, from about 20%, up to 70%, of the total manufacturing cost. Very efficient machinability, and even more importantly, reproducible machinability, are therefore necessary for the end-user to be competitive. The quality control of steel and steel products plays a key role in this regard. As a result of the work done, the analytical techniques of magnetic barkhausen noise (MBN) and pulse distribution analysis with optical emissions (PDA-OES), have proved useful in predicting steel machinability. They have been proposed as a tool for checking the final product and doing track analyses during the production cycle.

Automotive manufacturers are increasingly using hot stamping, because it enables them to produce complex geometries from high-performing materials. However, their industrial feasibility depends on the process efficiency, which depends on the cost of parts and performance of the tool used to produce them. It is therefore very important to be able to predict how many parts a tool can produce. A new high temperature tribometer (HTTM) has been developed for simulating the tool-workpiece interaction at high temperatures during hot forming. The development of a measuring methodology, and the setting up of a test facility to evaluate the tribo-thermo-mechanical behaviour of the tool-workpiece system, have made it possible to carry out simulative testing of friction and wear at high temperatures with applications in hot sheet metal forming. The results are relevant for their intended application and have the potential to be used for predicting hot forming tool life.

The rolling contact fatigue properties of steel play an important role in some applications. The fatigue tests are time-consuming and the resulting information, on steel inclusions responsible for fatigue failure, is limited. As a result of the work carried out, alternative meso-inclusion characterisation methods, such as extreme value analysis according to ASTM[49] E2283-08 based on light optical microscopy, high frequency ultrasonic testing, or fast fatigue tests on compressive rings, have been proposed as a way of significantly reducing testing time and money.

2.1.11 TGS8 - STEEL PRODUCTS AND APPLICATIONS FOR BUILDING, CONSTRUCTION AND INDUSTRY

TGS8 objectives are related to structural safety and construction design methods (with the emphasis on fire and the seismic resistance of steel, steel/concrete and – in some cases – reinforced concrete structures); improving forming processes and technologies for cutting and welding steel and composite joints; designing assembled structures to facilitate the easy recovery of steel scraps and their recycling; and prolonging the service life of steel products. Sustainability and energy efficiency need to be taken into account in construction. One of the most important outcomes of TGS8 research is the drawing up of design guidelines and proposals for

[49] The American Society for Testing and Materials (ASTM) is an international standards organization developing and publishing voluntary consensus technical standards.

standardisation, making it possible to put research results and outcomes to the broadest possible use, develop the use of steel solutions, and make the sector more competitive.

From 2011 to 2017, 70 TGS8 projects were monitored. Of the 70, 59 were research projects and 11 accompanying measures. Most of the projects carried out experiments, including large-scale tests on components/connections, parts and substructures. Combining the results of experiments with accurate numerical models and analyses, projects were often able to provide design guidelines and background documents making findings known among standardisation bodies, engineers, practitioners, etc., and underlining the relevance and practical application of results. The new versions of Eurocodes being developed, for instance, are based on RFCS results in relation to seismic performance, localised fire, composite connections, cellular beams, the shear capacity of composite beams, and the performance and applications of new materials.

The main topics of TGS8 projects can broadly be categorised as follows:

- fire protection
- seismic design of new constructions and retrofit of existing buildings
- design of new buildings with steel and composite structures
- development of new improved process technologies
- energy efficiency, reuse and sustainability of structures.

Fire protection

Almost six different projects related to fire engineering. They focused on developing specific methodologies for designing innovative connection systems for composite steel/concrete components, promoting the optimisation of cold-formed thin-walled profiles for structural members, and designing composite steel parts (mainly columns) subjected to localised fire. The structural performance of composite steel/concrete hollow-section columns and of cladding systems subjected to fire have been analysed in detail.

For example, the LOCAFI project provided a background document for designing steel members under localised fire based on the results of experimental tests. Numerical models, analytical design methods and a design guideline, with a step-by-step application of the model outlined in a simple Excel sheet, have been developed. The project has been improved by an accompanying measure (LOCAFI-Plus), making it possible to impart the knowledge acquired through seminars, design manuals and practical calculation methods. FIDESC4 is another example of a project able to provide innovative design rules for assessing the fire resistance of thin wall steel members (class 4 cross-section steel members), making steel more competitive than other construction materials such as concrete or timber.

Seismic design of new constructions and retrofit of existing buildings

About 14 projects dealt with seismic engineering, in relation to the design of new constructions and the retrofit of existing buildings.

Research focused on the development of new design procedures and guidelines for constructions made with ordinary and high-strength steels (HSS), to optimise the mechanical performance of materials, or on the promotion of new reinforcing steels with enhanced ductility. Several projects looked at industrial structures, including the development of optimised design guidelines for steel racks with thin-walled profiles, or of automated rack-supported warehouses that, during past earthquakes, have frequently suffered severe damages with economic and human losses. The INDUSE-2-SAFETY project also analysed industrial risk, providing a quantitative risk assessment methodology for the seismic loss prevention of petrochemical plants and components, including recommendations for improving European standards and codes. The EQUALJOINTS project, and its accompanying measure, also analysed the pre-qualification of steel joints, by carrying out a broad range of experiments on different types of seismic steel beam-to-column connections, enabling the development of design guidelines and pre-normative documents on the use of pre-qualified joints in constructions.

Three projects (PROINDUSTRY, STEEL-EARTH and INNOSEIS) aimed to develop anti-seismic steel-based devices for the protection and retrofit of existing constructions, including reinforced concrete and industrial steel buildings.

Design of new steel and steel/concrete composite structures

The majority of TGS8 projects in the reference period related to the design of new steel and composite steel/concrete structures and components.

Studies of composite structures were mainly devoted to the experimental and numerical assessment of how new types of connections behave in shear. In the case of the MEAKADO project, for example, they also analysed the influence of low seismic or impact actions. Research has provided design approaches and methodologies, guidelines and draft background documents for implementation in revised European standards. The behaviour of new composite SC structures (steel-concrete-steel composite) – not even covered by Eurocode 4 – has also been studied (SCIENCE project).

Several areas of research related to the development of innovative steel joint solutions, providing design guidelines to facilitate their employment; the adoption of high-strength steel bolted connections; and the development of 3D plug-and-play systems, also with cold-formed profiles. More generally, the possibility of designing with HSS has been studied closely, enabling the development of new guidelines (HILONG, RUOSTE, etc.).

The design of pipelines has also been studied, covering reliable methodologies for designing buried pipelines under monotonic and cyclic loading conditions, including aspects relating to soil-structure interaction, cracking control, and toughness requirements.

Problems with the design of new types of steel sheet profiles, including curved ones; the resistance to, and robustness of industrial plants in the face of, explosions; the design, assembly and optimisation of modular light steel structures; the analysis of relevant failure modes and the safety assessment of different constructions; offshore and onshore systems; ways of extending the life of buildings with steel and composite structures, have also been analysed.

Development of new improved process technologies

New technologies have been studied, whose purpose is to improve the process of welding steel elements using hybrid laser-arc technology, taking into account different steel grades (including in the HSS – JOINOX project), different profile thicknesses, different types of joint, to name but a few. The HIPERCUT project looked at modern cutting techniques, including laser-beam and plasma-arc cut edge, focusing on their effect on the fatigue and fracture strength of plates.

Energy efficiency, reuse and sustainability of structures

Nine projects looked at the energy efficiency, reuse and sustainability of different kinds of structures, introducing aspects of life cycle assessment. For example, the SB_STEEL project, one of the first attempts to standardise environmental footprint at the early stage of building design, aimed to optimise the carbon footprint of the steel solution. REDUCE and PROGRESS projects are two other good examples of advanced sustainable solutions. They provide methodologies for dismantling composite steel and multi-storey structures, and for reusing envelopes, frames, trusses, etc., to encourage circular economy-based material recycling. Other projects dealt with the use of recyclable materials, reduction of energy consumption, elimination of thermal bridges in steel claddings, to name but a few.

2.1.12 TGS 9 - FACTORY-WIDE CONTROL, SOCIAL AND ENVIRONMENTAL ISSUES

The scope of TGS9 is very large, covering instrumentation, control and automation, including artificial intelligence and advanced information technologies; the development of analytical techniques; the control and protection of the environment in and around the workplace; working conditions, including health and safety; the management of energy, water and material flow; the recovery and valorisation of by-products, including the preparation of scrap; the development of new processes for sustainable steel production; the development of sustainable products; life cycle assessment techniques; and the standardisation of testing and evaluation methods.

During the period 2011-2017, 34 projects were monitored, 15 on factory-wide control, 10 on the environment and 9 on new measurement techniques.

The projects can be categorised as follows from a technological point of view.

- Topics related to factory-wide control, such as decision support systems, through-process control solutions, cause and effect detection systems, and semantic techniques for storing and using knowledge acquired from operators and engineers.
- Measurement techniques for online steel quality assessment and process control.
- Reduction of CO_2 emissions using waste energy.
- Recycling of waste resources like slags or wastewater.
- Environmental monitoring and protection techniques.

Factory-wide control

Several technologies have been developed and industrially tested in this area, known as Industry 4.0: plant-wide monitoring solutions (e.g. SUPSYSCC); through-process control techniques (TECPLAN for example); supervisory systems for product quality and production performance along the complete production chain (SISCON for example); and systems to analyse cause and effect relationships between production conditions along the production chain and quality defects of intermediate and final steel products (AUTODIAG, PRESED for example), using data mining techniques. In PRESED and EVALHD, big data technologies (deep learning in the first, and multi-scale data representation in the second, project) were first used to very rapidly evaluate the large amounts of data coming from high resolution measurement systems, and in the case of EVALHD, from automatic surface inspection systems. It is now possible to do this in a few seconds instead of several hours, as in the past. I2MSTEEL has developed a completely new paradigm for factory- and company-wide automation and information technology. Here, software agents are used in combination with semantic modelling techniques to reallocate failed products to alternative orders by calculating the possible achievable product range, considering additional reworking steps. This could be a first step in the direction of self-organised production. In another project, the semantic modelling techniques mentioned above have been put into practice to use complex knowledge acquired from engineers or operators inside a computer-based system to decide if an intermediate product like a slab is suitable for the intended customer or not (KNOWDEC).

Measurement techniques for online steel quality assessment and process control

To analyse online the quality of intermediate or final steel products is one of the most important challenges in the steel industry. Several RFCS projects have covered this topic based on different measurement techniques: ultrasonic techniques, sometimes in combination with phased-array methods, have successfully been used to detect surface or subsurface defects in wire (MONWIRE, here in combination with optical technologies) or slabs (NDTCASTING). What's lacking is solutions to really check all products online and use the test results for production control purposes. The OMC project has taken a first step in the direction of non-destructive material characterisation by testing and modelling the microstructure of flat steel products, continued in the Product Uniformity Control (PUC) project. So there is still some work to do on determining the microstructure of steel online, but techniques being used (electromagnetic, ultrasonic) seem to be adequate for ensuring that the properties are constant along the product length, and the product really is uniform.

The CHECKSIS project has gone further towards developing automatic surface inspections systems (ASIS) (here: flat products). The aim of the project was to develop methods enabling the automatic verification of ASIS results. New methods for computer-aided ASIS supervision have therefore been developed, using artificial defects and synchronising two ASIS installed on the same production line. The systems are able to detect decreasing system performance, thereby ensuring long-term ASIS stability and documented reliability. The project results have been summarised in a first official standard for ASIS calibration and supervision procedures published as VDI/VDE/VDMA 2632 Part 4.1.

The method of laser-induced breakdown spectroscopy has been applied in several projects. In LACOMORE, for example, the aim was to provide a quantitative measurement of steel composition to identify online the transition section of cast products in the casting machine.

Reduction of CO_2 emissions using waste energy

Several projects looked at the potential for reducing CO_2 emissions at plants in metallurgical facilities, by developing waste heat recovery technologies. For this purpose, new technologies and processing approaches have been developed and tested under real processing conditions in industrial plants. Unused waste heat potential has been identified and the waste heat made available for use (RELOTEMP). The general approach has been based on measuring the energy flows of production plants, calculating corresponding balance sheets and integrating results from existing or newly installed sensors. All these inputs have been used to investigate direct reuse possibilities, by district heating, preheating combustion air, boiler water and process baths (RELOTEMP), or converting waste heat into electricity using the organic rankine cycle (ENCOP), steam engines (ENCOP, RELOTEMP), or thermoelectric power generation systems. The last ones have been investigated for different temperature levels (up to 100°C in THERELEXPRO, between 100 and 600°C in POWGETEG). Case studies have been carried out to investigate conversion possibilities and possible released CO_2 emissions. For example, a thermoelectric power generation system has been used for the first time to convert exhaust heat above 550°C into electricity, and its feasibility demonstrated. Economic feasibility studies have been carried out into the theoretical use of the new technologies for converting heat into electricity, mentioned above, with the payback period usually more than 5, and up to 10, years. The potential energy savings of direct use are 0.6-2.8% of the total energy input. Each steel plant has to check the potential of such a solution depending on its own situation (RELOTEMP).

Recycling of waste resources like slags or wastewater

The projects in this area aimed to reuse recyclable fractions of waste. Methods have been proposed to valorise converter slag directly as fertiliser, or after the absorption of phosphorous from wastewater (SLAGFERTILIZER, SLAGSOR). The RECONI project investigated the recycling and reuse of valuable compounds, such as nickel, from process liquids (acids) or neutralisation sludges. For wastewater reuse, sustainable concepts for water and facility management in the steel industry, on the basis of selective salt elimination and valorisation, have been developed (SELSA). Different treatment techniques, such as reverse osmosis, ion exchange, magnetic separation, and microfiltration (SELSA, MAGSEP, REFFIPLANT), have been tested for reusing wastewater from processes such as blast furnaces, hot rolling and pickling. The SELSA project has shown that for rinsing in the pickling process, freshwater consumption can be reduced by 90%. For the valorisation of the concentrate, several concepts have been considered, none of which were viable (SELSA). The ECOWATER project has made some progress in relation to reusing wastewater by reducing discharges of priority hazardous substances in coke oven effluents.

Environmental monitoring and protection techniques

Laser techniques (ASEMIS) have been proposed for the environmental monitoring of emissions. In the field of environmental protection, monitoring systems have been developed to identify particulate matter (PM) emission hotspots from a steel plant using LIDAR (Light Detection and Ranging). Techniques for reducing cyanide in wastewater have been investigated successfully (DYNCYANIDE). Gas washing waters, showing up as max. 4 mg/l cyanide-free, decreased about 73% in-tank after scrubber, or up to 99% in following treatment units (biological, formaldehyde dosage with aeration). Comparable cyanide lab and online measurement techniques adapted to the water matrix have also been developed (DYNCYANIDE). Cyanide measurements for cyanide contents < 1 µg/L (LOQ of 0.86 µg/L) have been developed, as well as an optimised cyanide measurement (deviation: <0.02 mg/L) including a sample pre-treatment. Biological denitrification has been shown to be a reliable, environmentally friendly and cost-saving alternative to the disposal of nitrate-rich pickling process water from pickling processes using nitric acid (NITRATEBIODEMO). In long-term trials, stable nitrate elimination rates >95% were obtained. For the EAF process, a methodology for assessing the environmental impact of EAF steelmaking plants has been developed (EIRES). Information on the impact of EAF emissions on air, water and soil, as well as energy, water and waste management, has been gathered, to put together a global index. Simulation models for the plants along the EAF steelmaking route have been developed and linked to a life cycle assessment tool, to predict the environmental impact of process alterations/modifications and identify potential improvements in the production cycle (EIRES).

2.2 Benefits of RFCS projects for the beneficiaries, the sector and society

2.2.1 Coal

a) Beneficiaries/sector

The projects run under the RFCS programme contributed to the sustainable development of the coal sector in many ways.

In economic terms, the projects have developed integrated solutions that contribute to improving the competitiveness of the coal sector. These solutions focused primarily on technologies for safe and efficient mine production, the responsible and environmentally sound closure of mines and the monitoring of mine sites after closure as part of post-mining activities.

The participating mine operators benefited from the development of new technologies that help ensure efficient and safe mine operation. As these products and processes were developed with the involvement of technology providers and OEMs, they also contributed to improving their competitiveness, both within the EU and internationally. The scope of processes and products developed focused mainly on the efficient integration and use of communication and sensor technologies and therefore is fully in line with the overall aim of digitalisation of the coal sector.

In social terms, several projects focused on the improvement of mine health and safety conditions, which led to a decrease in the number of accidents and the development of more sophisticated emergency response systems and technologies. In addition to gas control, dust control aiming at reducing black lung disease was also addressed, which made mines healthier and more attractive places to work. In addition, a higher level of automation in production led to fewer people needing to work in dangerous areas. Furthermore, the development of environmentally sound technologies, sophisticated monitoring tools and methodologies for abandoned mines and early warning systems to be used in cases of incidents increased public trust in mining activities.

In terms of sustainable development, one of the top priorities of a mining company is to minimise the impact of its operations on the environment and at the same time to take precautions at an early stage in order to leave the environment in which it operates in a good state. Coke batteries are already subject to strict environmental regulations in the EU, and in addition several projects focused on environmental issues, in line with reaching the United Nations Sustainable Development Goals (SDGs). They gave companies opportunities to improve efficiency while decreasing their harmful impact on the environment and prolonging battery life. Underground gasification and other gasification project technologies make it possible to use coal resources under certain acceptable conditions, which increases the diversity of energy sources used. Moreover, the technology readiness level has increased, bringing us closer to the possible utilisation of these technologies in the future.

There is no doubt that coal could be a good source of carbon for the variety of carbon materials that may be used in the near future.

Furthermore, similarly important coal projects have provided further innovation in the area of optimising the efficiency of power plants. One goal was to optimise innovative technologies such as a) the integrated gasification combined cycle (IGCC), which produces synthetic natural gas that is subsequently combusted in combined cycle gas turbines, and b) supercritical and ultra supercritical pulverised coal combined with more durable metals, which enables a more efficient combustion process and makes it possible for higher temperatures to exist in the boiler. This more efficient process allows a utility to produce the same amount of energy using less coal, which translates into lower GHG and other emissions. Even higher pressure and temperature power plants, known as ultra-supercritical, are using research and development to move towards potentially reaching an efficiency of 50%. One example is the RDK-8, which is a supercritical coal plant in Germany that achieves a thermal efficiency of 46%.

In addition, thanks to the coal projects funded by the RFCS programme, progress has been made in the following areas: flue gas desulphurisation, low nox and sox burners, fluidised bed combustion, activated carbon injection, mineralisation, coal gasification and storage and methanol production. All of these technologies now have higher energy efficiency and lower GHG emissions, making them competitive alternative products and services.

b) Society

A social cost-benefit analysis shows a new dimension to the long-term benefits provided by the technological innovations produced over the course of the programme: climate change and sustainability can be addressed through reductions in CO_2 emissions provided by a variety of fit-for-use CCUS methods developed by the involved consortia.

Furthermore, restoration and remediation methods have been developed for land and water bodies, as part of the mine life cycle. They add to the sustainability and responsible exploitation of coal and increase social acceptance by local and regional communities. The notion of green mining, supported by the RFCS programme, has led to the creation of green jobs at various stages of a mine's life cycle, and especially at its end which enables a smooth transition in the local economy.

In addition, the RFCS programme boosted the EU economy by making its energy generation technology more competitive. This was achieved through the development of technologies that increase the efficiency of new or retrofitted power plants while decreasing pollution. As a result, the EU was able to create more green jobs and, at the same time, to maintain competitive energy prices without compromising on environmental impact.

The programme's post-mining research projects identified the mining-induced environmental footprint as well as various safety concerns. Measures were proposed to address these challenges. In particular, the exchange of ideas and experiences between a number of involved countries brought positive and forward-looking results.

In essence, the main benefits for society are: increased power plant efficiency; demonstration of CO_2 capture at pilot scale; increase in fuel flexibility, combining fossil fuels and biomass; better emissions control; improved solid residue recycling.

2.2.2 Steel

a) Beneficiaries

Process development

The upstream domain represents a strong issue regarding environment and emissions. The projects addressed short-term incremental progress as well as breakthrough ideas in addressing climate change issues. The results of projects that focused on incremental progress included more stable and more efficient operations in sintering, cokemaking and blast furnaces, increased productivity and more flexibility regarding raw materials. These projects also led to a decrease in energy consumption and CO_2 emissions. The improvements were possible due to an efficient coupling of new knowledge related to the fundamentals of the processes and innovative measurement tools and systems, supported by extensive modelling work.

The development of alternative carbon carriers, ones originating from renewable sources and biomass, was investigated and the possibility to partly replace fossil carbon was tested in several processes (cokemaking, blast furnace, electric arc furnace). The benefit of this lies in increasing the flexibility of raw material use and decreasing the carbon footprint without making major changes to the process.

Drastically decreasing CO_2 emissions is one of the biggest challenges for the steel industry. Therefore, research is focusing on new breakthrough process alternatives for iron ore reduction and smelting. Some of these alternatives were successfully tested at different scales: laboratory, small pilot or demonstration scale, close to industrial conditions. Carbon-free processes were also further developed and investigated, including the electrolysis of iron ores and the hydrogen reduction of ores. However, several serious problems still have to be solved before success can be achieved at the industrial scale. The most significant of these relate to the storage of captured CO_2 and the costs of the carbon-free processes mentioned above. They are to be the focus of further research.

As regards steelmaking and casting operations, several projects have led to the development of robust and sustainable process conditions for new advanced steels, which are generally highly alloyed and require specific attention to development conditions and internal and surface quality issues.

In the downstream domain, in addition to productivity, the quality of intermediate products is also a key issue, with direct impact on the cost, delivery time and quality of the final product. Progress achieved by the projects essentially led to increasing line productivity, reducing overall energy consumption and improving steel quality. Implementing the project findings helped the EU steel industry to produce high-quality steel at a low cost and to benchmark the level of energy use, which had a beneficial impact on competition with non-EU producers. Quality issues are becoming more and more important in the downstream field because the product mix is evolving towards increased hardness, thickness and surface quality requirements.

In the finishing and coating areas, new process developments were achieved and implemented, resulting in improved product quality. One example is the new wire descaling techniques integrated into the pickling line, which improved pickling bath control in electrolytically supported pickling. Most of the new processes developed were implemented in the industrial lines.

The durability of coated products was improved due to the development of new coating materials such as new spinnable ZnAlMg alloys with improved corrosion resistance. More economical solutions for steel product use were found, such as adapting 'rough' structural steel as a direct substrate for photovoltaic devices or verifying (through laboratory and field exposure) the suitability of lean duplex stainless steel for urban and industrial waste water.

A sustainable increase in product quality and durability (increased lifetime) was achieved thanks to the design of optimal coatings for given corrosion conditions, using cheaper yet even more corrosion resistant products, improving surface quality with respect to surface defects.

Solutions for the conservation of resources and minimisation of the environmental load were developed and implemented as part of the projects, especially as regards the management of pickling chemicals and the design of new coatings.

Product development

Over 75% of the kinds of steel in use today did not exist 20 years ago. A number of projects aimed to increase the use of steel by improving the final properties of existing grades or developing new advanced steel grades for the most demanding applications. One of the most important achievements in the area of designing new generic steel grades was the development of the advanced high strength steels (DP, TRIP, TWIP) whose swift industrialisation still remains a priority for the steel industry. By participating in the relevant research projects, all application sectors (automotive, energy, construction, etc.) benefited from this. Various properties, like crash resistance, wear resistance, formability, stamping behaviour and fatigue, have been improved thanks to the RFCS programme. Steels with these improved properties represent a leap forward and put steel in a good position against other materials.

Another benefit of the RFCS projects is the generated knowledge about the use of new materials in new applications, e.g. using advanced high strength steel for lightweight automotive parts and structures. This makes it possible to implement new solutions that are competitive in terms of requirements (strength, formability, corrosion, weldability, etc.), costs (weight reduction, cheaper materials, etc.) and social impact (environment, safety, etc.).

Projects carried out in the construction and industry markets have developed a holistic approach that allows a sustainable and efficient use of steel. This has contributed to increasing steel's penetration in these markets. Projects of the 'accompanying measures' type ensured that research results had a longer-term impact by introducing guidance tools and recommendations (including norms and standards) to support steel users in the fields of fire engineering, structural performance, energy efficiency, and smart and safe construction.

Extensive knowledge was obtained during the co-development of new products and the associated process conditions. This made it possible to achieve better results that meet customers' high requirements regarding the level and consistency (lower scatter) of the metallurgical and surface properties of finished products.

Instrumentation, modelling and process control

Instrumentation plays a key role in the mastering of process conditions and product quality. Many projects have been devoted to the development of smart sensors and online measurement systems to provide full information on process parameters and product properties. These developments, tested in the laboratory and implemented on the lines, cover a wide range of interests, e.g.: improved testing procedures for raw materials and products, instrumentation of the casting machines, roll mark detection systems, flatness and levelling control systems, waviness control or surface inspection systems.

Different kinds of models have been developed in the frame of the projects, most of them being fed by data provided by the appropriate measurement systems. Especially noteworthy are: metallurgical based models, which combine chemical composition and heat treatment conditions to predict and optimise the properties of high strength steels; multi-physics models, which handle residual stress and strip flatness issues and; process operation models, which improve process performance and stability, for example in continuous casting and pickling.

Factory-wide process control was considerably improved by using: (i) online non-destructive measurement techniques to measure the quality properties of flat steel products, (ii) intelligent processing and extremely large data sets from several automatic surface inspection systems along the process chain, and (iii) new computer-based solutions for the common analysis of product quality information and process variables. Furthermore, several types of decision support systems have been developed, based on data acquired online as well as on human knowledge stored in computer data base form. Thanks to RFCS projects, many techniques in the field of Industry 4.0 have been used in specific industrial applications in the steel industry for the first time.

b) Steel sector and downstream industries[50]

The results produced by the RFCS projects in both process- and product development have significantly contributed to maintaining or even improving the competitiveness of the steel sector, and to maintaining the position of steel against alternative materials. In addition, the improvements made in the areas of energy efficiency, material efficiency, circular economy and the environment have helped reduce steel's environmental footprint, thus contributing positively to the image of steel as a green material.

The transport sector also benefited from research developed in the framework of the RFCS programme. In supporting lightweight solutions e.g. by using advanced high strength steels (AHSS) in transport vehicles, a significant decrease in fuel consumption (and consequently in CO_2 emissions) can be achieved, along with safety improvements.

Extensive knowledge has also been gained in the construction sector, and innovative solutions have been implemented. The application of new materials and solutions that are proven to be safe, efficient and economic make it possible to increase steel's market share.

The RFCS programme provides a platform for research organisations, academia, technology providers (engineering companies) and individual experts to meet and work together, and makes it easier for them to collaborate with industry as well. The RFCS programme has contributed and still contributes to the existence of several top level research institutes devoted to steel research and development in the EU. The programme allows people from the science and research fields to understand industry's points of view. In turn, people from the industry side get the opportunity to be informed about the latest technologies regarding for e.g. sensors, models, measuring devices, and communication tools. This high level of networking and information exchange, with regular and organised meetings between partners within the projects and with experts through project monitoring, is unique and is recognised as best practice all over the world.

The network of highly specialised RFCS experts allows an in-depth monitoring of projects. In addition, they ensure a high level of dissemination and implementation of project results in the EU

[50] Downstream industries can be defined as those industries processing into a finished or different product the output of other firms that are at previous levels of the material processing chain.

steel industry. The continuous improvement of best practices and technologies, combined with the efficient sharing of this knowledge, is a powerful tool for improving the global industry.

Project reports are available in the open domain, so non-project partners can also benefit from the results. Furthermore, most projects publish results of conferences and workshops and in addition several conferences specifically addressing dissemination of findings were organised.

In summary, RFCS projects positively contribute to addressing the major challenges the sector is facing to remain sustainable and competitive. The main beneficiaries in the steel and related sectors are:

- steel manufacturers,
- steel users (steel applications better match the needs of both steel manufacturers and users,
- end users (benefit from better steel products on the market),
- equipment manufacturers.

c) Society

The results achieved in the frame of the RFCS projects have helped to keep the European steel industry competitive and sustainable. This is important as the steel industry is a vital part of the whole European economy, as discussed in Chapter 1 of this report.

European society is very concerned about the environment and the recyclability or re-usability of steel products and solutions, as well as the more sustainable use of raw materials. The RFCS projects have significantly contributed to reducing the steel industry's environmental footprint, especially in the following areas: reducing CO_2 and other harmful emissions in upstream operations; improving the management of liquid and solid waste; improving material and energy efficiency; investigating carbon-neutral processes; developing renewable carbon sources; conserving natural resources through an increased use of secondary raw materials as part of a circular economy. Several projects demonstrated solutions to recycling waste materials and to reducing or even suppressing land filling, which has a positive impact on human health care. In addition, RFCS project results related to reducing production costs and increasing productivity have positively affected the prices of steel products, which is beneficial for European industry and society.

New products with improved functional properties developed thanks to RFCS projects, namely high resistance lightweight steels, have provided significant benefits to people in the EU, the end users of steel products. Indeed, these steels have made it possible to reduce fuel consumption and exploitation costs over a vehicle's lifetime, which has in turn resulted in lower CO_2 emissions. Meanwhile, the use of steels with higher strength, deformability and energy absorption capability has improved transport safety. Building safety has also been improved by using steel elements of higher strength, ductility, stiffness and better specific properties such as fire- and earthquake resistance. In addition, modern steel solutions have been investigated to help architects create innovative and aesthetic designs.

The implementation of new processes and technologies requested by society, in particular in the energy production sector, such as supercritical processes in fossil fuelled power plants or renewable energy generation systems (wind or solar), is made possible by the design and development of steels with appropriate properties meeting the requirements of the technical equipment needed.

The steel industry is also at the forefront of developing and implementing the concepts and systems of Industry 4.0, and these could also be disseminated in other process industries. In the short term, the move towards automation and the use of remote sensors have contributed to reducing the risks associated with dirty and risky operations in the work place. This development has in turn enriched the tasks of operators, making their jobs more attractive.

2.3 Coal and steel technological challenges for the next decade

The RFCS should identify programmes and innovation that contribute to the main goals of the European coal and steel industries for the coming decades: (i) to decrease the environmental load, especially GHG emissions, (ii) to make sustainable use of energy and resources, which includes implementing the concept of the circular economy, (iii) to develop new high-added-value and high-performance products, and (iv) to remain cost competitive in the long term.

To achieve these goals, the TG chairs have identified the challenges the RFCS should address in the future. These challenges are common across the whole coal and steel sectors although their breakdown and impact may vary from one domain to another.

2.3.1 The coal sector

1. Energy transition

   The RFCS should encourage and accompany the EU transition towards a low-carbon economy. They should also address the challenges of achieving an energy transition. More in detail, TG chairs recommend that RFCS projects focus on (i) reliable and affordable power supply; (ii) preservation of know-how and fostering innovation in the sector; (iii) socially fair and responsible regional development; (iv) efficient production and safety of mines, achieved by enhanced automation and digitisation and attractive workplaces.

2. Monitoring and safekeeping of mine sites after mine closure

   Interest in post-mining activities is increasing, both in the current and future context of European mines. Projects clearly need to solve related issues, such as mine water management and shaft stability. In addition, remediation of former mine sites and their new usage for renewable energy production (e.g. geothermal applications) should be considered.

3. Unconventional use of coal deposits
   Much theoretical work and pilot trials have been carried out, with valuable results. However, industrial application has so far not proven to be promising and needs further evaluation. The unconventional use of coal deposits has to be explored further in the next years.

4. Reducing the environmental impact of mining activities and clean coal technologies
   Climate change issues represent a major challenge for the coal sector. The sector needs to put more emphasis on CO_2 management, including CCS, CCU and CO_2 reuse in other industries.
   Innovative ideas related to clean technologies in the use of coal should be investigated, for example negative emission power plants, combining renewable and fossil fuels, integrating energy storage with power production, development of hydrogen route as an energy carrier.

5. Preservation of coke batteries
   In the next decade, coke batteries will continue their work since there is no replacement for coke in highly efficient ovens. Improving battery performance and extending battery life are big challenges, as is decreasing their harmful impact on the environment (by sealing coke oven chambers and through coke oven gas and waste gas capture and utilisation).

6. Coal as a carbon source
   Coal is a good source of carbon for the variety of carbon materials with high added value that will be requested in the future. Projects that secure innovative processing routes are needed.

2.3.2 The steel sector

1. Climate change

Responding to climate change issues remains a key RFCS challenge. It requires the development of new technologies, often breakthrough technologies, to develop low-carbon or carbon-neutral processes, with the objective first to move towards gradual decarbonisation and then to achieve sustainable fossil-free steel production. For example, the use of green hydrogen or green electricity for iron ore reduction should be supported by the RFCS programme to significantly reduce CO_2.

Conventionally, options for CO_2 mitigation could include top gas recycling in the blast furnace or end-of-pipe solutions like CCS or CCU. The use of biomass as an alternative carbon source is also worth exploring.

In the application of steels, improved LCA tools need to be developed so that it is possible to assess CO_2 emissions over the full life cycle of production and use of the steel products. This is of key importance in consolidating steel's leading position against competing materials.

2. Resource efficiency and the circular economy

The drive towards a circular economy needs to become an integral part of the RFCS programme, and should cover all steps of the production chain. Although the main focus is on steel scrap recycling, the circular economy concept should also be applied to other areas, like waste management to achieve zero-waste in processes, the reuse of steel parts and recycling of metals other than iron, e.g. nickel, chromium, silicon, aluminium etc. Special emphasis should be placed on external recycling in the frame of industrial symbiosis with other industrial sectors.

In addition, the circular economy concept is increasingly influencing steel product development, structure design and assembly techniques, and each product's whole life cycle is being considered, especially the possibility of dismantling, reusing or recycling it.

Sustainable water conservation needs to be considered as well.

3. Rational use of energy

Energy efficiency is a cross-cutting target along the whole production chain. It involves the rational and flexible use of energy sources, as well as the recovery of waste energy as the sensible heat of intermediate products (slags, slabs, coils, etc.).

4. New high-performance steels

The sustainable development of new high-performance steels requested by, for example, the automotive, construction and renewable energy markets for technologically challenging applications is a high priority objective. It calls for a permanent renewal of the product portfolio and involves the metallurgical design of new steel grades, as well as perfect control of the manufacturing chain from casting to the finishing steps. This is to ensure high quality, especially regarding cleanliness, surface quality and metallurgical properties.

The general tendency for these new steel grades is that they are harder and more alloyed, as well as having thinner and wider material geometries, which means that they are much more difficult to produce. Furthermore, the surface properties and coatability behaviour impacted by different oxide regimes and surface roughness properties are becoming more complex, requiring enhanced metallurgical control especially in relation to annealing and coating technologies.

5. Steel solutions for applications in demanding markets

The RFCS should also support the design and production of high-performance steel components and steel solutions for the highly demanding markets, particularly: (i) the mobility sector (lightweight solutions); (ii) the renewable energy sector (wind, solar, water), which strongly relies on steel; and (iii) the construction sector, in which there is a need for smart, sustainable and intelligent infrastructure that is high-performance and low-maintenance.

Steel's competitiveness against other materials like aluminium or reinforced plastics should be improved.

6. Industry 4.0

Digitalisation is expected to become one of the most important challenges to sustaining worldwide competition in the steel market. The industrial implementation of digital technologies to improve the process chain is being referred to as 'Industry 4.0'. The main concepts are cyber physical systems, digital twins and vertical and horizontal integration. Cyber physical systems combine the real industrial world with the 'cyber' world in the form of model descriptions of real plants and by connecting physical components using networks. Such model descriptions of plants, processes or products join up with other information like process, plant and product data to create ‘digital twins’.

Vertical integration (local process intelligence) means e.g. the combination of all data flow, including sensor information, and IT solutions related to the process control circuits with production planning systems (PPS) or enterprise resource planning (ERP) solutions. Horizontal integration (through process intelligence), where plants are connected through a data stream running through the process chain, makes it much more possible to correct processes based on earlier deviations, to ensure the right quality along the chain and to optimise material and energy flow along the processing line.

Many significant improvements can be expected as a result of applying the Industry 4.0 concepts described above: cost reductions; environmental protection, for example through CO_2- and energy reductions; higher yield and better product quality; and higher production flexibility.

The European steel industry operates many old installations (‘brown field’ factories as opposed to new ‘green field’ factories), and retrofitting them to make them fully compliant with Industry 4.0 is a major issue.

7. Cost effectiveness

The cost effectiveness of process and end products is a permanent major challenge to the European steel industry’s competitiveness against non-European producers and other materials.

8. People

The steel industry is also facing a major human resources challenge, namely the competition to recruit talented people. Responding to the challenges discussed in the previous section requires highly educated and skilled people. The issue is that in Europe most industries are seeking to employ similar profiles of people. This will become a major focus for the steel industry, which should also be considered as part of the RFCS programme. On the other hand, the Industry 4.0 revolution will certainly result in a radical change in the skills needed and a significant increase in complexity of employee tasks. Education programmes at school and continuous education requalification programmes for the employees should prepare for these changes so that the steel industry can adapt to the new requirements.

2.4 RFCS programme objectives and industrial research trends

The following paragraphs include the replies provided by TG chairs about the appropriateness and pertinence of the RFCS programme objectives, as stated in the legal basis (Council Decision of 29 April 2008, 2008/376/EC), with the industrial research trends and challenges identified.

Paragraph 4.4 of this report develops the high-level group’s proposals to review and update the coal and steel objectives described in Council Decision 2008/376/EC.

2.4.1 Coal sector

The Council Decision of 29 April 2008, Section 3, Articles 4 to 7 shows that there is general agreement among the coal TG chairs that, overall, research objectives are in line with industrial needs and research trends. However, the coal TG chairs also consider that the legal basis is to some extent conservative, representative of the past situation of the sector and not pro-active and forward-looking enough. Therefore, it seems that the research objectives need to be updated to include forward-looking trends.

2.4.2 Steel sector

Referring to the Council Decision of 29 April 2008, Section 4, Articles 8, 9 and 10, the steel TG chairs generally agree that the research objectives are globally in line with industrial needs and research trends expressed in the RFCS challenges identified for the future.

The research objectives and project areas listed in the current legal basis can cover the sector's industrial needs. However, the statements included in the legal basis are considered to be somewhat conventional and conservative. Consequently, the research objectives should be updated and restructured to more explicitly focus on forward-looking trends such as climate change, circular economy, digitalisation and Industry 4.0. Since the HLG of experts recommends that the RFCS research objectives should be designed to overcome future challenges, it follows that projects supported by the RFCS should also become more challenge-driven.

3. QUANTITATIVE ASSESSMENT OF RFCS PROJECTS

This chapter provides a thorough assessment of the projects surveyed, based on the five criteria of EU better regulation. The information presented is based on questionnaires completed by the coordinators of selected projects within the three coal TGs and the nine steel TGs. Section 2.1 provides a description of the approach used to put together this quantitative assessment, Section 3.2 presents an analysis of the questionnaires completed for coal and Section 3.3 presents an analysis of the questionnaires completed for steel.

3.1. Methodology used for the quantitative assessment

The questionnaire used was designed to measure the performance of reviewed projects in relation to five criteria: relevance, effectiveness, efficiency, coherence and EU added value. These criteria are in line with the Commission's better regulation guidelines[51].

The **relevance** criterion aims to establish how well the RFCS project addresses sector objectives and provides flexibility to adapt to new scientific and socio-economic developments. It also aims to assess whether the project achieves significant progress in the state of the art. It is important to note that, although projects are always in alignment with the RFCS programme objectives for both coal and steel, they are not always in strict alignment with the specific objectives of the TG to which they are assigned. This is considered a strength of the programme, as it facilitates integration between TGs, rather than allowing narrowly focused TG objectives to be prioritised.

The **effectiveness** criterion considers the extent to which the project objectives have been achieved. The questionnaires make it possible to identify the factors that led to success or, in cases where projects did not achieve their objectives, why success has not yet been achieved.

The **efficiency** questions address the relationship between allocated resources and the working methods implemented by the projects. Efficiency analysis also includes project management, the mobilisation of stakeholders, cost-benefit analysis and the possible impact of administrative and regulatory burden.

The evaluation of **coherence** involves looking at how well (or not) RFCS projects fit within the TG to which they are assigned. Coherence also considers the extent to which projects have synergies with other TGs of the RFCS programme.

The last criterion assesses **EU added value** and aims to evaluate project benefits and ascertain how well the project results have been exploited. It is important to analyse the added value of EU support, which is additional to the value of interventions at regional and national level.

The projects selected for review were chosen from among all the research and pilot and demonstration activities conducted during the review period. The selection ensures that there is a proportional representation of projects from each TG covering the main topics covered by RFCS funded projects. The budget of each project selected must be in line with the average RFCS project budget allocation in each TG and the projects must cover several European countries. In addition, approximately one third of the projects reviewed were selected as they are currently ongoing and reflect most recent developments and support foresight analysis in the RFCS programme.

The coordinator of each project analysed completed a questionnaire. Blank example questionnaires for both coal and steel projects are included in annex. A full list of selected projects is presented in Table 22, which identifies completed and ongoing projects as well as whether projects are funded via support for research or pilot and demonstration activities.

[51] See the European Commission's *Better Regulation: Guidelines and Toolbox*: https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox_en

3.2. Analysis of questionnaires on coal projects

This analysis is based on a representative sample of 11 ongoing and completed projects from the three TGs dedicated to coal (TGCs). The sample includes 10 research projects and one pilot and demonstration project. The following table presents an overview of the projects surveyed. The projects selected were chosen to provide a representative breath and spread of topics among the three coal TGs and a mix of completed projects, as well as few that are currently ongoing.

	Completed	Ongoing*	Total
TGC1 - Coal mining operation, mine infrastructure and management, unconventional use of coal deposits	3	2	5
TGC2 - Coal preparation, conversion and upgrading	2	-	2
TGC3 - Coal combustion, clean and efficient coal technologies, CO_2 capture	2	2	4
Total	7	4	11

* status in November 2018, when reviews were conducted

Table 21 Surveyed RFCS projects in the coal TGs

3.2.1. Relevance

Relevance of the RFCS coal project in addressing sector objectives

The sector objectives addressed by the projects analysed are:

- **Coal 1: Improving the competitive position of Community coal**. Always addressed by the projects in all TGCs 1, 2 and 3, in addition to individual sector objectives that are relevant to the overall aims of each TGC.
- **Coal 2: Health and safety in mines**. Always addressed by projects assigned to TGC 1 and, generally, not addressed by projects in other TGCs.
- **Coal 3: Efficient protection of the environment and improvement of the use of coal as a clean energy source**. This objective is addressed by most projects, whatever the TGC.
- **Coal 4**: **Management of external dependence on energy supply.** This objective is less often addressed and projects addressing the objective are assigned either to TGC1 or TGC3.

Coal 1: The nature of this RFCS objective and its wide definition, which covers all different phases of the coal production and utilisation chain, means that projects address a range of complementary aspects. These include:

- supporting short-, medium- and long-term coal production planning/scheduling in European mines;
- introducing modern techniques to remotely monitor geotechnical stability, and to handle and evaluate the information effectively in support of efficient coal production workflow and risk reduction;
- developing outburst and rockburst expertise that is valid and valuable for the European coal industry but also applicable in all coal mining countries worldwide, thus creating huge potential for technology transfer;
- developing new and innovative flexibility concepts for circulating fluidised beds technology, both in terms of fuels and operation;
- identifying profitable ways to utilise products with low added value (i.e. coal liquids) through transformation into carbon materials, such as activated carbons, graphene materials and activated carbon/graphene material composites, with tailored properties suitable as electrodes in electrochemical energy storage systems;

- contributing to the development of more efficient energy storage devices (e.g. higher power and energy density values than the traditional ones) and producing high added value carbon materials with a promising future using coal derivatives as feedstock.

Coal 2: The projects in this area focus on addressing health, safety and environmental issues related to mine operation. Examples of aspects covered include:

- ensuring safer operations through effective risk management and excavation guidance to optimise mineral excavations in open pit mines;
- monitoring geotechnical stability and carrying out risk analysis, numerical and physical modelling to evaluate geotechnical conditions in order to reduce risk for open pit mine operators;
- developing support management systems for gate roads located below 1,000 metres and for face salvages and other wide openings;
- using micro seismicity monitoring based methodologies to forecast and mitigate rock bursts, coal and gas outbursts in coal mines.

Coal 3: The projects that address this objective aim to identify ways of minimising the impacts of coal production, processing and utilisation, including the following objectives:

- optimising coal exploitation and reducing the impact of active and abandoned coal mines on the environment;
- designing and providing technical guidance on mine closure to minimise environmental risks and provide a planning tool to support mine closure;
- exploring experimentally the in-situ production of hydrogen through gasification of unminable coal seams, especially abandoned ones in deep mines targeted for closure;
- improving the flexibility and efficiency of coal power plants;
- assessing the feasibility of using amine-impregnated alumina solid sorbent as a suitable option to lead towards overall efficiency improvements of carbon capture integration into power plants through operational validation at a pilot plant;
- reducing the production of greenhouse gases by using appropriately chosen pre-dried lignite as a way of improving efficiency and creating fuel savings.

Coal 4: Projects addressing this objective focus on ways of upgrading the economic, energetic or environmental performance of coal utilisation processes through a variety of means. These included:

- using advanced, innovative monitoring and control systems for underground coal gasification;
- identifying existing and potential markets for pre-dried lignite utilisation and evaluating the technical and economic impact of lignite drying technologies and of the pre-dried lignite production and utilisation in existing lignite-firing and hard-coal firing power plants as well as in greenfield lignite-fired power plants and other industrial applications;
- addressing flexibility concerns and multi-fuel optimisation needs in coal utilisation together with other low rank fuels (i.e. lignite, biomass and even waste) alongside renewables.

Flexibility to adapt to new scientific and socio-economic developments

All projects analysed showed that their aims and results reflect the RFCS flexibility in adapting to new scientific and socio-economic developments. Some of the responses received are discussed below.

Scientific flexibility has been achieved through the use of the latest state-of-the-art technologies; in a few cases this involved expanding the remit of activities to cover additional needs. Examples include:

- in situ and remote sensing techniques (long/medium range laser scanning equipment, both terrestrial and airborne; UAV photogrammetric techniques with a range of different airframes/camera and INSAR analysis from satellites using cutting edge algorithms for processing),
- state-of-the-art numerical and physical modelling methods, used in all relevant project elements,

- study of methods and identification of the main needs that would move a technology development concept to industrial scale implementation (e.g. in underground coal gasification),
- addressing the need to reduce GHG emissions by developing efficient methods of carbon capture,
- higher energy efficiency, lower minimum load, faster ramp-up and flexibility in coal-based power generation to adapt to increased share of renewable energy sources in energy production.

Flexibility to adapt to new socio-economic developments has been achieved through the production of new guidelines and standards and the provision of robust scientific evidence that addresses new socio-economic concerns and realities. Examples include:

- addressing public concern, which is sometimes due to unfounded and misguided publicity for potential (e.g. seismicity) and adverse impacts of natural resources exploitation; the technology developed under one RFCS project analysed can be adopted by other projects and the consortium is already involved in co-operative initiatives.
- producing results and a specific guideline that can change the policy and practices related to the evaluation of damage induced by mining for induced seismicity for active and abandoned mines.

Progress beyond the state of the art

For most projects analysed, major progress beyond the state of the art has been reported.

Progress related to Coal 1 objectives includes:

- roadway support techniques that keep up with the demands for safer and more productive mining in ever deeper and more highly stressed mining environments;
- advances on a variety of issues related to coal mine support management systems, covering geotechnical investigations, numerical modelling, quality and support behaviour including optimisation of bolting systems and cost reduction;
- investigating new promising lignite drying technologies (e.g. the rotary dryer concept that uses flue gas as a drying medium, never tested for lignite drying before);
- a new fluidised bed drying concept using low-temperature heat as a drying medium, investigated experimentally with promising results when using low-grade heat sources.

Progress related to Coal 2 objectives includes:

- landslide scarp detection and vulnerability assessment using point cloud monitoring data (i.e. the analytical scarp detection model ASDM, a continuum modelling framework for modelling slope stability in open pit mines, a probabilistic-numerical methodology for the evaluation of slopes safety states, a Global Design Index (GDI) for assessing the vulnerability of buildings to damage from mining induced ground deformations);
- developing an understanding of the mechanisms that lead to seismic events in rock formations, which has universal application: the forecasting methods and mitigation measures developed and tested underground contribute significantly to the state-of -the-art in the field.

Progress related to Coal 3 objectives includes:

- significant progress achieved through the use of a large-scale physical model and centrifuge physical model to study the impact of ground movements on structures and infrastructure in areas influenced by mining;
- development for the first time of a detailed operational methodology that comprises the management of environmental risks during and after underground coal mine closure, containing specific guidance on appropriate approaches, tools and techniques, and with due consideration of economic issues.;
- utilisation of Ni-based alloys to increase steam temperatures up to 700°C in coal fired plants, improving power plant efficiency;
- achieving load response rates of 10% MCR/min, which considerably improves power plant flexibility over today’s state-of-the-art coal fired power plants (2% MCR within 30 seconds in primary load and 2-5% MCR /min at secondary load response mode).

Progress related to Coal 4 objectives includes:

- development of a novel microwave technology for the production of high-added-value carbon materials from coal-derived liquids with a lower energy consumption than conventional thermal treatment;
- production of tailored carbon materials with specific surface area, adequate surface chemistry and electrical conductivity (activated carbons and graphene materials produced from coal liquids polymerised by microwave heating);
- design of activated carbon/graphene composites producing active electrode materials suitable for hybrid devices of higher energy density.

3.2.2. Effectiveness

Progress towards attaining specific RFCS objectives

According to the comments provided in the questionnaires, progress towards attaining the specific objectives of RFCS has definitely been excellent or good. No project suggested that progress was poor. In all cases, the alignment of project objectives with the RFCS coal priorities was highlighted, which is very much in line with the comments outlined in Section 3.2.1.

Achievement of the RFCS programme's research objectives

Figure 15 illustrates the achievement of the programme's objectives in the four distinct areas of the RFCS programme for coal. In some cases, an area's narrow focus was indicated as being outside the scope of a given project (marked as 'na'). This was the case for 54% of Coal 3 projects analysed. However, in all of these cases other areas were highly rated. The achievement of the main RFCS objective related to the project analysed was always rated as high. Over 90% of projects aimed at efficient protection of the environment, with 46% and 45% high and medium achievement respectively.

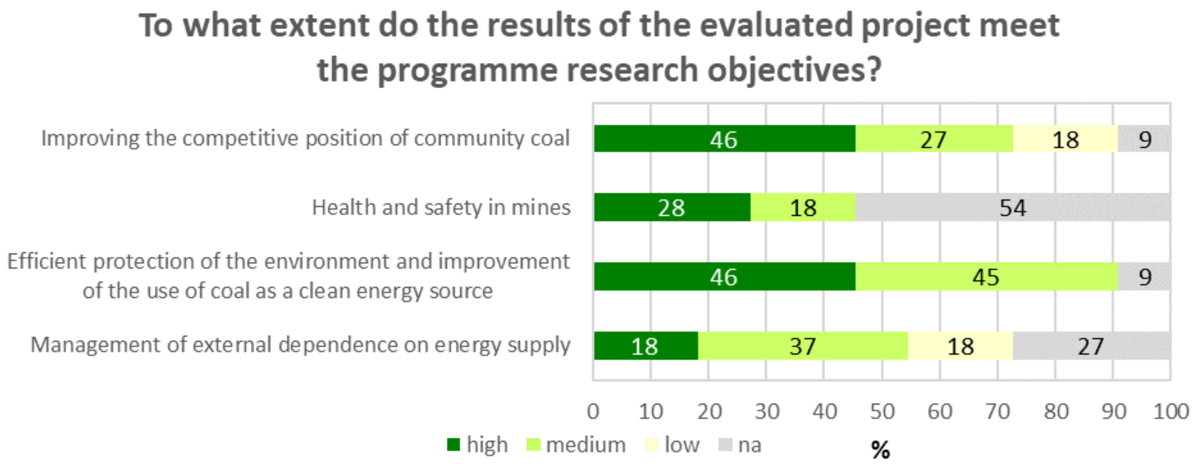

Figure 15 Achievement of RFCS programme objectives for the TGC projects surveyed

Achievement of individual objectives / benefits of the RFCS projects

The evaluation of individual project objectives and benefits based on the contract's Technical Annex and the Grant Agreement is considered to be very good. Figure 16 presents the results for projects for which responses were received (one out of 11 did not respond to the question on economic and social aspects, while two out of 11 did not reply on the subjects of environment and sustainability). For each individual objective, the percentage of analysed projects that reported at least a 30% level of success is shown.

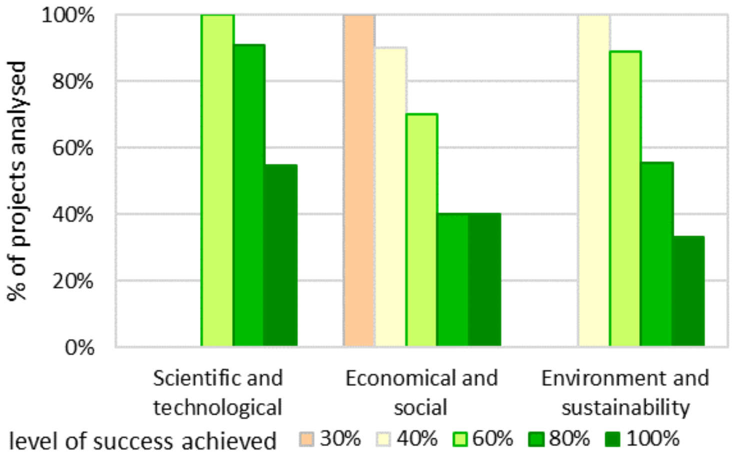

Figure 16 Achievement of individual project objectives for the TGC projects surveyed

Scientific and technological success is very high: all completed projects rated these at 80% or higher, with one ongoing project reporting a 60% achievement level so far. The projects have also been successful in terms of economic and social aspects, with four out of 11 projects reviewed reporting a 100% success rate and the remaining seven reporting at least 30% success. The success rate for environment and sustainable development is also very good, with only one project reporting a value below 60%. All projects report their highest achievement in the area of the key RFCS objective that they work on.

In general, the projects reached their specific objectives, with some also reporting results well beyond the objectives described in the original grant agreement.

Reasons for why in some cases objectives were only partially reached

As shown in Figure 17, in the very few cases in which objectives were only partially reached, more flexible time constraints would have allowed the projects to overcome difficulties, including scientific and technical problems (e.g. delays in experimental campaigns). For one out of the 11 projects surveyed, partners defaulting on payments and other financial problems made it impossible to fully reach the objectives.

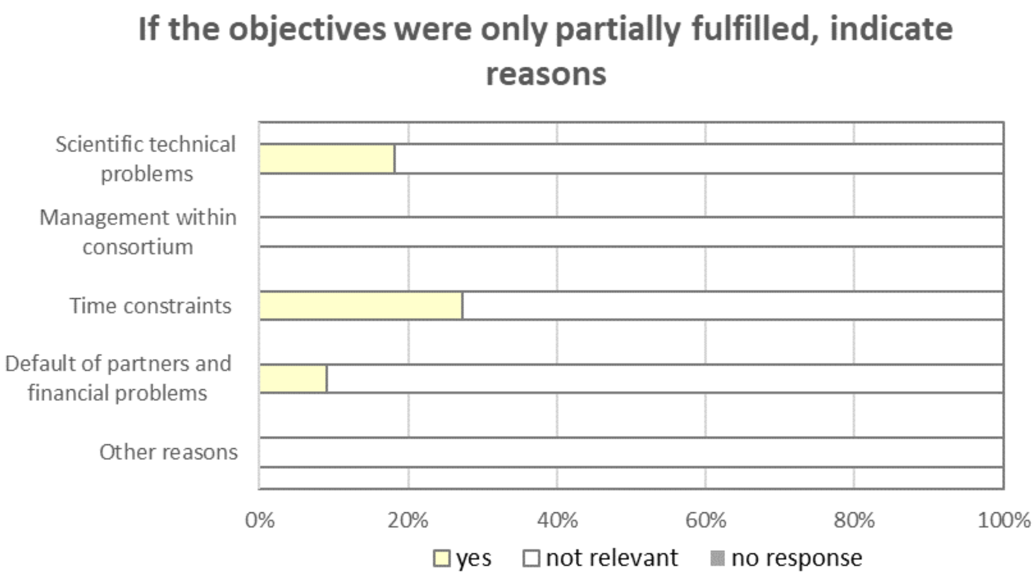

Figure 17 Reasons for why in some cases project objectives were only partially reached

Projects' key results and best practices

It was possible to specify results and best practices for 80% of projects analysed, both ongoing and completed projects. All completed projects were able to identify significant results (Figure 18).

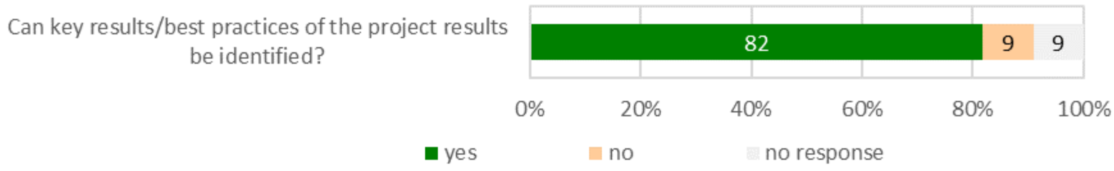

Figure 18 Possibility of identifying key results and best practices for the RFCS coal projects surveyed

Some examples are given below:

- development of a new testing bench for rockbolts; formulation of a reliable constitutive model of a rock-bolt and a cable-bolt; determination of the most important parameters that influence the behaviour of roadways in deep coal mines using one-at-a-time sensitivity analyses and Monte Carlo analysis (MCA);
- development of an algorithm for the support management system (SMS) for gate roads located at a depth of more than 1,000m;
- development of a suitable simplified SMS for face salvage and wide openings;
- publication of a handbook for a new European mining seismic intensity scale, GSI;
- development of methodologies for forecasting potential seismic events underground; development of methodologies for real time monitoring and data processing, and their implementation to warn mines of potential seismic risks; implementation of mitigation measures to ensure safe mining and production conditions underground;
- creation of a reference guide on soil gas monitoring in coal mining regions;
- specification of the technical, geological and environmental data that is necessary to develop a complete mine closure plan;
- validation of environmental impact modelling outputs: subsidence, underground and surface water and GHG emissions;
- definition of risk criteria for all different types of environmental impacts related to coal mine closure and post-closure; risk evaluation for the various environmental risks involved;
- underground coal gasification (UCG) results of two ex-situ and one in-situ test, development of method of monitoring, operation and process completion procedure for the in-situ experiment;
- determination of qualitative and quantitative limits for potential organic and inorganic contaminants from UGC; assessment of the effectiveness and efficiency of contaminant removal from groundwater by a reactive barrier;
- development of a model of roof convergence and evolution of fractured zone in rock mass resulting from the UCG operation, which makes it possible to determine the influence of UCG void filling; development of surface and cavity monitoring;
- development of a novel microwave technology for the polymerisation of coal liquids and production of carbon materials with favourable characteristics (e.g. specific surface area, chemical composition and electrical conductivity) by controlling the operational conditions for the transformation of coal liquids;
- development of symmetric/asymmetric supercapacitors and hybrid systems with improved electrochemical performance;
- conducting of experimental CCS activities in a demonstration facility, quantification of capture sorbent efficiency;
- evaluation of the technical and economic impact of lignite drying technologies in the thermal cycle of power plants;
- evaluation of the impact of pre-dried lignite co-firing in the firing systems and boiler operation of coal-fired plants, especially considering their new operating regimes.

3.2.3. Efficiency

Resources

The analysed projects consider that their budget is generally well balanced, utilised in a timely manner, most often in line with the original estimates and reasonable considering the project results. Since the first RFCS call for proposals in 2003, the coal and steel programme accumulated an annual average of €3.5 million of de-committed amounts (no longer payable to beneficiaries because eligible costs are lower than expected), recovered amounts and amounts that have not been committed at the end of the year with the signature of grant agreements[52]. If, during the life of a project, changes in budget distribution are required, these are made to ensure efficient management. Resources have even been returned to the Commission where necessary.

Project attractiveness for stakeholders

The involvement of stakeholders is considered satisfactory. Stakeholder support is increasing with increased awareness of RFCS projects and their results. Participation in workshops is one important way of engaging stakeholders, as are technical papers that communicate project results. In one of the 11 projects analysed, contact with stakeholders outside the consortium resulted in beneficial cooperation through data provision and techno-economic studies conducted over and beyond the original RFCS project plan.

Cost-benefit analysis

There is a reasonable balance between project results and resources used. It should be noted, however, that the co-funding nature of RFCS instruments limits the possibility of the balance between costs and benefits being unfavourable.

Management and administration

Project management and administration could be improved by giving the project coordinator more power to manage repercussions and budget allocation in case of a defaulting partner, when deadlines are not met. This change appears to have been made in the later stages of the review period.

Identification of administrative burden related to project implementation

Around 73% of the interviewed coordinators consider that implementing their projects does not generate major administrative burden (Figure 19). Several suggestions for improvements, including in the management of subcontracting, are provided in the Chapter 4 of this report.

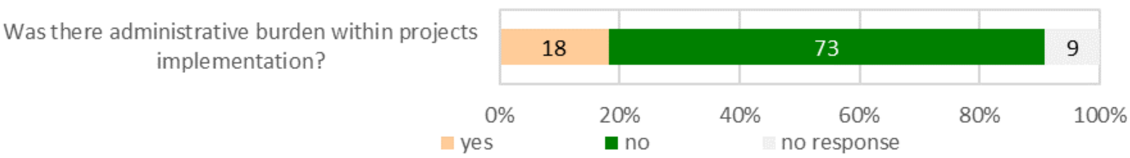

Figure 19 Administrative burden in RFCS coal projects surveyed

[52] Following Council Decision 2018/599/EC, amending Decision 2003/76/EC, these unused funds are automatically carried over to the next year in the general budget in accordance with Article 4(4) of the Council decision 2003/76/EC.

3.2.4. Coherence

Internal coherence among the different technical groups

Synergies with other TGs have not been identified, although in a few cases potential was noted.

Ensuring value for money

The coordinators consulted provided examples of expected interdisciplinary solutions resulting from the RFCS projects analysed. These include the following:

- development of methodologies that are interdisciplinary (e.g. the estimation of treatment failure probabilities and their uncertainty bounds in a probabilistic risk framework);
- development of materials and methods that involve interdisciplinary understanding and skills (e.g. combining material laboratory testing, field testing and numerical investigations in order to achieve a holistic investigation of new sophisticated materials that support running coal power plants more flexibly and efficiently);
- consideration of problems that are by nature interdisciplinary (worker safety and the economic efficiency of mining on the one hand, and extraction of deeper deposited coal seams on the other, both aiming to reduce external dependence on energy supply);
- development of testing and modelling procedures, which can also be applied in other contexts (e.g. civil engineering applications).

How accompanying measures can help ensure complementarity

The questionnaires highlighted that accompanying measures could be used to ensure complementarity between the different RFCS projects. However, this has not been implemented for TGC1 projects and for TGC2 and TGC3 has only been conducted to a limited extend and before the review period. It is recommended that the Commission should continue to organise an annual RFCS conference for projects to present and disseminate their findings. This can start within each TGC and later extend to involve all TGCs, if possible.

3.2.5. EU added value

Benefits for the European coal sector

The responses show a clear need for and clear benefit of running the RFCS projects at EU level. In addition to the value of knowledge exchange and effective mobilisation of resources, the projects' strategic importance for the European coal regions is also highlighted. Examples include:

- international cooperation allowing the exchange of knowledge and the implementation of methods and technologies across Europe;
- the relevance and availability of the methodologies and tools developed for any site, even ones outside Europe, which is a significant industrial benefit of strategic importance for the European coal sector;
- research of significant breadth and value, which cannot be carried out in any one country alone, especially in an ever contracting coal industry and with a decreasing expert pool; without cooperation at EU level, the industry would quickly deteriorate, along with expertise and potential for technology transfer.

Benefits for European society

Most projects have benefits that are of strategic importance to European society. Two specific examples are presented below:

- Lignite opencast and underground mining is associated with threats to adjacent regions and the environment. The RFCS projects dealing with these issues for the periods of mine operation, closure and post-closure have been beneficial not only for the mines and surrounding local areas but also for producers of electricity in several European countries. They have made a significant contribution to the secure production of electricity in Europe's coal mining regions and have benefited the people living in these regions.
- RFCS projects created technology transfer opportunities in several fields of study (e.g. hazard and risk reduction in producing mines, energy storage devices, improving

performance, flexibility and efficiency in coal-fired power plants).

Areas in which project results were used

Figure 20 illustrates the extent to which RFCS project results were used at various levels, as perceived by the coordinators who answered the survey questions. It includes information for both completed and ongoing projects. For ongoing projects (four out of the 11 projects analysed), some interviewees state that results were already partially used, while others do not specify exploitation of results at this time.

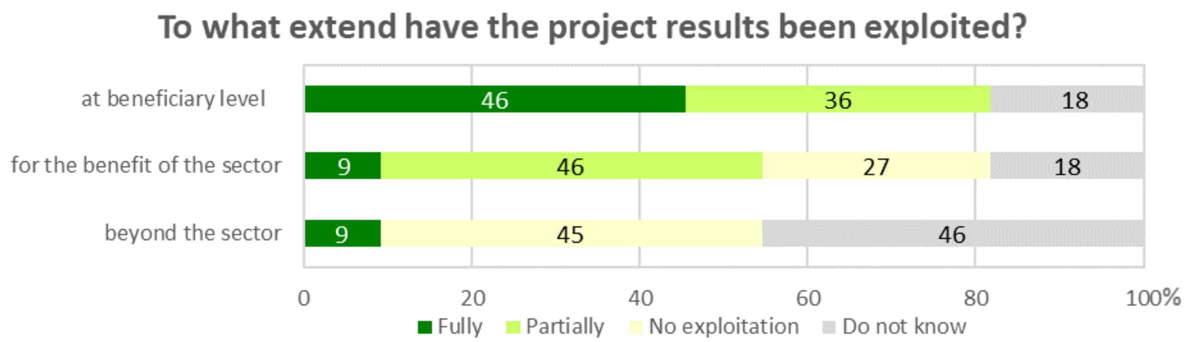

Figure 20 Exploitation of project results for the TGC projects surveyed

It is clear that the use of results at beneficiary level is strong, with 82% of projects reporting full or partial exploitation. This figure drops to 55% at sector level and further down to 9% outside the sector.

Examples of how project results were used

Here are a few examples of how projects results were used, both in completed and ongoing projects:

- new monitoring installation at mine site with integrated weekly risk and warning reporting to the mine;
- demonstration at pilot site;
- implementation at industrial site;
- new patent;
- utilisation of project results and reference guides to inform assessment and decision making by industry at other mine sites outside the original RFCS project;
- utilisation of project results in workforce training.

Use of project results after project completion

Figure 21 shows that around 55% of completed projects led to a new research and development project in the same field of investigation. A high percentage of results (37%) was commercially exploited, while 9% led to new patents.

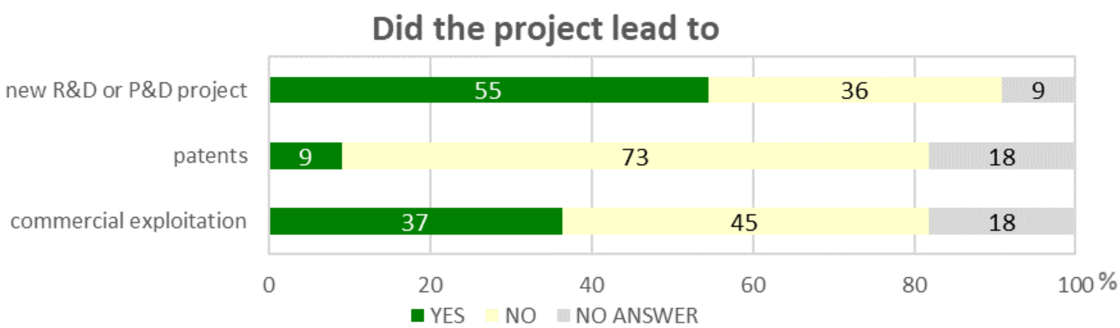

Figure 21 Ways in which project results were used by TGC projects surveyed

Benefits resulting from the projects

The benefits generated by the projects have been evaluated based on a number of criteria of possible benefits identified in the questionnaires:

- 16 criteria at beneficiary level;
- 14 criteria at sector level;
- 12 criteria for society-at-large.

Project coordinators could rate each criterion as excellent, good, satisfactory, poor, very poor or not applicable. Responses were provided both for current and completed projects. Figures 22 to 24 present the proportion of projects that identified benefits in a number of categories.

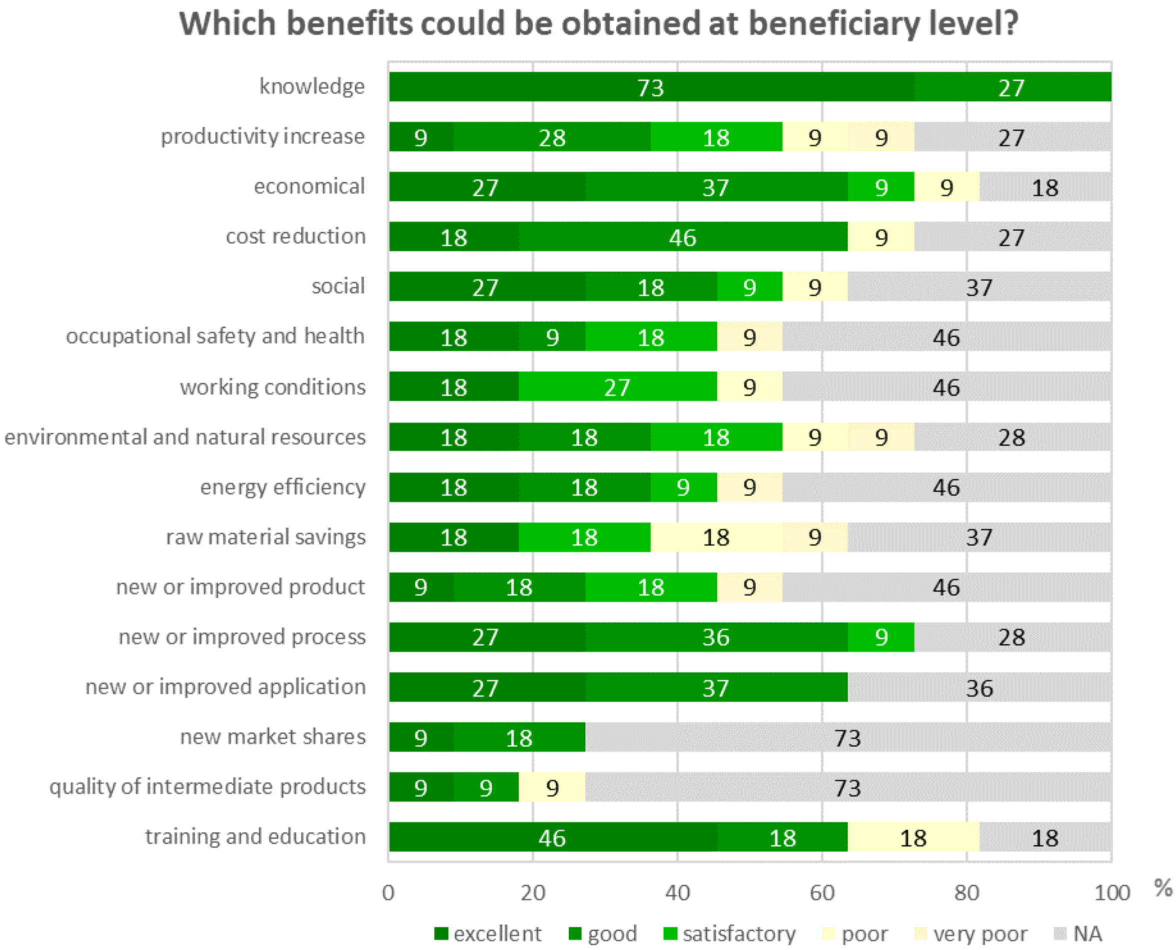

Figure 22 Benefits obtained at beneficiary level for the TGC projects surveyed

The improvement of knowledge is by far the most obvious benefit, as all the projects are rated as at least 'good' in this area, and 73% are considered 'excellent'. The most important benefits after knowledge are new or improved processes and economical aspects (both at 72%), followed by productivity increase, cost reduction, new or improved application and training and education (all at 64%). The other categories have lower scores.

At sector level (Figure 23), knowledge receives the highest score, with 91% of projects rated as at least 'satisfactory' in this area. Using the same criterion (% of an at least satisfactory rating), the most important benefits identified are economical (82%), environmental and natural resources and improved competitiveness (both at 73%), followed by productivity increase, social, occupational health and safety, and lastly training and education (all at 64%), working conditions (at 54%) and other categories.

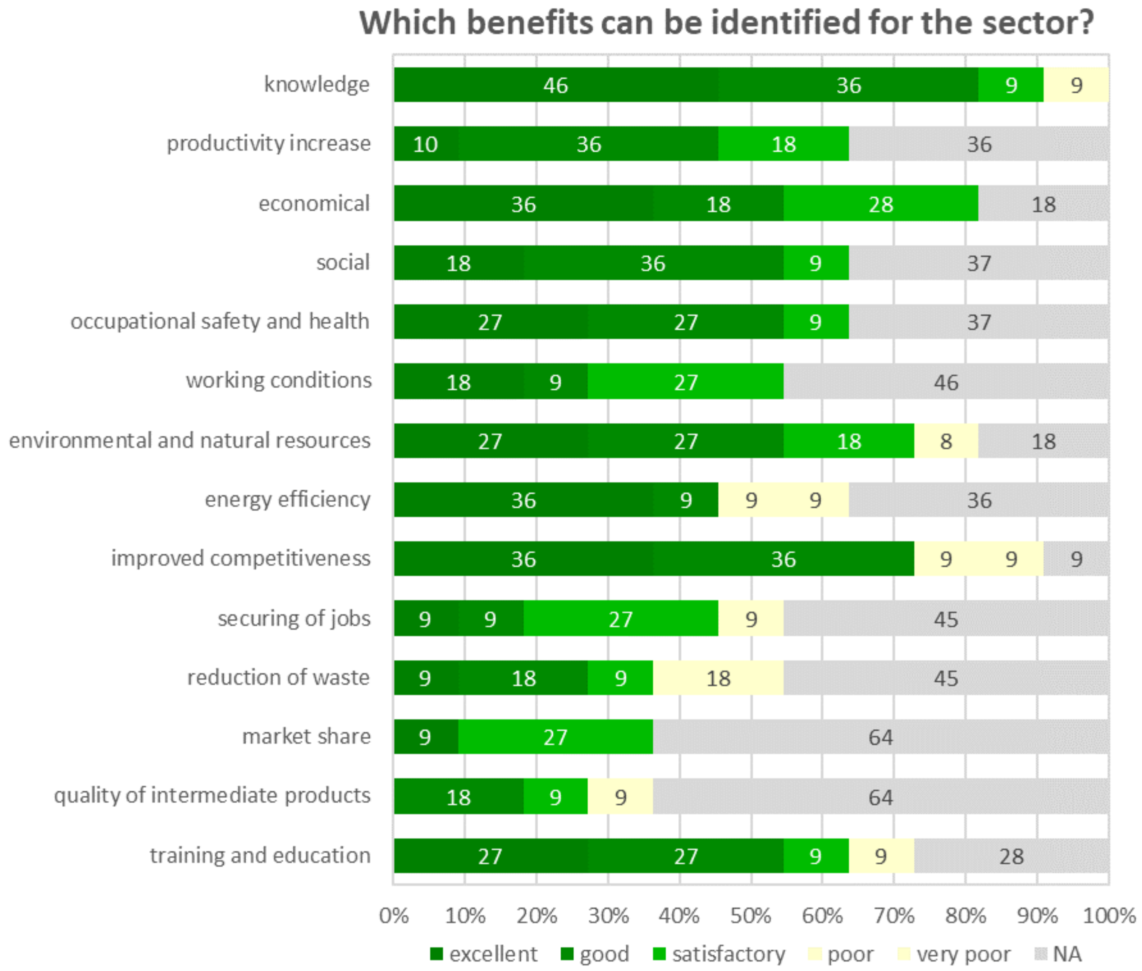

Figure 23 Benefits obtained at sector level for the TGC projects surveyed

For society-at-large, the major benefits are the increase of knowledge, with 73% of projects receiving at least a 'satisfactory' score. The next most significant benefits are economical aspects (63%), followed by the environmental and sustainability area and conservation of resources (54%), then European competitiveness, energy efficiency, social, occupational health and safety aspects (45%).

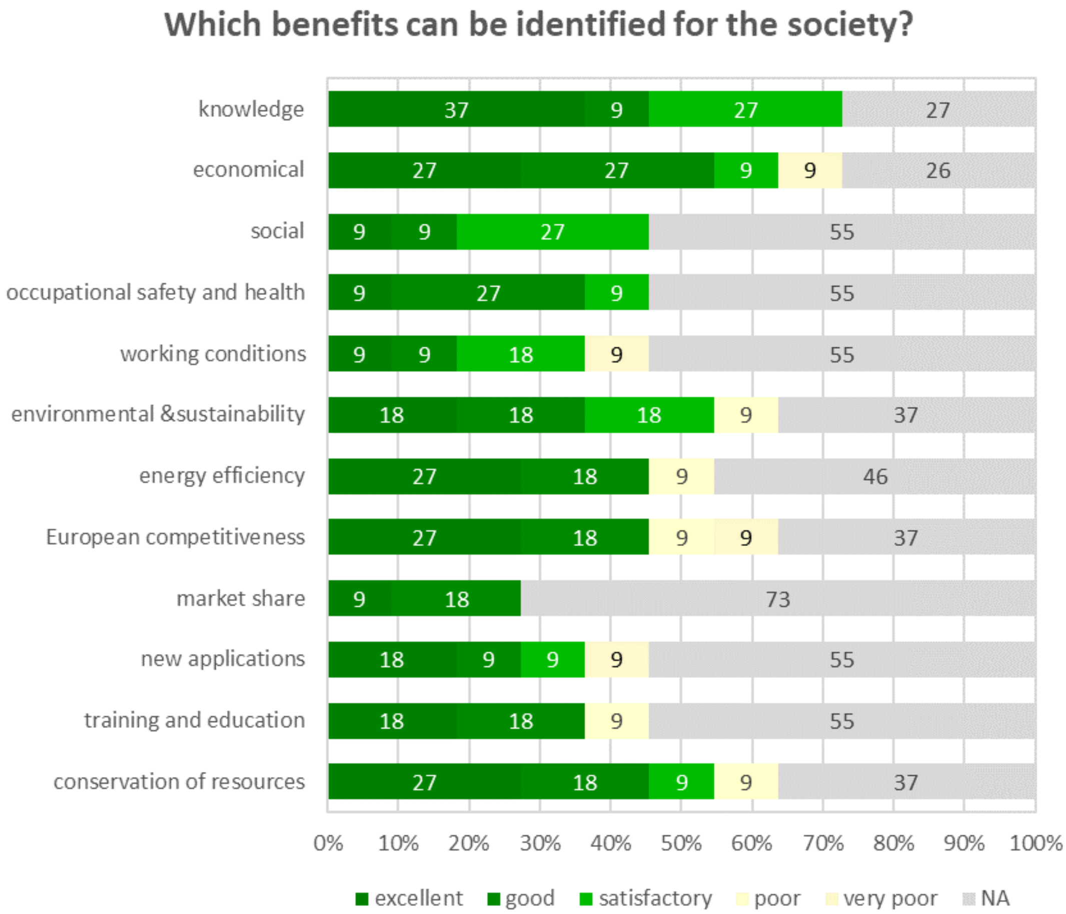

Figure 24 Benefits for society of the TGC projects surveyed

Method used to evaluate the benefits of RFCS projects

The last part of the questionnaire requested project coordinators to quantify, if possible, the benefits for beneficiaries/the sector/society, and to provide examples. Only 1 project out of the 11 analysed provided elements that could be quantified, and so it is not possible to reach reliable conclusions here. It is evident that in many cases it is difficult to quantify benefits (e.g. with figures such as € million/y or €/t). However, for several criteria that were analysed in the questionnaire and that are directly linked to quantifying benefits, the interviewees responded with high scores. Furthermore, most of the projects reviewed are research projects and some are still ongoing, and for these more time is needed before the monetary value of uptake and benefits can be quantified.

3.3. Analysis of questionnaires for RFCS steel projects

This analysis is based on a representative sample of ongoing and finished projects from the nine technical groups dedicated to steel, including 26 research projects and 2 pilot and demonstration projects. Table 22 presents an overview of the projects surveyed. The projects selected were chosen to provide a representative breath and spread of topics among the steel TGs and a mix of completed and currently ongoing projects.

	Completed	**Ongoing***	**Total**
TGS1 - Ore agglomeration and ironmaking	2	1	3
TGS2 - Steelmaking process	2	1	3
TGS3 - Casting	1	1	2
TGS4 - Hot and cold rolling processes	1	1	2
TGS5 - Finishing and coating	1	2	3
TGS6 - Physical metallurgy and design of new generic steel grades	1	2	3
TGS7 - Steel products and applications for automotive, packaging and appliances	2	1	3
TGS8 - Steel products and applications for building, construction and industry	6	0	6
TGS9 - Factory-wide-control, social and environmental issues	2	1	3
Total	18	10	28

* status in November 2018 when projects were surveyed

Table 22 RFCS projects surveyed per TG

A full list of projects analysed is provided in annex to this report. The following section presents the results of the analysis of these questionnaires.

3.3.1. Relevance

Relevance of RFCS steel projects in addressing sector objectives

The projects surveyed are considered to be fully in line with the TG to which they are assigned. In other words, there is a factual and clear alignment between the projects and the three research objectives for steel. The sector objectives addressed by the projects analysed are:

- **Steel 1: New and improved steel making and finishing techniques**. These are always addressed by the projects in TGS 1, 2, 3, 4, 5 and 9 and are sometimes also relevant for the projects assigned to TGS 6, 7 and 8, especially when there is a clear connection with the development of new steel grades or steel applications, and the process of their production.
- **Steel 2: RTD and the utilisation of steel**. Always addressed by projects assigned to TGS 6, 7 and 8. Generally not addressed by the other projects.
- **Steel 3: Conservation of resources and improvement of working conditions**. This objective is addressed by around 40% of projects, whatever the TG.

Steel 1: most of these projects aim to improve steel production processes or bring new or breakthrough solutions, specifically working towards:

- flexible production of coke, using alternative coals for hot metal production with lower CO_2 emissions;

- improving blast furnace operation (e.g. effect on coke properties under blast furnace conditions, optimising blast furnace inner state, use of innovative renewable carbon products) and sintering operation;
- optimising liquid steelmaking (e.g. multi-criteria through-process integration, dynamic stirring in secondary steelmaking);
- improving steel quality (e.g. new non-destructive control systems for surface defects of slabs, monitoring and advanced modelling for inspection of surface quality, optimisation of the through process geometry of hot rolled products, optimal control of shape and materials properties);
- setting up pilot and demonstration projects (e.g. new full-scale demo of alternative current in electropickling);
- improving energy efficiency (e.g. optimisation of the management of process gas in the integrated steel plant, dynamic stirring in secondary steelmaking to improve energy efficiency);
- making progress on Industry 4.0 in the steel industry (e.g. new automation and information paradigm based on holonic agent technology, multi-criteria through-process optimisation of liquid steelmaking).

Steel 2: these projects provide innovative solutions and tools such as:

- further increasing the utilisation of steel by improving sector competitiveness (e.g. design guide for steel-concrete structure to compete with reinforced concrete, new design rules for fire resistance assessment of thin wall steel members to better compete with concrete and timber, new tools to improve seismic protection of industrial structures that compete with reinforced concrete);
- widening steel's range of application (e.g. developing innovative applications of high performance steel in road restrain systems);
- developing new generic steel grades (e.g. innovative methodology to measure fracture toughness useful for the development of new generic steel grades, to simultaneously optimise mechanical and performance properties of quenching and partitioning (Q&P) steels);
- developing new manufacturing processes (e.g. in depth study of the stability of the hot forming process, which is critical for the production of new multiphase steel grades; development of new class of ultra-high strength materials with reduced manufacturing costs and reduced environmental impact);
- increasing safety though innovative design methods (e.g. development of new seismic protection tools, development of new method to predict fatigue life of automotive components under atmospheric weathering conditions, etc.).

Steel 3: in addition to addressing one of the first two objectives (Steel 1 or Steel 2), projects also addressed the Steel 3 objective in the following examples:

- use of biochar (e.g. charcoal from biomass) for sustainable electric arc furnace steel production;
- reducing the sector's environmental footprint (e.g. life cycle assessment methodology in steel applications in the automotive and construction industries, active building skin);
- improving working conditions when using steel solutions in the construction sector.

Progress beyond the state of the art

For most projects analysed, major progress in the state of the art has been achieved, with nearly 90% of projects analysed indicating that their progress has been good or excellent (Figure 25).

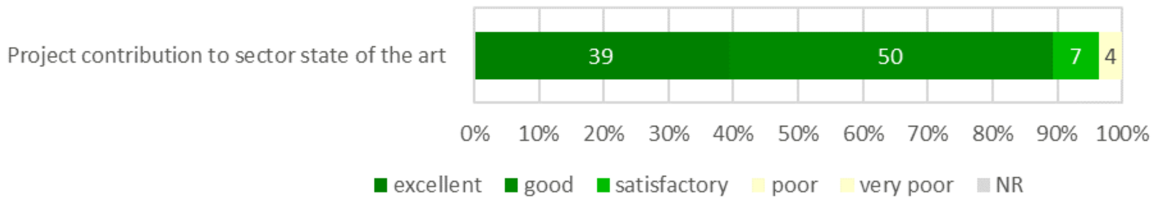

Figure 25 Progress in the state of the art

Significant progress in the state of the art related to Steel 1 objectives has been achieved, for example:

- a new innovative test procedure for evaluating coke reactivity and hot strength was developed and tested successfully in real blast furnace conditions;
- carbon bricks from different carbon materials have been identified and characterised, with potential use at the blast furnace to replace more expensive metallurgical coke;
- an ambitious target has been reached using a newly developed non-contact inspection system: to improve the final quality of steel products made from slabs, while saving energy, material and time e.g. during slabs scarfing, reducing production costs and increasing yield;
- progress was made in the operation of mixed acid pickling plants -- the operability of the new model-based online concentration monitoring system is now industrially applicable;
- a new approach was developed and makes it possible to react to production disturbances by adapting the process route for failed products. This enables the automatic reallocation of material, which is a significant improvement in comparison to the current state of the art, because the failed products can now be immediately reused instead of being scrapped, or can be sold in a secondary market.

Progress related to Steel 2 objectives includes the following:

- substantial knowledge and competencies have been developed on the behaviour of high performance steel used in new applications (e.g. in road restrain systems);
- a series of new tools, rules and methodologies has been developed to evaluate and increase the performance of steel products and systems in many areas (e.g. innovative design rules for fire resistance assessment class 4 cross section steel members, innovative calculation methods developed to optimise the design of widely used profiled steel sheets, creation of design methodologies for steel-concrete structures and connections, determining the fracture toughness threshold for cracking, etc.);
- several performance properties of quenching and partitioning steels (important for their applications in the automotive sector) have been investigated for the first time, including impact resistance, high strain rate behaviour, low cycle fatigue testing and hydrogen embrittlement;
- research results have been standardised with a number of guidelines (mostly in Eurocode format) so that the steel community as a whole can benefit from results.

Progress related to Steel 3 objectives has been achieved in the following areas:

- use of carbon products such as carbon bricks and activated nut coke as partial substitution of coke in the blast furnace;
- possible utilisation of low-grade biochar as a substitute for fossil coal in the EAF;
- new concepts and methods developed in the field of LCA for sustainable building projects.

3.3.2. Effectiveness

Progress towards attaining the specific RFCS objectives

According to the answers provided in the questionnaires analysed, progress towards attaining the specific RFCS objectives is definitely excellent or good. No project recorded poor progress (Figure 26).

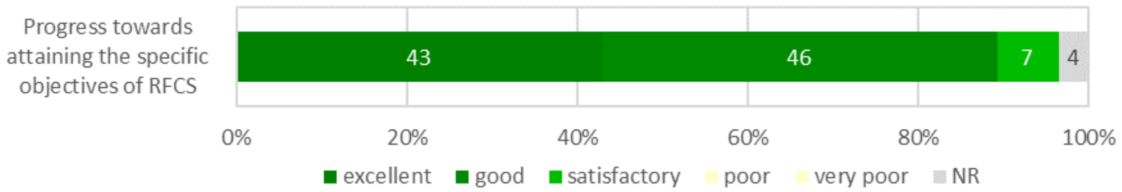

Figure 26 Progress towards attaining the specific RFCS objectives

Achievement of the programme's research objectives

Figure 27 shows the achievement of the programme's objectives in terms of three distinct and narrowly focused areas. In some cases, the narrow focus was indicated as out of the scope of a given project (marked as 'na'). However, even in these cases the project's achievement of the main RFCS objective related to it was always rated as high, which is positive.

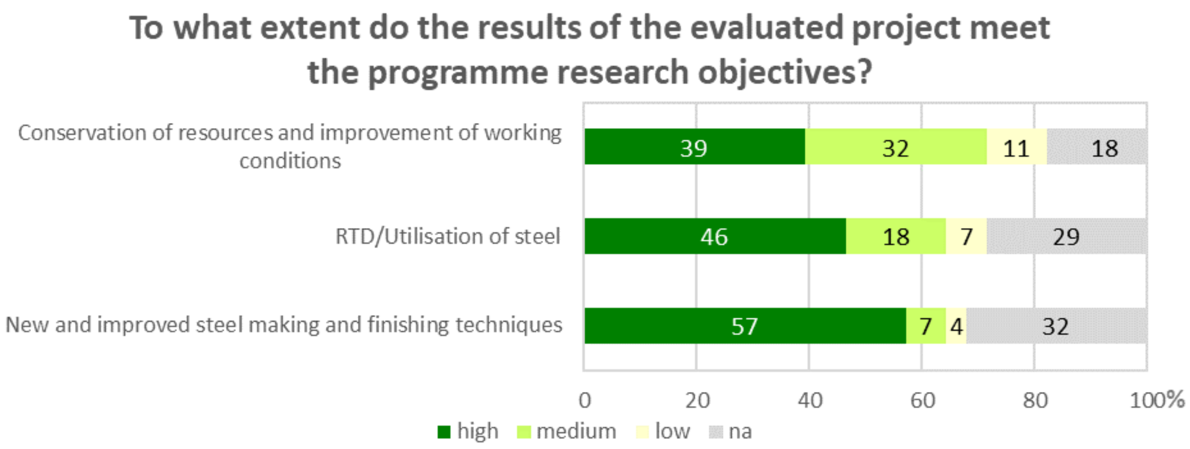

Figure 27 Achievement of RFCS objectives

Achievement of individual project objectives

The evaluation of individual project objectives and benefits against the Technical Annex of the Contract and the Grant Agreement is considered to be very good. Note, however, that the results presented in Figure 28 refer to completed projects only as it was difficult to provide a complete assessment of ongoing projects. For each individual objective, the percentage of analysed projects that reported a success level of at least 40, 60, 80 or 100% is shown.

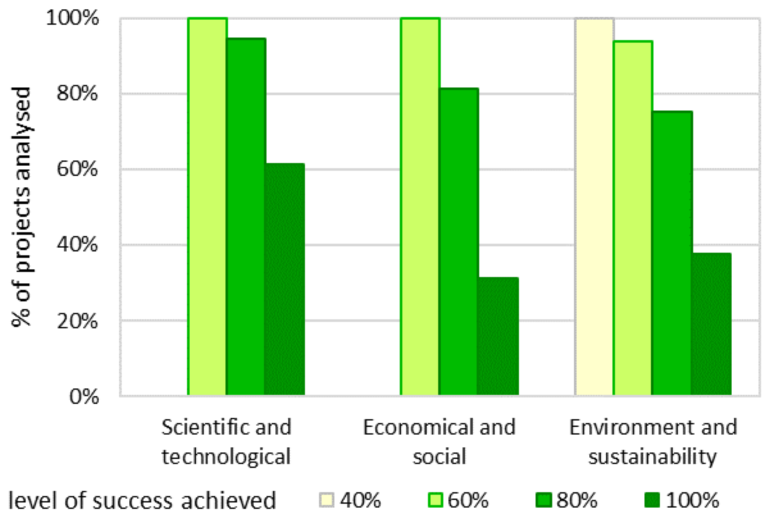

Figure 28 Achievement of individual project objectives

More specifically, scientific and technological success is very high; most projects rate it at 80% or higher. The projects are also successful on economic and social aspects, with most rating this at a 60% or higher level of achievement. The success rate in terms of environment and sustainable development is also good, but with lower overall scores. It is important to note that this last aspect as an individual objective is generally considered to be indirect.

Generally, projects are reaching their specific objectives, and sometimes they go well beyond the objectives described in their grant agreement. However, many projects could have gone even further given more time.

Reasons for objectives being only partially reached

Figure 29 shows cases where, due to difficulties encountered, projects only partially reached their objectives. There were few such cases. Difficulties encountered included time constraints and scientific technical problems.

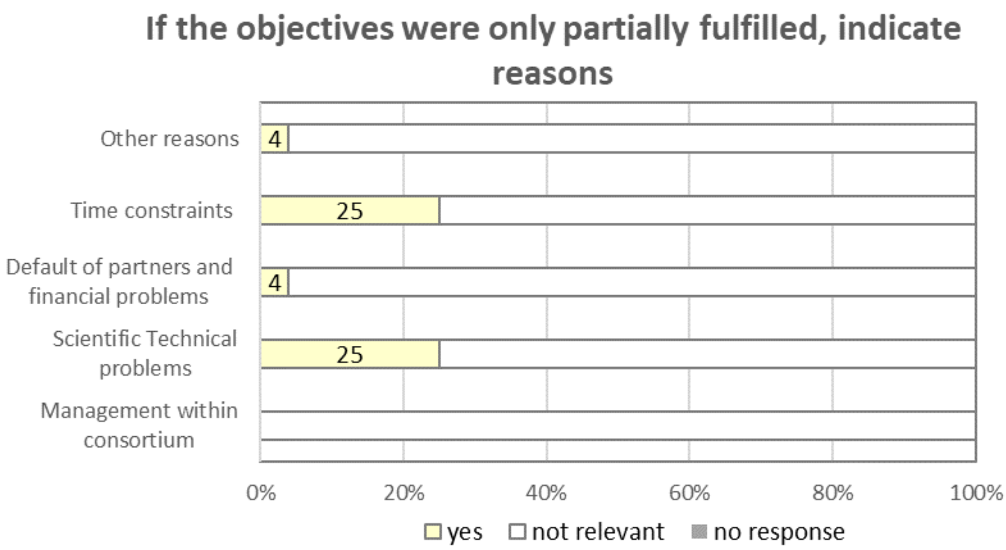

Figure 29 Difficulties encountered in achieving objectives

Identification of project key results and best practices

It was possible to specify results and best practices for 90% of the projects analysed, both currently running and completed projects. Moreover, all of the completed projects have identified significant results. Several examples are given below:

- a successful method for reducing the thermal reserve zone temperature of the blast furnace to reduce carbon consumption;
- use of carbon briquettes and activated nut coke by coating, as alternative energy resources in the blast furnace, with partial substitution of coke;
- electric arc furnace (EAF) charge trials: correct position of material into the basket; presence of oxygen diffusers on the EAF roof allowing to save energy, promoting post combustion;
- optimisation of stirring practices within the continuous caster with reduced power during electromagnetic stirring;
- process monitoring and optimisation tools in a through-process vision for the process chain of liquid steelmaking;
- development of automatic processing tools for evaluation and classification of hot rolled product quality;
- new electrolytic pickling process based on alternative current, which significantly improves productivity and reduces consumption of chemicals both for carbon and stainless steels;
- a novel transferable modelling approach, based on artificial intelligence techniques for optimisation of the management of process off-gases;
- optimised reallocation of failed products thanks to a novel I2M/Industry 4.0 approach combining semantic modelling and service oriented architecture;
- modelling of metal coating microstructure/corrosion behaviour for zinc-magnesium and aluminium-zinc coated steels;
- online monitoring of inner and surface defects of hot rolled wire;
- new shape-meter roll for hot rolled strips measuring flatness under strip tension;
- new chemical composition of quenching and partitioning steels for improved mechanical properties;
- a new experimental tool and associated methodology for crash-test performance assessment of advanced high strength steels (AHSS);
- development of best practices to improve the manufacturing process of hot forming of AHSS grades, which is cost- and energy efficient (e.g. integration of the annealing heat treatment in the hot stamping process);
- development of new seismic protection systems for industrial structures;
- development of numerical models for the mechanical behaviour of steel-concrete-steel (SC) structures and publication of guidelines for the design of SC structures;
- improved design rules for fire resistance assessment of thin wall steel members;
- new concepts and methods for the assessment of a sustainable building project, to be used for life cycle assessment at an early stage of building design;
- solutions to transform the facade of a building into an energy collector.

3.3.3. Efficiency

Resources

The interviewees consider that their budget is generally well balanced, most often in line with the original estimates and reasonable considering the project results (Figure 30)[53]. It is recognised that some changes in budget distribution may occur during a project's lifetime, and that it is still possible to stay in line with the overall planned budget. In some cases, additional resources have been assigned over and above the planned budget, and directly paid by the concerned partners using own resources.

[53] See paragraph 3.2.3 'Resources' for more information on the annual average of de-committed amounts from the RFCS programme.

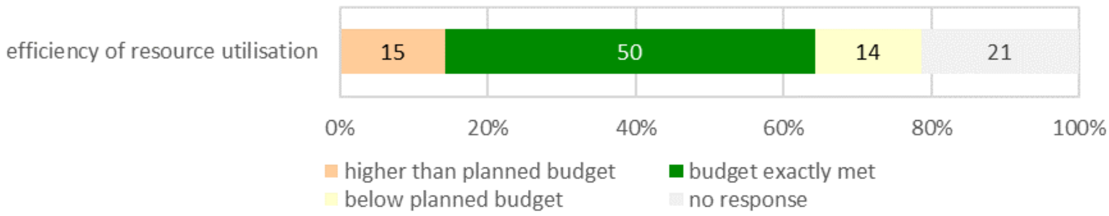

Figure 30 Actual vs expected budget

Project attractiveness for stakeholders

The involvement of stakeholders is considered satisfactory. Stakeholder participation in workshops is good, the level of traffic on project websites is high, and project beneficiaries (mainly the coordinators) often receive requests for further project details.

Cost-benefit analysis

Resources used are considered reasonable in the light of results that have been generated (Figure 31).

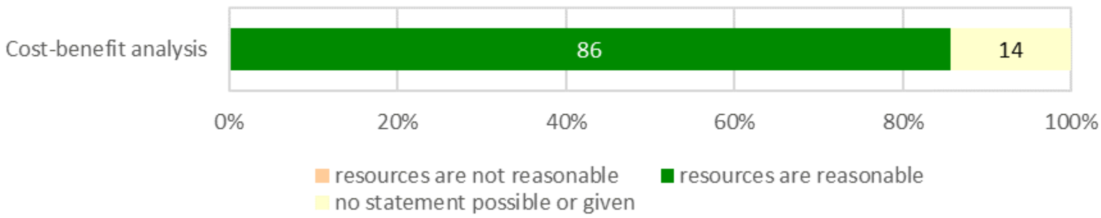

Figure 31 Resources used and results generated

Management and administration

Several recommendations for improving project management and administration were made:

- providing the coordinator with more legal power (means), for example in cases of a defaulting partner when deadlines are not met;
- providing management tools for preventing risks (e.g. delays);
- increasing the funding rate for SMEs (in order to achieve higher SME participation), which is also recommended for some of the research centres, depending on their funding models;
- having a management structure and funding strategy similar to those of the Framework Programme (H2020);
- providing the beneficiaries with brief RFCS guidelines, emphasising only the key procedures for project management with precise references to additional details if necessary (e.g. in case of a partner's resignation, procedure to accept a new partner, etc.);
- improved user support for the online platform for project preparation and management, including financial management;
- a dedicated part of the project (at the end of project period) could be devoted to results dissemination;
- shorter reports could help to reduce management workload at project level;
- replacing biannual physical meetings with frequent phone call/video conferences with the European Commission (e.g. every two months).

Identification of some administrative burden related to project implementation

Around 80% of the interviewed coordinators consider that the implementation of their projects does not generate major administrative burden. A few suggestions for improvements are proposed in Chapter 4 of this report.

3.3.4. Coherence

Internal coherence among the various technical groups

Synergies with at least another one or several TGS have been identified for 61% of selected projects (Figure 32).

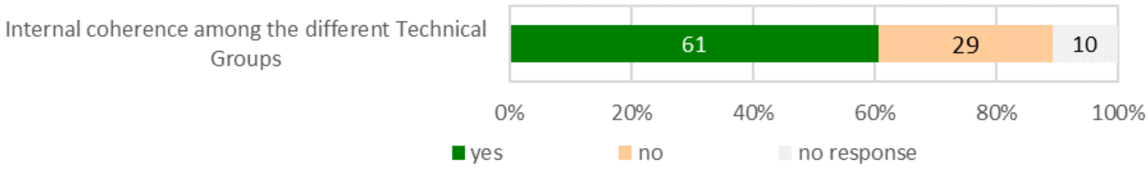

Figure 32 Occurrence of synergies among various TGS

Synergies have been identified for 77% of projects where the main objective is addressed within Steel 1 (new and improved steel making and finishing techniques), i.e. TGS 1, 2, 3, 4 and 5.

Synergies have been identified for only 30% of projects in which the main objective is addressed within Steel 2 (RTD and the utilisation of steel), namely TGS 6, 7 and 8.

The projects assigned to TG9 (factory wide control, social and environmental issues), which is a transversal technical group, always have synergies with at least one other TG.

Note that these synergies are to be considered as potential ones. This is because, generally, they have not yet been translated into practical actions. This could be an area to be developed in the future.

Ensuring value for money

The purpose here is to provide examples of expected interdisciplinary solutions. 40% of projects provide examples of interdisciplinary solutions that cut across several objectives of the RFCS programme. Synergies among various projects assigned to the same TG or to another TG are also noted.

- Several projects which belong to TGs 1, 2, 3, 4 and 5 and are addressed within Steel 1 contribute to energy and resource savings, and to CO_2 reduction. Others contribute to the improvement of product quality and the development of new products.
- Monitoring and models developed within TG 9 can be used in other areas of the process of steel production.
- Synergies have also been also identified between TGs of the coal group and TG 1 for ironmaking.
- Several projects in TG 6 and 7 have had an impact on optimising the production chain.

Projects in TG 6 dealing with physical metallurgy and the design of new steel grades have synergies with the areas covered by some other TGS, for the downstream part of steel production as well the development of new products and steel solutions.

How accompanying measures can contribute to complementarity

In their answers to the questionnaires, project coordinators underlined that accompanying measures could be used to ensure complementarity between the different RFCS projects. In particular, this has been the case for TG8, in which around 10 accompanying measures have been implemented over the review period in the construction and energy sectors. To a limited extent, accompanying measures have also been implemented for TG 2 (electric arc furnace, secondary metallurgy). The HLG recommends that the dissemination of project results is reinforced, and accompanying measures could be one of the tools that support this.

3.3.5. *EU added value*

Benefits for the European steel sector

All projects identify a clear need to run projects at European level, and clear benefits of this. Most projects also show their strategic importance for the European steel industry. Several examples are listed below:

- strong contribution of a number of projects to the improvement of steel competitiveness in Europe, both for steelmaking processes and steel products;
- reinforcement of networking among steel experts with extended knowledge both for steelmaking processes and steel products;
- efficient cooperation between the steel industry, research centres and academics;
- in a number of projects related to the Steel 1 objective, a consortium of several EU steel companies involved in the same project creates an ideal platform for successful results to be applied in industrial plants;
- improvement of energy efficiency in steel making (e.g. reduction of coke rate at blast furnace, optimisation of the use of process gases, multi-criteria through-process optimisation, dynamic stirring in secondary metallurgy);
- contribution to the reduction of CO_2 emissions (e.g. blast furnace optimisation, use of alternative carbon materials at blast furnace and electric arc furnace, optimisation of the management of the process gases);
- development of new steel or steel/composite solutions for construction and of advanced high strength steel for automotive applications, which is of strategic importance for the European steel sector and for European society;
- many projects related to the construction sector plan to deliver tools, rules, guides or methods that can be used at the European level (e.g. standardisation);
- the research programme meets a need that comes from the European steel market as a whole (e.g. European market demand for a third generation of advanced high strength steel, development of innovative solutions in composite materials, closer cooperation between steel makers and steel users).

Benefits for European society

More than 80% of projects show strategic importance for European society. A number of examples of societal benefits are listed below:

- preservation of resources, energy savings and environment protection are mentioned for a number of projects, across TGs;
- improved competitiveness over the whole value chain of steel, including end users;
- preserving workplaces in the steel industry;
- application of developed models and sensors in other EU industrial sectors;
- promotion of industrial symbiosis;
- contribution to reducing CO_2 emissions in the production of steel;
- contribution of steel use to a low carbon society (e.g. car weight reduction with advanced high strength steel, energy efficient buildings);
- utilisation of char from biomass in steelmaking requires creation of new local economies devoted to transformation of low-grade biomass into biochar (e.g. agricultural residues, waste from food companies) - this implies promotion of industrial symbiosis;
- for steel product development and steel applications, the domain of research is of strategic importance to European society (e.g. reduction of the environmental footprint of steelmaking, increase in European road safety thanks to new road restraint systems developed, reduced economic and environmental damage thanks to a better seismic protection system of industrial steel structures, development of advanced high strength steel for the automotive industry, increasing car safety).

Areas in which project results were used

The analysis shown in Figure 33 refers to both completed and ongoing projects. For ongoing projects (10 out of the 28 projects analysed), some interviewees already mention partial exploitation, while others do not specify any outcomes yet.

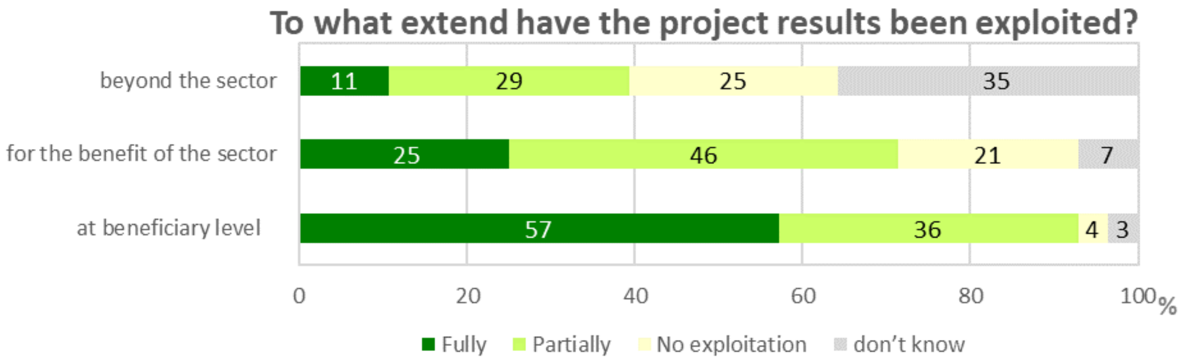

Figure 33 Areas in which project results can be used (for both completed and ongoing projects)

For completed projects, results are always used at beneficiary level, with around 60% of projects considering the results fully used and the rest as partially used. In 90% of completed projects, results are relevant for the whole steel sector and in around 50% projects results are relevant even beyond the sector.

Examples of project results being used

Below are several examples of how projects results have been used, both for completed and ongoing projects.

General examples of using project results in the steel sector:

- partial or full implementation of results at beneficiary level (see Figure 35);
- transfer to other sites;
- ideas for new projects, patents (see Figure 34);
- publications (conference papers, articles) for most completed projects.

Examples related to the steel production process:

- innovative multiphase model describing the behaviour of the blast furnace hearth, improving the prediction of hearth wear;
- optimisation of stirring practices within the continuous caster;
- improvement of the final quality of steel products using a novel non-contact inspection system;
- new approach of reallocating materials immediately to be reused instead of scrapped;
- truly novel shape-meter which makes it possible to measure hot strip flatness under tension, now successfully implemented at the hot strip mill;
- novel I2M[54] approach to predicting off-gas production and optimising their use.

Examples related to steel grade development and steel use:

- a new method of evaluating fracture toughness in thin advanced high strength steels developed to be used internally by the industrial partners (steel quality control and part design);
- developments related to high performance steels for road restraint systems, with findings already used by industrial partners; academic partners also use the results in educational activities;
- in corrosion resistance design, new codes were developed for testing corrosion and fatigue resistance of welded coated steel-based materials;
- development of rules for fire resistance assessment of class-4 cross-section members, with results which are used to generate new Eurocodes;

[54] Idea to market (I2M) approach.

– development of a new energy-generation steel skin, including a full scale façade which has been developed and installed in Spain;
– development of experimental and numerical data to fill gaps in current knowledge of the behaviour of steel-concrete structures and use of this for developing design guidelines: in addition to tens of publications and results that are used already in a pilot and demonstration project;
– development of innovative seismic isolation systems for existing and new buildings, where a new device has been further used and both numerical and experimental tests are in progress to demonstrate its effectiveness.

Use of project results after project completion

As shown in Figure 34, around 60% of completed projects led to a new research and development project in the same field of investigation.

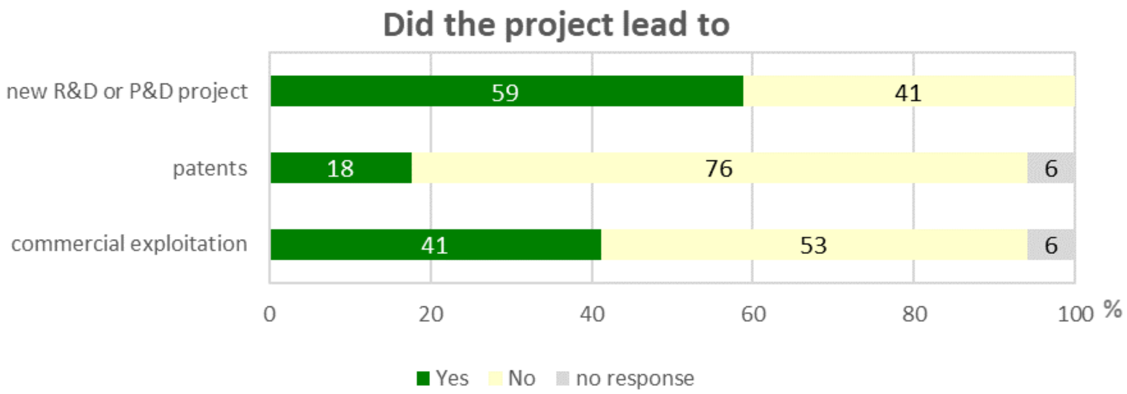

Figure 34 Use of project results after project completion

Around 20% of projects led to patents being registered. For approximately 40% of projects, results were used commercially. For 40% of projects related to the production process, results were directly implemented in steel plants.

Project benefits

The project benefits were evaluated based on a number of criteria of possible benefits suggested in the questionnaires:

- 17 criteria at beneficiary level,
- 16 criteria at sector level,
- 12 criteria for society-at-large.

This made it possible to rate each criterion as excellent, good, satisfactory, poor, very poor or not applicable. Responses were provided both for current and completed projects. Figures 35 to 37 present the proportion of projects that identified benefits per category.

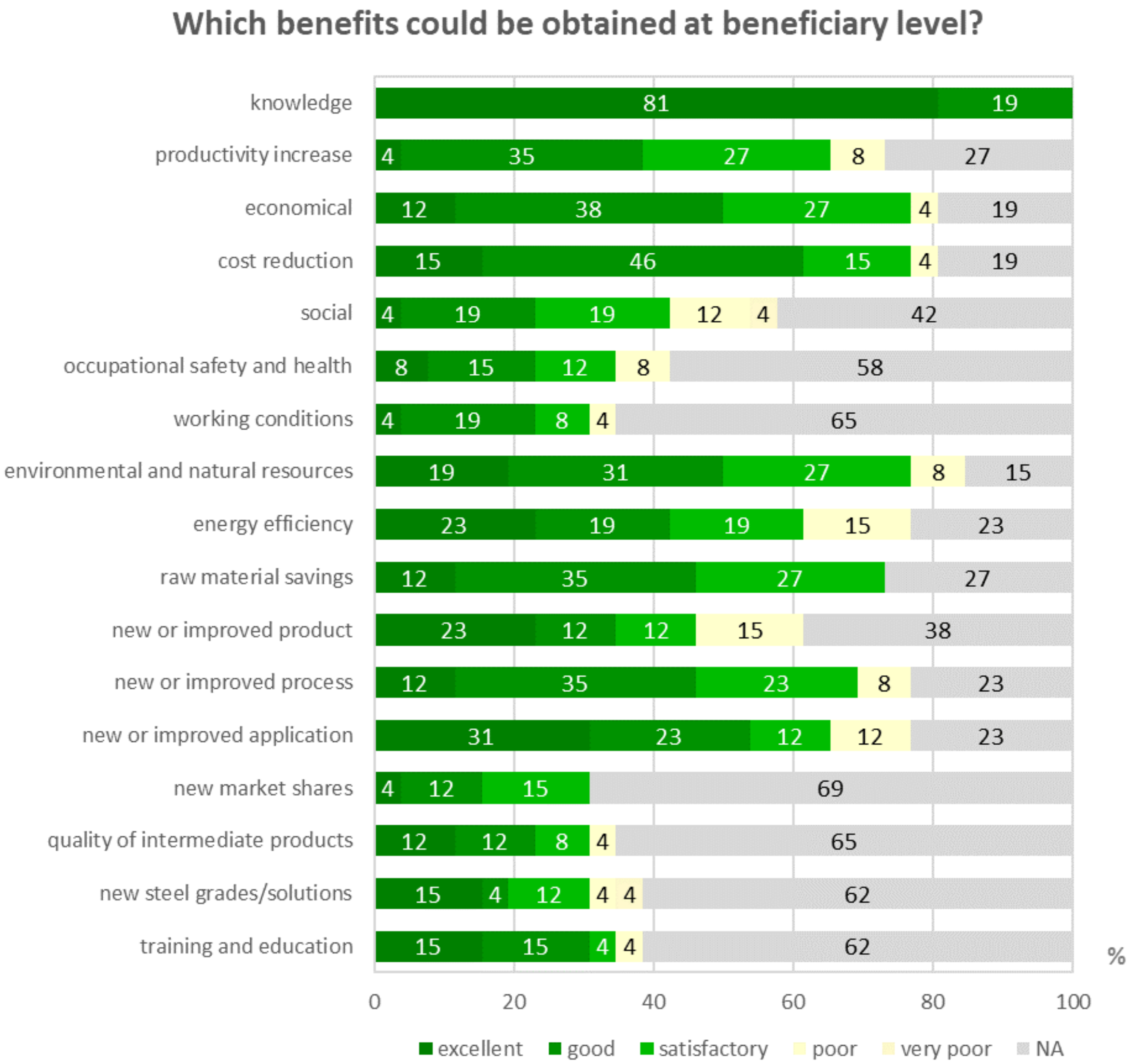

Figure 35 Benefits identified at beneficiary level

The improvement of knowledge is by far the most obvious benefit, as 100% of projects rate this as at least 'good', and 80% rate it as 'excellent'. The most important benefits after knowledge are environmental and natural resources (77%), cost reduction and economic impact (both at 76%), raw materials savings (74%), new or improved process (70%), new or improved application (66%), productivity increase (66%), energy efficiency (61%) and new or improved products (47%).

At sector level (Figure 36), knowledge once again receives the highest score, with 100% of projects rating it at as least 'satisfactory'. Using the same order (% of an at least satisfactory rating), the most important benefits identified are improved competitiveness (92%) and competitiveness of steel (84%), followed by economic impact (80%), environmental and natural resources (73%), energy efficiency (56%) and reduction of waste (53%).

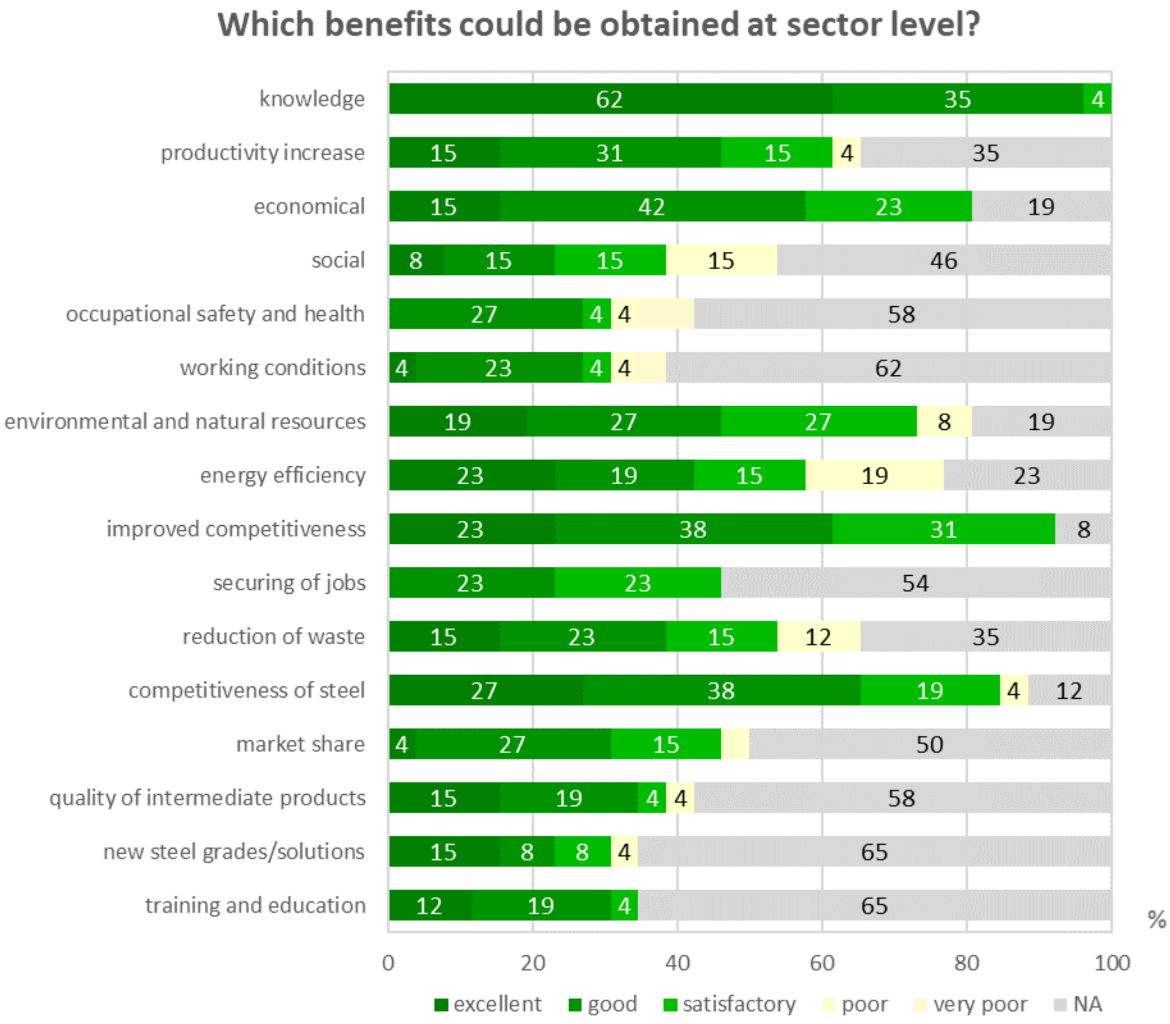

Figure 36 Benefits identified at sector level

For society-at-large, the main benefits are the increase of knowledge and improved European competitiveness, with 84% of projects rating both of these as at least 'satisfactory'. Next in line are environmental and sustainability aspects (77%), followed by economic impact (66%), the conservation of resources (59%), energy efficiency (58%) and new applications (50%). The benefits that are most important for Europe, i.e. those concerning the environment, resource conservation and energy efficiency, are addressed well by all the surveyed projects, which is fully in line with high level EU priorities.

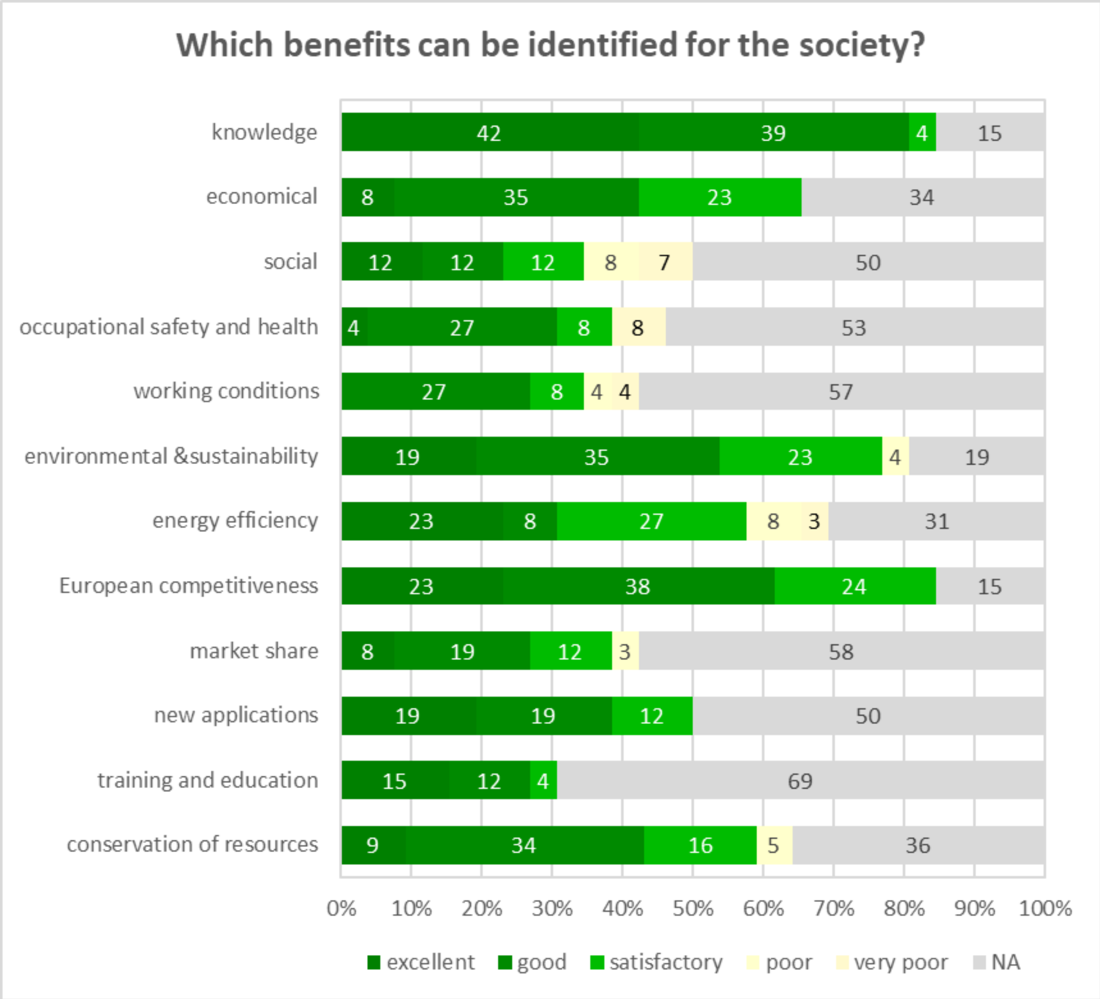

Figure 37 Benefits for society-at-large

Quantification of benefits

The last part of the questionnaire asked project coordinators to quantify the benefits for beneficiaries/the sector/society-at-large, if possible, and to provide examples. Elements for possible quantification were only provided for two projects out of the 28 analysed, so it is difficult to draw reliable conclusions here. It is evident that benefits are difficult to quantify (e.g. using figures such as million €/y or €/t). Some interviewees also noted that it is impossible to provide economic metrics due to EU competition laws. Nevertheless, interviewees assess several criteria directly linked to quantification of benefits at different levels as very high, which is very valuable. This includes positive economic impact, cost reduction, increased energy efficiency, increased productivity, waste reduction, conservation of resources and market share gains.

The question of quantifying the financial benefits of projects was tackled by the high-level group of experts and is discussed in Section 4.3.

4. RECOMMENDATIONS – THE FUTURE OF RFCS

The results of this monitoring and assessment exercise have confirmed the great value of the RFCS programme for the competitiveness and advancement of the European coal and steel sector. As evidenced in this report, the research activity carried out under the RFCS programme in the 2011-2017 reporting period brought significant and concrete benefits to the European coal and steel sectors, the whole economy and European society. In addition, the RFCS programme brought together the community of the European coal and steel industries as well as the corresponding research communities by fostering collaboration and knowledge exchange on the most relevant research activities. This achievement was important at the time of the ECSC Treaty, when the European coal and steel sectors experienced severe difficulties. It is still of the utmost importance today, when the future of these sectors in Europe relies on the well-coordinated and aligned efforts of industries and research communities contributing to the strategic long-term vision of the European Union — a prosperous, modern, competitive and climate-neutral economy. However, the results of this report indicate that achieving the EU's ambitious goals will still require an enormous amount of work. In particular, it appears necessary to adapt some administrative and technical guidelines of the RFCS programme to tackle future challenges. Therefore, the High Level Group of Experts — invited by the European Commission to carry out the monitoring and assessment exercise — strongly recommends further supporting the RFCS programme in a way that will do the utmost to help it continue its mission to achieve a prosperous, modern, competitive and climate-neutral economy by 2050. The HLG of Experts also formulated its recommendations with the aim of keeping an appropriate budget for the RFCS programme in future, in order to secure continued support for successful and ambitious activities and its attractiveness for stakeholders.

This chapter covers:

- the lessons learnt from the inputs of the TG Chairs (see details in Chapter 2);
- the results of the quantitative assessment of selected projects as provided by the project coordinators (see details in Chapter 3);
- an assessment of the leverage effect of the RFCS programme;
- recommendations of the HLG of experts on the management of the RFCS programme;
- recommendations of the HLG of experts on the key research topics the RFCS programme should address in future and the corresponding proposed modifications of the legal basis.

4.1. Lessons learnt from Technical Group Chairs' monitoring

This paragraph summarises the inputs provided by the TG Chairs (three TGs for coal and nine TGs for steel) for the monitoring and qualitative evaluation of the RFCS programme. It highlights the main technical and technological achievements of the RFCS projects between 2011 and 2017 and the benefits for the sector and society. It also presents the implementation of the RFCS programme's objectives, casting light on future technical and technological challenges.

Chapter 2 of this report describes in full detail the technological achievements attained by RFCS projects over 2011-2017 as well as their benefits. It also identifies the main technological challenges in coal and steel, suggesting new RFCS programme objectives to tackle these.

4.1.1. RFCS coal: outcomes of the projects — The TG Chairs' views

According to the three coal TG Chairs, over 2011-2017 the RFCS projects provided valuable results and contributed in several ways to the competitiveness and sustainable development of the sector in terms of economic, ecological and social improvement. Successes were achieved in automation and digitalisation, mine health and safety, protection of the environment, sustainable coal technologies and improved utilisation of coal.

The RFCS projects innovated on the communication infrastructures, automation technologies, integrated mine planning and highly efficient mining technologies, increasing high-capacity coal operation and coal production performance. A variety of projects concentrated on enhancing mine health and safety. These led to a lower number of accidents, increased the attractiveness of the workplaces and contributed to the development of sophisticated methods and tools for predicting rock mass behaviour and of emergency response systems and technologies.

One of the top priorities of a mining company is to minimise the impact of its operations on the environment, while taking all precautions at an early stage to return the environment to a habitable state when operations finish. The review of RFCS coal projects during the selected monitoring period indicated that considerable effort was made to address mine reclamation and restoration after closure.

Moreover, the RFCS improved several approaches and methodologies for upgrading coal deposits. Examples include underground coal gasification (UCG), the use of flooded coal mines as a source for thermal energy, as well as the upgrading of methane in ventilation emissions of working shafts and those emissions coming from abandoned mines. In addition, efforts were channelled into developing sustainable coal technologies through processes for clean and efficient coal technologies, CO_2 capture and co-firing of coal with solid waste or biomass. Key research activities were focused on: retrofitting concepts for lignite pre-drying and pre-dried lignite co-firing; operation of a full scale 1000MW plant (SCFB); development of mineral carbonation of coal fly ash for CO_2 sequestration; development of new active and conductive structure and surface-promoted catalysts; as well as strategies for setting up fuel blends and strengthening the position of solid fuel fired boilers. For improving the use of coal, progress was achieved in cokemaking, coal liquefaction, preparation and processing of coal-derived products for carbon materials, and coal gasification.

Overall, during the period under review, the RFCS programme's objectives were in line with industrial needs and well matched to industrial practice. All projects contributed to one or more of the objectives. In turn, all objectives were supported and addressed by projects underlining their importance and contemporary nature. However, the industry transformation needed to achieve a carbon-neutral economy requires, and is stimulating innovation in, products and processes. Affordable and clean energy is now as important for European competitiveness, growth and social well-being as securing the supply of and access to raw materials. In addition, industrial innovation has fundamentally changed over the last 10 years. The science, technology or corporate-driven innovation paradigm has been challenged by a new open, human, ecosystem-based collaborative innovation paradigm, leading to the development of new business models and new forms of cooperation across industries. Consequently, the objectives of the RFCS programme should be updated, restructured and explicitly focused on the forward-looking challenges and trends. In the view of the coal TG Chairs, the following key future research and innovation topics are recommended:

- mine automation and digitalisation,
- equipment efficiency and reliability,
- land reclamation and restoration,
- unconventional usage of coal deposits,
- mine health and safety,
- environmentally sound and socially accepted production,
- use of coal as a potential source for critical raw materials,
- carbon capture, usage and storage (CCUS),
- combining renewables and fossil fuels,
- integrating energy storage with power production,
- effort on plant flexibility for sector profitability,
- hydrogen route in technology for energy carrier from power plants,
- reuse of CO_2 in other industries and plant growth.

Last but not least, the TG Chairs recommend being prepared for the value of ETS emission allowances to rise, triggering large-scale investments by industry.

4.1.2. RFCS steel: outcomes of the projects — The TG Chairs' views

The steel TG chairs consider that the RFCS projects provided valuable results during the period under review (2011-2017). These results provide clear benefits to the project partners, the global steel sector and the whole of society.

More specifically, in the field of process development RFCS projects provided significant progress in cost reduction, productivity and energy and resource efficiency thanks to the solutions implemented in various steel plants. Moreover, new breakthrough technologies were evaluated and tested, with a special focus on CO_2 reduction. For instance, RFCS projects helped to evaluate and validate new breakthrough concepts, paving the way for carbon-lean smelting and reduction processes. In the short term, numerous solutions have been provided and implemented to decrease the environmental footprint of steel production.

In the field of product development and utilisation of steel, the projects contributed to the sustainable development of new products directly aligned with customers' needs. Numerous examples are found in the automotive area, with the lightweight solutions using advanced high-strength steels, and in the construction sector. The RFCS contributed to maintaining and strengthening the competitiveness of the steel industry in Europe by helping to focus on high-end products with a quality advantage over non-EU competitors.

Besides industrial outcomes, the RFCS projects also provided new knowledge and fostered knowledge-sharing between researchers, technologists and academics.

European society as a whole benefited from the RFCS projects through the limitation of the steel industry's environmental footprint due to emissions reduction and better conservation of resources and energy. Projects also improved the health and safety conditions of workers at their workplace and of consumers of steel products and goods. One typical example is the significant reduction in cars' fuel consumption and the increase in their safety thanks to the use of advanced lightweight steel parts. The life cycle analysis approach is especially valuable for quantifying the relevant benefits.

Regarding the RFCS programme's objectives, on the one hand steel TG Chairs consider that these were in line with industrial needs and industrial practice. All projects contributed to one or more of the objectives and, in turn, almost all objectives were supported by projects. On the other hand, the formulation of the objectives is considered somewhat conventional and conservative and unfit to cover the newest technological developments. Consequently, the objectives should be updated to align with the strategic long-term vision of the EU and to be more explicitly focused on forward-looking trends such as:

- climate change,
- resource efficiency,
- rational use of energy,
- new high-performance steels,
- steel and steel-based solutions for safe and improved applications,
- Industry 4.0 and digitalisation,
- cost effectiveness,
- adaptation of working conditions, and
- workforce skills.

4.2. Lessons learnt from the RFCS project assessment

This paragraph takes stock of the answers provided by a sample of 39 RFCS project coordinators in response to a detailed questionnaire on the qualitative and quantitative assessment of their project, including evaluation of the benefits.

Chapter 3 provides a thorough assessment of the projects surveyed. The monitoring and assessment exercise covers a total of 293 projects completed or launched in 2011-2017. Of these, about one third have been selected for a more detailed assessment involving interviews of the respective project coordinators by means of a questionnaire based on the five criteria of the EU's 'better regulation' initiative (relevance, effectiveness, efficiency, coherence, EU added value). For the 'Questionnaire for Assessment and Monitoring of RFCS projects', please refer to the Annex.

4.2.1. RFCS programme — Coal part

All the coal projects analysed responded very positively with regard to identifying how their aims and results reflect the RFCS projects' flexibility to adapt to new scientific and socio-economic developments. Furthermore, for most projects analysed major progress in the state of the art has been reported.

Respondents declared that progress towards attaining the specific objectives of the RFCS programme is either excellent or good (80%). No project suggested a record of poor progress. In all cases, the project's objectives were aligned with the RFCS coal objectives. The evaluation of individual project objectives and their benefits, in accordance with the Technical Annex of the Grant Agreement, is considered to be very good. Specifically, scientific and technological success is very high, rated at 80% or higher. In the few cases where the objectives were only partially fulfilled, it was indicated that more flexible time constraints would have allowed them to overcome hindrances, including scientific and technical problems.

The projects surveyed consider that their budget is generally well balanced (82%), utilised in a timely manner, in line with the original estimates, and reasonable considering the project results. Respondents have not indicated explicit synergies with other TGCs; in the few cases where synergies are mentioned, these are considered as potential rather than actual. Lastly, the respondents define the benefits at European level arising from RFCS projects. Besides the value of knowledge creation and exchange (up to 91%) and effective mobilisation of resources (55%), the projects' strategic importance for the European coal regions is also highlighted.

According to the RFCS project coordinators, the following future research objectives appear recommendable:

- production-related research challenges,
- application of modern automation and data transfer/processing technologies,
- supporting European technological leadership in clean coal technologies,
- sustainable energy generation at mine sites (geothermal energy generation),
- energy generation with methane,
- sustainable energy storage,
- UCG,
- circular economy aspects (alternative uses of mine dumps, integrated alternatives for mine sites, mine water uses, valorisation of waste),
- land rehabilitation and ecological restoration,
- socio-economic or political context analysis,
- utilisation of coal as a clean energy source,
- coal conversion to low carbon fuels,
- sustainable use of coal in terms of carbon capture and storage,
- alternative ways of mine infrastructure usage,
- transition of coal regions to create new activities based on existing knowledge, skills and resources.

4.2.2. RFCS programme — Steel part

The projects surveyed prove to be fully relevant to the RFCS steel programme's objectives. For most projects analysed, major progress in the state of the art has been reported. Incremental progress in cost efficiency and energy and raw materials efficiency has been achieved in the process development part of the programme. In addition, new breakthrough processes have been evaluated at different scales, from laboratory to pilot. In product development, innovative solutions and tools to develop new generic steel grades and new manufacturing processes for advanced steels have been proposed (e.g. multiphase steels or new advanced high-strength steels). Such a solution could widen the applications of steel in demanding markets such as transport and construction. Moreover, several projects contributed, directly or indirectly, to reducing CO_2 emissions and improving health and safety and working conditions.

The great majority of surveyed projects (90%) confirm the achievement of an excellent or good improvement in the state of the art. Indeed, the projects reached their specific objectives, sometimes going well beyond the objectives initially described in the grant agreement. However, it is noted that with more flexible time constraints, certain projects could have gone further in developing their concepts and their implementation.

90% of the projects analysed declare having identified specific results and/or best practices. In light of the results obtained, the projects' budget is judged to be balanced and reasonable. Furthermore, the projects show a high degree of exploitation by beneficiaries (full or partial exploitation of more than 90%) and by the steel sector (more than 70%). The degree of exploitation beyond the sector is lower, though still significant (full or partial exploitation of about 50%). About 40% of the projects recognise a commercial exploitation, whereas about 20% led to patents.

The development of new knowledge through research is regarded as the most important benefit generated by RFCS projects. At the level of beneficiaries, environmental protection, resource efficiency, cost reduction, improved processes and new applications were highly ranked, with a rating of excellent, good or satisfactory around 75%. At the sector level, steel competitiveness, economic impact, environmental protection and resource and energy efficiency rank high. Major benefits for society are stemming from the progress achieved on protecting the environment and on sustainability, energy efficiency and conservation of resources, as well as in the positive economic impact of such improvements. The result is very positive effects on the competitiveness of the EU steel industry.

4.3. Leverage effect of the RFCS programme

The in-depth assessment of the projects clearly pointed out that the financial returns of the RFCS projects, expressed by criteria such as economic impact, cost reduction, energy and material efficiency, and increased market shares, are rated very highly by the interviewees at both beneficiary and sector level. Overall, more than 70% of the coal and steel projects are evaluated as providing a very positive financial impact for beneficiaries.

These figures are at least as positive as those derived from the previous monitoring and assessment exercise published in 2013 and covering 2003-2010[55]. In the latter exercise, the monetary benefits generated by a representative sample of the projects under evaluation could be calculated on the basis of a detailed analysis of reliable figures provided by beneficiaries and industrial partners. The figures were derived from the effective industrial implementation of the projects' results. When the proven annual benefits were compared with the annual cost of the projects, it emerged that €1 of RFCS funding provided a benefit of €3 for the beneficiaries. Further, €1 spent by the beneficiaries in research and innovation supported by the RFCS generated about €5 of benefit. The HLG considers that these monetary benefits remain valid due to the continuation of the RFCS Programme, the actors involved and the results obtained. This assumption can also be justified by the similar structure of the project portfolio, the same RFCS programme objectives and the similar results of the qualitative and quantitative assessment. These financial figures were fully endorsed by the stakeholders of the previous monitoring and assessment exercise.

Extending the project benefits at sector level strongly depends on the dissemination efforts conducted by the project beneficiaries and other external factors. These include industry's willingness to implement project results, the associated implementation costs and local market conditions. Thus, the RFCS industrial research programme is leading the way for the industrial sectors to obtain the potential benefits from the projects, provided that the projects are implemented in ways that are consistent with companies' strategies. To capture these benefits, it is clear that additional efforts must be devoted at company and industrial level to implementing the solutions and technologies developed by the RFCS programme.

4.4. Expert Group Recommendations — Programme management and implementation

This paragraph details some HLG recommendations to renovate and improve the management and administration of the RFCS programme along the 'project life cycle'. The proposed recommendations apply to both coal and steel and take stock of the changes undergone by the programme until 2017 and beyond, as described in the Introduction and Chapter 1. The HLG also recommends a revision of the RFCS objectives for coal and steel described in Council Decision 2008/376/EC. The revision of the objectives proposed by the HLG concludes this chapter.

Budget and scope of the RFCS

The budget allocated to the annual RFCS calls for proposals was substantially decreased over 2011-2017 to €40 million/year[56]. It is recommended to keep the budget of the future RFCS calls for proposals at this level, as a minimum, to ensure significant funding is available to address the challenges facing steel and coal.

The members of the HLG identified certain technological topics in line with the EU long-term strategy which could not be financed by the RFCS programme alone because of their breakthrough nature and the scale of the corresponding financial needs. For this reason, the HLG recommends contributing to the development of breakthrough technologies in the coal and steel sectors which are necessary to achieve a climate-neutral European economy. In particular, the HLG recommends supporting both emblematic coal projects in the coal regions in transition and low-emission steel

[55] RFCS Monitoring and Assessment Report, DOI 10.2777/11062, European Union 2013.
[56] See Chapter 1, paragraph 1.1.2 Annual Budget of the RFCS Programme of this report for more information on the budget allocated to the RFCS annual call for proposals.

production projects by using part of the ECSC assets in liquidation. This would leverage innovation activities in the coal and steel sectors, in synergy especially with the Structural Funds and Horizon Europe. Nevertheless, this measure should be implemented in a way that will help to secure the budgetary envelope of the RFCS programme in the long term.

Proposal preparation, evaluation and granting

For an efficient and qualitative preparation of project proposals, as well as for their evaluation, the following recommendations are put forward.

Ensure the excellence of the proposals recommended for funding

The excellence of the RFCS programme is highly correlated with the technical competence of the experts involved as evaluators. With the 2019 RFCS information package, the scopes of the TGs change significantly, with new combinations of several technological fields in the different technical groups. This revision tends to make it increasingly difficult to select evaluators with such a wide range of competences. Moreover, this task is rendered even more difficult by the combination with other restrictions, such as the need for proportional representation of countries, conflict of interest issues and gender balance. Indeed, the evaluators need to be not only specialists in their own technological field but also very well aware of the industrial challenges in industry, and well experienced with the RFCS programme. The RFCS management should therefore take these issues into consideration when selecting the panels of evaluators.

Industrial relevance

The RFCS programme ought to reinforce its industrial orientation and impact. It is recommended to reassert this orientation and strengthen the evaluation criteria specifically addressing the potential for industrial applications. In parallel, the number of academic experts among the evaluators should be properly balanced with the number of industrial experts.

Remove priority bonus point

It is recommended to remove the priority bonus points for the RFCS programme. This is because the ratio of bonus points/overall points in the current evaluation procedure (with three evaluation criteria) does not justify the importance of bonus points in comparison to impact, excellence and implementation. Moreover, this recommendation would prevent double counting as the programme’s objectives will already be assessed and evaluated within the impact criteria.

Dissemination and exploitation of results

The quality and effectiveness of the dissemination and exploitation of the project results (including management of IPR) and the management of the research data, where relevant, are key to the success and added value of the RFCS programme.

Dissemination plan

Projects are already encouraged to include in their activities a well-organised plan for disseminating their results together with the related financial needs (e.g. costs and budget available). Nevertheless, dissemination and wider outreach of project results can be further improved, for example through seminars, publication in scientific journals and conference proceedings, participation in specialised conferences, etc.

Communication plan

An annual or biennal Research Exchange seminar and/or workshop, in addition to the annual RFCS conference organised and hosted by the European Commission, should be held to cover activities developed within closely related projects. This would allow exchange of ideas, discussion of results, improvement of methodologies and achievements, etc. Besides, the organisation of workshops and demonstrations to disseminate project results should be encouraged, as well as the development of accompanying measures (AM) for disseminating and communicating achieved technology developments. Lastly, synergies and clustering of RFCS projects within the RFCS programme as well as with relevant research framework programmes, such as Horizon 2020 and Horizon Europe, is highly recommended.

RFCS programme management	
1	Keep the budget of the future RFCS call at least at EUR 40 million per year.
2	Support breakthrough emblematic coal and steel projects in synergy especially with Structural Funds and Horizon Europe. This measure should be implemented in a way that will also help to secure the budgetary envelope of the RFCS programme in the long term.
3	Ensure the excellence of the proposals recommended for funding by selection of excellent evaluators.
4	Reinforce the industrial orientation of the RFCS and strengthen the evaluation criteria addressing the potential for industrial applications.
5	Distribute in advance, in common meeting of the Commission with SAG, CAG, COSCO, the annual budget of RFCS to the different TGs, depending on strategic challenges.
6	Remove the priority bonus point in the evaluation process.
7	Make the TG meetings a forum for technical discussion and dissemination of the results of the projects.
8	Develop efficient means for the quick dissemination of the project results (seminars, workshops, publications, …) and ensuring the corresponding budget.
10	Promote accompanying measures for the dissemination and communication of achieved technology developments.
11	Develop synergies and clustering of RFCS projects with relevant Horizon Europe projects.

Table 23 Summary of recommendations on the RFCS programme management

4.5. Expert Group recommendations — Forward-looking research trends

The recommendations for the future of RFCS provided in this paragraph express the shared views of the independent experts of the HLG. These views may also reflect, to some extent, the inputs provided by the TG chairs (details in Chapter 2) for coal (TGC) and for steel (TGS) and by the assessments of the selected RFCS projects compiled by project coordinators (details in Chapter 3).

The challenges facing the steel and coal sectors and the preliminary recommendations for the future of RFCS were discussed at the conference 'Steel and Coal: a New Perspective — Research and Innovation in Action' (held in Brussels on 28 March 2019) and endorsed by the stakeholders.

4.5.1. Coal — Recommended key research topics to address future challenges

The coal research community is exploring innovative solutions to support climate protection and coal regions in transition. This transition could be achieved by taking advantage of the opportunities presented within the existing infrastructure and repurposing assets and technologies to meet EU policy objectives. The coal industry calls for targeted support to deploy technologies to shape decarbonisation and support the coal regions in transition. The future challenges of the coal sector and the key research trends which the HLG recommends for support by the RFCS programme are briefly presented below.

Carbon capture, utilisation and storage (CCUS)

CCUS is key to reducing global CO_2 emissions. It involves the geological storage of CO_2, typically at a depth of 2-3 km, as a permanent solution. Large-scale CCUS projects are operational in Norway, Algeria and Australia, each storing millions of tonnes of CO_2. Carbon dioxide captured from coal power plants is already used as a value-added commodity in enhanced oil recovery in the US and Canada. CCUS also describes the permanent storage of carbon in building materials or plastics. Algae farming allows CO_2 to be converted to biomass and processed into biofuels. There are still several innovative opportunities to be explored. CCUS with sector coupling will enable a smooth transformation of the whole energy-supply system by using the existing infrastructure to enable the transition from fossil fuels to renewable energy sources. This approach avoids structural dislocations, offers financial feasibility and minimises risk to energy-supply security.

Alternative use of coal mine infrastructure supporting renewables

The EU energy system is shifting from using fossil fuels towards incorporating a significant share of renewable energy sources. The coal industry can be a significant contributor to meeting these objectives. The alternative use of coal areas for renewables comprises all activities focusing on the sustainable use of mine sites and coal regions to support the energy transition, like pumped hydroelectric storage or geothermal energy.

Geothermal energy

New geothermal power plants offer the possibility of reusing the infrastructure that remains after the decommissioning of conventional power plants. Such sites are already well connected to the electricity grid. The production of geothermal energy in these sites would offer them a new lease of life which, with heat supply to nearby consumers, can be particularly economically attractive.

Hydro-electricity storage

The integration of electricity storage facilities into the grid represents a central task in the conversion of the energy supply to renewables. Besides batteries, pumped storage power plants using existing underground coal mine infrastructure offer a valuable prospect for abandoned mines.

Clean coal technologies

Clean coal technologies are a way to meet the above-mentioned objectives by deploying supercritical (SC) and ultra-supercritical (USC) coal-fired power plants with efficiencies of 42-48%. These technologies are applied as high-efficiency, low-emission (HELE) power plants. A supercritical steam generator operates at very high temperature (about 600°C) and pressures (above 22 MPa), where the liquid and gas phases of water are no longer distinct. In Japan and South Korea, about 70% of coal-fired power already comes from supercritical and ultra-supercritical power plants.

Energy storage

Thermal energy storage (TES) offers the prospect of using existing infrastructure. A TES power plant can be adapted to an existing coal power plant connected in parallel with the steam generator or boiler. The energy storage unit is heated using electricity during periods of lower power demand and low power prices, thus storing electrical energy in the form of heat. When power prices are high (e.g. in periods of peak demand) the heat is recovered and converted back into electricity using the existing steam plant infrastructure and turbo generators. In this way, intermittent or variable power from renewable energy sources is used to underpin power-system security. The modular nature of TES systems allows each plant to be sized according to the volume of renewable energy sources that need to be integrated.

Valorisation of coal products and non-energy uses

The valorisation of coal products comprises all activities aiming at upgrading and adding value to coal products. This includes their use for non-energy purposes, such as coal gasification, integrated hydrogen production or the use of coal as a source of critical raw materials. In addition, attempts to address aspects of the circular economy aimed at minimising and reusing waste by closing material loops, e.g. reuse of mine water, should be emphasised.

Coal gasification

Gasification uses coal and other carbon-based resources for the production of high-purity chemical feedstocks via chemical synthesis. The gasification route opens up a variety of new markets for coal, such as synthesis gases (carbon monoxide and hydrogen), base chemicals (e.g. methanol and ammonia), liquid and gaseous fuels (e.g. dimethyl ether (DME), polyoxymethylene dimethyl ethers (OMEn) and synthetic natural gas) and waxes. Projects that begin by gasifying coal will substitute the coal with biomass, wastes and residues. Thus, gasification is the starting point for a sustainable circular-carbon economy.

The synthesis step of the chemical process allows hydrogen from other sources to be integrated, turning carbon dioxide from the gasification process into useful products. As the supply of hydrogen from renewable sources grows, so more biomass, wastes and residues can be fully converted into useful chemical products, thus lowering the carbon footprint to nearly zero.

Integrated hydrogen production

The production of hydrogen at existing coal-fired power plants could be one way to deliver sector-coupling through energy storage. During periods of low power prices, electrolysers at existing power plants could use electricity to produce hydrogen for storage. The hydrogen will be used directly in the transport sector or added to natural gas supply (hythane) for use or storage (line packing) in the existing natural gas pipeline system. To add even more flexibility, the carbon dioxide (CO_2) emitted from the power plant can be combined with the hydrogen to produce synthesis gas from which many useful chemicals and liquid fuels can be produced.

As more and more new renewable sources of electricity come online, the electricity demand of the electrolysers could be met from these new sources. Adding gas turbines would allow surplus hydrogen to be used for power production during periods of low or no renewables generation. With a heat recovery steam generator (boiler), the whole of the coal plant's steam cycle can be integrated into a new clean energy system.

Coal to x (chemicals, agriculture)

Desertification can be reversed by enabling land to remain arable. The production of humic acid can be used as a carbon-neutral plant fertiliser in the agricultural sector.

Coal as a source for critical raw materials

Besides the fact that coking coal is currently classified by the European Commission as a critical raw material, coal deposits consist of a variety of different sub-minerals. This offers both the opportunity of wider use that will add value and a potential source of critical raw materials.

Mining 4.0: Mine automation and digitalisation

The efficiency, sustainability and safety of mine production can be increased by enhancing mine automation and digitalisation and developing advanced mining technologies. This includes developments in ruggedised sensor technologies, condition monitoring, real time monitoring and control, advanced data processing systems, and equipment efficiency and reliability. In addition, advanced mining technologies offer the potential to maintain and foster the technological leadership of EU mining equipment manufacturers and suppliers in sustainable mining practice. This contributes to the global trend from labour to technology-intensive mining and promotes the cleaner use of coal by countries outside Europe.

Safety, health and environmental protection

Increasing mine health and safety while reducing the environmental impact and emissions of mine operations will lead to safer and more attractive workplaces and increased acceptance by society of mining activities.

Post-mining land rehabilitation and ecological restoration

Post-mining reclamation is the process of restoring land that has been mined to a natural or economically useful state. Land rehabilitation and ecological restoration creates new landscapes that meet a variety of goals. These range from restoring productive ecosystems to creating industrial estates, commercial centres, residential housing, transport infrastructure and community resources such as parks and lakes. Therefore, developments should focus on new methods and approaches for closing mines as well as their long-term stability and safety, and should consider socio-economic or political context analysis.

Keeping, maintaining and enhancing knowledge about EU deposits, mine sites and technologies

The EU energy system is undergoing a transformation as governments and industry work towards a completely new configuration of the system, shifting away from fossil fuels (coal, oil and natural gas) to incorporate a significant share of renewable energy sources. At the same time, coal is still an important resource, including for non-energy purposes. In addition, the conditions for coal extraction in Europe are among the most difficult in the world — the technical developments necessary have led to today's technological leadership. Mining conditions are becoming increasingly difficult worldwide, with the result that there is great potential for exchanging knowledge and transferring technology.

Thus, the EU's large reserves of indigenous coal may continue to play a significant role for decades to come, by supporting a secure and affordable energy transition. It is therefore important to keep, maintain and further improve knowledge of the EU's coal deposits, existing and former mine sites and production technologies.

	Recommended key research topics for the coal sector
C1	Carbon capture usage and storage.
C2	Alternative use of coal mine infrastructure areas supporting renewables : geothermal energy, hydro-electricity storage.
C3	Clean coal technologies.
C4	Energy storage.
C5	Mining 4.0: mine automation and digitalisation.
C6	Valorisation of coal products and non-energy uses : coal gasification, integrated hydrogen production.
C7	Coal to X, including Critical Raw Materials.
C8	Safety, health and environmental protection.
C9	Land rehabilitation and ecological restoration, post-mining.
C10	Maintaining EU mine sites and deposits for future use.

Table 24 Summary of recommended research topics for coal

4.5.2. Steel — Recommended key research topics to address future challenges

The steel sector is heavily committed to the long-term EU strategy for achieving a prosperous, modern, competitive and climate-neutral economy by 2050. For many years, the EU steel industry has been at the forefront of research and development to explore breakthrough technologies for reducing its carbon footprint, with many projects supported by the European Commission.

The challenges and recommended research trends of the steel sector for the future presented below are fully consistent with the priority research areas[57] set out in the frame of the European Steel Technology Platform (ESTEP) for sustainable steel production.

Emissions reductions and facing climate change

Responding to climate change remains at the top of the RFCS's challenges, in accordance with the ambitious EU targets for reducing GHG emissions. It is addressed in the upstream area and requires the development of new breakthrough technologies to achieve low-carbon or carbon-neutral steelmaking processes and eventually fossil fuel-free steel production. Huge steelmaking plant adaptations will be necessary e.g. shifting from the current BF-BOF process to the direct reduced iron (DRI)–electric arc furnace (EAF) route. Achieving short-term CO_2 reductions requires further development of existing infrastructure and production processes to reduce the use of fossil carbon by substituting green carbon and renewable energy. The knowledge gained from RFCS projects is supporting and accelerating the transformation process to CO_2-free steel production.

The efforts aimed at further development and eventual industrial implementation of technologies such as CCS or CCU should be continued as these technologies for smart carbon usage (SCU) may contribute to mitigating CO_2 emissions. One example is the production of fuels or basic chemicals from steel mill gases. Here, CO_2 originates from BF and BOF gas and hydrogen originating from coke oven gas or produced by water electrolysis represents a possible way for subsequent hydrocarbon production. The production of oxygen during electrolysis and its direct use in the steel mill is a side benefit of the process. Alternative processes for the production of hydrogen, like pyrolysis of methane, should also be further developed. The same goes for the technologies based on the generation, supply and use of green hydrogen or green electricity for iron ore reduction. These contribute to massive CO_2 reduction and may foster the development of processes achieving

[57]ESTEP Strategic Research Agenda 2017. Available online : https://www.estep.eu/library/publications/2017-sra/

carbon direct avoidance (CDA). In the former case the work should be focused on searching for realistic ways to store or use CO_2 on an industrial scale, corresponding to the scale of the 'supply' of this waste gas. Development of CDA should be focused on finding ways of making green technologies industrially feasible (i.e. cost-effective). Process integration (PI) aims at reducing the use of fossil carbon. Options include recycling or making better use of steelwork gases (e.g. recycling of BF top gas as an auxiliary reducing agent), partially replacing coal by either natural gas or biomass, increasing the scrap/hot metal ratio and replacing iron ore by hot briquetted/direct reduced iron. PI may also include the option of final storage of captured carbon (CCS).

Resource efficiency and circular economy

Energy

Energy efficiency is a cross-cutting target along the whole production chain which requires efficient and flexible use of energy sources. This use of energy sources (gas, coal and electricity) is becoming more and more important in the steel industry for commercial and strategic reasons. These include international competition as well as geopolitical issues such as security of energy supply and GHG emissions. Economical use of energy reduces CO_2 emissions and saves natural resources. Moreover, energy and CO_2 emissions can be saved by recovering waste heat. However, further preconditions have to be met to make existing techniques for waste heat utilisation and heat recirculation economically attractive. For this reason research is necessary in this field.

Furthermore, energy policy demands the flexible use of energy sources in industrial processes. This brings new challenges for plant operators. Changes in the composition and heating value of energy carriers must be compensated for by using suitable foresight systems. Negative impacts on processes and product quality are inadmissible. In addition, the energy demand of companies must match with available resources within the supplier networks. Fluctuations in the grid are increasingly influenced by the needs of connected customers and changes in weather conditions, due to the increasing ratio of renewable energy in the energy mix. Smart Grid solutions in this field are under development but research is still necessary to find the best solutions to connect steel producers much more closely to the energy suppliers.

The use of PI tools should be developed to optimise the distribution of energy in the plants and the interactions with the surrounding area.

Other resources

The concept of recycling should cover all steps in the production chain, not only the recycling of scrap. The reuse of steel parts or recycling of metals other than Fe, e.g. Ni, Cr, Si, Al etc., should be developed. A critical challenge is to maintain the high quality of final products when using secondary raw materials. In addition, reusing by-products (e.g. slags, sludges, dusts) by recovering valuable compounds as inputs or cascading for other use has to be developed. Technologies for using biomass and plastics as substitutes for fossil materials should also be developed. Furthermore, the adaptation of raw material use for new steelmaking processes as well as future quality requirements have to be considered in the general context of scarcity of raw materials.

The sustainability of steel production is also related to water management and conservation. Here new challenges have appeared in recent years, such as very hot and dry summers with the consequence that groundwater is very low and the remaining water in rivers is warmer than in the past. New ideas are needed to find solutions to these difficult conditions in the future. Furthermore, a stronger connection between water management and quickly changing conditions in the production process, e.g. through Industry 4.0 solutions, could help to overcome limitations in today's water management.

Circular economy

The circular economy has a real and significant impact on the conception of steel products, the design of the structures and the assembly techniques. Consideration needs to be given to extending the lifetime of products, their maintenance and repair, and product take-back and remanufacturing. Digital platforms like the internet of things should be set up to optimise resource use and maximise value.

For process and product development, life cycle thinking (LCT) should be systematically promoted and used to assess the CO_2 emissions and other climate impacts over the full life cycle of production and use of steel products. This should lead to the consolidation of steel's position at the forefront against competing materials.

New high-performance steels

The RFCS should support the development and production of a new generation of high-performance steels. These should aim to provide a good combination of properties in respect of ultra-high strength, good toughness and excellent wear-resistance while using cheaper alloying and being more environmentally friendly (e.g. steel grades with lower carbon content, steel components with longer lifetime without loss of performance, …). Another critical challenge is to increase these properties while reducing manufacturing costs. The new generation of high-performance steels have to serve highly demanding markets. This is particularly the case in the transport/mobility sector, where lightweight solutions are required; in the renewable energy sector (wind, solar, water), which relies strongly on steel; in the equipment sector (such as the mining industry), which will be able to produce better equipment with high added value; and in the construction sector, where there is a growing need for smart, sustainable and intelligent infrastructures combining high performance with low maintenance.

The metallurgical design of the new steel grades, as well as the perfect control of the whole manufacturing chain, to ensure the achievement of high-quality products must be considered. This evolution requires increased metallurgical knowledge to predict online the mechanical properties of steel with the help of innovative sensors and more sophisticated and reliable design and production models and methods.

Steel-based solutions for safe and improved applications

New safe, environmentally friendly and improved steel, composite and steel-based solutions should be developed to improve and widen the use of steel.

In the transport sector, RFCS should address the safety and weight reduction challenges. Therefore, RFCS should support innovative steel solutions that reduce vehicle mass (lightweight construction innovations), benefiting both fuel consumption and CO_2 emissions, while fulfilling the requirements of security (e.g. better energy absorption), comfort and performance. This also means that the development of new design principles and simulation methods in advanced engineering to fully seize the advantages of the third generation of advanced high strength steels should be encouraged. This would constitute a clear advantage for the European automotive sector over its competitors.

In the construction sector, the development of positive-energy steel buildings with integration of renewable energy resources capable of providing both energy efficiency and enhanced user comfort and wellbeing should be promoted. The RFCS should also consider new composite hybrid solutions in steel construction that help reduce carbon footprints (e.g. steel and wood materials). The development of advanced steel construction products with improved performance (mechanical, environmental, acoustic, …) and adapted design should be strongly fostered. Last but not least, to facilitate the entry of the steel construction sector into the digital age, a dedicated digital strategy should be encouraged (e.g. development of digital construction tools such as BIM-Building Information Modelling objects representing steel construction solutions in use).

In the energy sector, steel has a very important role to play. The development of advanced materials at an affordable cost for producing, storing and transporting energy is a key strategy to decrease GHG emissions resulting from power generation. It should be considered in the RFCS programme.

Digitalisation

The steel industry is entering the era of digitalisation and Industry 4.0. It is critical to sustain the worldwide competition in the steel market, create a fully circular economy and solve all future aspects of CO_2 reduction and energy management. The main concepts in this field are cyber physical systems, Digital Twins, vertical/horizontal integration and self-organised production. The RFCS programme should actively support these vital developments in the steel industry.

Vertical integration (local process intelligence) means, for example, the combination of all data flow, including sensor information, and IT solutions of the process control circuits with production planning systems (PPS) or enterprise resource planning (ERP) solutions. For each single process/plant, vertical integration has to be achieved on the basis of local conditions. Horizontal integration (through process intelligence), where plants are 'connected' through a data stream floating through the production chain, makes it much easier to ensure the right quality in a through-process manner and to significantly improve several logistic aspects in the long process-chain of steel production. Horizontal integration furthermore covers the strong IT-based connection between steel producers and all other players in the complete supply chain, such as raw materials suppliers, customers, IT services, logistics companies, etc. Digital Twins have to be specially interpreted for the steel industry and will be the basis for several improvements in vertical as well as horizontal integration.

The application fields of new digitalisation solutions are cost reductions, product quality improvements, realisation of a 100% circular economy and reduction of any kind of environmental contamination.

It has to be considered that the European steel industry is operating with installations of various ages on 'brownfield' sites. Their retrofitting to make them compliant with Industry 4.0 is a key issue to be taken into account in the RFCS programme.

Modelling and development of sensors

A cross-cutting issue is the modelling of material, plants and processes as an indispensable precondition for many of the research needs described above. The first choice here is always the application of first principle models to describe the physical, chemical or metallurgical conditions. Nevertheless, today additional technologies like data-driven, stochastic or semantic modelling are powerful solutions to support the first principle models in cases where they fail, e.g. in the form of hybrid modelling approaches. Continuous research is necessary in this field and should be supported by the RFCS.

Another very import aspect is the availability of powerful, smart and low-cost sensors to detect the quality features of intermediate or final products, the condition of plants and processes or environmental conditions around the steel works. This is another cross-cutting issue which significantly influences the success of many of the above-mentioned research needs for the steel industry. For example, Industry 4.0 will not become reality in the steel industry without powerful and smart sensors.

Cost-effectiveness and products of high quality

The cost-effectiveness of the process and of end products is a permanent cross-cutting challenge of major importance for the European steel industry's ability to compete against non-European producers and other materials. It is directly connected to the previous challenges. The RFCS should therefore continue to support incremental developments to increase cost-efficiency in the global context of climate change and strong competition.

The same holds true for ensuring the highest quality standards of intermediate and final products along the complete steel production chain. Single processes and process chains have to be continuously adapted to meet the increasing demands of customers. Digitalisation will play an important role in this field but it can help only if the technological processes and the corresponding plants are highly technologically advanced. This has to be ensured in future and RFCS can help significantly.

Recommended key research topics for the steel sector	
S1	Reducing emissions and addressing climate change.
S2	Energy efficiency and flexibility along the whole production chain.
S3	Resource efficiency, including recycling, reuse, substitution of fossil fuels, water management.
S4	Development of circular economy.
S5	Design and production of new high-performance steels, steel components and global solutions for the highly demanding markets.
S6	Steel-based solutions for safe and improved applications.
S7	Implementation of digitalisation and Industry 4.0 technologies in steel production.
S8	Cost effectiveness in process and end products, high quality of products along the production chain in the global context of climate change and strong competition.
S9	Health and safety at the work place and around the workplace.

Table 25 Summary of recommendations for steel research topics

4.5.3. Recommended cross-cutting themes for coal and steel

Beside the key research trends and technological developments, cross-cutting themes to address future challenges in both the coal and steel sectors are evident and are recommended for support by the RFCS programme.

Skills and people

Considering the development of coal and steel production technologies and the challenges mentioned above, the workforce will become a major human challenge. As in Europe most industries are moving in the direction of requiring highly educated and skilled people, an issue will be the competition for talented staff. Conversely, the Industry 4.0 revolution will enrich the tasks of workers, who in turn will call for their competencies to be further developed. Projects developing education, including lifelong learning, or requalification programmes for the workforce should also be supported by the RFCS Programme. Additionally, improving working conditions and health and safety at the workplace remain important for the coal and steel industry to be able to attract people.

International cooperation

Actions in the EU alone will not solve the climate challenge, so a global effort is necessary to reduce CO_2 emissions. International exchanges and collaboration should therefore be encouraged in order to share lessons learnt and best practices and to promote technology transfer.

Innovation capacity

The development of products, processes and services aimed at producing and exploiting marketable solutions should be encouraged. Therefore, in terms of innovation projects intellectual property rights (IPR) issues should be given more consideration, as should increasing the funding rate to 100% for universities, research institutions and start-ups.

Social acceptance and trust

The negative societal perception of mining and the raw materials sector limits its capacity to innovate and wider implementation of novel products, processes and services which are contributing to the overall goal of net-zero carbon emissions. Often this perception, which leads to a lack of acceptance and trust, is due to a lack of societal awareness of the need for raw materials and steel for our daily lives, societal welfare, competitiveness and growth. Activities and projects should therefore focus on improving social awareness and acceptance of the coal and steel industry through broader public information.

Recommended cross-cutting topics for the coal and steel sectors	
CS1	Work force skills development: knowledge management and lifelong learning and education, including aspects of re-qualification and re-employment.
CS2	Development of the means for wider society learning to enhance social awareness and acceptance of the coal and steel industry.
CS3	Development of products, processes and services aiming at marketable solutions and exploitation.

Table 26 Summary of the recommended cross-cutting topics for coal and steel sectors

Based on the above recommendations, the HLG of experts suggests and puts forward a revision of the RFCS objectives for coal and steel described in Council Decision 2008/376/EC. The revision of research objectives is outlined in the following table, in the right-hand column.

Proposed revision of the RFCS research objectives - Council Decision 2008/376/EC

Original Text	Proposed amendments
Section III Research objectives for coal	
Article 4 **Improving the competitive position of Community coal**	**Article 4** **Improving the *sustainability of the coal sector***
1. Research projects shall aim to reduce the total costs of mining production, improve the quality of the products and reduce the costs of using coal. Research projects shall encompass the entire coal production chain as follows: (a) modern techniques for surveying deposits; (b) integrated mine planning; (c) highly efficient, largely automated excavation and new and existing mining technologies corresponding to the geological characteristics of European hard coal deposits; (d) appropriate support technologies; (e) transport systems; (f) power supply services, communication and information, transmission, monitoring and process control systems; (g) coal preparation techniques, oriented to the needs of the consumer markets; (h) coal conversion; (i) coal combustion.	1. *Projects shall encompass the entire coal production chain, with special attention to its sustainability. Projects shall focus on the development of:* *a)* modern techniques for surveying *coal and lignite* deposits*, as well as coalbed methane and geothermal resources linked to such deposits;* *b)* highly efficient, largely automated *exploitation technologies, including* new and *improved* mining technologies *appropriate* for the geological characteristics of coal *and lignite* deposits; *c) new and improved technologies for coal and lignite processing and use with lower environmental and climate impacts;*
2. Research projects shall also aim to achieve scientific and technological progress with a view to gaining a better understanding of the behaviour and control of deposits in relation to rock pressure, gas emissions, the risk of explosion, ventilation and all other factors affecting mining operations. Research projects with these objectives shall present the prospect of results applicable in the short or medium term to a substantial part of Community production.	2. Projects *in the field of coal production* shall aim to achieve scientific, *sustainable* and technological progress with a view to gaining a better understanding of the behaviour and control of rock pressure, gas emissions, the risk of explosion, ventilation, *slope stability* and all other factors affecting mining operations. *Special attention should be given to strengthening European technological leadership in highly efficient and advanced mining technologies and supporting technology transfer.* Projects with these objectives shall *offer* the prospect of results applicable in the short or medium term *and be relevant to the sustainability of coal production.*

3. Preference shall be given to projects that promote at least one of the following: (a) integration of individual techniques in systems and methods and the development of integrated mining methods; (b) substantial reduction of production costs; (c) benefits in terms of mine safety and the environment.	3. Projects shall focus on : a) integration of individual techniques in systems and the development of integrated mining methods; *b) development and deployment of advanced coal exploitation technologies that depend on automation and digitalisation;* *c) gasification of coal and lignite, co-processing of coal and lignite with other energy sources such as solid wastes or biomass, or carbon dioxide capture, storage and use technologies, with a view to promoting the circular economy including carbon recycling in fuels and materials;* *d) improvements in the flexibility and performance of coal-based energy supply supporting a clean energy system;* *e) alternative and sustainable uses of coal and lignite, mining wastes and residues from coal use, including non-energetic uses and the production of raw materials, with a view to promoting the circular economy and the substitution of carbon-intensive materials.*
Article 5 **Health and safety in mines** Issues concerning mine safety, including gas control, ventilation and air-conditioning with a view to improving underground working conditions and occupational health and safety as well as environmental issues shall also be taken into account in the projects covering the activities referred to in Article 4(1)(a) to (f).	**Article 5** ***Improving* health and safety** *Health and safety in the extracting industry as well as in post-mining regions is a social challenge.* Issues concerning safety *in coal mines* with a view to improving working conditions, occupational health and safety, *as well as health and safety issues associated with coal supply and use,* shall be taken into account in the projects covering the activities referred to in *Article 4(1)(a) to (c).*

Article 6 **Efficient protection of the environment and improvement of the use of coal as a clean energy source**	**Article 6** **Minimising environmental impacts of coal**
1. Research projects shall seek to minimise the impact of mining operations and the use of coal in the Community on the atmosphere, water and the surface within the framework of an integrated management strategy with respect to pollution. As the Community coal industry is undergoing constant restructuring, the research shall also be geared towards minimising the environmental impact of underground mines destined for closure.	1. Projects shall seek to minimise the impacts of mining operations and the use of coal on the *climate*, atmosphere, water and the surface within the framework of an integrated management strategy with respect to pollution. As the EU coal industry is *evolving*, research shall be geared towards minimising the environmental impact of mines both before and after closure.
2. Preference shall be given to projects that envisage one or more of the following:	2. Projects shall focus on:
(a) a reduction in emissions from coal utilisation, including capture and storage of CO_2;	a) reducing emissions from coal *use*, including *the* capture, *storage and use of CO_2 and 'hydrogen production from coal', especially when integrated into a clean energy system;*
(b) a reduction in greenhouse gas emissions, in particular methane, from coal deposits;	b) reducing greenhouse gas emissions, in particular methane;
(c) the return to the mine of mining waste, fly ash and desulphurisation products, accompanied, where relevant, by other forms of waste;	c) returning to the mine mining waste, fly ash and desulphurisation products, accompanied, where relevant, by other forms of waste;
(d) the refurbishment of waste heaps and the industrial use of residues from coal production and consumption;	d) refurbishing waste heaps and making industrial use of residues from coal *and lignite* production and *use;*
(e) the protection of water tables and the purification of mine drainage water;	e) protecting water tables and purifying mine drainage water *and wastewater from coal protection and use;*
(f) a reduction in the environmental impact of installations which mainly use Community coal and lignite;	f) reducing the environmental impact of installations which mainly use coal and lignite;
(g) the protection of surface installations against the effects of subsidence in the short and long term.	g) protecting surface *infrastructure* against the effects of subsidence in the short and long term;

Article 7 **Management of external dependence on energy supply** Research projects shall relate to the prospects for long-term energy supply and concern the upgrading, in economic, energy-related and environmental terms, of coal deposits which cannot be extracted economically by conventional mining techniques. Projects may include studies, the definition of strategies, fundamental and applied research and the testing of innovative techniques which offer prospects for the upgrading of Community coal resources. Preference shall be given to projects integrating complementary techniques such as the adsorption of methane or carbon dioxide, coal bed methane extraction and underground coal gasification.	**Article 7a** ***Ensuring the security of energy supply*** Research projects shall relate to the prospects for long-term energy supply and concern the upgrading, in economic, energy-related and environmental terms, of coal deposits that cannot be extracted economically by conventional mining techniques. **Article 7b** ***Supporting coal regions in transition*** *In synergy and/or sequencing with other EU programmes, projects shall relate to the repurposing of former coal and lignite mines and coal-related infrastructure in line with a clean energy transition in the coal regions. Repurposing shall include the non-conventional exploitation of coal and lignite deposits where this has the prospect of being economic and environmentally sustainable.*
Section IV **Research objectives for steel**	
Article 8 **New and improved steelmaking and finishing techniques** Research and technological development (RTD) shall aim to improve steel production processes with a view to enhancing product quality and increasing productivity. Reducing emissions, energy consumption and the environmental impact as well as enhancing the use of raw materials and the conservation of resources shall form an integral part of the improvements sought. Research projects shall address one or more of the following areas: (a) new and improved iron-ore reduction processes;	**Article 8** **New, *sustainable and low-carbon* steelmaking and finishing processes** Research and technological development (RTD) shall aim to improve steel production processes with a view to raising product quality and increasing productivity. Reducing emissions, energy consumption, *the carbon footprint and other* environmental impacts, as well as conserving resources, shall form an integral part of the improvements sought. Projects shall address one or more of the following areas: *a)* new and improved *sustainable iron- and steelmaking processes and operations, with*

(b) ironmaking processes and operations; (c) electric arc furnace processes; (d) steelmaking processes; (e) secondary metallurgy techniques; (f) continuous casting and near net shape-casting techniques with and without direct rolling; (g) rolling, finishing and coating techniques; (h) hot- and cold-rolling techniques, pickling and finishing processes; (i) process instrumentation, control and automation; (j) maintenance and reliability of production lines.	*particular attention to carbon direct avoidance (use of hydrogen and electrical steelmaking) and smart carbon usage (carbon capture and storage (CCS) as well as carbon capture and utilisation (CCU));* *b)* process and process chain instrumentation (incl. the detection of properties of intermediate and final products), modelling, control and automation *including digitalisation and application of big data, artificial intelligence and any other advanced technologies;* *c) process integration and process efficiency;* *d) maintenance and reliability of steel production tools;* *e) techniques for increasing the energy efficiency of steel production by recovery of waste heat, prevention of energy losses, hybrid heating techniques and energy management solutions.*
Article 9 **RTD and the utilisation of steel** RTD shall be undertaken in respect of the utilisation of steel to meet the future requirements of steel users and to create new market opportunities. Research projects shall address one or more of the following areas: (a) new steel grades for demanding applications; (b) steel properties addressing mechanical properties at low and high temperatures such as strength and toughness, fatigue, wear, creep, corrosion and resistance against fracture; (c) prolonging service life, in particular by improving the resistance of steels and steel structures to heat and corrosion; (d) steel-containing composites and sandwich structures; (e) predictive simulation models on microstructures and mechanical properties; (f) structural safety and design methods, in particular with regard to resistance to fire and earthquakes; (g) technologies relating to the forming, welding and joining of steel and other materials; (h) standardisation of testing and evaluation methods.	**Article 9** ***Advanced steel and applications*** *Research and innovation shall focus on meeting* the requirements of steel users *to develop new products* and on creating new market opportunities. Projects shall address one or more of the following areas: a) new advanced steel grades; *b) improvement of steel properties such as mechanical and physical properties, suitability for further processing, suitability for various applications and various working conditions;* *c)* prolonging service life, in particular by improving the resistance of steels, steel structure *and steel components* to heat and corrosion, *mechanical and thermal fatigue and other deteriorating effects;* *d)* predictive simulation models on microstructures and mechanical properties *or* digital models on microstructures, mechanical properties and production processes *or models for prediction of microstructure and related mechanical performance;* e) steel structures' safety and design methods, in particular with regard to resistance to fire and earthquakes; *f) steel-based retrofit and rehabilitation solutions for existing constructions;* g) technologies relating to the forming, welding and joining of steel and other materials; h) standardisation of testing and evaluation methods; *i) emerging steel processing: nanometallurgy and additive manufacturing, including*

	3D/4D printing; *j) sustainable engineering and eco-design of steel products and applications;* *k) high- performance steels in the mobility sector, such as lightweight and safety solutions and e-mobility.*
Article 10 **Conservation of resources and improvement of working conditions** In both steel production and steel utilisation, the conservation of resources, the preservation of the ecosystem and safety issues shall form an integral part of the RTD work. Research projects shall address one or more of the following areas: (a) techniques for recycling obsolete steel from various sources and classification of steel scrap; (b) steel grades and design of assembled structures to facilitate the easy recovery of steel scrap and its reconversion into usable steels; (c) control and protection of the environment in and around the workplace; (d) restoration of steelworks sites; (e) improvement of working conditions and quality of life in the workplace; (f) ergonomic methods; (g) occupational health and safety; (h) reduction of exposure to occupational emissions.	**Article 10** **Conservation of resources*, protection of the environment and circular economy*** In both steel production and steel utilisation, the conservation of resources, the preservation of the ecosystem, *the transition to a circular economy* and safety issues shall form an integral part of the *R&I* work. Projects shall address one or more of the following areas: a) techniques for recycling obsolete steel *and by-products* from various sources and *for improving the quality of steel scrap;* *b) treatment of waste and recovery of valuable secondary raw materials, including slags, inside and outside the steel plant;* *c) design of steel grades and assembled structures to facilitate the easy recovery of steel for recycling or reuse;* *d) utilisation of process gases and elimination of waste gas emissions;* *e) control and protection of the environment in and around the steel plant: gaseous, solid or liquid emissions, water management, noise, odours, dust,…;* *f) life cycle assessment and life cycle thinking.*

	Proposal to draft a new article on training and education for both steel and coal workers ***Article 11*** ***Management of work force and working conditions in the coal and steel sectors*** *Projects shall address one or more of the following areas:* *a) improving workforce management to meet the challenge of employment losses resulting from implementation of Integrated Intelligent Manufacturing, predictive models for workforce demand and workforce relocation;* *b) developing and disseminating competencies to keep pace with new manufacturing technologies such as digitalisation and to reflect the principle of lifelong learning;* *c) improving working conditions, including health, safety and ergonomics in and around the workplace.*

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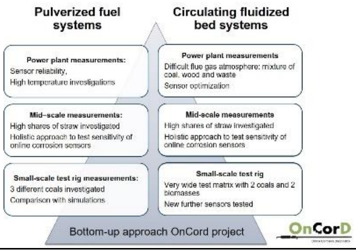
Annex 1 - RFCS success stories over 2011-2017

Acronym	 **OPTI-MINE**[58] (Reference: RFCP-CT-2011-00001 – TGC1) *Demonstration of process optimisation for increasing efficiency and safety by integrating leading edge electronic information and communication technologies (ICT) in coal mines*
Abstract	Increasing cost pressure requires optimised operation processes in coal mining. OPTI-MINE integrates and demonstrates the newest ICT developments, many originating from earlier RFCS projects, to increase the efficiency and safety of mining operations through holistic process optimisation. Five European mines in five different countries, two ICT system integrators and two universities demonstrated and assessed the reliability and impact of the process on cost effectiveness, safety and the environment through industrial scale demonstrations with different focuses. The scientifically proven results and a strong dissemination programme will boost the use of these integrated ICT systems in European mines and strengthen European mining technology on global markets.
Major outcomes	• Demonstration of technical operation capability of ICT networks and many ICT applications in five European underground mines demonstrated. • Improvement of software tools and hardware components, necessary to connect and integrate different devices, systems, applications into the network. • Transparency, efficiency, safety enhancements and cost savings have been observed in several fields. Example: the average level of information about the locations of transport units underground was raised by about 60%. • Development of data, know-how and expertise for performance assessment were developed. • Development of key performance indicators (KPIs) and impact evaluations. • Determination of process improvements. • Demonstration of application fields: material logistics, personnel communication and information, personnel tracking, environmental monitoring, machine communication, conveyor monitoring; longwall control from surface.
Main benefits for stakeholders, the sector and society	The benefits demonstrated by this comprehensive optimisation of mining processes are related to considerable improvements in process and economic efficiency, mine safety, occupational safety and environmental impacts in the underground mining sector. • Reduction in production and equipment downtimes. • Cost reduction in investment, installation, application, operation and maintenance of communication systems. • Cost reduction in production control and monitoring. • Efficient use of resources by using one common IT network for all applications. • High reliability of the network infrastructure. • Timely and effective information of workers in emergency situations and guidance to safe areas. • Energy savings e.g. through more efficient and less frequent underground transport of materials. • The open network platform allows the integration of new and existing country-specific equipment from different manufacturers.

[58] The synopsis as well as information on projects' duration, budget and consortia are available under the public documents on the RFCS website: https://ec.europa.eu/info/files/rfcs-funded-projects-2003-2015_en

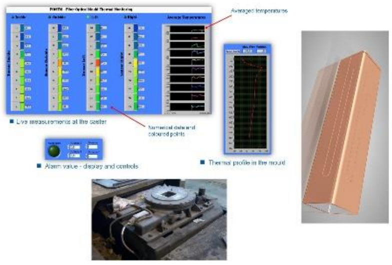
Title	 **HUGE2** (Reference: RFCR-CT-2011-00002 – TGC2) *Hydrogen oriented underground coal gasification for Europe - Environmental and Safety Aspects*
Abstract	The project focused on safety and environmental aspects of underground coal gasification (UCG). An underground trial has been carried out in mine testing a two borehole system and reactive barriers usage. The most serious environmental concerns related to UCG were investigated, i.e. contamination of underground aquifers and potential leakage of poisonous and explosive gases into the surrounding strata. The works were focused on finding practical ways to prevent possible leakages by use of reactive barriers. A complex system of environmental telemetric monitoring was built and tested. Technical and ecological risk assessments were also carried out.
Major outcomes	The main results of the project were as follows: • development of a method of monitoring, operation and process completion procedure for the in-situ UCG, based on the results of two UCG *ex situ* and one *in situ* experiments; • recommendations for an interactive environmental monitoring and protection system; • determination of qualitative and quantitative limits for potential organic and inorganic contaminants; • development of mathematical models for water and gas migration in various materials (rock, coal, coke), based on experimental measurements including groundwater migration and contaminants propagation in rock mass; • definition of main hazards, tools and risk strategy for the UCG process and elaboration of the decision-support system for hazards and malfunctions; • model of roof convergence and evolution of fractured zone in the rock mass resulting from the UCG operation; • surface and cavity monitoring method; • assessment of the effectiveness and efficiency of contaminant removal from groundwater by permeable reactive barriers. Examples of 3 of the 16 publications issued : *Kapusta K., Stańczyk K. Chemical and toxicological evaluation of underground coal gasification (UCG) effluents. The coal rank effect.* ***Ecotoxicology and Environmental Safety****, 2015, 112, 105-113* *Wiatowski M., Kapusta K., Świądrowski J., Cybulski K., Ludwik-Pardała M., Grabowski J., Stańczyk K. Technological Aspects of Underground Coal Gasification using Oxygen in the Experimental "Barbara" Mine,* ***Fuel****, 2015, 159, 454–462.* *K. Soukup, V. Hejtmánek, P. Čapek, K. Stanczyk, O. Šolcová Modeling of contaminant migration through porous media after underground coal gasification in shallow coal seam,* ***Fuel Processing Techn****ology*, *2015, 140:188-197*
Main benefits for stakeholders, the sector and society	The HUGE2 project has played a complex role in the development of UCG technologies, an important element of clean coal technology proposals for Europe. It has enabled the strengthening of consolidation between the European laboratories involved in the development of UCG technology and the continuation of collaboration between European experts and European coal companies. The project has also helped to overcome legal and formal restrictions by improving knowledge of the environmental constraints and hazards as well as providing the tools to help overcome these constraints. HUGE2 has delivered the resources and opportunities for the development of the Clean Coal Technology Centre in the Central Mining Institute, Poland.

Title	 **Oncord** (Reference: RFCR-CT-2014-00010 – **TGC3**) *Online corrosion monitoring for the combined combustion of coal and chlorine-rich biomasses in pulverised fuel and circulating fluidised bed systems*
Abstract	The trend towards renewable energy sources is leading to an increased share of biomass used in solid fuel-fired power plants. This development and the demand for increasing live steam temperatures result in severe operational problems, such as high temperature corrosion which can lead to unscheduled power plant shut downs and decreased boiler availability. Co-firing biomass is often limited to high-quality wood materials. It has been observed that the proper combination of coal and chlorine-rich biomass significantly reduces corrosive deposits. Within the Oncord project, co-firing of chlorine-rich biomasses at high shares and with elevated steam temperatures is enabled by using coal and its ash as a protective agent. Coal and its inorganic constituents such as sulphur and alumina-silicates are able to prevent the formation of alkali chlorides, and consequently chlorine-rich deposits. Two online corrosion sensors were tested under aggressive conditions and long-term exposure tests in pulverised fuel and fluidised bed systems of varying size. The project provides strategies for setting up fuel blends and strengthening the position of solid fuel-fired boilers, particularly the position of coal since it enables the use of low-grade biomass in highly efficient combustion systems.
Major outcomes	Both online corrosion sensors were shown to be ready for utilisation in large-scale power stations. Both sensors demonstrated a fast response to changes in the boiler flue gas atmosphere which could enable their use in fuel blend control. With improved reliability, availability and maintainability there is a clear economic benefit to the plant operators. As one of the main outcomes of the project, a holistic online corrosion measurement system for alkali-chloride induced corrosion was developed. The whole system was shown to be reliable in several experiments. Based on the results of the experiments, a number of corrosion mitigation strategies for co-combustion environments have been developed that boiler operators can use both for PF and CFB firing systems. This can be used to optimise asset integrity management, for example, ensuring that the replacement of superheater elements occurs during an appropriate planned shutdown to avoid unexpected losses of operation time. Small-scale experiments can be used in the future to assess the compatibility of different fuel blends and their suitability for PF or CFB combustion applications.
Benefit for stakeholders, the sector and society	The project has made a very valuable contribution to the understanding of the processes occurring during the co-combustion of low-grade fuels with coal. Boiler operators interested in realising co-firing projects can use the derived conclusions to inform their decision-making. The results from the *OnCord* project are transferable to a certain extent to the interaction of corrosion-reducing additives used in pure biomass combustion. The cost-saving potential of the corrosion management solution for an ~140 MW CFB boiler, for example, is approx. €400,000/year. The payback time for the investment in a corrosion monitoring system is approximately 1 year.

Acronym	 **HISARNA B and C** (Reference: RFSR-CT-2011-00002 – TGS1) *HIsarna experimental campaigns B and C*
Abstract	HIsarna is a new ironmaking concept developed under FP6-ULCOS, characterised by very low CO_2 emissions and direct use of coal and ore. It combines previous developments known as CCF and HIsmelt. The project's main objective is to gain a detailed understanding of the process principles and hardware performance, and thus knowledge of the robustness of the process concept. Following the design of experiments and related engineering, trials are to be carried out in the HIsarna experimental plant in IJmuiden. These trials should eventually provide information for a future scale-up of the process.
Major outcomes	During the project two experimental campaigns with the pilot plant were successfully carried out. These showed the technical feasibility of the process, the coal rate, the product quality and the flexibility to use a wide range of raw materials. Low grade ore and steam coals were tested. During campaign C the hot metal from the HIsarna plant was delivered to the steelmaking shop for further processing into steel. The test campaigns also confirmed that the HIsarna off-gas is suitable for CCS because of its highly concentrated CO_2 and low N_2 content. The tests were so successful that the project partners decided to continue the test work with another campaign (D) after the completion of the subsidised programme.
Benefit for stakeholders, the sector and society	Prior to the recent campaign, E, the pilot plant was substantially upgraded with a new off-gas system, a new control system and dedicated coal and ore storage, preparation and supply systems. The objective of this upgrade was to make longer full continuous trial periods possible and test the operational performance of the process and the plant components. A dedicated crew for five-shift continuous operation was hired and trained. In total over 65 FTE. Campaign E, which investigates the long-term process stability, has just been completed and was supported by Horizon2020, SILC-II, Tata Steel, ArcelorMittal, Thyssen Krupp Stahl and Voestalpine. The engineering study for an industrial scale HIsarna demonstration plant has been started. It is intended to operate this plant well before 2030. The HIsarna technology can contribute to a more sustainable steel industry because of its high energy efficiency and favourable off-gas composition for the application of CCS or CCU. The technology can also contribute to a circular economy because of its ability to recycle Zn-containing waste oxides. The Zn will be concentrated in the process dust. The 'Reclamet' project that investigates the recovery of Zn is supported by the EIT-Raw materials, Tata Steel, CRM, Technical University of Delft and Nyrstar.

Title	 **GREENEAF2** (Reference: RFSP-CT-2014-00003 – TGS2) *Biochar for sustainable EAF steel production*
Abstract	The objective of GREENEAF2 was to apply as standard practice the use of char from biomass as a substitute for fossil coal in electric arc furnaces. The initial GreenEAF project demonstrated the feasibility of using char in EAFs but also highlighted the need to further investigate certain aspects, such as: - charging in the bucket: preliminary industrial trials were promising, but char reactivity must be controlled and EAF operating practice optimised; - injection: in order to promote slag foaming, injection systems have to be improved. Modification of injection systems has already been studied but field validation is required. The effects on plant productivity, costs, environmental issues, materials handling and storage are also evaluated.
Major outcomes	The main outcomes from the project activities and industrial trials are the following. • Solid biochar and solid biomass can replace fossil coal; better results were obtained in an industrial furnace equipped with oxygen diffusors which allowed the partial recovery of the energy from the volatile content of biogenic material, contributing to energy saving (6% obtained in the project tests). • Regarding the injection, the results of the industrial tests were only partially satisfactory; in fact the slag foaming behaviour, which is essential in the EAF process (with important effects in energy efficiency, furnace maintenance, noise emissions and formation of NOx), occurred in a discontinuous manner. This means that foaming can be obtained, but redesign of the injector is necessary. • LCA assessment evaluation showed a 15% reduction in CO_2 emissions.
Benefits for stakeholders, the sector and society	The benefits for stakeholders are: • creation of new local economies; • consolidation of steel as a ‘green’ product; • improvement of collaboration among local institutions and other industrial sectors (such as food companies). The benefits for the sector are: • contribution to a reduction in CO_2 emissions without drastic modification of the production cycle; • possibility to reuse low grade biomass and waste from the food industry, promoting industrial symbiosis activities; • biochar prices do not fluctuate like those of fossil raw materials. The benefits for society are: • creation of new local economies.

Title	**Hirods** (Reference: RFSP-CT-2013-00006) On-Line High sensitive Roll Mark Detection System: industrialization and assessment
Abstract	Roll marks represent on average the half of defects observed on the cold rolling mill. They are tiny defects barely visible on the strip at this process stage, in the majority of cases. Their automatic detection would be the most efficient at this stage in terms of product quality and costs savings, but no adapted industrial device on the market exists. Nevertheless, a previous RFCS project, ROLLMARK, demonstrated that a modular system based on the multi-reflectivity measurement should be able to detect on-line roll marks, even the tiniest. EU savings of such industrial system have been evaluated at about 9M€/year in Europe. This system will also enable steel producers to offer high-quality products especially for automotive industry and enhance their brand image. HIRODS is a demonstration project aiming at providing an industrial high sensitive detection system able to efficiently detect online roll marks at the cold rolling mill exit and thus avoid their reproduction on long series of steel coils. This industrial system is based on the ROLLMARK project, in which measurements and detection potentials have been validated. Some detector modules were installed at the ArcelorMittal Sagunto's tandem mill exit to validate the possibility of on-line measurements in real industrial environment. Hirods contributed: - to complete the system implementation at the tandem mill in order to monitor the full steel strip width, - to optimize the data processing algorithms specifically developed to reach a high level of roll marks detection, - to integrate them in the system processors to obtain an automatic inspection system, - to provide the most suitable and ergonomic system for an easy use by operators, - to assess the completed system in real industrial conditions and determine its performance level. The expected performance is an on-line roll mark detection rate of at least 92% with an overdetection rate lower than 10%.

Title	 **FOMTM** (Reference: RFSP-CT-2012-00007 – TGS3) Fibre optical thermal monitoring at CC billet mould
Abstract	The aim of this pilot & demonstration project was to develop and demonstrate improved control of the initial solidification process at meniscus level to enhance surface quality of as-cast products. The innovative fibre optical temperature measuring technique (FOTS) was therefore applied at billet moulds of a six-strand caster. Forty temperature measurement positions were spread onto four faces of each mould. Two moulds were equipped and about 340 heats were measured. No significant indications of wear caused by the harsh environment at the caster could be observed at the fibres, not even after the mould revamping procedure. Online operating software was developed to visualise information on the process behaviour in the mould, especially regarding the thermal profile, and alarm values for unwanted process situations. Investigations with different steel grades, mould powders and the impact of varying powder quantities were carried out. It was demonstrated how different casting parameters and strategies of powder addition affect the surface quality. Additional effects could be observed especially at the start of casting when the rim is being settled. For example, the analysis of the cast samples in relation to FOTS data showed the dependence of longitudinal crack formation and further surface defects on temperature behaviour. Regarding this, optimised operating procedures and alarm values were developed and tested successfully.
Major outcomes	The pilot installation of the novel measuring technique using FOTS has demonstrated that this technology can survive under the harsh environment conditions of a caster. With the chosen layout and corresponding handling of the FOTS sensors insertion in the mould it was even possible to withstand the revamping procedure. The FOTS system allows analysis of the solidification process behaviour and process events that happen inside the mould. A relationship between these events and the surface quality of the products has been observed, which has helped to develop new solutions to improve the process control and the strand quality. The operator receives detailed visual information on the thermal behaviour in the mould, and undesired process conditions become recognisable. An alarm value was developed especially for unwanted occurrences during mould powder addition.
Benefit for stakeholders, the sector and society	- Development of a suitable online recording and analysis of the thermal mould data, to assess mould powder performance, slag rim behaviour and the initial solidification in terms of homogeneity. - Provision of validated new solutions to improve casting strategies, process control and strand quality. - Enhancement of surface quality of as-cast products. The FOTS technology can also be transferred to other types of moulds and casters, and also to other similar industrial plants where conclusions can be obtained from temperature profiles in comparable temperature ranges.

Title	 **ACE-PICK (Reference: RFSP-CT-2014-00013 – TGS5)** *First worldwide full-scale demonstration of alternating current (AC) electrolytic pickling on carbon and stainless steel coils*
Abstract	An innovative electrolytic pickling process, based on alternating current (AC), has been developed at laboratory scale for carbon and stainless steels. AC represents a real breakthrough in the pickling process. Laboratory tests showed for stainless steel grades a much higher efficiency than conventional treatment in terms of reducing pickling time, saving on use of fresh chemicals and minimising environmental impact. Also, surface quality is enhanced by AC pickling due to the fact that shot blasting and/or abrasive brushing can be eliminated or reduced. Regarding carbon steel, laboratory tests and also the RFCS 'NEXTEP' project confirmed that AC electrolytic pickling can be used as a booster to increase the productivity of pickling lines or increase their flexibility in terms of the range of products that can be treated at the same line speeds. This is particularly the case for carbon-steel (C-steel) grades that normally result harder to be pickled such as special C-steel grades. The main objectives of this project are to install an AC pickling section on an annealing and pickling line (and to validate at full industrial scale the new AC process/technology on both stainless steel and carbon grades). The main activities carried out were the following: 1. design, installation and erection of the new electrolytic section for use with the AC process, 2. laboratory definition of working conditions with the AC on stainless steel and carbon grades, 3. design of an innovative filtering system for removing unsolved scale and online validation test, 4. durability and reliability evaluation of the technological solutions employed, 5. long-term pickling tests on hot and cold rolled steel grades, 6. qualitative and comparative surface characterisation, 7. evaluation of the effects of AC on consumption of fresh chemicals and sludge production, 8. technical-economical balance of the benefit of AC process/technology compared to conventional ones.
Major outcomes	A new AC tank has been conceptually designed on the basis of labs trials and intensive modelling activities. The line was successfully started up at the Marcegaglia A&PL.1. The operating procedures for both S-steel and C-steel have been defined and optimised through extensive industrial trials (more than 3 years of line-running and more than 400kt of stainless steel produced). The reliability and flexibility of the adopted technologies (cell arrangement, sludge removal, electrodes,…) were demonstrated through an intensive monitoring campaign and offline evaluations. In addition, the cost/benefit evaluations were made considering a lot of line configurations.
Benefit for stakeholders, the sector and society	Regarding stainless steel grades, the AC pickling contributes to a dramatic improvement in line productivity (A&PL.1 up to 25%) and produces a meaningful reduction in fresh chemicals consumption (up to 25% vs mixed acid). The lower use of chemicals results in a major reduction in the environmental impact of the pickling process. Considering C-steel, the AC technology may be used only in specific cases when it is necessary to have increased production with the same available space that does not permit longer pickling tanks. It will be also convenient when in an existing line it is necessary to process difficult grades of material that should be processed at a lower speed.

Title	**NEWQP (Reference: RFSR-CT-2011-00017 NEWQP – TGS6)** New advanced high strength steels by the quencing and partitioning (Q&P) process
Abstract	This project developed new advanced high strength steel grades by means of the "Quenching and Partitioning" (Q&P) process for application in the automotive sector with improved strength, ductility and strain hardening. Q&P opens the way to develop steel microstructures based on the exceptionally advantageous combination of austenitic and martensitic phases at the industrial scale. The industrial applicability of the Q&P process will be improved in terms of compositions, treatments and properties as galvanisability and weldability to develop a controlled and reproducible production process for these materials, and be prepared for future developments. Project web page: http://newqp.ctm.com.es/
Title	**S+G** (Reference: RFSR-CT-2012-00026 – **TGS8**) Innovative steel glass composite structures for high-performance building skins
Abstract	High-innovation of products is a worldwide key-competitive factor. The most important technological achievements in modern architecture are attained by constructing smart building skins, usually by combining glass and metal (so far mainly aluminum). S+G project studies composite Steel+Glass systems for highperformance skins using revolutionary adhesive junctions meeting requirements of: energetic/structural efficiency, aesthetical high value (free-form design), reuse and recycling. Because of differential thermal expansion with glass, those adhesive junctions are compatible with steel only. This is a keyfactor in the intermaterial competition (steel vs. aluminium) and for the competitiveness of the European steel and building industry throughout the world.

Title	 Project funded by the European Union's Research Fund for Coal and Steel (RFCS). **HIPEBA (Reference:** RFSR-CT-2014-00021 – TGS7) *HIgh PErformance steel for safer and more competitive safety BArriers*
Abstract	Safety barriers or road restraint systems (RRS) are protection devices installed on roadsides to contain and redirect errant vehicles. Steel is the most widely used material in their manufacture (typically roll-formed profiles, from mild steel such as 235JR). The **main goal** of the HIPEBA project was to **develop safer and more competitive** RRS by using **high-performance steels.** The Project put the focus on the following scenarios: • **Urban areas**: protecting pedestrians from vehicle intrusions in scarce space. • **Very high containment**: increasing the maximum restraint level for heavy good vehicles (up to 60,000 kg)(1) (1)This means 34% higher containment level than the current maximum ('H5b') To achieve this goal, a scientific-based material choice and **comprehensive analysis of the material characteristics** that contribute to improving a safety barrier at each stage of its life cycle was carried out. Product manufacturing, installation, impact response, durability and maintenance were assessed to determine **how the high-performance steels improve** the barrier systems. The selected steels were implemented into demonstration prototypes that were tested for final validation. The performed cost-benefit analysis showed an excellent ratio between the costs and societal benefits (estimated **casualties reduction**) due to the increase in the containment level using high performance steels in RRS.
Major outcomes	Two systems made of high-performance steels (S700MC) were tested, with the following results: • **34% more energy absorption** level than the current maximum (Standard EN 1317); • **31% weight reduction** (kg/m) due to using high-performance steels; • **8% lower purchase price** than a system with equivalent restraint level made of mild steels; • **cost-benefit ratio**(2): 1.92 (for H5b system made of HPS); • **net present value**(NPV)(3): 57.187 (€/km) (2) In a CBA all welfare effects are measured in terms of their equivalent money value. **Cost-benefit ratio = Societal benefits (€) / Implementation costs (€).** (3) A positive value for NPV means that over the measured life time the discounted cash inflows are higher than the discounted cash outflows of a project. **Net present value (NPV) = Present value benefits - Present value costs.** To calculate the present value (year 0) of each yearly cost and benefit, along the full time frame of the barrier life, a discount rate is applied.
Benefit for stakeholders, the sector and the society	From the industrial side, the cost analysis **showed a clear cost reduction** in each stage of its life cycle due to the use of high-performance steels. This clearly increases the competitiveness of companies which use high-performance steel in their products. The use of high-performance steels allows to provide systems with higher containment levels. These systems will be able **to reduce the fatalities and injuries resulting from accidents** involving these barriers, yielding direct benefits to society. The **project's results proved** that RRS manufactured with high-performance steels bring benefits from **both an industrial and societal point of view**.

Title	**PUC** (Reference: RFSR-CT-2013-00031- PUC – TGS9) *Product Uniformity Control*
Abstract	The uniformity of the microstructure of steel strip over coil length and between different coils of the same grade is key to consistent material behaviour at steel manufacturers' proprietary processes like rolling and customers' processes like pressing and deep-drawing. Evidently, stable and consistent processes yield optimal product quality and maximise efficiency, giving minimal loss of material and energy over the entire production chain. The uniformity of a coil can be monitored and improved only using continuous product measurements over the full length of the strip. Practically all measurement techniques to monitor the microstructure online are based on sensing the electromagnetic and ultrasonic properties. Despite many efforts, however, the steel research community has not established unique and universal relationships between the online measured parameters and microstructure. Against this background, the Product Uniformity Control (PUC) project does not aim for absolute prediction of microstructure parameters but looks for relative relationships in order to improve the uniformity of steel strip. The PUC project follows an integrated research path of modelling, laboratory tests and dedicated plant trials to improve understanding of the relationship between microstructure and online measured parameters. It also aims to understand and reduce cross-sensitivities of the sensor systems to measurement conditions like speed and lift-off. Finally, it investigates the quality and monetary benefits from applying continuous product uniformity monitoring in the steel industry.
Major outcomes	Numerical models have been developed describing the electromagnetic and ultrasonic properties for different steel microstructures with variations in grain size, grain elongation, crystallographic texture, phase balance and stress. Models have been validated using dedicated laboratory studies with reference microstructures. In addition, sensor models have been built to predict the output of non-destructive, inline measurement instrumentation, as a function of steel grade and measurement conditions. In certain cases, data inversion could be applied to retrieve material properties from sensor data. Based on statistical analysis of inline data, algorithms have been developed to classify coils according to their product uniformity. Accordingly, non-uniform strip sections could be identified, which were cut into samples for laboratory characterisations. In this way, inline measured non-uniformities could be reproduced by lab measurements and could even be attributed to variations in microstructure.
Benefits for stakeholders, the sector and society	The results demonstrate that process measurements and inline product property measurements can be used to select strip sections with microstructure variations. In particular, for continuously annealed steels, savings can be achieved by setting better cutting positions, reducing repair effort (including repair of coil ends) and improving coil logistics. Moreover, a smart inline measurement strategy can be beneficial to the yield of advanced high-strength steels. With a total European production of HDG strip of about 25 Mt per year, the potential monetary benefits have been estimated at about €60-70 m annually for the European steel industry. The PUC consortium has actively disseminated the results by publishing more than 30 scientific papers and participating in international conferences.

Annex 2 - Rules of Procedure and Terms of Reference

EUROPEAN COMMISSION
DIRECTORATE GENERAL FOR RESEARCH & INNOVATION

Directorate D - Industrial technologies
D.4 - Coal and Steel

RULES OF PROCEDURE OF THE EXPERT GROUP ON RFCS MONITORING AND ASSESSMENT (7 YEARS)

September 2018

THE EXPERT GROUP ON RFCS MONITORING AND ASSESSMENT (7 YEARS),

Having regard to Council Decision 2008/376/EC[59] on the adoption of the Research Programme of the Research Fund for Coal and Steel and on the multiannual technical guidelines for this programme, in particular Article 38 and 39 thereof,

Having regard to Commission Implementing Decision of 30.05.2018 C(2018) 3245 final and in particular point 1.3 of its Annex,

Having regard to the standard rules of procedure of expert groups[60], HAS

ADOPTED THE FOLLOWING RULES OF PROCEDURE:

Point 1

Operation of the group

The group shall act at the request of its chairman with the agreement of DG RTD - Unit D4 - Coal and Steel (hereinafter referred to as the Commission).

Point 2

[59] OJ L 130, 29.05.2008, p.7., amended on 29 May 2017 with Council Decision 2017/955
[60] C(2016)3301 (Annex 3)

Convening a meeting

Meetings of the group are convened by the Chair, with the agreement of DG RTD either on its own initiative, or at the request of a simple majority of members after DG RTD has given its agreement.

Joint meetings of the group with other groups may be convened to discuss matters falling within their respective areas of responsibility.

The Commission shall send the invitations to the experts.

All meetings will be presided by the Chair. The meetings shall be located in Brussels. The date of the meeting shall be proposed by the Commission for approval of the Expert Group.

Point 3

Agenda

The Commission shall draw up the agenda in consultation with the Chair and send it to the members of the group together with the invitation to the meeting at least 15 days before the meeting takes place.

The agenda shall be adopted by the group at the start of the meeting.

Point 4

Documentation to be sent to group members

The secretariat shall send the invitation to the meeting and the draft agenda to the group members no later than 15 calendar days before the date of the meeting.

The secretariat shall send documents on which the group is consulted to the group members no later than 15 calendar days before the date of the meeting.

In urgent or exceptional cases, the time limits for sending the documentation mentioned in paragraphs 1 and 2 may be reduced to five calendar days before the date of the meeting.

Point 5

Opinions of the group

As far as possible, the group shall adopt its opinions, recommendations or reports by consensus.

In the event of a vote, the outcome of the vote shall be decided by simple majority of the members. The members that have voted against or abstained shall have the right to have a document summarising the reasons for their position annexed to the opinions, recommendations or reports.

Point 6

Sub-groups

The Commission may set up sub-groups for the purpose of examining specific questions on the basis of terms of reference defined by the Commission. Sub-groups shall operate in compliance with the Commission's horizontal rules on expert groups ('the horizontal rules') and shall report to the group. They shall be dissolved as soon as their mandate is fulfilled.

The members of sub-groups that are not members of the group shall be selected via a public call for applications, in compliance the horizontal rules61.

Point 7

Invited experts

The Commission may invite experts from outside the group with specific competence on a subject on the agenda to participate in the work of the group on an ad hoc basis.

Point 8

Observers

Individuals/organisations/public entities may be granted an observer status, in compliance with the horizontal rules, by direct invitation.

Organisations/public entities62 appointed as observers shall nominate their representatives.

Observers and their representatives may be permitted by the Chair to take part in the discussions of the group and provide expertise. However, they shall not have voting rights and shall not participate in the formulation of recommendations or advice of the group.

Point 9

Written procedure

If necessary, the group's opinion or recommendation on a specific question may be delivered via a written procedure. To this end, the secretariat sends the group members the document(s)

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3 [61] See Articles 10 and 14.2.

4 [62] To be inserted as required.

on which the group is being consulted. However, if a simple majority of group members asks for the question to be examined at a meeting of the group, the written procedure shall be terminated without result and the Chair shall convene a meeting of the group as soon as possible.

Point 10

Secretariat

The Commission shall provide secretarial support for the group and any sub-groups.

Point 11

Minutes of the meetings

The Commission shall prepare meaningful and complete minutes, recording the main discussions on all the points on the agenda. The minutes shall be sent to the members of the group.

The Members shall give their feedback on the minutes. The minutes shall be adopted by the group at the start of the next meeting.

The Commission, in consultation with the Chair, shall draft minutes of any ad hoc or joint meetings.

Point 12

Attendance list

At each meeting, the Commission shall draw up an attendance list also specifying, where appropriate, any Member States' authorities, organisations or other public entities to which the participants belong.

All participants shall be requested to sign the attendance list at each meeting.

Point 13

Conflicts of interest

Notwithstanding the data provided on the standard Declaration of Interest form, members of the Expert Group appointed in their personal capacity shall notify the Commission representative ahead of a meeting of the group of any (potential) conflict of interest with any of the information to be discussed.

Should a conflict of interest, which may compromise the capacity to act independently, arise, the Commission shall take all appropriate measures, in compliance with Article 11 of the horizontal rules.

Conflicts of interest shall be reported in writing. Information registered must be adequate, relevant and not going beyond what is necessary for the purpose of the management of the conflict of interest.

Point 14

Correspondence

Correspondence relating to the group shall be addressed to the Commission, for the attention of the Chair.

Correspondence for group members shall be sent to the e-mail address which they provide for that purpose.

Point 15

Transparency

The Expert Group on RFCS Monitoring and Assessment (7 Years) shall be registered on the Register of Commission Expert Groups.

As it concerns the group composition, the following data shall be published on the Register of Commission Expert Groups:

The name, nationality and gender of individuals appointed in a personal capacity;

The name nationality and gender of observers.

Individuals who do not wish to have their names disclosed may submit a request to the Commission for derogation from this rule. Derogation shall be granted where justified on compelling legitimate grounds in relation to the specific situation of the individual, in particular where disclosure of the expert's name could endanger their security or integrity.

The Commission shall make available all relevant documents, including the agenda, the minutes and the participants' submissions, either on the Register of Commission Expert Groups or via a link from the Register to a dedicated website, where this information can be found. Access to the dedicated website shall not be submitted to user registration or any other restriction. In particular DG RTD shall publish the agenda and other relevant background documents in due time ahead of the meeting, followed by timely publication of the minutes. Exceptions to publication shall be foreseen where it is deemed that disclosure of a document would undermine the protection of a public or private interest as defined in Article 4 of Regulation (EC) N° 1049/200163.

In accordance with Regulation (EC) no 45/2001 of the European Parliament and of the Council of 18 December 2000 on the protection of individuals with regard to the processing of personal data by the European Institutions and bodies and on the free movement of such data, explicit consent to the publication of group members' data on the RFCS website is required.

Point 16

Access to documents

Applications for access to documents held by the group will be handled in accordance with Regulation (EC) No 1049/20016 and detailed rules for its application[64].

Point 17

Deliberations

In agreement with the Commission (DG RTD), the group may, by simple majority of its members, decide that deliberations shall be public.

[63] Regulation (EC) No 1049/2001 of the European Parliament and of the Council of 30 May 2001 regarding public access to European Parliament, Council and Commission documents (OJ L 145, 31.5.2001, p. 43).

[64] Commission Decision 2001/937 of 5.12.2001. OJ L 345 of 29.12.2001, p. 94.

TERMS OF REFERENCE

EXPERT GROUP ON RFCS MONITORING AND ASSESSMENT (7 YEARS)

1. Context and background information

As regards to the legal basis of the Research Programme of the Research Fund for Coal and Steel (RFCS), it is outlined in the Council Decision n° 2008/376/EC of 29 April 2008, published in the Official Journal of 20 May 2008, ref. OJ L 130/7, laying down the multi-annual technical guidelines for this programme.

As foreseen in article 38 of this decision, the Research Programme shall be subjected to an assessment and monitoring exercise on completion of the projects financed during every period of seven years. In line with the Better Regulation Guidelines of the European Commission, the exercise shall focus on the effectiveness, efficiency, relevance, coherence and EU added-value of the programme. In the same article, it is foreseen that the Commission shall be assisted by a panel of highly qualified experts.

2. Purpose, objectives and scope

The purpose of such exercise is to produce a review of the Research Fund for Coal and Steel between 2011 and 2017 and a possible revision of the multi-annual technical guidelines. In addition, the findings of the exercise shall give input to the synergies between the RFCS Programme and the next EU Framework Programme for Research and Innovation.

The main objectives of the assessment and monitoring exercise are:

- To analyse the functioning of the RFCS Programme;
- To draw recommendations for the improvement of the operation of the RFCS Programme;
- To assess the expected benefits of the programme;
- To review the programme according to the 5 criteria of the EU better regulation evaluation (effectiveness, efficiency, relevance, coherence and EU added-value).

In particular, the assessment and monitoring exercise should address the following points:

- Relevance:
  - Is the RFCS Programme tackling the right issues?
  - Flexibility to adapt to new scientific and socio-economic developments
  - Addressing specific stakeholder needs

- Effectiveness:
  - Short-term outputs from the programme/projects
  - Progress towards attaining the specific RFCS objectives
  - Early success stories

- Efficiency:
    - Budgetary resources
    - Programme's attractiveness
    - Cost-benefit analysis

- Coherence:
    - Internal coherence
    - External coherence

- EU added value:
    - RFCS projects demonstrating EU added value
    - Benefits for the European coal and steel sectors

Special attention shall be paid to lessons learnt and any possible improvement of the current procedures and to any possible reduction of administrative work for the Commission and the beneficiaries.

The scope of this exercise is to monitor and assess the projects of the Research Programme which were signed between 2011 and 2017 and for which the Deliverables and Reports have been accepted by the Commission Services.

The exercise shall encompass all aspects of the operation of the Research Programme including the programme objectives and to draw, if needed, any recommendation for improvement. The exercise shall encompass the results of a sample of individual RFCS projects thanks to the insights coming from three RFCS accompanying measures.

3. Working approach and methodology

The work shall be divided among the inputs from the chairs of the Technical Groups, the Expert Group and the inputs from three Accompanying Measures (LowCarbonFuture and GRISPE PLUS for Steel and CoalTech2051 for Coal).

The Chairs of the Technical Groups shall be requested to provide a qualitative/monitoring evaluation of the RFCS Programme based on a specific template.

The inputs from the three Accompanying Measures shall focus on the quantitative/assessment part of the programme, based on the five Better Regulation Guidelines.

The experts shall collect both information and summarise, producing a final report.

The monitoring and assessment shall be carried out by data analysis, evaluation of reports, insights of the Technical Groups Chairs and of the Accompanying Measures. The methodology will comprise:

- Screening of a sample of RFCS projects signed between 2011 and 2017
- Technological developments in the different coal and steel areas - reports from the Chairs of the Technical Groups
- Statistical evidences from the Commission - coverage of Technical Groups, budget, research or demo/pilot, consortium size and composition, Member States participation
- Analysis of reports provided by the Accompanying Measures, eventually by questionnaires to Coordinators

- Identification and description of benefits to the sector and society
- Recommendations by the experts

4. Distribution of the work among experts

The Chair in close collaboration with the Commission will prepare and follow the planning, the progress against the key milestones and ensure the quality of the final report. The Commission will provide guidance for the experts. The experts will be responsible for the proofreading and feedback of the report.

Three rapporteurs will feed the report with the inputs from the three Accompanying Measures and from the Chairs of Technical Groups. The experts will review, comment on and approve the final reports. The experts shall submit the final report to the Commission.

5. Meetings, reporting and deadlines

The following planning is foreseen (exact dates will be determined by the Commission):

- Summer 2018 - First meeting with Expert Group - Start exercise – Review of ToR, of Methodology and definition of tasks
- Fall 2018 - Second meeting - Delivery of interim results, including presentations from the Technical Groups Chairs
- March 2019 – Third meeting - Validation seminar with stakeholders and policy-makers
- May 2019 – Draft final report
- September 2019 – Publication of final report

The major outputs of the monitoring and assessment to be submitted to the Commission are:

- A first intermediate report for review and consultation in CAG and SAG in September 2018
- A validation seminar with key stakeholders in March 2019
- A draft report to be submitted to the Commission by May 2019
- A final report to be published at the end of 2019

The intermediate report shall outline the main findings of the programme and its role to the community and the European Union as a way to feed the discussions for the next EU Framework Programme for Research and Innovation.

The final report shall include an analysis of findings and a set of conclusions and recommendations reflecting the objectives of the monitoring and assessment on the basis of the five criterion underlined in the EU better regulation guidelines. The main section of the final report should include a largely self-contained executive summary (5 pages).

The final report shall be written in English and be provided to the Commission electronically. No confidential information may be included as it will be published. The final report shall be prepared in two iterations:

- A draft version which shall be discussed with the Commission and the Expert Group in order to discuss and validate the preliminary results obtained, to benefit from the feedback, comments and suggestions and to ensure the full relevance and usefulness.
- A final version which shall take into account the remarks made.

6. Expert profile

The nature of the proposed tasks requires a high qualified Expert Group in the field of coal and steel sectors, with a good knowledge about the RFCS programme.

Annex 3 - Validation Conference 'Steel and Coal: A New Perspective – Research and Innovation in Action'

On 28 March 2019, the European Commission's Directorate-General for Research and Innovation organised and hosted the conference 'Steel and Coal: A New Perspective — R&I in Action'. The event, which gathered more than 100 stakeholders from the steel and coal communities, explored the prospects for technological breakthroughs for steel and coal in a world in transition faced with the challenges of globalisation, decarbonisation and digitalisation. The conference was also an opportunity to discuss with stakeholders the preliminary results of the seven-year monitoring and assessment of the RFCS programme. Stakeholders were invited to express, on a flash card distributed to all those present, their observations on the preliminary results of the RFCS monitoring and assessment as well as their reflections on future challenges for the RFCS Programme, emerging trends in R&I and ways to maximise the impacts from R&I. The results of this consultation are summarised and presented below. The publication *Steel and Coal: A New Perspective. European Research and Innovation in Action*[65] lays out the complete proceedings of the conference.

Possible emerging trends and future challenges in R&I
The production of 'blue' hydrogen with coal-generated electricity was highlighted as an area of research worth exploring under the RFCS programme.
The dissemination of research results on the risks associated with mining water usage and its high temperature was outlined as a possible relevant research trend.
Future research may also address the decommissioning of power plants.
The need to improve energy efficiency, infrastructure and the production of renewable energy was underlined. Some stakeholders mentioned the success of the pioneering project ITER, which operates an experimental facility to demonstrate the scientific viability of fusion as a future sustainable energy source. Cooperation among energy-intensive industries emerged as a possible solution to counterbalance the challenge of producing fossil-free energy.
Attention was drawn to the necessity of reskilling workers as well as training young workers to reflect an increasingly digitalised steel industry. The European Commission's initiative 'Blueprint for Sectoral Cooperation on Skills' addresses skills gaps that may prevent promising industries from growing. The aims of the blueprint in the steel sector are: to assess the current situation of the workforce and address critical aspects (knowledge transfer, skills shortage, recruitment, among others), assess the state of the national VET systems and improve the image of the steel sector.
The path to achieve a carbon-neutral economy by 2050 and quantification of results
Measuring air quality is essential to quantify and monitor the reduction in NOx, SOx and CO_2 emissions in view of achieving a carbon-neutral economy by 2050.
The conference stressed the importance of quantifying the impact and added value of RFCS co-funded projects. The importance of quantifying the reduction in GHG emissions and the decarbonisation of production processes was particularly stressed.
The need to improve industrial symbiosis and collaboration among sectors to achieve a fully circular economy was raised.

[65] European Commission DG RTD, 'Steel and Coal: European Research and Innovation in Action', 2019. Available online: https://publications.europa.eu/s/mmQ7

Innovation leakage vs. Open Europe
A few stakeholders raised concern over the deployment of technology co-funded by EU programmes in non-EU countries. Other stakeholders replied stressing the need to inform about and spread awareness of intellectual property rights (IPR) and their application. During the conference, participants were reminded that competition can drive innovation, but also that international cooperation plays a crucial role. The European Union is indeed an open area, allowing exchanges within its borders and beyond them.
Administrative remarks
A few stakeholders suggested revising the co-funding rate applied by the RFCS programme for the reimbursement of staff costs. However, it was recalled that the RFCS co-funding rate is compensated by a relatively high success rate of project proposals.
The communication of the impact of research and innovation is key in order to disseminate and convey the research results and sustain Europe's socio-economic model and values as well as its global competitiveness. RFCS regularly publishes synopses of ongoing and closed projects (e.g. Synopsis of RFCS projects 2015-2018). Some stakeholders advised further improving the narrative on R&I by clustering projects and identifying flagship projects.

ANNEX 4 - QUESTIONNAIRE FOR ASSESSMENT AND MONITORING OF RFCS PROJECTS

TG:		
Project number:		
Project Title and Acronym		
Instruments:	**Research project** **Accompanying measure**	**Pilot project** **Demonstration project**

1. RELEVANCE[1]

1.1 The relevance the of RFCS project to address sector objectives

Please explain how the project aims to contribute to sector wide objectives. In particular, describe how well the objectives of the project (still) correspond to the needs within the programme.

1.2 Flexibility to adapt to new scientific and socio-economic developments

Please assess how well the project is adapted to subsequent technological or scientific advances or to changes of the wider socio-economic or political context? (N.B. could include issues related to the specify policy here e.g. social, environmental) What are the emerging needs that the project does not cover?

1.3. Does the project provide a significant progress in the state of the art?

Please explain how the project contributes to sector state of the art.

[1] This section aims to determine whether the original objectives of the EU intervention/programme are still relevant and how well they still match the current needs and problems. It covers questions related to "Why?". This section should be factual and identify if there is any mismatch between the objectives of the intervention and the (current) needs or problems.

2. EFFECTIVENESS[2]

2.1 - Progress towards attaining the specific objectives of RFCS

In this section please explain to what extent the expected chain of results of the project is likely to contribute to support the specific objectives of the RFCS programme.

2.2 - To what extent do the results of the evaluated project meet the programme research objectives?

	High	medium	low	NA
Steel				
New and improved steel making and finishing techniques	☐	☐	☐	☐
RTD / utilisation of steel	☐	☐	☐	☐
Conservation of resources and improvement of working conditions	☐	☐	☐	☐

Please give recommendations on possible new objectives for the RFCS Programme

[2] Effectiveness analysis considers how successful the thematic activity/instrument has been in achieving or progressing towards its objectives. The assessment should form an opinion on the progress made to date and the role of the thematic activity/actions in delivering the observed changes. If the objectives have not been achieved, an assessment should be made of the extent to which progress has fallen short of the target and what factors have influenced why something hasn't been successful or why it has not yet been achieved. Consideration should be given to whether the objectives can still be achieved on time or with what delay. In addressing the issues below – to the extent possible given the early stage of the implementation of the project – please consider the outputs/results/impacts in all dimensions: direct/indirect, positive and negative, intended/unintended, expected/unexpected.

2.3- How far did the project achieve its individual objectives / benefits according to the Technical Annex of the Contract / the Grant Agreement?

	100%	80%	60%	40%	20%	0%
Scientific and technological success	☐	☐	☐	☐	☐	☐
Economical and social success	☐	☐	☐	☐	☐	☐
Environment and sustainable success	☐	☐	☐	☐	☐	☐

Additional comments:

2.3 - If the objectives were only partially fulfilled, indicate reasons

Management within consortium ☐

Scientific Technical problems ☐

Default of partners and financial problems ☐

Time constraints ☐

Other reasons / comment?

3) Can key results/best practices of the project results be identified?

Yes ☐ **No** ☐

Which?

3. EFFICIENCY[3]

3.1 Resources

Please analyse budget data presented in the project description. In case of deviations from expectations, try and identify the reasons. Are the resources mobilised in a timely manner, are they well targeted?

3.2 Project's stakeholders' attractiveness

Please explain whether the mobilisation of stakeholders corresponds to the one expected to fulfil the specific objectives of the RFCS project.

3.3 Cost-benefit analysis

Are the resources reasonable in light of the results that have been or are likely to be generated? Please also consider indirect/unexpected/unintended/negative results in your assessment.

3.4. Management and Administrative

How could the management/administration at the project level (e.g. management of the consortium, of the contract, etc.) be improved to enhance the effectiveness of the project?

3.5 Did administrative burden exist for the implementation of the evaluated project?

Yes ☐ **No** ☐

If yes, how did they influence the project implementation, management and success? What could be improved?

[3] Efficiency considers the relationship between the resources used by an intervention and the changes generated by the intervention (which may be positive or negative). Typical efficiency analysis will include analysis of administrative and regulatory burden and look at aspects of simplification. Efficiency analysis should always look closely at both the costs and benefits of the EU intervention as they accrue to different stakeholders.
Simplification, aspects related to the funding model of RFCS, use of resources, externalisation aspects and cross-cutting issues will be addressed for the overall Programme.

4. COHERENCE[4]

4.1 Internal coherence among the different Technical Groups

Please explain to what extent the project has synergies with other Technical Groups (9 for Steel). List the implicit and explicit linkages across the several TGs that you can identify. How is coordination ensured between the different initiatives? Provide illustrations or gaps, overlaps and synergies.

4.2 Ensuring that every euro spent counts twice

If available please provide examples of expected interdisciplinary solutions which cut across multiple specific objectives of RFCS programme

4.3 How is complementarity ensured between the different project by the Accompany Measures?

4.4 How would you suggest clustering the Technical Groups to limit the transaction costs of RFCS projects evaluation and at the same time ensuring technical consistency? At the moment there are 9 Technical Group for steel

[4] The evaluation of coherence involves looking at a how well or not different actions work together, internally and with other EU interventions/policies.

5. EU ADDED VALUE[5]

5.1 Benefits for the European steel sector

Was/is there a clear need and clear benefit to carry out the project at European level instead? *What are the industrial benefits for the related European sector? Does the project demonstrate a strategic importance for the European steel industry?*

5.2 Benefits for the European society

Was/is there a clear need and clear benefit to carry out the project at European level instead? *What are the societal benefits for the European Union? Does the project demonstrate a strategic importance for the European society?*

5.3 To what extend have the project results been exploited?

	Fully	Partially	No exploitation	Don't know
at beneficiary level	☐	☐	☐	☐
for the benefit of the sector	☐	☐	☐	☐
beyond the sector	☐	☐	☐	☐

Comment

[5] This section aims to demonstrate and assess the value resulting from EU intervention that is additional to the value that could result from interventions which would be carried out at regional or national levels. The section should present arguments on causality and draw conclusions or projections and estimations, based on the evidence to hand, about the performance of the EU intervention. Typical questions on EU added value are: What is the additional value resulting from the EU intervention(s), compared to what could be achieved by Member States at national and/or regional levels? To what extent do the issues addressed by the intervention continue to require action at EU level? What would be the most likely consequences of stopping or withdrawing the existing EU intervention?
In the following paragraph please list the activities within your programme that have the highest additional value compared to what could be achieved by Member States at national and/or regional levels. The following criteria should be used for the relative assessment of the different areas:
1. Effectiveness: where EU action is the only way to get results to create missing links, avoid fragmentation, and realise the potential of a border-free Europe.
2. Efficiency: where the EU offers better value for money, because externalities can be addressed, resources or expertise can be pooled, an action can be better coordinated.
3. Synergy: where EU action is necessary to complement, stimulate, and leverage action to reduce disparities, raise standards, and create synergies.

5.4 How have the project results been exploited?

5.5 Did the project lead to:

	Yes	No
commercial exploitation	☐	☐
patents	☐	☐
new R&D or P&D project	☐	☐

Other exploitation?

5.6 Which benefits could be obtained at beneficiary level?

	Excellent	good	satisfactory	poor	very poor	NA
knowledge	☐	☐	☐	☐	☐	☐
productivity increase	☐	☐	☐	☐	☐	☐
economical	☐	☐	☐	☐	☐	☐
cost reduction	☐	☐	☐	☐	☐	☐
social	☐	☐	☐	☐	☐	☐
occupational safety and health	☐	☐	☐	☐	☐	☐
working conditions	☐	☐	☐	☐	☐	☐
environmental and natural resources	☐	☐	☐	☐	☐	☐
energy efficiency	☐	☐	☐	☐	☐	☐
raw material savings	☐	☐	☐	☐	☐	☐
new or improved product	☐	☐	☐	☐	☐	☐
new or improved process	☐	☐	☐	☐	☐	☐

new or improved application	☐	☐	☐	☐	☐	☐
new market shares	☐	☐	☐	☐	☐	☐
quality of intermediate products	☐	☐	☐	☐	☐	☐
new steel grades/solutions	☐	☐	☐	☐	☐	☐
training and education	☐	☐	☐	☐	☐	☐

5.7 Is it possible to quantify the benefit for the beneficiary and if so, what is it?

Others?

5.8 Which benefits can be identified for the sector?

	Excellent	good	satisfactory	poor	very poor	NA
knowledge	☐	☐	☐	☐	☐	☐
productivity increase	☐	☐	☐	☐	☐	☐
economical	☐	☐	☐	☐	☐	☐
social	☐	☐	☐	☐	☐	☐
occupational safety and health	☐	☐	☐	☐	☐	☐
working conditions	☐	☐	☐	☐	☐	☐
environmental and natural resources	☐	☐	☐	☐	☐	☐
energy efficiency	☐	☐	☐	☐	☐	☐
improved competitiveness	☐	☐	☐	☐	☐	☐
securing of jobs	☐	☐	☐	☐	☐	☐
reduction of waste	☐	☐	☐	☐	☐	☐
competitiveness of steel	☐	☐	☐	☐	☐	☐
market share	☐	☐	☐	☐	☐	☐
quality of intermediate products	☐	☐	☐	☐	☐	☐
new steel grades/solutions	☐	☐	☐	☐	☐	☐
training and education	☐	☐	☐	☐	☐	☐

Others?

5.9 Is it possible to quantify the benefit for the sector and if so, what is it?

5.10 Which benefits can be identified for the society?

	Excellent	good	satisfactory	poor	very poor	NA
knowledge	☐	☐	☐	☐	☐	☐
economical	☐	☐	☐	☐	☐	☐
social	☐	☐	☐	☐	☐	☐
occupational safety and health	☐	☐	☐	☐	☐	☐
working conditions	☐	☐	☐	☐	☐	☐
environmental & sustainability	☐	☐	☐	☐	☐	☐
energy efficiency	☐	☐	☐	☐	☐	☐
European competitiveness	☐	☐	☐	☐	☐	☐
market share	☐	☐	☐	☐	☐	☐
new applications	☐	☐	☐	☐	☐	☐
training and education	☐	☐	☐	☐	☐	☐
conservation of ressources	☐	☐	☐	☐	☐	☐

Others?

5.11 Is it possible to quantify the benefit for the society and if so, what is it?

5.12 As Coordinator, please explain how the benefits have been evaluated?

ANNEX 5 – LIST OF PROJECTS QUANTITATIVELY ASSESSED

In progress	Completed*

TG Coal 1 - Coal mining operation, mine infrastructure and management, unconventional use of coal deposits		
SLOPES	RFCR-CT-2015-00001	Smarter Lignite Open Pit Engineering Solutions
MERIDA	RFCR-CT-2015-00004	Management of Environmental RIsks During and After mine closure
MAPROC	RFCR-CT-2015-00005	Monitoring, Assessment, Prevention and Mitigation of Rock Burst and Gas Outburst Hazards in Coal Mines
COMEX	RFCR-CT-2012-00003	Complex Mining Exploitation: optimizing mine design and reducing the impact on human environment
AMSSTED	RFCR-CT-2013-00001	Advancing Mining Support Systems to Enhance the Control of Highly Stressed Ground
TG Coal 2 - Coal preparation, conversion and upgrading		
HUGE 2	RFCR-CT-2011-00002	Hydrogen Oriented Underground Coal Gasification for Europe - Environmental and Safety Aspects
SuperCoal	RFCR-CT-2015-00006	Coal-liquid based upgraded carbon materials for energy storage
TG Coal 3 - Coal combustion, clean and efficient coal technologies, CO_2 capture		
ASC2*	RFCP-CT-2013-00009 *	Amine-impregnated Alumina Solid Sorbent for CO_2 Capture
NIBALO725	709976 (2016)	Nickel Based Alloys for Operation of 725°C Steam Plants
DRYLIG	RFCR-CT-2014-00009	Competitive pre-drying technologies and firing concepts for flexible and efficient lignite utilisation
FLEX FLORES	754032 (2017)	FLEXible operation of FB plants co-Firing LOw rank coal with renewable fuels compensating vRES

* Funded via the Pilot and Demonstration instrument, all others are Research projects

TG Steel 1 - Ore agglomeration and ironmaking		
InnoCarb	RFSR-CT-2010-00001	Innovative carbon products for substituting coke on BF operation
FlexCoke	RFSR-CT-2013-00001	Flexible production of coke using alternative coals - effects on coke properties under blast furnace condition
OptiBlaFins	RFSP-CT-2015-00001	Optimizing Blast Furnace Hearth Inner State
TG Steel 2 - Steelmaking process		
TotOptLis	RFSR-CT-2010-00003	Multi-criteria through-process optimisation of liquid steelmaking
GreenEAF2	RFSP-CT-2014-00003	Biochar for a sustainable EAF steel production
DynStir	RFSR-CT-2015-00004	Dynamic stirring for improvement of energy efficiency in secondary steelmaking
TG Steel 3 - Casting		
NDTSlab	RFSP-CT-2013-00004	Innovative non-contact, non-destructive prototype system for automatic detection of surface and subsurface defects in slabs
Support-Cast	754130 (2017)	Supporting control by inspection of surface quality and segregation on cast products through integration of novel online monitoring and advanced modelling into an accessible cloud access platform
TG Steel 4 - Hot and cold rolling processes		
InfoMap	RFSR-CT-2015-00008	Integration of complex measurement information of thick products to optimise the through process geometry of hot rolled material for direct application
OptiShamp	RFSR-CT-2011-00011	Optimal control of shape and materials properties
TG Steel 5 - Finishing and coating		
ACE-Pick	RFSP-CT-2014-00013*	First Worldwide full-scale demonstration of Alternating Current (AC) Electrolytic PICKling on carbon and stainless steel coils.
MicroCorr	RFSR-CT-2015-00011	Improving steel product durability through alloy coating microstructure
MacoPilot	709694 (2016)*	Optimisation of the mixed acid online monitoring and control in stainless steel pickling plants.

TG Steel 6 - Physical metallurgy and design of new generic steel grades		
TIANOBAIN	709607 (2016)	Towards industrial applicability of (medium C) nanostructured bainitic steels
OptiQPAP	709755 (2016)	Optimization of Q&P steels designed for industrial applications
TOUGH-SHEET	RFSR-CT-2014-00015	Measurement of toughness in high strength steels sheets to improve material selection in cold forming and crash-resistant components
TG Steel 7 - Steel products and applications for automotive, packaging and appliances		
AUTO FATCOR	RFSR-CT-2011-00021	Combined corrosion and fatigue strength of joined materials for body-in-white and structural automotive applications design
HIBEPA	RFSR-CT-2014-00021	HIgh PErformance Steel for Safer and more Competitive Safety BArriers
HotForm	RFSR-CT-2015-00017	New multiphase AHSS steel grades for hot forming, with improved formability and reduced springback
TG Steel 8 - Steel products and applications for building, construction and industry		
SB_STEEL	RFSR-CT-2010-00027	Sustainable building project in steel
FIDESC4	RFSR-CT-2011-00030	Fire design of steel members with welded ot hot-rolled class 4 cross-section
BASSE	RFSR-CT-2013-00026	Building Active Steel Skin
PRO INDUSTRY	RFSR-CT-2013-00019	Seismic protection of industrial plants by enhanced steel based systems
GRISPE	RFSR-CT-2013-00018	Guidelines and Recommendations for Integrating Specific Profiled steel sheets in the Eurocodes
SCIENCE	RFSR-CT-2013-00017	SC for Industrial, Energy and Nuclear Construction Efficiency
TG Steel 9 - Factory-wide-control, social and environmental issues		
GasNet	RFSR-CT-2015-00029	Optimization of the management of the process gases network within the integrated steelworks
I2MSteel	RFSR-CT-2012-00038	Development of a new automation and information paradigm for integrated intelligent manufacturing in steel industry based on holonic agent technology
Monwire	RFSR-CT-2012-00041	Quality and process monitoring system based on surface and internal defect detection for hot and cold wire

* Funded via the Pilot and Demonstration instrument, all others are Research projects

ANNEX 6 – LIST OF RFCS PROJECTS QUALITATIVELY ASSESSED

Projects Qualitatively Evaluated in the RFCS Monitoring and Assessment Report (2011-2017)											
TGC1	TGC2	TGC3	TGS1	TGS2	TGS3	TGS4	TGS5	TGS6	TGS7	TGS8	TGS9
RTRO-Coal	RATIO-COAL	**NIBALO725**	**ULCOS**	**GREENEAF**	**SHELL-THICK**	InfoMap	**VADPSHEET**		**2010- 2013 CHARMA**	**LOCAFI**	**SUPSYSCC**
SLOPES	**ECOCARB**	**FLEXICAL**	**IDEOGAS**	**GREENEAF2**	**SUPPORT-CAST**	OptiShamp	ATCORAS		2010-2013 GPHS	**LOCAFI-Plus**	TECPLAN
GasDrain	DENSICHARGE	PC-FLOX	**ULCOS TGRBF**	RIMFOAM	TICLOGG		MIROCORR		2011-2014 DURADH	INDUSE-2-SAFETY	**SISCON**
BEWEXMIN	ESTIVAL	**FLOX-COAL-II**	**HISARNA**	PROTECT	**INNOSOLID**		**ICONTENS**		2011-2014 ENFASS	EQUALJOINTS	**AUTODIAG**
AMSSTED	**SPRITCO**	**DRYLIG**	**HISARNA B&C**	**FLEXCHARGE**	**SHELL-THICK**		INMARS		**2011-2014 STEELTAC**	PROINDUSTRY	PRESED
PRASS III	**INNOWATREAT**	CARINA	**CONSISTENT BF**	OPTISCRAPMANGE	NNEWFLUX		**ZINCOBOR**		2011-2014 TESTTOOL	**STEEL-EARTH**	EVALHD
M-SmartGRID	BINGO	CAL-MOD	CHARFOCO	**ADAPTEAF**			MACO-PILOT		**2011-2014 MAC D**	INNOSEIS	I2MSTEEL
OPTI-MINE	COWEST	**ASC2**	EXTUL	**BATHFOAM**			**ACE-PICK**		2011-2015 AUTOFATCOR	MEAKADO	KNOWDEC
FEATureFACE	ALTERAMA	ECLAIRL	SUSTAINTAP	BOFDEPHOS			NOSTICKROLLS		**2012-2015 TWIP4EU**	SCIENCE	**MONWIRE**
INDIRES	**HUGE2**	ACCLAIM	TOSICO	SLACON			BOLT ZnAlMg		2012-2015 STT	HILONG	NDTCASTING
AVENTO	**MEGA PLUS**	**RECaL**	INSIMI	STIMPROVE			ORSC		2013-2016 INCAFAT	RUOSTE	CHECKSIS
ROCD	CO2freeSNG	OXYCORR	OPTIPER	ONDECO			**WAVISURF**		2013-2016 FREQTIGUE	JOINOX	**LACOMORE**
EXPRO	CO2freeSNG2.0	**COALBYPRO**	**OPTISTOVE**	DYNSTIR			**STEELPV**		2014-2017 IMMAC	**HIPERCUT**	RELOTEMP
MAPROC	**LIG2LIQ**	BIOXYSORB	IMPCO	**OPTDESLAG**			**DUPLEXWASTE**		**2014-2017 HIPEBA**	SB_STEEL	ENCOP
TeleRescuer	FECUNDUS	CERUBIS	**FLEXINJECT**	**LADLIFE**					2014-2017 Toolsteel	**REDUCE**	THERELEXPRO
INREQ	NOEMI	SMARTBURN	**INNOCARB**	PLUGWATCH					2015-2018 JOININGTWIP	**PROGRESS**	POWGETEG
CERES	COALPHENES	DEVCAT	FLEXCOKE	LADTHERM					2015-2018 HOTFORM		**SLAGFERTILIZER**
STAMS	**SUPERCOAL**	CRAMUFAT24		LOWCNEAF					2015-2018 ICUT		SLAGSOR
MANAGER	EUROFIBRES	**FLEXFLORES**		TOTPTLIS					2015-2018 EFFIPRESS		RECONI
MERIDA	I3UPGRADE	**ONCORD**									**SELSA**
COGAR	PROMOTEE										MAGSEP
COAL2GAS	**DIRPRIMCOAL**										REFFIPLANT
LoCAL											**ECOWATER**
METHENERGY PLUS											**ASEMIS**
VAM											DYNCYANIDE
											NITRATEBIODEMO
											EIRES

LEGEND	
	Project also quantitatively assessed (Accompanying Measures).
	TGs state to have reviewed and assessed a certain number of projects.
Bold	Projects more quoted and mentioned by TG Chairs

The second report on the seven-year monitoring and assessment of the Research Fund for Coal and Steel (RFCS) programme analyses the benefits delivered by the RFCS projects between 2011 and 2017. It is the outcome of the work of the High-Level Expert Group according to the RFCS legal basis (Council Decision 2008/376/EC, Art. 38).
This report encompasses a qualitative evaluation and quantification of the benefits triggered by the RFCS programme as well as its development over the period analysed. It sheds light on the progress achieved by the RFCS programme as well as on the next challenges and research trends upon which the programme may focus in the coming years.
This publication also demonstrates that fundamental research leading towards breakthrough technological innovations is pivotal to face challenges as decarbonisation and the shift towards a circular climate neutral economy, globalisation and digitization. The RFCS goal is to continue protecting our natural environment, improving people’s health and wellbeing while strengthening European industrial competitiveness, for the benefit of all people in Europe.

Studies and reports

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