Proposal for

CLEAN STEEL PARTNERSHIP

under the Horizon Europe Programme

Proposal for a
European Partnership under Horizon Europe
Clean Steel - Low Carbon Steelmaking

(Version 15 July 2020)

About this proposal

In autumn 2019 the Commission services asked potential partners to further elaborate proposals for the candidate European Partnerships identified during the strategic planning of Horizon Europe. These proposals have been developed by potential partners based on common guidance and template, taking into account the initial concepts developed by the Commission and feedback received from Member States during early consultation.1 The Commission Services have guided revisions during drafting to facilitate alignment with the overall EU political ambition and compliance with the criteria for Partnerships.

This document is the partnership proposal, released for the purpose of ensuring transparency of information on the current status of preparation (including on the process for developing the Strategic Research and Innovation Agenda / Roadmap). As such, it aims to contribute to further collaboration, synergies and alignment between partnership candidates, as well as more broadly with related R&I stakeholders in the EU, and beyond where relevant.

This informal document does not reflect the final views of the Commission, nor pre-empt the formal decision-making (comitology or legislative procedure) on the establishment of European Partnerships.

In the next steps of preparations, the Commission Services will further assess these proposals against the selection criteria for European Partnerships. The final decision on launching a Partnership will depend on progress in their preparation (including compliance with selection criteria) and the formal decisions on European Partnerships (linked with the adoption of Strategic Plan, work programmes, and legislative procedures, depending on the form). Key precondition is the existence of an agreed Strategic Research and Innovation Agenda / Roadmap. The launch of a Partnership is also conditional to partners signing up to final, commonly agreed objectives and committing the resources and investments needed from their side to achieve them.

The remaining issues will be addressed in the context of the development of the Strategic Research and Innovation Agendas/ Roadmaps, and as part of the overall policy (notably in the respective legal frameworks). In particular, it is important that all Partnerships further develop their framework of objectives. All Partnerships need to have a well-developed logical framework with concrete objectives and targets and with a set of Key Performance Indicators to monitor achievement of objectives and the resources that are invested.

Aspects related to implementation, programme design, monitoring and evaluation system will be streamlined and harmonised at a later stage across initiatives to ensure compliance with the implementation criteria, comparability across initiatives and to simplify the overall landscape.

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[1]For further details, please see: https://www.era-learn.eu/documents/final_report_ms_partnerships.pdf

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A multiannual Roadmap (also including a Strategic Research and Innovation Agenda) is under preparation. By relying on a participatory approach, ESTEP has been defining strategies and common lines of intervention to achieve the objectives of the Clean Steel Partnership. After various rounds of consultation with the relevant services of the European Commission, the Roadmap will be published in draft version on the ESTEP website to allow for a five-week public consultation. This consultation aims to collect feedback from the broader steel sector as well as from Member States, the civil society and any other relevant stakeholder. The Roadmap will be updated to account for the comments and feedback received from consulted stakeholders. The final version of the Roadmap will undergo an additional one-week public consultation to inform stakeholders about all changes made. The Roadmap will be finalised by September 2020, in order to start the co-programmed Partnership in 2021.

Table of contents

List of acronyms

BF	Blast Furnace
BOF	Basic Oxygen Furnace
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Usage
CCUS	Carbon Capture, Utilisation and Storage
CDA	Carbon Direct Avoidance
CE	Circular Economy
cPPP	Contractual public-private partnership
CO_2	Carbon Dioxide
COSCO	The Coal and Steel Committee
DG CLIMA	Directorate-General for Climate Action
DG ENER	Directorate-General for Energy
DG ENV	Directorate-General for Environment
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
DG R&I	Directorate-General for Research and Innovation
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EASME	The Executive Agency for Small and Medium-sized Enterprises (EASME)
ECSC	The European Coal and Steel Community
ERDF	The European Regional Development Fund
ESTEP	The European Steel Technology Platform
ETS	The EU Emissions Trading System
EU	The European Union
EUROFER	The European Steel Association
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GVA	Gross Value Added
H_2	Hydrogen
HBI	Hot-briquetted Iron
HDRI	Hot direct reduced iron
ICT	Information and Communications Technology
IP	Intellectual Property
IPCEIs	Important Projects of Common European Interest
kg/tCS	kilogram/tonne of crude steel
KPI	Key Performance Indicator
KWh	Kilowatt-hour
Mt	Million tonnes
PPP	Public-Private Partnership

R&D	Research and Development
R&D&I	Research, Development and Innovation
R&I	Research and Innovation
RFCS	The Research Fund for Coal and Steel
RTOs	Research and technology organisations
SCU	Smart Carbon Usage
SET Plan	The Integrated Strategic Energy Technologies Plan Action 6
SDG	The Sustainable Development Goal
SPIRE	The contractual Partnership "Sustainable Process Industry through Resource and Energy Efficiency"
SRIA	Strategic Research and Innovation Agenda
TF	Task Force
TGR-BF	Blast furnace with top-gas recycling
TRL	Technology Readiness Level
TWh	Terawatt-hours
UN	United Nations

1. Executive summary

1.1. Context, problems and strategic opportunities

- The Clean Steel Partnership is designed to tackle two major challenges: climate change and sustainable growth for the EU.
    - In line with the European Green Deal, the Clean Planet for All strategy and the Paris Agreement, it takes an integrated approach to fighting climate change and contributes to moving towards climate neutrality by 2050, zero-pollution for a toxic free environment and a circular economy using digital technologies as enabler as well as new forms of collaboration.
    - It supports the EU commitment to the United Nations Sustainable Development Goals.
    - It contributes to sustainable growth based on knowledge and innovation, as promoted by the Horizon Europe framework.
- CO_2 emissions from the steel sector will not sufficiently decrease compared to 1990 levels without major technological breakthroughs.
    - Decarbonising the steel sector is crucial not only to reduce emissions, but also to preserve the current competitive position of EU steelmaking.
    - Moving to a more circular economy will generate GHG emissions reductions.
    - Any action for decarbonisation must be immediate and coordinated across Member States, production routes and technologies, and with sufficient public support.
- The Partnership will help remove R&D&I and systemic bottlenecks such as the transition from the pilot phase to industrial-scale deployment, high technology risks, large capital requirements and higher production costs.

1.2. Vision, objectives and impacts

- The Clean Steel Partnership nurtures the long-term vision of supporting the EU leadership in the transformation of the steel industry into a climate-neutral sector.
    - It seeks to accelerate the transformation of the steel industry by tackling important R&D&I challenges and bringing a range of breakthrough technologies for clean steel production up to large scale demonstration by 2030.
- More specifically the Partnership aims to develop technologies at TRL8 to reduce CO_2 emissions stemming from EU steel production by 80-95% compared to 1990 levels by 2050, ultimately leading to climate neutrality.
    - This general objective aligns with commitments set by the European Green Deal and contributes to UN Sustainable Development Goals.
- Specific and operational objectives are set to support the general objectives and must be achieved in 7-10 years.
- The Partnership will promote a transformational change in how R&D&I activities are conducted in the steel sector.
    - It will play a crucial role in identifying, bringing together, coordinating and enabling multiple breakthrough technologies with high decarbonisation potential.

    - It will rely on strong collaboration and joint commitment from both the private and public sectors, thus reducing overlaps in R&D&I efforts and funding and ensuring better synergies and larger impacts.
- Positive spillovers on suppliers will foster green energy generation, efficient production systems, and hydrogen technologies. As regards customers, R&D&I investment in the steel sector will lead to the production of a cleaner, high-quality steel, which in turn will stimulate the production of goods with lower lifecycle impacts.
- The Clean Steel Partnership will not only create synergies with other sectors, but also opportunities for collaboration across Member States and Associated Countries to develop breakthrough technologies.
- A vibrant EU steel industry will allow to sustain economic growth, preserve high-quality jobs, and ensure leadership in renewable energy technologies.

1.3. Necessity for a European partnership

- The Commission considers the Clean Steel Partnership as one of the tools to achieve the targets set out in the European Green Deal.
- The Partnership ensures higher degree of additionality compared to transnational joint calls and R&I projects under Horizon Europe. It allows to:
    - Remove systemic bottlenecks affecting the EU steel industry by ensuring sufficient coordination in R&D&I activities;
    - Remove R&D bottlenecks by supporting the steps necessary to go from piloting to commercial deployment of new technologies and leveraging private investments;
    - Plan ahead a timely intervention to decarbonise the EU steel industry;
    - Progressively phasing out from public support for R&D&I and to sequencing the Partnership with other funding schemes.
- The Partnership contributes to common objectives of Horizon Europe, thus ensuring the directionality of the intervention to the Programme. It supports the following Horizon Europe objectives:
    - Fostering the Union's competitiveness in all Member States and industries;
    - Creating and diffusing high-quality knowledge and skills;
    - Tackling global challenges will be supported by the Partnership's contribution to different SDGs;
    - Fostering innovation and technological development;
    - Facilitating collaborative links in European R&I.
- The Partnership will generate a strong EU added value by:
    - Collaborating with other partnership candidates: upstream (Clean Hydrogen, Clean Energy Transition), midstream (Process4Planet), downstream (People-centric sustainable built environment, Made in Europe).
    - Contributing to Horizon Missions on climate-neutral and smart cities, soil health and food, and on adaptation to climate change including societal transformation.
    - Creating synergies with other EU funding opportunities such Research Fund for Coal and Steel, Innovation Fund, LIFE Programme, European Regional Development Fund, InnovFin, InvestEU, CEF Programme, IPCEIs, Modernisation fund, Cohesion funding.

- Establishing mechanisms of cooperation with Member States to create additional synergies with national and regional policies and programmes.

1.4. Activities and resources

- The Partnership is centred around 12 technology building blocks, which can contribute separately to the areas of intervention, or jointly to enable a higher level of CO_2 emission reduction in steel production.
- The total expected budget for R&D&I projects falling within the wider boundary of the Partnership is EUR 2.0 billion.
  - Major private investment would match public funding from Horizon Europe and the Research Fund for Coal and Steel.
  - Additional private investment would complement funding coming from other public sources (e.g. other EU programmes, as well as national and regional programmes relying on co-financing mechanisms).
- A number of external conditions must be met for these investments to be realised:
  - Policy: EU continues considering low-carbon manufacturing industries – including the steel sector – a pillar of its industrial policy. EU and Member States continue their support towards the circular economy, and establish a supportive regulatory framework.
  - Economy: state aid framework (IPCEIs), a stable financing flow from both public sources (e.g. ETS Innovation Fund, loans and guarantees from InvestEU) and private sources, availability of competitively-priced low CO_2 energy supply, common European hydrogen strategy, and consistent policies against carbon leakage.
  - Societal: availability of a highly skilled workforce and awareness of EU citizens for clean steel products.
- The Partnership will establish systematic exchanges with relevant bodies managing other Horizon Europe initiatives and other EU actions and programmes, to avoid duplication, clarify overlap, foster collaboration and maximise synergies.
- The Partnership has already identified several national policies, programmes and activities that may create high synergies when it comes to R&D&I activities contributing to the decarbonisation of the steel industry.

1.5. Governance, composition, openness and transparency

- The Clean Steel Partnership will be established between the European Commission and the European Steel Technology Platform (ESTEP).
- The Partnership will include the entire EU steel value chain community (steel producers, customers, suppliers, plant builders, steel processors, RTOs), will involve any other relevant stakeholders beyond the steel industry, and will be constantly open to new partners.
- The Partnership will continuously cooperate with public entities at all levels to ensure the alignment of research, innovation and deployment strategies with EU, national and regional programmes and policies, in order to maximise efforts.
- The governance of the Partnership will rely on the following bodies:
  - The 'Partnership Board', which includes representatives from both the public and private side.

    - The ‘Implementation Group’, which is the general assembly of the Partnership.
    - The ‘Task Forces’, which will provide technical expertise to support the work of the Implementation Group.
    - The ‘Programme Office’, which is responsible for coordination and communication activities.
    - Two additional external bodies:
        - The ‘Expert Advisory Group’, which is composed of external experts of steelmaking and related technologies
        - The ‘Stakeholder Forum’, including all relevant stakeholders that are not members of the Partnership and may contribute to the successful implementation of the Partnership.
- Participation in Call for Proposals will be open to both members and non-members of the Partnership.
- Strategies to ensure easy and non-discriminatory access to information about the initiative and to stimulate the participation of new partners include: a dedicated website, LinkedIn and Twitter accounts, mailing lists, annual workshops, thematic and networking events, and membership campaigns.

2. Context, objectives, expected impacts

2.1. Context and problem definition

Summary

The Clean Steel Partnership in context

- The Partnership is designed to tackle two major challenges: climate change and sustainable growth for the EU.
- In line with the European Green Deal, the Clean Planet for All strategy and the Paris Agreement, it takes an integrated approach to fighting climate change and aims at moving towards climate neutrality by 2050, zero-pollution for a toxic free environment and a circular economy.
- Support the EU commitment to the United Nations Sustainable Development Goals.
- Contribute to sustainable growth based on knowledge and innovation, as promoted by the Horizon Europe framework.

Problems, drivers and strategic opportunities

- Key problems: CO_2 emissions from the steel sector will not sufficiently decrease compared to 1990 levels without major technological breakthroughs.
- Decarbonising the steel sector is crucial not only to reduce emissions, but also to preserve the current competitive position of EU steelmaking.
- Moving to a more circular economy will generate GHG emissions reductions.
- A vibrant EU steel industry allows to sustain economic growth, preserve high-quality jobs, and ensure leadership in renewable energy technologies.
- Any action for decarbonisation must be immediate and coordinated across Member States, production routes and technologies, and with sufficient public support.

R&D&I and systemic bottlenecks

- Key bottlenecks: the transition from the pilot phase to industrial-scale deployment, high technology risks, large capital requirements and higher production costs.
- The 'funding gap': significant financing support requires the willingness of the public sector to participate in risk-sharing.
- The 'adoption gap': commercial diffusion of technologies deployed at industrial scale.
- Market failure: the diffusion of more carbon efficient technologies remains below the social optimum and this justifies public support.
- The lack of a holistic framework for a coordinated approach to decarbonise the steel industry.

Links with past projects and initiatives

Various relevant R&D&I projects including:

- Research Fund for Coal and Steel: 150 projects in total on steel processes, steel products and steel applications, with 40% reaching commercial exploitation and 20% leading to patents.
- SPIRE: R&D&I projects with a cross-sectoral perspective.
- Green Steel for Europe: a technological roadmap and funding analysis.

2.1.1. The Clean Steel Partnership in context

The Clean Steel Partnership aims to tackle two major challenges that the EU is facing at the moment:

- **climate change**, which has been addressed in the latest year by a number of more and more ambitions policies.
- the need for the EU to ensure a **sustainable growth** for the continent.

This Partnership is developed in the context of the EU's goal to achieve climate neutrality by 2050, thirty years from today, as laid down in the **European Green Deal**[2] climate goals, and – in parallel - to move towards zero-pollution for a toxic free environment and a circular economy. The Green Deal clearly states that current policies will not suffice in reaching this target, thereby **stressing the urgent need for further collaborative efforts across all levels and sectors**.[3] As investment cycles in the steel industry are 20 to 30 years, developing, testing and scaling up technologies for climate neutral steel production must start now to ensure the full roll-out across the EU by 2050.

The Green Deal is an integral part of the EU strategy to achieve the UN's 2030 Agenda and Sustainable Development Goals. The Agenda aims at providing a global blueprint for peace and prosperity and consists of 17 goals. Among those, **the Partnership can contribute to the Sustainable Development Goals** related to sustainable production and consumption, and in particular to the urgent fight against climate change.[4]

In order to achieve these goals, **the steel sector must play a key role** in such collaborative efforts as it is responsible for 20% to 25% of industrial CO_2 emissions covered by the EU Emissions Trading System (ETS). The steel industry is indeed committed to contributing to the achievement of the emission targets and has been at the forefront of Research and Development and Innovation (R&D&I) breakthrough technologies to reduce the climate footprint for many years.[5] As a partnership building upon R&D&I, the 'Clean Steel' Partnership is proposed within the broader framework of **Horizon Europe** cluster 4.

The economic and social importance of the steel sector for the EU sustainable growth

Steel is at the heart of everyday life for citizens and societies as it is an input for industries like automotive, energy production and networks, urban and long-distance transport infrastructures, and general mechanical engineering industries. Furthermore, steel is a key material in changing environments as it provides for solutions to infrastructure and construction needs around the world, to build climate-resilient cities and coastal protection. It represents around 95% of all metals produced.[6] It is infinitely recyclable, and its by-products and waste energies can be valuable resources.

[2] European Commission (2019), the European Green Deal, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, 640. Hereinafter also: 'EU Green Deal'.

[3] EU Green Deal, at pp. 8-9.

[4] The SDGs to which the Partnership can contribute include: SDG 8 – promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for, SDG 9 – build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation, SDG 12 – ensure sustainable consumption and production patterns, and SDG 13 – take urgent actions to combat climate change and its impacts.

[5] European Commission (2018), European Steel: The Wind of Change.

[6] For further details, please see: greenspec.co.uk/building-design/steel-products-and-environmental-impact/

Box 1: Facts on steel economy and production routes

The steel industry is integral to the global circular economy and thus the successful delivery and maintenance of a sustainable future, which is underlined by some key facts/data:

- With an output of 168 million tonnes of crude steel per year (2018), the EU is the second largest producer in the world[7];
- The EU-steel sector has an annual turnover of EUR 166 billion and is responsible for 1.3% of EU GDP[8];
- Steel is a genuine EU industry with 500 production sites across 23 EU countries and employed 320,000 people directly in 2018. The total number of jobs enabled by the steel industry is 7.9 times the steel industry's own employment (i.e. around 2.6 million EU jobs are supported in total)[9];
- The Gross Value Added (GVA) of steel production is EUR 20.7 billion. Total GVA supported by the steel industry is 5.8 times the steel industry's own GVA[10];
- Steel production in Europe is around 10% of global production (1.8 billion tonnes in 2018)[11], but Europe's competitive position has deteriorated in recent years and prices worldwide have dropped, partly due to global steel overcapacities;
- Regulatory costs do impact the competitiveness of EU steel production as they fall in the area of 20% to 30% of margins and maybe even higher than 100% in some years.[12]

The production of steel in the EU is at the moment widely performed through two production routes, namely the so-called integrated blast furnace (BF)/basic oxygen furnace (BOF) route and the electric arc furnace (EAF) route. Currently, about 60% of steel is produced via the BF/BOF route and 40% via the EAF route.

BF/BOF route	*EAF route*
Steel produced from the primary raw material iron oxide by removal of the oxygen with carbon in the BF process and treatment of the so-called hot metal with oxygen in the BOF process to remove the diluted carbon in the melt. These two process steps together with the use of the process gases to recover the chemical energy create a total of 1.3 to 1.8 t of CO_2 per tonne of crude steel.[13]	Steel produced using recycled steel (scrap) in the electric arc furnace (EAF) reactor. Metallic material is collected and melted down by electric energy (typically between 70-60%) and chemical energy from natural gas and coal (30-40%). The electrical energy intensity is of about 400-500 kWh (kilowatt-hour) per tonne of steel. Therefore, for scrap-EAF, only around 80-120kg/tCS (kilogram/tonne of crude steel) of CO_2 are directly generated by the production process, while the balance to the total 250-350kg/tCS come from indirect emissions.
Both routes have in common the secondary metallurgy process for treating the liquid steel produced from both BOF and EAF to adjust the steel composition and casting. Liquid steel is cast to certain shapes, dimension and weights of crude steel (billet, blooms, slabs, ingots). These semi-finished products are formed through "hot rolling" at a temperature of about 1,300 °C. Hot rolled steel may afterwards go through various processing steps such as heat treatment, cold rolling or surface treatment. These two steps can be integrated in the production process or can be stand-alone. They are usually responsible for about 150-200 kg/CO_2 per tonne of crude steel.	

Source: Author's own elaboration.

[7] EUROFER (2019), 2019 European Steel in Figures, eurofer.org/News%26Events/PublicationsLinksList/201907-SteelFigures.pdf; p. 13.

[8] European Commission (2016), 'Steel: Preserving sustainable jobs and growth in Europe' (COM(2016)155), and 'A renewed EU Industrial Policy' (COM(2017)479).

[9] EUROFER (2019), 2019 European Steel in Figures, eurofer.org/News%26Events/PublicationsLinksList/201907-SteelFigures.pdf; p. 7.

[10] Ibid.

[11] Ibid., p. 13.

[12] CEPS (2013), Assessment of cumulative cost impact for the steel industry, ceps.eu/system/files/steel-cum-cost-imp_en.pdf

[13] Steel Institute VDEh (2019), Update of the Steel Roadmap for Low Carbon Europe 2050. Part I: Technical Assessment of Steelmaking Routes, p. 40; European Commission (2018), European Steel: The Wind of Change, p. 19.

Steel production is a capital-intensive sector where EU steelmakers must compete in the highly competitive global market, thus making the developing, testing and scaling up of new technologies a significant economic risk. Within this setting, **the viability and competitiveness of the EU steel industry must be preserved during the decarbonisation process.** The viability of both the BOF and EAF production routes must be preserved, as they remain necessary to ensure the EU steel sector has the capacity of delivering high-quality steel using different raw materials, thereby ensuring strategic capability.

With the current **COVID-19 pandemic**, the situation of the EU economy overall and the steel industry in particular has become critical, giving the Clean Steel Partnership even more prominence. The situation is dire for the steel industry due to various factor:

- The demand is collapsing and severe cuts to production across the Union have been implemented. Even though manufacturing activities have restarted, there are so far little signs for improvement and the demand for steel is still falling.
- Such a challenge followed an already difficult decade, during which the EU producers had to thrive in an oversaturated global steel market.
- Currently, other regions affected by the crisis are producing for stockpiling, creating the threat of continued low global steel prices.

At the same time, the current crisis also places further importance on the EU steel industry in economic, employment, and social terms. The European Commission has already taken several steps to support the economic recovery of various industries throughout the EU. These range from three immediate safety nets via a new recovery instrument ('Next Generation EU') up to a reinforced proposed long-term budget and full flexibility on fiscal and state-aid rules.[14] Additionally, the Commission has underlined that the recovery should remain committed to a just transition towards climate neutrality.[15] Moreover, the current crisis once more demonstrates the importance of **keeping critical manufacturing local**, like medical and energy equipment, to all of which steel is essential.[16]

Finally, as the EU steel industry is globally unique in having suggested a path to green steel, the pandemic is increasing the risk of '**carbon leakage**', i.e. in shifting steel production outside of the EU, resulting in a loss of jobs and GDP for our continent, and no net – or even negative – impacts on global carbon emissions. As the health crisis will fade, climate change will remain the great risk of our time. It is thus, essential that the important role of steel in combating climate warming and building a sustainable economy is further acknowledged and supported by the public side through this Partnership.

All in all, the competitiveness of the steel industry must be preserved being an important engine of value-added and employment within the EU, both directly and indirectly as shown above. This is because steelmakers participate in wider value chains including sectors which are crucial for the EU

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[14] Overview of the recovery plan from the European Commission: https://ec.europa.eu/info/live-work-travel-eu/health/coronavirus-response/recovery-plan-europe_en; last accessed: 04.06.2020; and the Council: https://www.consilium.europa.eu/en/policies/covid-19-coronavirus-outbreak-and-the-eu-s-response/; last accessed; 04.06.2020.

[15] Ibid.

[16] See letter by EUROFER to the Presidents of the European Institutions, available at: https://www.estep.eu/assets/CSP-letters/2020401-COVID19-Letter-Commission-President-Ursula-von-der-Leyen.pdf ; https://www.estep.eu/assets/CSP-letters/2020401-COVID19-Letter-European-Council-President-Charles-Michel.pdf ; https://www.estep.eu/assets/CSP-letters/2020401-COVID19-Letter-EP-President-David-Sassoli.pdf .

competitiveness, like construction, automotive, mechanical engineering, energy generation and networks, mobility, and defence. Also, steel is a material enabling the deployment of green energy technologies, and thereby vital in the path to a climate-neutral EU. In a nutshell, **steel is vital to the EU economy**, as repeatedly recognised in EU policies.[17]

2.1.2. Problems, drivers and strategic opportunities

Problems and problem drivers

In the context of the EU policies and challenges discussed above, the Partnership is called to address a key problem: **CO_2 emissions from the steel sector will not sufficiently decrease compared to 1990 levels without major technological breakthroughs**. In a nutshell, the decarbonisation of the steel sector is necessary, but will not take place without a major systemic push. This push, in turn, requires a coordinated joint R&D&I effort, which needs to cover the whole steel industry – i.e. both the BF-BOF and the EAF routes – and which must be immediate, given the steel investment cycles.

The use of carbon in the steel industry and emission of pollutants are closely interrelated. Breakthrough technologies within the Clean Steel Partnership will alter the emission profiles from industrial plants and are expected ultimately to have significant beneficial effects. Research activities will take a holistic, integrated approach to decarbonisation, including emissions reductions and building the circular economy, in line with the ambitions of the European Green Deal. The problems tackled by the Partnership, and their drivers where relevant, can be summarised as follows:

- **Limited further reduction of emissions from steel production under the current technologies.** The European Commission has clearly stated that the current pathway will not allow for the climate and energy targets to be met. As the steel sector contributes significantly to CO_2 emissions, **the EU objective of climate neutrality cannot be achieved without an immediate intervention to decarbonise the EU steel industry**. This is apparent considering the following drivers:
  - Steel industry processes are responsible for between 4 and 7% of global GHG emissions.[18]
  - About the same ratio applies to the EU and its steel industry, which accounts for annual emissions of around 200 million tonnes (Mt) of CO_2.[19] This represents about 20% to 25% of industrial CO_2 emissions under the EU ETS data[20].

[17] European Commission (2013), 'Action Plan for a competitive and sustainable steel industry in Europe'(COM/2013/0407 final); European Commission (2017), 'Steel: Preserving sustainable jobs and growth in Europe' (COM(2016)155), and 'A renewed EU Industrial Policy' (COM(2017)479).

[18] European Commission (n.d.), Energy Efficiency and CO_2 Reduction in the Iron and Steel Industry, setis.ec.europa.eu/system/files/Technology_Information_Sheet_Energy_Efficiency_and_CO2_Reduction_in_the_Iron_and_Steel_Industry.pdf

[19] Emissions Data for the EU steel industry differ slightly depending on the source, they are accounted with 221 Mt CO_2 for the year 2015. See Navigant Netherlands B.V. (prepared for EUROFER) (2019); they are accounted with 190 Mt CO_2 for 2015, see: Institute for European Studies (IES) (2018), Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe, p. 21.

[20] For further details, please see: eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1; for brief discussion on data, see Footnote **Error! Bookmark not defined.**.

- Between 1990 and 2015 the greenhouse gas (GHG) emissions from steel production in the EU went down by about 26%[21], a development that can be attributed partly to improved production processes and partly to lower production.[22]
- The optimization of the production processes is already very high, and they are close to their thermodynamic limits, leading to a situation where no significant emission reduction can be expected anymore only based on energy efficiency improvements.[23]

Hence, further efforts for R&D&I are necessary for the steel sector to achieve its targets and help the EU achieve its overall targets. Those R&D&I efforts can allow the industry to proceed along a 'decarbonisation pathway', which would reduce CO_2 emissions in the steel sector by 80% to 95% by 2050.

- **Risk of worsening the EU steel competitive position.** Decarbonising the steel sector is crucial to reduce emissions, but it also needs **to preserve the current competitive position of EU steelmaking, the number of jobs created, and its technological leadership**. Indeed:
  - Despite the difficult position of European steel in the global market, it still represents around 10% of global production[24].
  - The economic slowdown since 2015 had a negative impact on global steel demand and the glut of overcapacity, mainly in China[25], has depressed steel prices worldwide. Meanwhile, steel imports from China to the EU also have surged in the last three years.[26]
- **Long investment cycles need immediate action.**
  - Any intervention must be immediate, because the investment cycle in this industry takes between 20 and 30 years.[27]
  - Moreover, being a capital intensive industry, the investments required will strain the economics of the EU steelmakers, which operate in a highly competitive global market, including players located in regions with no or limited carbon regulation, or low carbon costs.

Therefore, the industry should embark in a large investment cycle while bearing the pressure to remain competitive, facing a cost- and time-intensive implementation of low-carbon technologies (including engineering, permitting, construction). **The Clean Steel Partnership thus seeks to**

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[21] Emissions data differs, as outlined. The CO_2 emissions reduced from 298 Mt to 221 Mt CO_2 according to Navigant Netherlands B.V. (prepared for EUROFER) (2019), Update of the Steel Roadmap for low-carbon Europe 2050.
Emissions reduced from 258 to 190 Mt CO_2 according to Institute for European Studies (IES)(2018), Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe. Both amount to a 26% reduction in emissions.

[22] Navigant Netherlands B.V. (prepared for EUROFER) (2019), Update of the Steel Roadmap for low-carbon Europe 2050, p. 18-19.

[23] Indeed, in the baseline scenario, the total CO2 emissions of the steel industry will be only 10-15% lower in 2050 than in 1990, accounting for the estimated growth in production. Namely, the business-as-usual (BAU) trajectory would cause reduction of about 10% compared to 1990 levels; a reduction of 15% compared to 1990 would be achieved with retrofitting technology and low-carbon electricity being available. For further details, please see: EUROFER (2019), Low Carbon Roadmap: Pathways to a CO_2-Neutral European Steel Industry.

[24] European Commission (2016), Steel: Preserving sustainable jobs and growth in Europe, (COM(2016)155), p. 3.

[25] Estimated at around 350 million tonnes. For further details, please see: European Commission (2016), Steel: Preserving sustainable jobs and growth in Europe, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank, COM(2016)155.

[26] Ibid.

[27] See 'EU Green Deal', p.7.

accelerate this process by focusing on important R&D&I challenges and prepare a range of breakthrough technologies for clean steel production for large scale demonstration by 2030 at the latest.

- **Diversity and dispersion of steelmaking requires coordinated efforts across stakeholders and technologies.** The intervention must not only be immediate, but also coordinated across countries, production routes and technologies, because:
  - The steel industry is dispersed across the EU, encompassing 500 production sites in 23 Member States.
  - Different routes – BF-BOF and EAF – are used for steel production, whose competitiveness and viability must be secured by developing appropriate technological solutions[28].

  This illustrates that there can be no 'one-size-fits-all' approach to tackling the climate targets of the steel industry, and rather a **large number of technologies need to be developed in parallel and deployed in different EU production sites**. The coordination is further essential as the developed solutions from successful R&D&I efforts must be enabled across the entire industry in a concerted effort for them to gain the necessary traction.

- **Availability of zero-carbon electricity and hydrogen must be ensured**. The decarbonisation depends on a number of external factors, and namely related achievements in neighbouring industries. A key driver is the high availability of zero-carbon electricity and carbon-free and affordable hydrogen, because:
  - Since 1990, the energy consumption of the iron and steel sector has decreased considerably,[29] but the green transformation of the steel industry according to the 'current project trajectory' will require a significantly higher electricity use than the business-as-usual scenario.
  - While the business-as-usual projections estimate an electricity consumption for the EU steel industry of 55 terawatt-hours (TWh) per year, the 'current project trajectory' estimates 162 TWh, not accounting for the additional electricity used to produce hydrogen (estimated 234 TWh/year).[30] The CO_2-free electricity will also be important to produce hydrogen, which plays a key role in the transition towards low-carbon steel across many pathways and technologies.
- **Increased cost during transition.** Public support for R&D&I in the steel industry is required because of the high investments and higher production costs engendered by clean steel technologies. More in details:
  - Calculations estimate that the 'current project trajectory' will require investments of about EUR 52 billion, that is 53% more than in the business as usual scenario. The yearly production costs for clean steel in 2050 would amount to EUR 81-112 billion, compared to EUR 74-91 billion under the business-as-usual scenario.[31] As a consequence, clean steel is expected to cost substantially more than conventional steel.
  - In a competitive market environment, in which not all competitors face similar environmental regulation, the lack of public support would put EU steelmakers at a serious competitive

[28] While studies expect the share of scrap-based EAF in the production to increase from 40% in 2018 to up to 50% by 2050, both routes will remain a permanent feature of the EU industry.
[29] Institute for European Studies (IES) (2018), Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe, p. 22.
[30] Navigant Netherlands B.V. (prepared for EUROFER) (2019), Update of the Steel Roadmap for low-carbon Europe 2050, p. 23.
[31] Ibid.

disadvantage, in a market which is already oversaturated. Therefore, a supportive EU policy framework could define a proper mix of pull and push measures that shape new business models, create markets for climate-neutral, circular economy steel products and bridge the initial cost gap between conventional and low-carbon products.

As a consequence, public support and the coordinated effort of the Clean Steel Partnership can play an important role to reduce the economic risk for the industry to upscale solutions and processes to the industrial scale. Even when R&D&I efforts succeed, the costs and risks of enabling them at the industrial level can prevent them from gathering the necessary momentum.

- **Risk of carbon leakage.** EU energy-intensive industries such as steel already face higher costs than their competitors not only because of the ETS. Without a joint public-private endeavour, the path towards decarbonisation may end up in carbon leakage. Given the economic importance of the steel industry, both directly and indirectly for other industry sectors, this is a risk that the EU should avoid at all costs. The EU Green Deal takes this risk into serious account, also suggesting possible policy measures to tackle it, such as a **carbon border adjustment mechanism**.
- **The impact of the COVID-19 pandemic**. The current COVID-19 pandemic increases the reliance of the steel industry on external factors and sufficient public support to contribute to its path towards clean steel. The containment measures across the continent have further aggravated an already difficult situation for the steel industry. Collapsing demand places a significant economic strain on the industry, making it difficult not only to invest in new technologies but also to provide quality-employment. This places increasing importance on public support and coordination as envisaged in the Clean Steel Partnership.[32]

Strategic Opportunities

While the steel industry is among the most energy-intensive and CO_2 emitting industries, it has a very high potential for CO_2 abatement if the right R&D&I framework is provided. In the first step, the Partnership will allow steelmaking plants across the EU to demonstrate how individual technologies carry a reduction potential of 20-90% of CO_2 emissions by 2030. Overall, **the Partnership can thus enable the steel sector to meet its decarbonisation targets, fostering in turn the EU to meet its overall climate commitments until 2030 and 2050**.

There are two main technological trajectories for decarbonisation:

- Carbon Direct Avoidance (CDA), that is to avoid emitting carbon during steelmaking; and
- Smart Carbon Usage (SCU), consisting in ways to reduce the fossil carbon used in steel production (process integration, PI) and ways to avoid emitting carbon to the atmosphere (Carbon Capture, Utilisation, and Storage - CCUS).

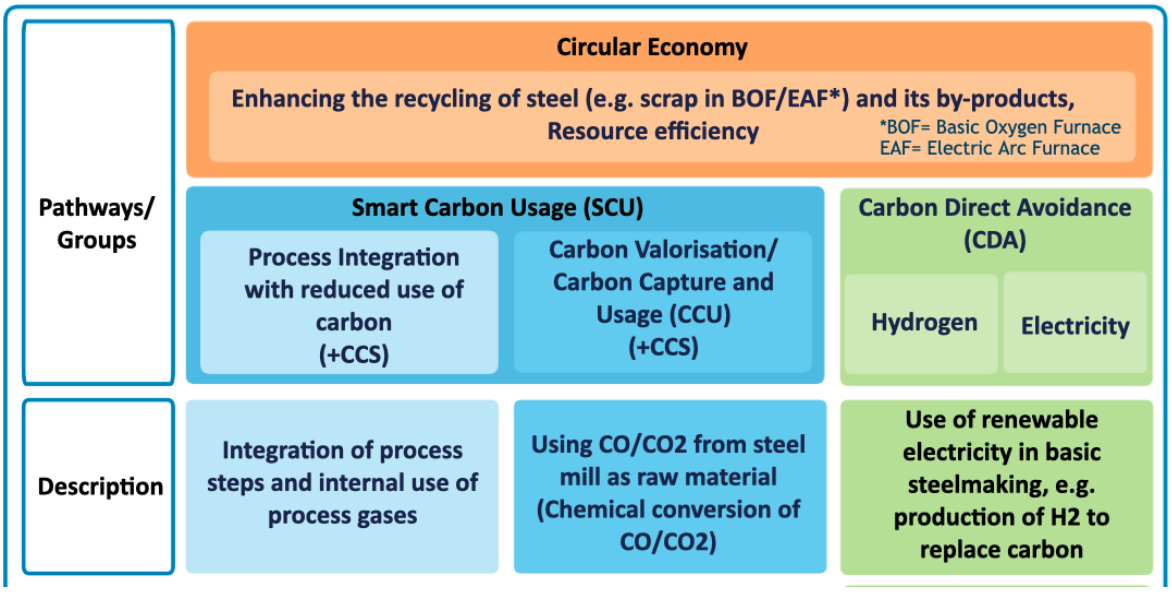
Furthermore, Circular Economy (CE) projects, promoting for example on the recycling of steel, the usage or recycling of by-products, and resource efficiency,[33] can support both pathways. The relation among the

[32] The steel sector has already taken initiative in addressing the EU Presidents to call for important decisions that can help the steel industry sailing through this crisis. These include crisis and security related import restrictions, a recognition of steel mills as essential to keep them operational during confinement, aid to avoid carbon leakage due to CO_2 costs in power prices under the ETS, and support against carbon leakage on direct emissions.

[33] Ibid.

various pathways is illustrated in **Error! Reference source not found.**. **Error! Reference source not found.** and Table 1 provide examples of the reduction abatement of various technical solutions and combinations thereof.

Figure 1: Technological Pathways and technologies to reduce CO_2 emissions of the EU steel industry[34]



Source: Low Carbon Roadmap: Pathways to a CO2-Neutral European Steel Industry, EUROFER, November 2019.

Figure 2: CO_2 Abatement Potential of Technologies in Steel by 2050, ultimately leading to climate neutrality

Smart Carbon Usage (SCU) and Carbon Direct Avoidance (CDA)		CO_2 abatement potential * (up to...)
SCU	CCU	80-95% with CCS and H_2
SCU	Process Integration	80-95% with CCUS
CDA	Hydrogen based steelmaking	80-95%
CDA	Iron ore electrolysis	80-95%

*Note: *= Potential CO2 reduction compared to BOF route in case of full-scale implementation. CO2 reduction of the entire steel industry depends on the combination of technologies.*

Source: European Partnership "Clean Steel – Low-Carbon Steelmaking", Presentation by EUROFER in the Horizon Europe framework, 02.11.2019.

[34] Pre-conditioning (cleaning, separation, concentration) of steel mill gas streams for process integration, carbon storage and carbon use is specific to the steel sector; furthermore, the upgrade of purified CO/CO_2 streams for use in CCU can also be specific to the steel sector.

Table 1: Trajectories for 80-95% CO_2 abatement[35]

Scenario A	Scenario B
• All projects currently under investigation for the decarbonisation of the steel industry are scaled up to their full potential at the industrial level. • Up to 75% CO_2 reduction with low-CO_2 energy. • Up to 85% less CO_2 with CO_2-free energy.	• Mix of the lowest emitting technology of the SCU in combination with the EAF route, or a mix of the lowest emitting technology of the CDA also in combination with the EAF route, both increasing the use of scrap and/or the mix of direct reduced iron (DRI)/hot briquetted iron (HBI). • Up to 80% reduction of CO_2 with low-CO_2 energy. • Up to 95% less CO_2 with CO_2-free energy.

Source: Author's own elaboration.

While the reduction of CO2 emissions is the main strategic opportunity that can be taken by the Partnership, it will also enable achieving other occasions, and namely:

- **Maximising R&D&I synergies and value added.** A coordinated effort to decarbonise the EU steel industry may further maximise synergies, reduce overlaps and ensure critical mass in R&D&I activities. The know-how generated from the R&D&I under this Partnership could make the steel industry a first mover in industrial-scale decarbonisation. This would ultimately allow the steel industry to lead other sectors by generating, *inter alia*, spill-over of know-how to such sectors. Breakthrough technologies in areas like the use of hydrogen will be valuable for the greening of other energy-intensive industries. The decarbonisation of the steel industry could, therefore, represent a corner stone for the EU to become a leader in the R&D&I of green industries, possibly allowing it to export its know-how and technologies beyond the EU and foster ambitious climate visions elsewhere.
- **Keeping EU leadership in steel technologies.** Next to becoming a pioneer in research on technologies, the Clean Steel Partnership may enable the steel industry to become a market leader on clean steel.
- **Reduce fossil fuel dependence.** By becoming greener, the EU steel sector – and the EU as a whole – may become less dependent on fossil energy/feedstock. Furthermore, a climate-neutral and competitive steel sector could be at the heart of the EU being at the forefront of green energy networks, as steel is a key enabler of technologies like wind turbines or solar photovoltaic with proper steel grades and steel applications.[36]
- **Becoming the incumbent in new markets.** New markets may emerge, such as for hydrogen, carbon feedstocks or by-products of the steel production, in which the EU could take a strong market position. The Partnership may enable the opportunity for the EU to be a global economic leader based upon innovation, cutting-edge technology, premium quality, and efficient production. The steel industry being at the heart of such a development would also secure the presence of a strategic industry in Europe as a key part of important (future) value chains.

[35] According to: Update of the Steel Roadmap for low-carbon Europe 2050, Navigant Netherlands B.V. (prepared for EUROFER), April 2019.
[36] European Commission (2018), European Steel: The Wind of Change.

2.1.3. R&D&I and systemic bottlenecks

The steel sector of the EU has a broad research footprint dedicated to low-carbon innovation. This includes strong collaboration with universities, research institutions and companies. There is no shortage of ideas and existing technical concepts are promising. Research is highly active in both main pathways, SCU and CDA, and in the CE (**Error! Reference source not found.**). R&D&I in all three areas has already been fostered by previous interventions (see examples of relevant projects further below), but **further challenges remain**, which the private sector is unlikely to solve on its own given the **existing research bottlenecks and market failures**.

Industrial deployment of key technologies.

The first bottleneck concerns **going from piloting to industrial-scale deployment**. Testing the most promising technologies at industrial scale entails:

- high technology risks, i.e. the risk that the technology does not prove effective 'in the field', thus wiping out the value of the previous R&D&I investments;
- very large capital requirements;
- higher production costs than conventional technologies. Furthermore, the current overcapacity glut implies that most of the upgrading will consist of brownfield conversions of existing sites, which are more expensive than greenfield investment.[37]
- such accelerated transition may lead to dismantling and rebuilding assets that, even if fully depreciated, still guarantee returns on investments, generating stranded costs for the investors.

A key challenge to overcome is thus the so-called **valley of death** between research and deployment of breakthrough technologies. Research financing currently focuses on primary R&D&I, while support towards industrial deployment is lacking:

- **research organizations** do not have the scale to fully shoulder the cost of deployment;[38]
- **commercial companies** cannot bear the high technological and economic risks, given their exposure to international competition.

Therefore, in the valley of death a **'funding gap'** emerges and bridging this gap will require significant financing support including the willingness of the public sector to participate in the risk-taking. Risk-sharing at demonstration phase is critical to enable test and approval phases by value chain partners and to allow technologies to mature, in order to establish technologies and trajectories that will allow achievement of the climate targets.

Another major challenge of the technology life cycle consists of the **'adoption gap**', that is the commercial diffusion of technologies which have already been deployed at industrial scale**.** The funding and adoption gaps can hit simultaneously very promising technologies, thus stifling some of the best opportunities to address the grand climate challenge in the years ahead. Especially within a highly competitive global market, fast action is essential to remain at the forefront of international low-carbon steelmaking, while being internationally competitive and collaborate beyond European borders to tackle a global problem.

[37] Brownfield conversions identify the retrofitting of existing plans, while greenfield investments correspond to new investment in production capacity.
[38] European Commission (2018), European Steel: The Wind of Change, p. 28.

Integration in the production system

While some supporting technologies are advancing well on their own, **their integration into the production system remains a challenge** still. Even if the low-CO_2 technologies reach maturity, their market uptake will depend on their operational costs. On the one hand, minimising those costs will have to become one of the main areas for further R&D; on the other hand, some form of cost compensation for green projects up to the first production is essential for overcoming this barrier to entry. Under high barrier to entry, a **market failure** thus arises in so far as the diffusion of more efficient technologies, i.e. those with lower external costs, remains below the social optimum. This is coupled with the other typical market failure concerning the deployment of low-carbon technologies, i.e. costs remain with the manufacturer while benefits accrue to the society at large and even spread outside Europe. All in all, these market failures represent sound economic reasons for public intervention in this area.

Availability of low CO_2/CO energy vectors

Furthermore, **availability and large supply of CO_2-low or CO_2-neutral energy vectors** (mainly electricity and hydrogen) at affordable costs is also a necessary pre-condition for the successful transformation of the steel sector. This mandates the proper functioning of the energy markets and timely development of adequate infrastructure, notably in the fields of electricity, hydrogen, CO_2 transport and storage. For investment planning, a careful mapping of the current state and the future requirements of the EU's energy infrastructure is therefore of utmost importance. This needs to be supported by an appropriate regulatory framework of the energy system.

2.1.4. Links with past projects and initiatives

The Clean Steel Partnership will **build upon previous partnerships and other related EU funded R&D&I programmes:**[39]

- In the context of R&D&I in the steel sector, a key role is performed by the **Research Fund for Coal and Steel (RFCS).** The programme, which would likely play a role in the financing of this Partnership, has been leading in bringing together the different actors and the various institutional levels, i.e. the industry, Member State representatives, technical experts, and researchers. The last evaluation of projects under the RFCS programme has shown some important progress, such as in the areas of more efficient operations in sintering, coke-making, and BF and in decreasing the energy consumption and CO_2 emissions in steel production. There is a wide variety of projects, more than 150 in total with different focuses going from steel processes to steel products and steel applications. The projects show high exploitation by beneficiaries and by the steel sector, but less so beyond it. Furthermore, the projects showed the EU added value and the need to run R&D&I projects at European level.[40]
- Among the various relevant R&D&I projects (a selection of which is listed in Annex 1), between 2004 and 2010 a project called **ULCOS (Ultra Low-CO_2 Steelmaking)** was financed by the European Commission under the 6th Framework Programme. ULCOS was a major research and technological development programme with the ultimate objective to develop technologies to reduce CO_2 emissions per tonne of steel by more than 50% based on CCS. Breakthrough technologies included:
    - BF with top-gas recycling (TGR-BF);

[39] Proposal 'Green Steel'

[40] European Commission, DG for Research and Innovation (2020), RFCS – Monitoring & Assessment Report (2011-2017)

    - A new smelting reduction process (HIsarna);
    - Advanced direct reduction (ULCORED); and
    - Electrolysis of iron ore (ULCOWIN and ULCOLYSIS).
- Beyond RFCS, there are other projects and initiatives, to which the Clean Steel Partnership can link and build upon. Some of them are:
    - **"Green Steel for Europe"**, funded by the European Parliament and administered by the Directorate-General for Research and Innovation (DG R&I) – Unit D3. It shows the political commitment of different EU institutions, and will prepare, *inter alia*, a roadmap and technologies for the transformation of the steel industry to achieve the 2030 and 2050 climate and energy targets, and will assess the economic, social, environmental impacts of the industrial transformation and EU-level policy options.
    - HYBRIT, example of a **private-public partnership (PPP) at the national level** as a joint venture between three companies: SSAB (steel), LKAB (iron ore), and Vattenfall (energy), co-sponsored by the Swedish Energy Agency. It indicates that carbon-free steel can still be competitive, but also shows it requires significant support from the government with regards to *inter alia* carbon-free electricity, infrastructure, research initiatives, and financing.[41]
    - Several major players in the European steel industry have started **individual decarbonisation projects**, which could inspire or become components of the Clean Steel Partnership (see Annex 1, list of projects).
    - The steel sector is a **partner in the cPPP SPIRE under Horizon 2020**, jointly with other energy-intensive industries and will continue its engagement in R&D&I projects with a cross-sectoral perspective.[42]

[41] European Commission (2018), European Steel: The Wind of Change, p. 18.

[42] The envisaged contractual arrangement partners of Clean Steel already signed a letter of memorandum with Process4Planet (see Annex 2) – the consortium managing and implementing the cPPP - and with the Clean Hydrogen partnerships (see Annex 3), to ensure the alignment of RD&I programmes and avoid duplication.

2.2. Common vision, objectives and expected impacts

Summary

Objectives

- General objective: to develop technologies at TRL8 to reduce CO_2 emissions stemming from EU steel production by 80-95% compared to 1990 levels by 2050, ultimately leading to climate neutrality. This objective aligns with commitments set by the European Green Deal and contributes to UN Sustainable Development Goals.
- Specific and operational objectives are set to support the general objectives and must be achieved in 7-10 years.
- All specific and operational objectives are defined in line with the impact pathways of Horizon Europe.

Vision and ambition

- The Partnership nurtures the long-term vision of supporting EU leadership in the transformation of the steel industry into a climate-neutral sector:
  - Intermediate step: develop technologies reducing CO_2 emissions from steel production by 50% by 2030 compared to 1990 levels;
  - Final ambition: reducing CO_2 emissions by 80-95% by 2050, ultimately achieving climate neutrality.
- The Partnership also contributes to the shared vision of an EU sustainable economy through:
  - Sharing its technological knowledge along industrial value chains;
  - Supporting EU's ambition to become a global leader in renewable energy.

Links and collaboration opportunities with other Partnership candidates, Missions and Union Programmes

- Potential collaboration with other partnership candidates: upstream (Clean Hydrogen, Clean Energy Transition), midstream (Process4Planet), downstream (People-centric sustainable built environment, Made in Europe).
- Contribution to Horizon Missions on climate-neutral and smart cities, soil health and food, and on adaptation to climate change including societal transformation and linkage to Horizon Clusters 4 and 5.
- High potential of synergies with other funding opportunities such Research Fund for Coal and Steel, Innovation Fund, LIFE Programme, European Regional Development Fund, InnovFin, InvestEU, CEF Programme, IPCEIs, Modernisation fund, Cohesion funding.

Investment needs

- Between 2020 and 2027, collective investments from the public and private side estimated to EUR 2 billion.
- Major private investment directly linked to the Partnership would match public funding for the Clean Steel Partnership from Horizon Europe and the Research Fund for Coal and Steel.
- Additional private investment would complement funding coming from other public sources (e.g. other EU programmes, as well as national and regional programmes relying on co-financing mechanisms).

Transformational changes

- The Partnership will promote a transformational change in how R&D&I activities are conducted in the steel sector. It will play a crucial role in identifying, bringing together, coordinating and enabling multiple breakthrough technologies with high decarbonisation potential.

- Transformational changes in R&D&I activities decarbonising the steel sector are achieved by relying on strong collaboration and joint commitment from both the private and public sectors
- By engaging a large number of public and private stakeholders, the Partnership aims to establish an integrated approach, from research to demonstration of potential technologies to decarbonise the steel industry, within a single Roadmap; this approach will reduce overlaps in R&D&I efforts and funding, ensuring better synergies and larger impacts.
- The positive spillovers on suppliers will consist in them having more incentives to further develop research in green energy, efficient production systems, and hydrogen technologies
- As regards customers (downstream), R&D&I investment in the steel sector will lead to the production of a cleaner, high-quality steel, which in turn will stimulate the production of goods with lower lifecycle impacts
- The Clean Steel Partnership will not only create synergies with other sectors, but also opportunities for collaboration across Member States and Associated Countries to develop breakthrough technologies.

Exit strategy

- The Partnership aims to fund projects bringing technologies from TRL 6 (and in exceptional circumstances TRL 5) to TRL 8. As soon as a key technology is fully developed and ready for roll-out (TRL=8), this technology will be phased out of the scope of the Partnership as well as funding from Horizon Europe.
- In operational terms, the Clean Steel Partnership will perform an intermediate assessment of the degree of accomplishment of the specific and operational objectives in line with the mid-term evaluation Horizon Europe, which is expected for 2024.
- R&D&I objectives will be achieved with the funding from 2021-27 under the Partnership, follow-up without further co-funding from Framework Programmes, but leveraging & sequencing other EU and other national funding opportunities such as Innovation Fund, InvestEU, CEF and IPCEIs.

Roadmap preparation

- A multiannual Roadmap (also including a Strategic Research and Innovation Agenda) is under preparation.
- The Roadmap will be published in draft version on the ESTEP website to allow for a public consultation to collect feedback from the broader steel sector as well as from Member States, the civil society and any other relevant stakeholder.
- The Roadmap will be updated to account for the comments and feedback received from consulted stakeholders and finalised by September 2020, in order to start the co-programmed Partnership in 2021.

2.2.1. Objectives

General objective and contribution to SDGs (timeframe: 10-30 years)

The **general objective** of the Partnership is to develop technologies at TRL8 to **reduce CO_2 emissions stemming from EU steel production by 80-95% compared to 1990 levels by 2050**, ultimately leading to climate neutrality.[43] This will contribute to the EU effort towards a climate-neutral continent. At the same

[43] This substantial reduction of CO_2 emissions will be accompanied by additional neutralisation measures, e.g. industrial symbiosis, enabling other industries to decarbonise by relying on steel product applications.

time, this objective is to be achieved while **preserving the competitiveness and viability of the EU steel industry**[44] and making sure that EU steel production will be able to meet the growing EU demand for steel products.

This general objective **is in line with the climate ambitions and commitments set by the European Green Deal**, which introduces a coherent framework and reaffirms previous commitments and visions such as the UN's 2030 SDGs, the Paris Agreement and associated pledges, and the "Clean Planet for All" Commission strategy.[45] In the Green Deal Communication, the Commission considers **the Clean Steel Partnership as a strategic tool to achieve its targets**.

By meeting the general objective, the Clean Steel Partnership will **contribute to UN's 2030 Agenda and** SDGs. The Partnership will particularly support:

- **Goal 3 on Good Health and Well-being.** By decarbonising the steel industry, the Partnership will contribute to reducing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
- **Goal 8 on Decent Work and Economic Growth**. By increasing the circularity of materials and improving productivity and efficiency in steelmaking, the Partnership will ensure sustainable growth and better working conditions.
- **Goal 9 on Industry, Innovation and Infrastructure**. Innovation in the steel sector will lead to less resource-intensive infrastructural solutions and to transformative innovation in other industrial sectors, thus further contributing to growth, technology development, and enhanced resource efficiency.
- **Goal 12 on Responsible Consumption and Production**. By relying on a circular economy approach, the Partnership will foster the promotion of responsible consumption and production patterns.
- **Goal 13 on Climate Action**. The Partnership will facilitate research, development and demonstration of technologies that eliminate CO_2 emissions in the steel sector.

Specific and operational objectives (timeframe: 7-10 years)

The general objective of the Clean Steel Partnership translates into a number of specific objectives to be **achieved in the next 7 to 10 years**:[46]

- **Specific objective 1.** Enabling steel production through **carbon direct avoidance (CDA)** technologies at a demonstration scale.
- **Specific objective 2.** Fostering **smart carbon usage (SCU – Carbon capture)** technologies in steelmaking routes at a demonstration scale, thus cutting CO_2 emissions from burning fossil fuels (e.g. coal) in the existing steel production routes.[47]

[44] Both BOF and EAF and including the wider steel value chain.
[45] Cf. Section 2.1 above.
[46] This timeframe is determined in accordance with the framework of the Horizon Europe Programme, which runs from 2021 to 2027. Three more years are added to the end-year of the programme, as projects starting in the last year of the Programme may need to be completed between 2027 and 2030.
[47] This specific objective exclusively focuses on the steelmaking process. By way of example, it does not cover projects that aim to use gases from steelmaking as a feedstock in processes of other sectors; by contrast, it does cover projects aiming to prepare/treat such gases to meet the requirements of other sectors.

- **Specific objective 3.** Developing deployable technologies to **improve energy and resource efficiency (SCU - Process Integration)**.
- **Specific objective 4:** Increasing the recycling of steel scrap and residues, thus improving smart resources usage and further supporting a **circular economy** model in EU.
- **Specific objective 5:** Demonstrating **clean steel breakthrough technologies** contributing to climate neutral steelmaking.
- **Specific objective 6:** Strengthening the **global competitiveness of the EU steel industry** in line with the EU industrial strategy for steel.[48]

A shown in Table 2, for each specific objective, one or more **operational objectives** are identified. Each operational objective is then accompanied by **key performance indicators** (KPIs) and **targets** which allow measuring the achievement of such objectives, complemented by indicators to track the progress on the European Green Deal's zero-pollution for a toxic free environment objective.

In line with the targets set for each operational objective, the Clean Steel Partnership aims to realise the following ambitions:

- **Achieving TRL 8 by 2030 in at least 12 building blocks** funded by the Partnership.
- **Implementing by 2027 at least two demonstration projects leading to 50% CO_2 emission reduction** compared to 1990 levels for the plants where the projects are implemented.
- **Implementing by 2034 at least two demonstrations of a technological pathway (CDA, SCU-Carbon Capture, SCU-Process Integration, Circular Economy) leading to 80% CO_2 emission reduction** compared to 1990 levels if the demonstration technology is fully implemented.

Table 2: Objectives, KPIs and targets of the Clean Steel Partnership

Operational objectives	KPIs	Target 2030
Specific objective 1: Enabling steel production through CDA technologies		
Replacing carbon by renewable energy	• Decrease of scope I and II CO2 emissions proven at a demonstration scale	• TRL8 > 40% CO2 reduction compared with reference operation at TRL 6
Development of H_2-based reduction and/or melting processes	• Reduction degree of iron oxides • Replacement rate of fossil carbon by hydrogen injection • Replacement rate of natural gas by H_2 in the feed of the direct reduction plant	• TRL8: > 90 % reduction degree of iron oxides • TRL8: > 10 % replacement rate of fossil carbon at injection point • TRL8: > 50 volume-%
Electrolytic reduction	• Electric efficiency of the electrolytic cell	• TRL8: > 85% electric efficiency
Specific objective 2: Fostering SCU technologies in steelmaking routes		
Improving process integration with reduced use of carbon (e.g. gas injection in BF), upstream and downstream	• Decrease of process related CO2 emissions proven	• TRL8: > 25 % reduction compared with reference operation

[48] European Commission (2013), Action Plan for a competitive and sustainable steel industry in Europe'(COM/2013/0407 final); European Commission (2016), 'Steel: Preserving sustainable jobs and growth in Europe' (COM(2016)155)

Operational objectives	KPIs	Target 2030
Increasing the use of non-fossil carbon	• Share of non-fossil carbon proven in reducing and/or melting process	• TRL8: > 20 % of non-fossil fuels/ reducing agent
Capturing CO_2 for CCU and/or CCS	• CO_2 capture rate from process/off gases	• TRL8: > 95 % from dedicates gas stream
Conditioning of metallurgical gases (containing CO_2, CO, CH_4, etc.) to meet specifications to finally produce chemical feedstock/alternative fuels[49]	• Share of carbon content of the process gas (CO_2/CO) provided to be transformed into products	• TRL 8: more than 65 % of C
Specific objective 3: Developing deployable technologies to improve energy and resource efficiency (SCU Process Integration)		
Increasing the use of pre-reduced iron carriers	• Share of pre-reduced iron carriers out of total Fe carriers	• TRL8: > 20 % pre-reduced Fe carriers in iron and steelmaking process
Developing technologies to reduce the energy required to produce steel	• Decrease the use of energy per tonne of steel for clean steel making	• +TRL8: > 10 % specific energy consumption reduction for a dedicated process
Specific objective 4: Increasing the recycling of steel scrap and residues to increase smart resources usage and further support a circular economy model in EU		
Enhancing the recycling and re-use of industrial residues of the steel production process	• Re-use and recycling of solid residues co-generated during the steel production process and reduction of their landfilling rate	• TRL8: internal and external recycling and re-use rate > 85 % (in total)
Enhancing the recycling of steel scrap	Scrap pre-treatment and cleaning technologies and scrap yard management procedures and techniques for: • Progressively increasing the uptake of low-quality scrap grades (post-consumer) into high quality steel grades • Progressively replace the use of pre-consumers grades with post-consumer grades • Progressively replace the use of solid pig iron with post-consumer grades	• TRL8: Low quality scrap input share over the total scrap input increased by at least 50% or more compared to the usual practice for a specific steel quality
Specific objective 5: Demonstrating clean steel breakthrough technologies contributing to climate neutral steelmaking		
Achieving TRL 8 by 2030 in most of the technology building blocks funded by the Partnership	• Percentage of projects that reach high TRL	• Share of projects in the Partnership with TRL7: >85% • Share of projects in the Partnership with TRL8: >75%

[49] The "**U**se"-part of this CC**U** approach is foreseen to be supported by the Processes4Planet partnership.

Operational objectives	KPIs	Target 2030
Demonstrating clean steel breakthrough technologies by 2030 that enable at least a reduction in GHG emission compared to 1990 levels for similar plants	• Number of demonstration projects	• TRL8: 2 projects > 80% CO2 reduction compared with reference operation
Specific objective 6: Strengthening the global competitiveness of the EU steel industry		
Creating a new market for 'clean steel' products[50]	• % of clean steel out of total EU steel demand	• Start rolling-out clean steel and its products
Contributing to the EU's efforts towards ensuring growth and jobs with long-term stability	• GVA generated by the steel industry and key steel-supplied value chains	• Increase GVA by 2% compared to 2020 • (target needs to be revised after COVID19)
Establishing EU steel industry as a leader in low-carbon steel and ensuring standardization and global market uptake of successful technologies developed in the EU	• Global market share of EU technology providers	• +10% in global market share of EU technology providers
Fostering R&D collaboration between EU companies and science in the clean steel value chains	• Number of visiting periods of external researchers working on projects funded by the Partnership • Number of calls in collaboration with other Partnerships	• > 10 visiting period (CDA, SCU, Circular Economy) • > =5 linked or joined calls
Upskilling steel workforce	• Number of supporting dedicated programmes (EU, national), with which the Partnership operates in synergy	• >= 3 dedicated supporting programmes

Source: Authors' own elaboration.

While aiming at achieving the specific and operational objectives presented in Table 2, the Clean Steel Partnership will also contribute to attaining additional **energy and environmental goals**.

- Technologies deployed to decarbonise will contribute to protecting **the health of EU citizens and ecosystems** in line with the European Green Deal, both directly (by reducing CO_2 emissions) and indirectly (by **reducing other types of industrial emissions to air, soil and water**). In this context, *ad hoc* indicators will be used to monitor and reduce the impact of projects funded by the Clean Steel Partnership on industrial emissions other than CO_2. These will be integrated in a semi-quantitative indicator expressing the progress towards the European Green Deal's zero-pollution for a toxic free environment objective, which will be presented in reports alongside the KPIs.

[50] The creation of a new market for 'clean steel' products would benefit from the creation of a labelling/certification scheme for clean steel based on a life-cycle assessment approach. This initiative may be initiated by ESTEP and EUROFER to complement and further support the Clean Steel Partnership activities.

- By increasingly relying on electricity to produce steel or hydrogen needed for steel production, steel plants will be able to further contribute to the **balancing of the power grid** by participating in demand-response mechanisms and by providing new opportunities for energy storage.

All the specific and operational objectives of the Clean Steel Partnership are defined **in line with the objectives and impact pathways of Horizon Europe**. A detailed analysis of the **directionality** between the Clean Steel Partnership and Horizon Europe is provided in Section 2.3 of this document.

2.2.2. Vision and ambition

The Clean Steel Partnership nurtures the long-term vision of supporting the European leadership in the **transformation of the steel industry into a climate-neutral sector**. Furthermore, as the steel industry is a centrepiece of the European economy, this Partnership has the potential of contributing to the EU ambitions in the area of **industrial policy** and **sustainable economic growth**. The Partnership seeks to accelerate the transformation of the steel industry by tackling important R&D&I challenges and bringing a range of breakthrough technologies for clean steel production up to large scale demonstration by 2030, at the latest.

The opportunities coming from this Partnership can:

- Support a climate neutral and competitive steel production in the EU;
- Allow to export successful EU technologies for low-carbon steel making to large markets outside the EU (e.g. China, India, Japan, US);
- Make the steel sector less dependent on fossil energy/feedstock (e.g. high-quality coking coal);
- Secure the presence of strategic industry in Europe as key part of important (future) value chains;
- Enable spill-overs of know-how to other industries (e.g. Carbon Capture Usage in chemicals, Carbon Capture and Storage, hydrogen);
- Enhance processes for the smart use of resources inside the steel processes (for instance pre-conditioning of material/gas flows), thus further enabling the contribution of the sector to the EU circular economy strategy and the EU energy transition.

The Partnership's vision is in line with the EU Green Deal[51], which has underlined once more that the overarching vision for the EU future must be:

- To **reduce CO_2 emissions**;
- To **keep the increase of global temperature rise well below 2°C,** and to pursue efforts to limit the temperature increase to 1.5°C;
- To foster a **circular economy** for greater resource efficiency and decreased negative environmental impact;
- To use **digital[52] technologies** as critical enabler for attaining sustainability goals.;
- To create **new forms of collaboration[53]** through alliances and large-scale pooling of resources such as IPCEI;
- To achieve a "**zero-pollution for a toxic free environment" ambition** in order to protect the health of Europe's citizens and ecosystems.

[51] EU Green Deal section 2.2.3, page 18
[52] EU Green Deal section 2.1.3 page 9
[53] EU Green Deal section 2.1.3 page 9

Sustainable growth

The Clean Steel Partnership vision will contribute to the ambition to **decarbonise the EU economy** as a whole. For the EU to remain a **global leader in sustainable economic growth**, the steel industry should reduce its footprint by producing clean steel, and share its technological knowledge along industrial value chains (see 'broader impacts' below). For this ambition to realise, geographical proximity is key, as the cross-industry spill-overs can take place only if a strong presence of the steel industry in the EU is preserved. The steel industry is, however, under heavy competitive pressure from global markets and imports to the EU from regions with less immediate decarbonisation efforts. It will be vital to **ensure a competitive steel sector in the EU** to secure economic growth, high-quality employment, and innovation throughout the connected industrial value chains.

The European Commission has further stressed that improving the sustainability of the EU economy must not come at the expense of citizens and workers, as it should consist in a **just transition**.[54] A strong and competitive clean steel industry will contribute to the achievement of this ambition in several ways, since the European steel sector is highly important for employment and GVA,[55] both directly as well as indirectly, by enabling employment and production in other industries. The challenging tasks ahead will further require **highly skilled workers**, and in reverse will offer those workers employment opportunities.

Broader impacts

Steel can contribute to fulfilling the EU vision of a systemic sustainable transition by enabling **key transformations in other sectors**. For instance:

- A key to a decarbonised economy for the EU will be the availability of CO_2-free electricity, which is one of the reasons why the EU has set out to become a **global leader in renewable energy.**[56] As steel is an essential material for such an energy system, clean steel will be necessary to reach this common vision, for two main reasons:
  - Renewable energy generation creates **new value chains, which will most likely lead to an increased demand for steel** in the upcoming decades. A report by the Institute for European Studies of the Vrije Universiteit Brussel, for example, calculates that the expected additional 600 GW of offshore wind capacity would in itself require 108 million tonnes of steel.[57]
  - New energy technologies will require steel for storage and transportation.
- European societies are currently undergoing changes, in which steel is playing a crucial role. Further to CO_2-free energy production and distribution, another example is the changing **mobility of citizens within urban areas**, which will require the extension of affordable urban transport infrastructure. Steel is essential for such infrastructure, as it represents a strong, fire-resistant, and anti-corrosive material, needed for underground and open-air railway systems.58

[54] European Commission (2016), Steel: Preserving sustainable jobs and growth in Europe, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank, COM(2016)155
Source: 'EU Green Deal'.
[55] See Section 2.1 above.
[56] A Clean Planet for All: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral company, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank, COM(2018) 773, 28.11.2018.
[57] Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe, Institute for European Studies (IES), September 2018, p. 53.
[58] Navigant Netherlands B.V. (prepared for EUROFER) (2019),Update of the Steel Roadmap for low-carbon Europe 2050 ,

- Steel plays an important role in **construction, automotive and mechanical engineering**[59]. A coordinated framework can thus entail the spreading and exchange of knowledge from the steel sector to other industries. Close cooperation between the steel and the automotive industry already exist[60] and will become even more important in the future. For instance, as the automotive sector is currently going through a transition towards electric vehicles, steel will not only remain a key material for the production of vehicles, but the pooled knowledge of the two industries will be vital for a sustainable EU economy.[61]

Perspective and strategy

This Partnership can tackle and support a range of shared visions and ambitions for the European steel industry and the EU. The development of new technologies, the improvement of production processes, and the decoupling of economic growth from carbon emissions achieved so far show that past joint public-private efforts have delivered very positive outcomes[62] and witness the potential for the present Partnership to go beyond such outcomes. Therefore, to achieve and up-scale breakthrough technologies and work towards common visions and ambitions, **further public and private efforts will be necessary**.

The EU has already shown the ability to decouple economic growth from CO_2 emissions and to reduce both energy use and emissions while achieving GDP growth.[63] In this regard, the steel sector has shown the commitment and ability to adjust to changing environments and to become a leading industry in innovation. During this transformation process, the industry has become more capital intensive, and labour productivity has increased considerably[64]. While the EU steel industry is structured to produce and deliver all types and qualities of steel products, its competitiveness is mainly linked to high-quality and often tailor-made products and services in demanding end-user segments. Consequently, **the EU steel industry's competitive position is strongly connected to product innovation and value creation**, supported by advanced technological development. In order to fulfil the raised ambitions of CO_2 emissions reduction, **a deepened Partnership is necessary for achieving climate objectives and preserving a vibrant, and high-value-added industry able to manufacture high-quality products** [65].

In order to reach the steel industry's long-term visions of reducing CO_2 emissions, **its immediate and intermediate ambitions consist of piloting and demonstrating breakthrough technologie**s that can significantly reduce the steel climate footprint. This demonstration phase will be essential as an initial step towards the longer-term visions. As no single company or even single Member State can develop and employ technological breakthroughs alone, the Partnership **will be crucial to share risks between and private and public actors and allow the necessary ambitious steps**.

[59] EUROFER (2019), 2019: European Steel in Figures, p. 25.
[60] Update of the Steel Roadmap for low-carbon Europe 2050, Navigant Netherlands B.V. (prepared for EUROFER), April 2019.
[61] Ibid., p. 34-37.
[62] See Section 2.1 above.
[63] A Clean Planet for All: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral company, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank, COM(2018) 773, 28.11.2018.
[64] ECORYS SCS Group for the European Commission (2008), Study on the Competitiveness of the European Steel Sector. Within the Framework Contract of Sectoral Competitiveness Studies – ENTR/06/054
[65] Navigant Netherlands B.V. (prepared for EUROFER) (2019), Update of the Steel Roadmap for low-carbon Europe 2050.

2.2.3. Links and collaboration opportunities with other partnership candidates, missions and Union programmes

Links and collaboration opportunities with other partnership candidates

The Clean Steel Partnership falls under Pillar II of the Horizon Europe Programme on **"Global Challenges and Industrial Competitiveness"** and, more specifically, within **Cluster 4 - Digital, Industry and Space**. This Cluster aims to achieve three main objectives, which are (i) ensuring the competitive edge and autonomy of EU industry, (ii) fostering climate-neutral, circular and clean industry, and (iii) bringing major contribution to inclusiveness. The Clean Steel Partnership will largely contribute to these objectives.

The Partnership is also linked to the activities performed under **Cluster 5 - Climate, Energy and Mobility**. The main objectives of this cluster are to fight against climate change and improve the competitiveness of the energy and transport industry as well as the quality of the services that these sectors bring to society. Reduction of GHG in steelmaking process, including through energy efficiency and the use of renewable energy, is remarkably connected to the objectives of this Cluster. In addition, the steel industry can be an important interlocutor for balancing and stabilizing the electricity grid in Europe.

Against this background, the Clean Steel Partnership can benefit from collaboration with other **partnership candidates** in Cluster 4 and 5, to ensure good complementarities, avoid overlaps and generate synergies to maximize the economic, social and environmental impacts of the Horizon Europe programme. The full achievement of some of the objectives of the Clean Steel Partnership may be affected by the successful completion of R&D&I projects that are expected to be funded in the context of the "**Clean Hydrogen**" and the "**Processes4Planet**" partnerships. For this reason, the Clean Steel Partnership has already signed Joint Declarations with these two partnerships to foster cooperation and ensure the achievement of shared objectives. In Table 3, other partnership candidates and relevant collaboration opportunities have been classified based on their potential interaction with the steel value chain (upstream, midstream and downstream).

Table 3: Links and collaboration opportunities with other partnership candidates

Partnership candidate and cluster	Collaboration opportunities
Upstream	
Clean Hydrogen (cluster 5)	The proposed partnership "**Clean Hydrogen**" sets the objectives to accelerate the market entry of nearly-zero GHG-emission hydrogen-based technologies across energy, transport and industrial end-users. Hydrogen is one of the most effective solutions to substitute carbon-based energy resources in steelmaking, particularly if the hydrogen is produced from renewable energy sources.[66] Clean Steel has been keeping communication open with the Clean Hydrogen and established formal mechanisms of consultation to prepare the relevant Work Programmes in order to maximise synergies. The two partnerships have agreed on the area of cooperation, according to which (i) hydrogen technological development dealing with clean hydrogen production, distribution and storage will be within the scope of Clean Hydrogen, (ii) development of a new steel production plant or process will be within

[66]For further details, please see: fch.europa.eu/sites/default/files/FCH%202%20JE%20Annual%20Work%20Plan%20and%20Budget%202019%20%28ID%205167414%29.pdf, p.36

Partnership candidate and cluster	Collaboration opportunities
	the scope of Clean Steel, and (iii) the integration of the production, distribution and storage of hydrogen in the steel making process is an area for cooperation between the two partnerships. Clean Steel will be given the opportunity to review the list of topics and projects envisaged by Clean Hydrogen, and the other way around. In addition, the two partnerships committed to exchange information on events and calls, share success stories and ensure harmonious allocation of projects. A Joint Declaration of collaboration between the two partnerships was signed in May 2020.
Clean Energy Transition (cluster 5)	The Clean Steel Partnership also sees potential synergies with the proposed Partnership "**Clean Energy Transition**" insofar as it will help develop new technologies for renewable energy and decarbonise the EU energy sector. In fact, renewable energy is a key input to sustain the decarbonisation of the EU steel sector. In line with what proposed above, to foster synergies, Clean Steel may introduce formal consultation mechanisms with the Clean Energy Transition Partnership, limited to specific parts of the respective Work Programmes.
Midstream	
Processes4Planet – Transforming the European Process Industry for a sustainable society (cluster 4)	The proposed Partnership "**Process4Planet**" aims to transform European process industries to (i) make them carbon neutral by 2050, (ii) turn them into circular industries together with material and recycling industries, and (iii) enhance their technological leadership at global level and international competitiveness. The Clean Steel Partnership and Processes4Planet have been working closely to align R&D&I objectives and plans. Shared areas of collaboration between the two Partnerships include, *inter alia*, carbon capture, circular business models and practices. This collaboration has been materialised into a Joint Declaration signed in September 2019 and regular dialogues between the two Partnerships since then. Accordingly, the two Partnerships have agreed that any technological development or innovation aiming at avoiding CO_2 emissions that is specific to the steel production or the steel value chain will be within the scope of Clean Steel Partnership. Meanwhile, technological developments or innovations that would be of cross-sectorial interest will be pursued under Processes4Planet. Formal mechanisms of consultation will be established to prepare the relevant Work Programmes and ascertain that synergies are maximised, while avoiding overlaps. As proposed above, the Clean Steel Partnership may be given the opportunity to review the Roadmap and Work Programmes of Processes4Planet, and the other way around. In addition, a coordination workshop will be arranged on a yearly basis to present and discuss completed, ongoing and planned activities of the two Partnerships.
Downstream	
People-centric sustainable built environment (Built4People) (cluster 5)	The proposed partnership "**Built4People**" focuses on technology and socio-economic breakthroughs for an improved built environment to support the achievement of EU 2050 decarbonisation goals and the transition to clean energy and circular economy, while improving social wellbeing, mobility and competitiveness. Construction is the biggest steel-using industries, accounting for

Partnership candidate and cluster	Collaboration opportunities
	about 35% of steel demand in Europe in 2018.[67] Meanwhile, buildings currently account for 39% of the global energy-related carbon emissions, including 11% from materials and construction.[68] Therefore, a collaboration between the Clean Steel and Built4People Partnerships would contribute to lowering the environmental impacts of the construction sector by relying on clean steel inputs and, in turn, to establish a market for clean steel. In this respect, while there is no risk of overlaps between the two Partnerships, some mechanisms of consultation may be established to prepare relevant Work Programmes and maximise synergies. For instance, the Clean Steel Partnership may be asked to review specific parts of the Built4People Work Programmes and Roadmap, which may be affected by the quality, quantity and carbon content of steel available in the EU.
Made in Europe (cluster 4)	There are strong linkages between Clean Steel and the "**Made in Europe**" Partnerships. "Made in Europe" sets objectives to achieve a competitive discrete manufacturing industry with a world-leading reduction of the environmental footprint whilst guaranteeing the highest level of well-being for workers, consumers and society. The achievements of CO_2 reduction and circularity in the steel industry will have a multiplier effect down the manufacturing chain. Therefore, dialogue and collaboration with the "Made in Europe" partnership can maximize the value creation for society and respond to the customers demand for customized products with a lower impact on the environment. Formal mechanisms of consultation may also be established with this Partnership.

Source: Authors' own elaboration.

Links and collaboration with Horizon Europe missions

In line with its objectives, the Clean Steel Partnership will be able to contribute to the following R&D&I **Missions of the Horizon Europe** Programme:

- The **Mission on Climate-neutral and smart cities**.[69] The Mission aims to improve the quality of life of citizens living and/or working in cities and metropolitan areas, contributing to global targets on climate change and sustainable development. Steel accounts for an important part of the materials needed for cities' infrastructure. Therefore, decarbonising the steel industry can contribute to the goals on climate-neutral cities.
- The **Mission on soil health and food**.[70] The Mission provides a powerful tool to raise awareness on the importance of soils, engage with citizens, create knowledge and develop solutions for restoring soil health and soil functions. Decarbonising the steel industry will be beneficial to the soil health thanks to the increasing steel contribution to a circular economy and initiatives such as 'zero landfill' in the steel sector.

[67] For further details, please see: oecd.org/sti/ind/45145459.pdf; p.2
[68] For further details, please see: Eurofer (2019), 2019 European Steel in Figures, p.25
[69] For further details, please see: ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/mission-area-climate-neutral-and-smart-cities_en
[70] For further details, please see: ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/mission-area-soil-health-and-food_en

- The **Mission on Adaptation to climate change including societal transformation**.[71] The Mission focuses on solutions and preparedness for the impact of climate change to protect lives and assets. It will include behavioural changes and social aspects by addressing new communities beyond usual stakeholders, which help lead to a societal transformation. Clean steel products may contribute to such a transformation.

Ideally, while it is unlikely that initiatives under the Clean Steel Partnership will overlap with those funded in the context of the three Missions, **formal mechanisms of consultation** could be established (on request from the European Commission) to maximise synergies. More specifically, the Clean Steel Partnership may be given the opportunity to review Missions' Work Programmes, and the other way around.

Links and collaboration with other Union programmes

The Clean Steel Partnership is expected to:

- Support **first industrial deployments** (pre-study, post-optimisation of technologies); and
- Launch a number of industrial pilots to demonstrate: i) technical feasibility of technologies with **easy-to-catch potential**; and ii) technical feasibility of **disruptive technologies** that should lead to ambitious CO_2 emission reduction potential within the existing and developing energy infrastructure.

These features distinguish the Clean Steel Partnership from other initiatives and programmes and allow for synergies between projects developed under the Partnership and those potentially funded by **current Union funding programmes for R&I**, including:

- **Research Fund for Coal and Steel.**[72] The fund supports R&I projects in coal and steel sectors. Funded projects cover, inter alia, (i) production processes, (ii) application, utilisation and conversion of resources, (iii) environmental protection and (iv) reduction of CO_2 emissions from coal use and steel production. As part of the funding for the Clean Steel Partnership is expected to come from **ECSC in liquidation** (which is a unique feature of this Partnership), the Clean Steel Partnership may need to ensure compliance with both Horizon Europe and Research Fund for Coal and Steel rules. Specific arrangements will be decided in cooperation with the European Commission.

- **ETS Innovation Fund**.[73] The programme focuses on innovative low-carbon technologies, namely (i) low-carbon technologies and processes in energy intensive industries, (ii) CCU , (iii) construction and operation of CCS, (iv) innovative renewable energy generation and (v) energy storage. The fund is open to projects from energy intensive industries, including the steel sector. The Innovation Fund would complement Horizon Europe through helping scale up and bring to the market breakthrough technologies developed under the Clean Steel Partnership.

- **LIFE Programme**.[74] Main objectives of the LIFE programme include (i) resource-efficient, low carbon and climate resilient economy and (ii) improve the development, implementation and

[71] For further details see: ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/mission-area-adaptation-climate-change-including-societal-transformation_en

[72] For further details, please see: ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/research-fund-coal-and-steel-rfcs_en

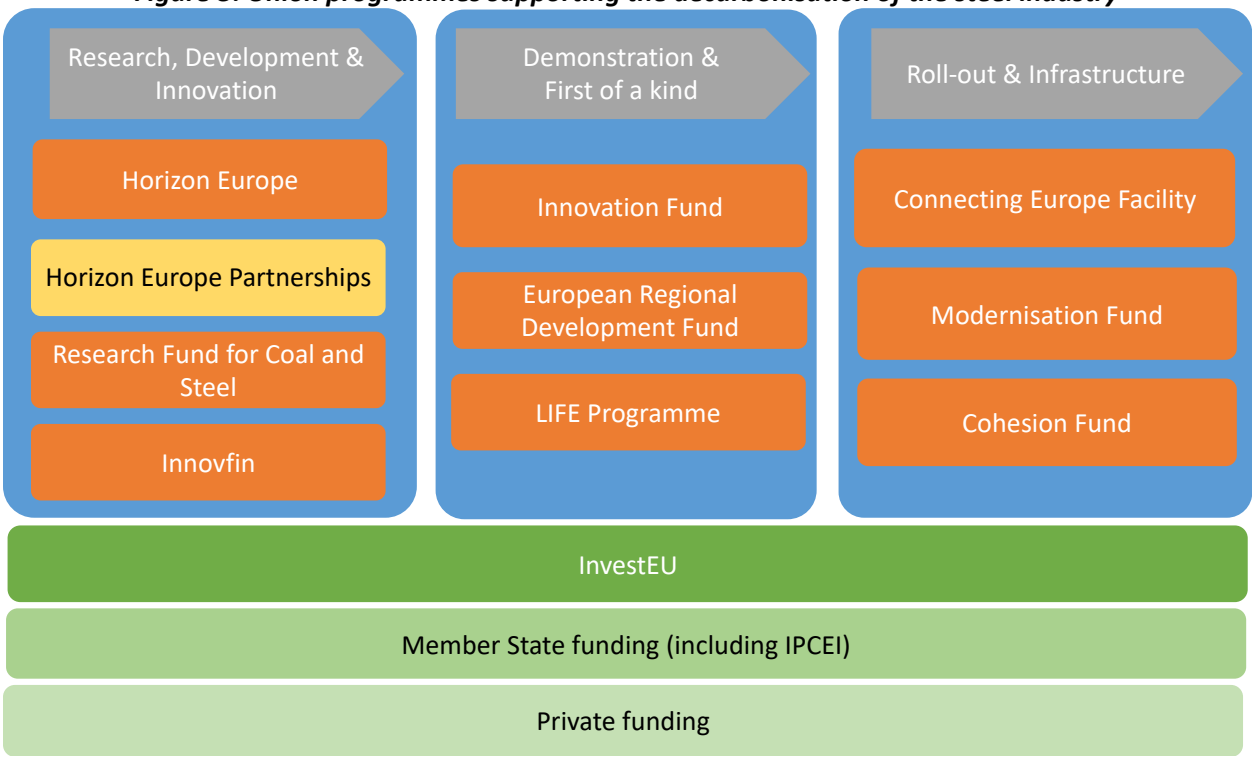
[73] For further details, please see: ec.europa.eu/clima/policies/innovation-fund_en

[74] For further details, please see: ec.europa.eu/easme/en/section/life/life-legal-basis#inline-nav-1

enforcement of EU environmental and climate policy and legislation, and act as a catalyst for, and promote, the mainstreaming of environmental and climate objectives into other policies and practices.

- **European Regional Development Fund**.[75] The ERDF supports economic and social cohesion in the EU by correcting imbalances between its regions. R&I and the low carbon economy are among the four priority areas of investment of the fund.
- **InnovFin**.[76] InnovFin financing tools cover a wide range of loans, guarantees and equity-type funding. Financing is either provided directly or via a financial intermediary, most usually a bank or a fund.
- **InvestEU Fund under Invest EU Programme**[77] (successor of the Investment Plan for Europe/the Juncker Plan). The Fund mobilises public and private investment using an EU budget guarantee. Among its four main policy areas, the Fund will support sustainable infrastructure, research, innovation and digitisation.

Figure 3: Union programmes supporting the decarbonisation of the steel industry



Source: Authors' own elaboration.

Besides these EU funding programmes it is worth mentioning the label "**Important Projects of Common European Interest" (IPCEI)**[78]**.** This is a special mechanism for state aid relaxation that allows Member

[75] For further details, please see: ec.europa.eu/regional_policy/en/funding/erdf/
[76] For further details see: eib.org/en/products/blending/innovfin/index.htm
[77] For further details, please see: ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan-europe-juncker-plan/whats-next-investeu-programme-2021-2027_en
[78] For further details, please see: eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C_.2014.188.01.0004.01.ENG

States to co-finance projects that make important contribution to the common objectives. Eligible projects must develop new products or services with high R&I content and/or the deployment of a fundamentally innovative production process.

There are also other relevant financing programmes that can complement Clean Steel Partnership activities, including the **Connecting Europe Facility**[79] (CEF Programme). While the main focus of this programme is on investment in the transport and energy sector, there is high potential of financing for cross-border infrastructural projects, for example on carbon capture and storage technologies in steelmaking. Rolling-out of relevant infrastructure can also be supported by the **Modernisation Fund**[80] and **Cohesion Fund.**[81]

It is worth mentioning that the ongoing 'Green Steel for Europe' project is exploring opportunities for blending and sequencing funds stemming from the Clean Steel Partnership with those available in the other Union programmes. This would, on the one hand, favour the phasing out of the Clean Steel Partnership and, on the other hand, support the full-scale industrial deployment of the technologies developed under the Partnership. Additional synergies may be developed with national funding programmes as well as upcoming EU-level funding programme, such as those linked to the **Just Transition Mechanisms**[82], envisaged in the European Green Deal.

The Clean Steel Partnership commits to closely **monitor the evolution of complementary funding opportunities** and to ensure synergies between activities funded by the Partnership and those eligible for funding under other EU and national funding mechanisms.

2.2.4. Investment needs

The resources needed to deploy the activities foreseen by this Partnership are as follows:

- Based on the estimated industrial efforts from the steel sector in R&D&I projects needed to achieve the objectives of the Clean Steel Partnership, the total resource requirement is estimated at around **EUR 3 billion.**[83]
- Due to the collaboration among steel producers, reasonable synergies are expected compared to the company by company approach, which reduce the **investment need** to approximately **EUR 2.55 billion** for the next decade (up to 2030).
- For the Partnership period of 2021 to 2027, collective investments needed from the public and private side are estimated at **EUR 2 billion**[84] (the **'wider boundary'** of the Partnership), and the remaining funding (estimated to be EUR 0.55 billion) will be allocated to the period immediately after the Clean Steel Partnership, **2028-30**, where some projects will still be completed.
- It is expected that the public and private investment within the **scope** of the Clean Steel Partnership will amount to at least **EUR 1.4 billion;** those are the resources necessary to deliver

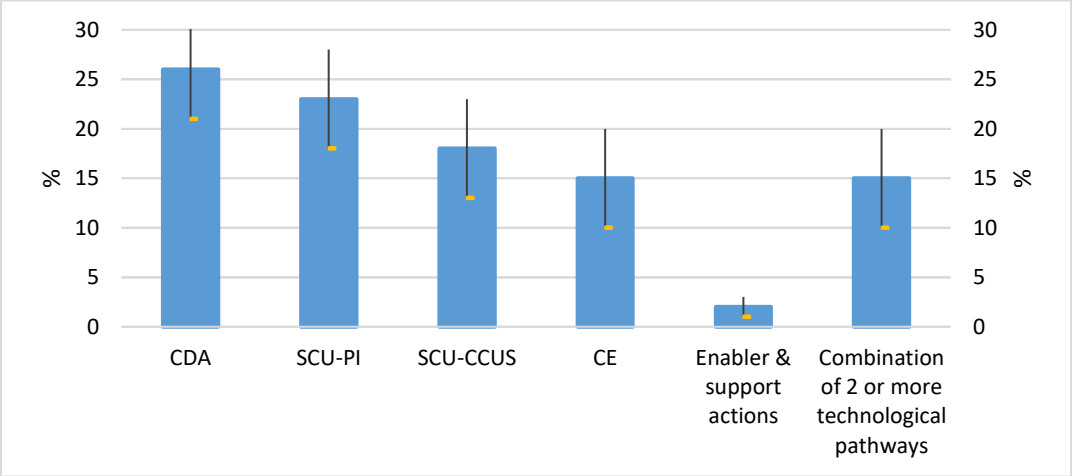
[79] For further details, please see: ec.europa.eu/inea/en/connecting-europe-facility
[80] For further details, please see: https://ec.europa.eu/clima/policies/budget/modernisation-fund_en
[81] For further details, please see: https://ec.europa.eu/regional_policy/en/funding/cohesion-fund/
[82] For further details, please see: ec.europa.eu/regional_policy/en/newsroom/news/2020/01/14-01-2020-financing-the-green-transition-the-european-green-deal-investment-plan-and-just-transition-mechanism
[83] Data collection in the frame of: SET Plan action 6, IPCEI, Innovation Fund (IF), 2019 update of the LowCarbon roadmap for steel.
[84] The private side committed to finance up to EUR 1 billion by matching public contributions (see letter from CEOs of major EU steel companies to President Juncker, available at: https://www.estep.eu/assets/CSP-letters/20180925-Letter-to-Pres.-Juncker-and-College-of-Commissioners-on-Low-Carbon-Steel.pdf)

on a Clean Steel Strategic Research and Innovation Agenda in the period 2021-2027. Major private funding would match public funding from the Union, such as Horizon Europe and the Research Fund for Coal and Steel. ~~European Coal and Steel Community (ECSC) assets in liquidation. Indeed, an important role could be played by ESCS assets in liquidation, this being a unique feature of the Clean Steel Partnership.~~

- Within the wider boundary of the Partnership, additional private investment would complement funding coming from other public sources (e.g. other EU programmes, as well as national and regional programmes relying on co-financing mechanisms).

As discussed in Section 2.1 above, the main technological pathways towards low-carbon steelmaking are SCU and CDA, aligned with an increased circular economy. Based on the analyses of the investment needs in R&D&I by the steel stakeholders, the investments should be split over the different areas of intervention approximately as shown in **Error! Reference source not found.**[85].

Figure 4: Budget per area of intervention (average values, range min to max)



Source: Author's own elaboration based on internal consultation.

Table 4 further decomposes the contribution per area of intervention over the various periods of the Partnership.

Table 4: Allocation of budget by areas of intervention of the Clean Steel Partnership

Areas of intervention	**2021-2023**	**2024-2025**	**2026-2027**	**2021-2027**
	Total (%)	***Total (%)***	***Total (%)***	***Total (%)***
Smart carbon usage via process integration	10.4%	6.9%	5.8%	23.0%
Carbon Direct Avoidance	11.7%	7.8%	6.5%	26.0%
Smart carbon usage via CCUS (specific to steel)	8.1%	5.4%	4.5%	18.0%
Circular economy	6.8%	4.5%	3.8%	15.0%

[85] The enablers and support actions are not incorporated into the technological pathways because their role is of high importance even though the budget required by them is lower.

Combination of pathways	6.8%	4.5%	3.8%	15.0%
Enablers & support actions	1.4%	0.9%	0.8%	3.0%
TOTAL	**45.0%**	**30.0%**	**25.0%**	**100.0%**

Source: Author's elaboration on consultation with ESTEP members.

The Clean Steel Partnership is expected to generate **direct and indirect leverage effects.** More specifically:

- The Partnership will **collaborate with the upstream and downstream value chains**, thus leveraging R&I investments in order to ensure that clean steelmaking technologies, ICT systems and tools and other components needed will be fit for purpose. This will turn the higher level of ambition to reduce CO_2 emissions by 2030 (30%[86] instead of 23% as stated in the 2019 update of the low carbon steel study) into reality.
- The rapid development of new technologies and its upgrade to demonstration scale will have **spill over effects to other energy-intensive sectors**, as the underlying technologies have reasonable commonalities (see **Error! Reference source not found.**);[87]
- Once a technology has successfully been demonstrated, commercialisation of the technology requires a significant investment. Industry indicators show **an additional investment is needed of around EUR 9 billion** for the first roll out. The sector is committed to make these investments for the most promising technologies being developed in the Partnership if the corresponding supportive conditions are in place, notably the right infrastructure and a supportive regulatory and financial framework.

2.2.5. Transformational changes

The Clean Steel Partnership will generate deep changes in the **R&D&I ecosystem of the steel industry** by developing and combining a multiplicity of innovative technologies. In fact, there is no single solution to decarbonise the steel sector. Rather, many different technological pathways have to be followed to achieve climate neutrality. In addition, combining different technologies has proven to generate more CO_2 reduction than separate deployment of such technologies. Therefore, the Partnership will promote a transformational change in how R&D&I activities are conducted in the steel sector. More specifically, the Clean Steel Partnership will play a crucial role in **identifying**, **bringing together, coordinating and enabling multiple breakthrough technologies** with high decarbonisation potential.

Transformational changes in R&D&I activities decarbonising the steel sector are achieved by relying on **strong collaboration and joint commitment** from both the private and public sectors. In line with this approach, the Partnership will engage all relevant stakeholders, including industrial players, the research community, academia, Member States and civil society organisations to ensure that any R&D&I initiatives will lead to positive impacts within and beyond the steel sector. Sectoral impacts will mostly consist in a more efficient use of R&D&I resources. By engaging a large number of public and private stakeholders, the Partnership aims to establish an **integrated approach**, from research to demonstration of potential technologies to decarbonise the steel industry, within a single Roadmap. This approach will reduce overlaps in R&D&I efforts and funding, ensuring **better synergies and larger impacts**.

[86] EUROFER (2020), A Green Deal on Steel: Priorities for Transitioning the EU to Carbon Neutrality and Circularity. 30% reduction in 2030 compared to 2018 level (also announced in EUROFER letter dated 21 Feb 2020 to Frans Timmermans).
[87] VUB study, 9 Sep 2018.

When looking at the **broader R&D&I ecosystem**, the innovation introduced by the Partnership will cross-fertilise both upstream and downstream sectors.

- The positive **spillovers on suppliers** (upstream) will consist in them having more incentives to further develop **research in green energy, efficient production systems, and hydrogen technologies**. For instance, by deploying CCU technologies, the steel and chemical industries would contribute to the production of low carbon synthetic fuels and chemical feedstock. The introduction of breakthrough technologies for the steel sector would also send an input for the electrification of the economy, and a significant rise in demand for renewable electricity, in particular for the production of H_2 to be used as a feedstock, thus supporting the green energy transition in the EU.
- As regards **customers** (downstream), R&D&I investment in the steel sector will lead to the production of a cleaner, high-quality steel, which in turn will stimulate the production of **goods with lower lifecycle impacts**. Indeed, steel is considered a mitigation enabler. With its strength and durability, it enables savings in other industries. An analysis of several case studies showed that CO_2 savings in other industries can outweigh the emissions created by the production of the necessary steel at a ratio of 6 to 1.[88] In addition, the steel industry produces important raw materials in the form of by-products, e.g. for the construction sector and the cement industry, that can further reduce the climate footprint of such industries.

Finally, the Clean Steel Partnership will not only create synergies with other sectors, but also opportunities for **collaboration across Member States and Associated Countries** to develop breakthrough technologies. In addition, the Partnership will establish collaboration with other **national and regional programmes** investing in R&D&I activities to support the development and rolling out of new technologies and innovative solutions to reduce GHG emission in steel production. A detailed description of the Partnership's approach to strengthen its collaboration with Member States and Associated Countries are presented in Sections 2.3 and 3.1 of this Proposal.

2.2.6. Exit strategy

Over the period 2020-2030, the Clean Steel Partnership will **develop and test at a large scale the technologies required to achieve a climate neutral EU steel industry by 2050**. The Partnership aims to fund projects bringing technologies from TRL 6 (and in exceptional circumstances TRL 5) to TRL 8. As soon as a key technology is fully developed and ready for roll-out (TRL=8), **this technology will be phased out of the scope of the Partnership** as well as funding from Horizon Europe and successor Framework Programmes. More generally, after the end of the Partnership, the long tradition in collaborative R&D&I by the EU steel industry (started over 15 years ago) will ensure the progressive improvement, optimisation, upscaling and roll-out of low-carbon steelmaking technologies developed under the Clean Steel Partnership.

In operational terms, the Clean Steel Partnership will perform an intermediate **assessment of the degree of accomplishment of the specific and operational objectives** set out in Section 2, in line with the mid-term evaluation Horizon Europe, which is expected for 2024. The assessment will rely on the KPIs

[88] Boston Consulting Group & Steel Institute VDEh (2013), Steel's contribution to low-carbon Europe 2050. Technical and economic analysis of the sector's CO_2 abatement potential.

identified for each operational objective and analyse, *inter alia*, the contribution of key technologies[89] developed under the Partnership to achieving such objectives. Over the period 2020-2027, the Partnership is expected to complete 12 projects resulting in building blocks at TRL7, six projects resulting in building blocks at TRL 8 and two demonstration projects. These demonstration projects, which will combine different building blocks, will target technologies that have up to 50% CO_2 mitigation potential (compared to 1990 levels) by 2027. The Partnership will also decide to invest with expenditure in the period 2027-2034 into additional four projects resulting in building blocks at TRL7, six projects resulting in building blocks at TRL 8 and two demonstration projects supporting technologies with up to 80% of CO_2 reduction (compared to 1990 levels). **Specific intermediate targets for each KPI** are provided in the Roadmap accompanying this Proposal.

It is planned that all key technologies for the technological pathways are **fully developed at TRL 8 or higher**, allowing for phase-out from Framework Programme funding.

When accounting for possible synergies stemming from a coordinated approach to R&D&I ensured by the Partnership, the full cost to develop the required technologies between 2020 and 2030 is EUR 2.55 billion. While the wider boundary of the proposed partnership, once taking into account the efficiency gains from a coordinated approach, requires investments estimated at EUR 2 billion for the 2021-2027 period, it is expected that the scope of the partnership encompasses public and private investment of at least EUR 1.4 billion, to deliver on a Clean Steel Strategic Research and Innovation Agenda, the roadmap. The achievement of the Clean Steel Partnership objectives, therefore, will not prevent the steel sector from applying for other public funding sources. In fact, the EU steel industry will need to **rely on additional funding (public and private) outside the Partnership** to fully achieve the general objective proposed above and deploy the technologies developed under the Partnership.

2.2.7. Roadmap preparation

A **multiannual Roadmap** (also including a Strategic Research and Innovation Agenda) is under preparation. By relying on a **participatory approach,** which ensure a broad involvement of key actors of the EU steel value chain, ESTEP has been defining **strategies and common lines of intervention** to achieve the objectives of the Clean Steel Partnership. After various rounds of consultation with the relevant services of the European Commission, the Roadmap will be published in draft version on the ESTEP website to allow for a **five-week public consultation**. This consultation aims to collect feedback from the broader steel sector as well as from Member States,[90] the civil society and any other relevant stakeholder.[91] The Roadmap will be updated to account for the comments and feedback received from consulted stakeholders. The final version of the Roadmap will undergo an additional one-week public consultation to inform stakeholders about all changes made. Table 5 outlines the timeline for preparing the Roadmap (activities in italics have already been completed). **The Roadmap will be finalised by September 2020**, in order to start the co-programmed Partnership in 2021.

[89] A key technology can be one building block or a combination of building blocks.
[90] Representatives from all EU Member State will be contacted to participate in the consultation process.
[91] The members of the Advisory Board of the "Green Steel for Europe" project funded by the European Parliament will be contacted to foster participation in the consultation. The Advisory Board is composed of relevant stakeholders, beyond the steel sector.

Table 5: Timeline to prepare the multiannual Roadmap

Date	Topic	Details
09 Dec 2019	*Kick-off of task force (TF) "Clean Steel Partnership"* *Involvement of external competence and resources*	*Decision on structure.* *Four chapters: Vision, R&I Strategy, Expected Impacts and Governance.*
04 Feb 2020	*Governance structure of the Partnership*	*Basic decision by TF Clean Steel Partnership.*
07 Feb 2020	*Steel producers' inputs on foreseen activities following the building block approach and its impact the technological pathways*	*17 steel producers (representing all production routes of EU) responded with around 200 activities.*
28 Feb 2020	*1st draft of roadmap incl. SRIA*	*Alignment between SRIA and Template for Clean Steel Partnership*
02 Mar 2020	*Presentation to steel community*	*ESTEP & EUROFER meetings*
March-April 2020	*Steady update of roadmap in consultation with EC Services*	
24 Mar 2020	*Consultation of CEOs of the steel producers on the draft roadmap, in particular on KPIs and targets*	
20April 2020	*Submission of the 2nd draft Roadmap to the European Commission*	
End of June 2020	Update of Roadmap based on Commission's comments on the Proposal: 3rd draft Roadmap	
July 2020	Start of 5-week public consultation of the Roadmap	Web-based, hosted and organised by ESTEP. Representative from all EU Member States will be invited to participate.
Sep 2020	Start evaluation of consultation feedback	
Sep 2020	Update of Roadmap based on the feedback from stakeholders: 4th draft Roadmap	
Oct 2020	Start 1-week public consultation	Inform about modifications compared to 3rd draft
Oct 2020	Final Roadmap of Clean Steel Partnership	

Source: Author's own elaboration.

2.3. Necessity for a European Partnership

Summary

Additionality

- The Commission considers CSP as one of the tools to deploy to achieve the targets set out in the European Green Deal.
- The Partnership allows higher degree of additionality compared to transnational joint calls and R&I projects under Horizon Europe:
  - Removing systemic bottlenecks affecting the EU steel industry by ensuring sufficient coordination in R&D&I activities;
  - Removing R&D bottlenecks by supporting the steps necessary to go from piloting to commercial deployment of new technologies and leveraging private investments;
  - Planning ahead a timely intervention to decarbonise the EU steel industry;
  - Commitment from partners to progressively phasing out from public support for R&D&I and to sequencing the Partnership with other funding schemes.
- There is a **strong EU added value** component in this Partnership investing in a modernised and sustainable steel industry.

Directionality

- The Partnership contributes to common objectives of Horizon Europe, thus ensuring the directionality of the intervention to the Programme. It will support the following Horizon Europe objectives:
  - Foster the Union's competitiveness in all Member States and industries;
  - Creating and diffusing high-quality knowledge and skills
  - Tackling global challenges will be supported by the Partnership's contribution to different SDGs.
  - Fostering innovation and technological development.
  - Facilitating collaborative links in European R&I

Meaningful collaboration with Member States

- CSP will seek for collaboration with national policies and programmes that may generate synergies with the activities funded by the Partnership, including additional financing opportunities e.g. from relaxation of state aid intensity via the status of IPCEIs, and the ERDF.
- These synergies will be identified, *inter alia*, through the ongoing 'Green Steel for Europe' Project, and the Integrated Strategic Energy Technologies Plan (SET Plan).
- To make this potential collaboration viable, the governance of the Partnership envisages mechanisms to cooperate with Member States

There is a strong EU added value in the Clean Steel Partnership investing in a modernised and sustainable steel industry. As discussed in Section 2.1, the Clean Steel Partnership is mentioned among the tools that the Commission could deploy to **achieve the targets set out in the European Green Deal**.[92] In fact, the decarbonisation of the EU steel industry will play a central role to reduce CO_2 emissions in the EU by 2030 and ensure climate neutrality by 2050.

[92] "Partnerships with industry and Member States will support research and innovation on transport, including batteries, clean hydrogen, low-carbon steel making, circular bio-based sectors and the built environment", EU Green Deal, p. 18.

Additionality

In this context, the Clean Steel Partnership will ensure a strong commitment from all actors of the steel value chain towards decarbonisation, thus leading to a **higher degree of additionality** compared to research activities funded by the Horizon Europe Programme.

- The Clean Steel Partnership will **remove systemic bottlenecks** affecting the EU steel industry (see Section 2.1) by ensuring sufficient coordination in R&D&I activities. A **coordinated approach** across stakeholders, technologies, production routes and countries is the most effective way to ensure that the EU climate and energy targets and long-term strategy for climate neutrality will be successfully achieved. More specially, steel production activities are spread across different EU Member States, and production technologies are different from plant to plant. Therefore, a variety of new technologies (and a combination thereof) need to be simultaneously deployed in different EU production sites. Neither a single company nor a single Member State is capable of developing breakthrough technologies to drastically reduce CO_2 emissions in the steel sector. In this context, a coordinated approach to R&D&I activities is key to (i) maximise synergies and avoid duplications of efforts, (ii) cover different technological paths while stimulating healthy competition among them, (iii) share risks among public and private actors, and (iv) ensure critical mass to decarbonise the steel industry in a timely fashion.
- The Partnership will **remove R&D bottlenecks** (see Section 2.1) by supporting the steps necessary to go from piloting to commercial deployment of new technologies and **leveraging private investments**. Activities to identify, develop and test the most promising technologies at the industrial scale are very costly and entail high risks. In addition, clean steel will cost substantially more than conventional steel, and steel is a global commodity, produced by global companies and priced globally. Hence, cost competition may favour low-cost steel over low-carbon steel, and shift production outside the EU. Emission reduction in the steel sector to net-zero by 2050 will require costly new production processes and major increase of capital investment. Pan-European public and private investments are therefore needed to favour the uptake of new climate-neutral technologies, reduce risks and catalyse further investment to decarbonise the steel sector. Additional private investments are ensured by the commitment of the Partnership's members to complement public funding.
- The Clean Steel Partnership will allow to plan ahead and timely perform the required R&D&I activities. **A timely and well-planned intervention** to decarbonise the EU steel industry is essential to achieve the EU climate and energy targets and long-term strategy for climate neutrality. Indeed, the EU steel industry contributes to a significant share of the CO_2 emissions in the EU. With no change in the current production process (baseline scenario), total CO_2 emission of the EU steel industry in 2050 would only 10-15% lower than 1990 values, accounting for small increase in steel production in the coming years.[93] Immediate intervention is needed due to the long investment cycle in the steel industry (20-30 years) and long time-to-market for low-CO_2 steel projects. The Partnership will identify research gaps and priorities in the Clean Steel Partnership's Roadmap.
- The additionality of the Partnership is also achieved through the **commitment from partners to progressively phasing out** from public support for R&I. As discussed in Section 2.2.6, the members of the Partnership are aware of the limited duration of the financial support from the Union side,

[93] EUROFER (2019), Low Carbon Roadmap: Pathways to a CO_2-Neutral European Steel Industry.

and will indicate the time needed to achieve the objectives, and a plan for phasing out EU funding in the future.

As discussed in Section 2.1, all the previous efforts done by the steel industry and the results obtained so far need now to be integrated into a single-minded and coherent framework, something that can be better managed via a Partnership. Indeed, the scale of the challenge, the need to coordinate a plethora of private and public actors in a workable multi-stakeholder environment, and the amount of resources envisaged suggest that other, looser, coordinated approaches and efforts would risk missing the objective. The Clean Steel Partnership would allow to get the whole steel industry in the EU on board, to cover different technological paths, to share risks among public and private actors and to give birth to a European sustainable re-industrialisation. There is, therefore, a **strong EU added value** component in this Partnership investing in a modernised and sustainable steel industry.

Directionality

Besides potential to achieve higher additionality, the Clean Steel Partnership will make a contribution towards **common objectives of Horizon Europe**, thus ensuring the **directionality of the intervention** to the Programme. The desired directionality will be achieved through a common vision between the Clean Steel Partnership and the Horizon Europe, ensuring alignments of the impacts and objectives of the Partnership and those of Horizon Europe. More specifically:

- Through strengthening the global competitiveness of the EU steel industry, the Partnership will support the Programme's **objective to foster the Union's competitiveness in all Member States and industries**. More specifically, the Partnership aims among other at creating a new market for 'clean steel' products, ensuring growth and jobs with long-term stability in steel and steel-associated sectors, and contributing to the standardisation and global market uptake of successful technologies developed in the EU.
- The Partnership will support to the Programme's **objective on creating and diffusing high-quality knowledge and skills**, contributing to full engagement of Union's talent pool. This goal will be achieved through the upskilling of the steel workforce, aiming to engage workers in clean-steel training activities foreseen by the Partnership.
- The Horizon Europe Programme's **objective on tackling global challenges** will be supported by the Partnership's contribution to different SDGs.
- The Partnership's objective on promoting decarbonising technologies in the steel sector aligns with the Programme's **objective on fostering innovation and technological development**. Some of the technologies developed in the steel industry may also be applied, *mutatis mutandis*, in other energy-intensive sectors.
- Finally, the Clean Steel Partnership will help achieve the Programme's **objective on facilitating collaborative links in European R&I** by fostering R&D&I collaboration between EU companies operating in the steel industry and those operating in green value chains that may rely on clean steel. This objective will be attained by setting up clusters and development/implementation of projects between eligible entities across and beyond the EU.

Meaningful collaboration with Member States

Clean Steel will identify **national policies and programmes** which may generate synergies with the activities funded by the Partnership. More information about these programmes, strategies and plans is already presented in Section 3.1 and Table 6. A more detailed and comprehensive analysis of national policies and programmes will be performed when implementing the Partnership in projects following calls for accompanying measures. In addition:

- The Clean Steel Partnership will benefit from the results of the ongoing 'Green Steel for Europe' Project, which will look among others into **possible synergies between EU level funding schemes and national and regional funds**.
- The Partnership will look into opportunities to cooperate with the country members of the **Integrated Strategic Energy Technologies Plan Action 6** (SET Plan),[94] which has identified the steel sector as one of its four priority areas in its Implementation Plan.[95] The Partnerships considers this platform as a good channel to streamline collaboration with the Member States sharing the climate-neutral objective in the steel sector.

It is also important to mention that the Partnership may seek additional financing opportunities e.g. from relaxation of **State Aid intensity via the status of IPCEIs,** and the **ERDF** (deployed at Member State or regional level) for the upscaling and deployment of low carbon solutions developed in the context of the Partnership. As mentioned in Section 2.2, these funding channels open the door to potential projects aiming at decarbonising the steel production processes at Member State level.

Finally, to make this potential collaboration viable during the implementation phase of the Partnership, a **mechanism to cooperate with Member States** via the so-called 'Stakeholder Forum' has been developed within the governance structure of the Partnership (see Section 0). In addition, Member States authorities may play an even more active role in the Partnership by participating in the discussion and decision-making process of the Partnership as observers (free of charge) or full members (see Section 0). Finally, Member State will be consulted to prepare and update the Roadmap of the Partnership.

[94] The SET Plan aims at accelerating the energy system transformation through coordinated or joint investments between European countries, private stakeholders (research and industry) and the European Commission. For further details see: setis.ec.europa.eu/about-setis/community

[95] For further details see: setis.ec.europa.eu/system/files/set_plan_ee_in_industry_implementation_plan.pdf

2.4. Partner composition and target group

Summary

- Partner composition relies on an open and participatory approach: steel producers, customers, suppliers, plant builders, steel processors, RTO, research and academia, and societal representatives, and any other relevant stakeholder may participate in the Partnership.
- Partnership will create the critical mass to attract and involve a broad spectrum of stakeholders from the very beginning.
- Cooperation with public entities is key to ensuring the alignment of research, innovation and deployment strategies with EU, national and regional programmes and policies, in order to maximise efforts.
- The Partnership will also establish a mechanism of coordination with the worldsteel Association to foster international efforts towards the decarbonisation of the steel industry, while ensuring full protection of confidentiality and IP rights

The **scale of the transformation needed** to deliver substantial emissions reduction in the EU steel production is paramount. The intensity of the R&D&I work required makes it impossible for individual companies acting alone to achieve such a target, as it would require investments that are well beyond the private sector's capacity, over a cycle far longer than the expected. Given these limitations, as further discussed in Section 2.3 on additionality, the Clean Steel Partnership is uniquely positioned to **build the required technical background and confidence for stakeholders** involved to continue their work towards a climate neutral EU steel industry.

The Clean Steel Partnership relies on an **open and participatory approach**, which is detailed in Section 3.4. The Partnership is open to the entire European steel value chain community, e.g. to all EU based steel stakeholders, comprising steel producers, customers, suppliers, plant builders, steel processor, research and academia, and societal representatives.

All relevant stakeholders will have to be involved and committed if the steel sector is to succeed in its transformation. Therefore, the Clean Steel Partnership will **create the critical mass to attract and involve a broad spectrum of stakeholders** from the very beginning. This will enable the Partnership to interact with such stakeholders and achieve the objectives described in Section 2.2.1. Going beyond the current ESTEP membership, the following types of Partners will form the initial core members of the Partnership:

- **Steel producers**, which are central actors to maximise the impact of the R&D&I solutions developed within the framework of the Partnership.
- **Plant builders and technology providers**, which have a key role in refitting the current assets of the steel industry as well as in the transformation of the EU steel industry towards climate neutrality. In addition, the plant builders are key players to promote and deploy the technologies and innovations developed in the frame of the Partnership. The development is likely to happen in collaboration with other stakeholders like steel producers, research and technology organisations (RTOs), and academia.
- **Steel processor,** which also perform energy-intensive activities and play an increasingly important role in the decarbonisation of the steel industry.

- **Academia and research institutes,** which can contribute by conducting scientific research in the field and testing new technologies and concepts.
- **RTOs**, which bring the core competence in applied technologies into the Partnership, i.e. an essential element to perform the activities summarised in Section 3.1 and aiming at high TRLs.
- **Public authorities** (international, European, national, regional, local), which are in charge of developing policies, legislation, initiatives and programmes further accompanying the decarbonisation of the steel industry and ensuring the proper implementation of such instruments.
- **Standardisation bodies**, i.e. non-governmental organisations that establish and maintain technical standards for steel products and technologies and can contribute to enhance the global uptake of EU technologies and solutions.
- **Engineering offices**, which are essential for the design of new solutions.
- **Companies operating in the energy sector,** whose efforts to provide low-carbon energy are essential to achieve the highest possible target in terms of CO_2 emission reduction in the steel industry.
- **Industrial Gas Suppliers**, which develop solutions for the steel sector in its transition towards climate neutrality (notably in the fields of hydrogen use and off-gases recycling), and will contribute by providing technical and economic input requested for the global R&D&I solutions.
- **End-users of steel**, which can help: i) ensure climate change mitigation across the steel value chain and beyond, with larger societal benefits; ii) create a new market for clean steel and associated products**.**

These categories of members will be contacted by relying on the existing **networks of contact of ESTEP[96] and EUROFER[97] as well as of their members**, which can ensure the required level of national and international outreach.[98]

To attract more members, the Partnership will also rely on the stakeholder list that has been prepared and delivered in the context of the Green Steel for Europe project. In addition, where needed, additional members will be engaged via dedicated membership campaigns. Annex 4 presents a preliminary list of expected members of the Partnership. This list already demonstrates a good geographical balance, as well

[96] The European Steel Technology Platform (ESTEP) brings together all the major stakeholders in the European steel industry. ESTEP membership includes major steel manufacturers, universities and research institutions active in steel research, major users of steel such as car manufacturers, and public bodies like the European Commission and national governments. ESTEP aims to engage in collaborative EU actions and projects on technology, which are tackling EU challenges (notably on renewable energy, climate change (low-carbon emission), circular economy) in order to create a sustainable EU steel industry. For further details of the role played by ESTEP in the governance of the Clean Steel Partnership, please see Section 0.

[97] The European Steel Association (EUROFER) represents the entirety of steel production in the European Union. EUROFER members are steel companies and national steel federations throughout the EU. The major steel companies and national steel federations in Switzerland and Turkey are associate members.

[98] The networks of ESTEP and EUROFER includes among others the following organisations and bodies: AEGIS Europe; A.SPIRE AISBL; Alliance for Materials; Alliance of Energy Intensive Industries; BusinessEurope; CEPS; Commission expert group on climate change policy; Commission operational expert group of the European Innovation Partnership on raw materials; Construction for products; EMIRI (Energy Materials Industry driven Research Initiative); European Energy Forum; European shippers Council; Expert group on the exchange of information on the best available techniques related to industrial emissions (IED Art. 13 Forum); High Level Group on Energy Intensive Industries; Industrial Emissions Alliance; Industry4Europe; Innovation Fund Expert Group; Manufuture (Technology Platform); Metals for Buildings Association; Raw materials supply group; Network of stakeholders that are parts of the SET Plan action 6, action 9; Steel Advisory Group for RFCS; Strategic Forum for IPCEIs; Trade contact group; and worldsteel association.

as a balance between umbrella organisations and individual companies. The list is in progress of being updated.

In this context, it is worth remarking that cooperation with public entities is key to **ensuring the alignment of research, innovation and deployment strategies with EU, national and regional programmes and policies, in order to maximise efforts**. The Clean Steel Partnership will work in close cooperation with the European Commission, which will be represented in the body governing the Partnership (the so-called 'Partnership Board' presented in Section 0). In cooperation with the European Commission, the Partnership will also engage national and regional administrations. Proper interaction with public entities is ensured by the **governance mechanisms** envisaged for the Partnership (via the so-called 'Stakeholder Forum' described in Section 0) as well as via **dedicated calls** to be included in the Work Programme. In addition, the Partnership will reach out to national industry associations, platforms and research organisations which are currently not linked yet to the Partnership. Finally, based on the proposed governance, the Clean Steel Partnership will interact with a much larger group of stakeholders beyond the steel industry including other sectoral associations (e.g. energy-intensive sectors, energy sector, etc.), trade unions, consumer protection bodies, NGOs and representatives of the civil society (the 'Other Stakeholder Group' within the so-called 'Stakeholder Forum' described in Section 0), which will be actively engaged to shape the Partnership and key element thereof, such as the multiannual Roadmap.

Finally, a global level playing field is of utmost importance for the survival and competitiveness of the EU steel sector, as well as to effectively mitigate climate change, which is a global problem. To **foster international efforts towards the decarbonisation of the steel industry**, as detailed in Section 3.4, the Partnership will establish mechanism of coordination with the worldsteel Association. When it comes, however, to R&D&I activities, international cooperation will only be established when **reciprocity** is ensured. This includes IP right protection, as well as treatment of investment and public procurement. The geographical scope of the Partnership will follow the rules set out for the functioning of the Horizon Europe programme, or the stricter rules set out for the Research Fund for Coal and Steel, where applicable.

3. Planned Implementation

3.1. Activities

Summary

Proposed activities

- The Partnership is centred around 12 Building Blocks:
  - Gas injection technology
  - CO_2-neutral iron-ore reduction
  - Melting of pre-reduced and reduced ore, scrap and iron rich low value residues
  - Adjustment of today's production to prepare for the transition towards climate neutrality
  - CO/CO_2 utilisation, CO_2 capture and storage in steelmaking
  - Raw material preparation
  - Heat generation for clean steel processes
  - Energy management / Energy vector storage (H_2, electricity, intermediate materials, …)
  - Steel-specific circular economy solutions
  - Enablers (skills, digitalisation)
  - Low CO_2 emissions downstream processes
  - Innovative steel applications for low CO_2 emissions

Coordination mechanisms

- The Partnership will establish systematic exchanges with relevant bodies managing other Horizon Europe initiatives and other EU actions and programmes, to avoid duplication, clarify overlap, foster collaboration and maximise synergies.
- Coordination mechanisms have already been established with the Process4Planet and the Clean Hydrogen Partnerships.
- The Partnership will continue to set up similar arrangement with other initiatives including People-centric sustainable built environment (Built4People), Made in Europe and Clean Energy Transition Partnerships.
- With specific regard to coordination with the Research Fund for Coal and Steel, the ideal setting would feature one single funding mechanisms relying on both Horizon Europe funds as well as ECSC assets. In case this will not be possible, the Partnership will work with separate but coordinated Calls from Proposals under the two funding programmes.

Potential synergies with national programmes

- The Partnership has started to identify several national policies, programmes and activities that may lead to high synergies when it comes to R&D&I activities contributing to the decarbonisation of the steel industry
- Coordination mechanisms with Member States and regional authorities and the consultation process to finalise the Roadmap are expected to maximise synergies with national policies, programmes and activities.

3.1.1. Proposed activities

The scope of the Clean Steel Partnership is centred around 12 Building Blocks, which are composed of areas of R&D&I focus (RIF).[99] The main facilities that will be in the focus of the Clean Steel Partnership are the ones of liquid steel production and the associated.[100] At the same time, downstream processes already contribute significantly to CO_2 emissions and will be highly relevant in achieving emission reduction targets. In order to **e**stablish a critical mass of actors and activities committed to urgent measures, all steel producers have to be involved. Moreover, CDA implies the move towards using more EAF. The Partnership aims to guarantee that the best solutions for BF-BOF, EAF and for downstream processes will be developed and prepared (e.g. Innovation Fund, IPCEI, EIB, etc.).

The link between the Building Blocks and the technological pathways is shown in Section 2.2 (when describing the process to prepare a Roadmap for the Partnership) and will be further detailed in the Roadmap. The proposed activities are fully aligned with the operational objectives proposed for the Clean Steel Partnership and will therefore contribute to the achievement of the specific and general objectives presented in Section 2.2. This consistent approach also ensures that the needs and problems presented in Section 2.1 will be fully addressed, thus ultimately contributing to tackle two main challenges faced by the EU, i.e. climate change and sustainable growth.

The envisaged actions can be categorised by a **matrix**. The content of the activity will follow the 12 Building Blocks,[101] while the impact is measured towards the technological pathways (CDS, PI, CCUS and CE). The **12 Building Blocks of the Clean Steel Partnership** are described in the following paragraphs. As mentioned above, only the combination of building blocks will provide impactful solutions to mitigate CO_2 emissions. Hence, the description of the building blocks does not reflect the importance or priority of any building block.

1. Gas injection technology for clean steel production

- The Building Block encompasses **several activities with different timing in terms of industrial deployment**.
- Gas injection technology aims to **reduce the CO_2 footprint of the steel production**, for which the injection of gases needs to be adjusted, optimised and/or developed. The carbon footprint may be reduced moderately with a rapid industrial deployment for some cases. For other options, with the potential for very low CO_2 emissions, intermediate steps are needed before full industrial deployment.
- From a technical standpoint, this building block covers **new process technologies for co-injection and new injection ports, e.g. for BF, DRI plants but also for EAF**. **New control techniques** will also have to be developed, considering process needs, safety issues and

[99] The proposed activities take into full consideration the outcome of the RFCS project "LowCarbonFuture", deliverable D 6.3; D24: "Compiled list of identified research needs".

[100] The CO2 emission of the steel sector is an average value between the primary and secondary route, with the BF-BOF route in the EU averaging 1800 kg CO2/t of liquid steel and 80-120 kg CO2 direct and 250-350 kg CO2 indirect emissions under the EAF route. For scrap based EAF and purely green hydrogen/electricity based CDA, emissions could be as low as 60 kg CO2 /t liquid steel, which for the moment is the operational minimum.

[101] All activities envisaged under the main technological pathways – see Section 2.2.4 – will be carried out via open calls.

economic aspects. Further activities in this building block are related to **gas treatment** and the investigation of the impact on refractories and burners.

2. CO2-neutral iron-ore reduction for clean steel production

- This building block includes R&D&I activities related to the metal reduction processes using hydrogen, renewable electricity, or biomass. A key component is **direct reduction with high amounts of hydrogen**, whereby impacts on the DRI properties and the process conditions have to be carefully investigated.
- Among technologies related to the **use of electricity**, activities will cover plasma technology and electrolytic reduction at low or high temperature.
- With respect to **biomass**, the use of different sources will be investigated including their adaptation to different processes. The sources will cover carbonisation and pyrolysis processes and biomass use (lump or pulverised) and biogas injection technology.
- A significant part of the activities will furthermore focus on the **adaption of the process control**, considering both the single reduction processes and the control along the production chain (e.g. electrolyser, DR, EAF). A general horizontal objective is to ensure **high levels of safety** when operating with new/modified reducing agents.

3. Melting of pre-reduced and reduced ore, scrap and iron rich low value residues for clean steel production

- The building block covers **low-carbon dioxide emission technologies** for melting iron-bringing feed materials with variable content of carbon and variable metallization, including low-value iron-based sources. The properties of the feed materials while melting will be investigated in new and adapted processes across the three technological pathways.
- Adaptations on existing EAF melting are envisaged to **replace traditional use of carbon and hydrocarbons** with carbon-neutral substitutes and hydrogen.
- This building block also covers the **demonstration of new reduction process technologies** for the recovery of metal contents to be used as scrap replacement from low value residues by pre-reduction or reduction smelting with H_2, biogas, CO_2-lean electricity and carbon bearing residues. Part of the activities will furthermore focus **on new sensors and tools** for the real time management inside the reactors of liquid metal and slag temperature and composition.

4. Adjustment of today's production to prepare for the transition towards climate neutrality

- This building block considers techniques and tools which support the immediate decrease of the carbon footprint on industrial level, for example by the integration of first shares of **hydrogen or renewable electricity** into already existing industrial plants. It considers techniques and planning tools as well to support the later steps of decarbonisation on industrial level.
- The technical scope can involve (i) the plant **gas distribution systems** (including mixing stations, furnaces and combustion technologies); (ii) the plant **electricity networks** which also need to be adjusted to enable the gradual increasing integration of renewable energies; and (iii) the necessary **adaption of material ecosystems** (e.g. iron sources, slags, residues, water) during the stepwise transition.
- This building block can be exploited at multi-fold level. In a nutshell, flexibility can basically involve the production cycle itself and the energy and materials supplied, by introducing:

- **adaptation of process control**;
- **flexible technologies for combustion;**
- **coordination of clean carbon steel production chains with CCUS processes**.

- Concerning the flexibility actions involving materials and energy supplied, the use of a wide control range of heating capacity by modular heating technologies will be explored. Integration of fuel cells can also bring back energy into the system. Materials can involve the use of alternative coal-based products for non-fossil coke, as well as an increased use of non-fossil energy and reactants in downstream processes.

5. CO/CO_2 utilisation, CO_2 capture and storage in steelmaking

- The utilisation of CO and CO2 from steel plants can be done in different ways and for various applications. **R&D&I is first necessary in the preparation of the gaseous stream containing CO/CO_2**: depending on the envisioned use, the gaseous stream, either process gas or off-gas to be released to the atmosphere, must first be prepared, potentially involving cleaning, compressions, drying, sulphur removal, separation, conversion, reforming, concentration, etc. These steps are generally highly energy consuming and potentially also include substantial changes in the gas network of steel plants.
- In order to utilise CO/CO_2 from steel plants and to establish the quality and marketability of the various obtainable products, significant efforts are necessary to improve performances of additional processes. Possible secondary residues also have to be marketed or recycled to ensure optimal environmental performances. In this field, the use of **life cycle impact assessment tools** will be of paramount and these CO/CO_2 utilisation processes require some hydrogen. Hence, the building block applies both to SCU and CDA.
- Finally, **CO_2 storage** is generally considered as a fall-back option with excessive costs and potential environmental and societal issues. It is however an option that potentially allows handling the large CO_2 volumes produced by the current steel plants. This option will also have to be considered in the portfolio of R&I.

6. Raw material preparation for clean steel production

This building block is related to the two main raw-materials in the iron and steelmaking route: the iron-ore and the scrap.

- As far as **iron ore** is concerned, the availability of high-grade iron ores is expected to become a more critical factor, as demand will increase. Therefore, technologies for the upgrade and the use of low-quality iron ores are needed.
- The research on **scrap** will focus on the best available and applicable technologies for the reduction of impurities in post-consumer scrap. The aim is to **remove these impurities before melting** and also to improve the sorting of scrap. The benefits at CO_2 emission reduction level are immediate. Moreover, scrap management and charge optimization concur to **material and cost saving with rational use of resources**. **Scrap cleaning actions**, including metal, paints, waste removal, can also lead to added value production.
- Also, **pre-heating technologies** using waste heat in off-gas are covered by this building block, as pertinent to the EAF production technology in reducing CO_2 emissions. In integrated steel mills, available surplus BOF gas could be used as fuel in the scrap preheating process.
- Finally, suitable **process control and monitoring** are further included in the scope of the building block.

7. **Heat generation for clean steel processes**

- This building block focuses on **energy efficiency, energy recovery and energy carriers without fossil carbon**.
- Steel processes are energy-intensive, as metal processing require high temperatures, which will lead to **off gases with useful energy content** that should be utilized to maximize energy performance. In addition, many processes exist with their own heat energy input needs, which can be approached within the framework of PI for both **waste heat usage, heat recovery and residual gas recovery**.
- Heat energy recovery and generation can be pursued via:
  - **pre-heating of non-fossil energy feeds** to primary and secondary processes;
  - **pre-heating of raw materials** to primary and secondary production;
  - **preheating of non-fuel feeds**;
  - **recovery of heat from hot processes and other waste**; and
  - usage within other related fields.
- To increase energy efficiency and recovery, it will be key to enable the efficient transfer of heat from unconventional sources, which will require new materials and combustion processes. Additionally, these new sources require that heat exchange materials are suitable for this new environment, and that the systems can be used flexibly depending on the availability of renewable resources.

8. **Energy management / Energy vector storage (e.g. H2, electricity, intermediate materials) for clean steel production**

- Despite the increasing fluctuations in the provided energy mix, reliable energy supply is essential for a consistent and effective steel production. The **storage and distribution of energy** is an important means to compensate increasing fluctuations and availability related to seasonal effects and renewable sources. The research on storage technologies, the needs-based distribution and their integration into the steel production chains is not limited to the **energy sources** but will also include **energy rich intermediate materials**.
- This building block will consider chemical (H2, intermediate materials), electricity and heat storage (e.g., for waste heat recovery from slag) and transportation. Moreover, emphasis will be placed on reusing existing facilities (e.g. gasholders out of service, grids) as energy storage, as well as buffer solutions for grid balancing. Novel process-gas storage processes are also relevant to technology improvement, as well as technologies that involve molten salts technology for high temperature energy storage.

9. **Steel-specific circular economy solutions**

- The first topic to address in the context of this building block is "**2050 scrap blending wall**". There are still limitations linked to the availability of scrap with the right quality, as the presence of tramp elements such as non-ferrous metals might limit the use of ferrous scrap for production of certain steel grades. Scrap treatments, processing and cleaning, will be an opportunity linked to the recovery of certain non-ferrous fractions, such as tin, copper and zinc. Research efforts on this topic are necessary because **valorisation of low-quality scrap streams** is one of the key elements for fostering a green transition of the steel production as a whole.

- The second one is the "**materials recirculation with high recycling rate**". There is still a huge room for improving the yield of the iron and steel making route by r**ecovering of metal contents from metal oxides**.
- The third topic covered by this building block is the "**residue valorisation**". To reach the **full circularity of the steel sector**, every material stream (residue) generated together with steel has to find its proper fate, to be re-used, recycled or recovered. Research efforts are, therefore, treatment for primary steelmaking slags to recover the metal and mineral phase, conditioning the properties of minor residues, and for developing new processes to **lower the demand for primary resources** and **reduce landfill volume**. At the same time additional applications and final use for residuals streams must be identified for mitigating the risks of over demanding legislations in **full respect of environmental safety and human health**.
- In this building block, definitions of **common life cycle impact assessment tools** are mandatory to monitor the effect of the steel specific CE solutions on the environment and in particular on GHG reduction in both direct and indirect ways or by avoiding transportation.

10. Enablers (skills, digitisation) for clean steel development

- The transition of steel production to low carbon technologies corresponds to a revolution for most major technical and organisational processes. There is a strong need for enablers, to plan and handle such revolution and to **make possible the sustainable steel production** under the terms of the new technical and organisational boundary conditions along and around the steel production chains.
- Beyond such boundary conditions defined also by the decarbonisation of steel production, this building block considers the **demands of digitalization, CE and sustainability:**
    - As first, a large group of activities can be characterised by the orchestrated integration of **new digital tools for monitoring and control** inside the novel architectures of ICT and the extensive use of Industrial Internet of Things (IoT) approach.
    - Because of the parallel important activities to develop **new measurement techniques covering the new processes**, **conditions and resources**, IoT allows the easy and fast integration of the new measurement techniques into the set of data streams to be monitored and offline and online used for process setup and control and knowledge extraction
    - To do so, Cybersecurity aspects must be deployed with specific strategies devoted to the steel sector. The management of such integrated manufacturing system.
    - To handle the new process conditions and the corresponding new issues, Machine Learning and Artificial Intelligence techniques will play an ever-increasing role.

According to the standardized description of the ICT and automation systems, all three automation levels of Plant Control, Scheduling and Production Planning and Control will be affected.

11. Low CO2 emissions downstream processes

- This building block starts from the consideration that the new scenarios based on CDA and SCU pathways consider new feedstock that will be available in a big quantity at steel plants. The **feedstock can be used as low carbon fuels** to replace, in part or totally, the natural gas. Therefore, **fuel flexibility** is one of the pillars of this building block, leading to the development of **high efficiency, low emission multi-fuel burners technology** that allow the

downstream steel processing to remain aligned and take advantage from the gradual decarburization of liquid steel production. The **combustion of hydrogen-enriched hydrocarbons or finally of 100% green hydrogen** seems to be the most promising development, however the extension of the fuel flexibility concept towards an effective zero CO_2 emissions target, can also require the adoption of **new carbon-free energy carriers** such as bio-fuel, ammonia or methanol.

- **Furnace efficiency** is the second pillar. Introducing innovations in the **technology of the metallic-bundled heat recuperators** and/or in using additive manufacturing can open new opportunity for improving the efficiency. Moreover, the heat content of the flue gases, which cannot be recovered to the combustion chamber of the furnaces, is lost in normal conditions. R&D&I will address the potential reuse of such heat loss for thermal processes operated at lower temperature. In addition, energy input into the furnaces and material treatment could be electrified.
- Nitrogen oxides (NOx) emissions are a further challenge to reach substantial CO_2 reduction. The increase of NOx emission is well known in case of hydrogen rich fuels (such as today for the coke oven gas). Extension of flameless concept and oxyfuel combustion is a research topic to lead to energy saving and accordingly **less CO_2 emissions and at the same time less NOx emissions**.
- Finally, **hot charging** can be considered, but must be made more effective and more robust in giving positive outcomes, using adaptive dynamic techniques for controlling the process while artificial intelligence can have a positive contribution and may open new research paths to be explored.

12. Innovative steel applications for low CO2 emissions

- Steel is a base material for economic, **applied for building and infrastructure, mobility and transport, energy and engineering and other metal products**. Infrastructure allowing operation at flexible energy supply (for instance pressure vessels for intermediate storage e-gas) rely strongly on specific steel grades and design.
- Solutions **generating renewable energy** rely strongly on steel: e.g. towers, engines, transmissions in wind power, support systems for solar power, vessels and tubings in solar heat, and many other applications.
- In the field of **mobility**, the design and deployment of light weight components and advanced high strength steel solutions enables the transport of goods and people with low specific energy need.
- The development of modern high strength grades in combination with advanced technologies for assembling allows the further optimisation of steel use in **buildings and infrastructure** – similar characteristics can be realised with reduced amount of steel, thus lower CO_2 impact on the overall structure.

3.1.2. Coordination mechanisms

Potential **links and collaboration opportunities** with other Partnership candidates, Horizon Europe missions and initiatives as well as other Union Programmes are described in Section 2.2.3. The Clean Steel Partnership intends to establish **systematic exchanges with relevant bodies managing other Horizon Europe initiatives as well as other EU actions and programmes** in order to avoid duplication, clarify overlap, foster collaboration and maximise synergies.

A good example is represented by the **letter signed by ESTEP and EUROFER with Processes4Planet**, which sets out clear rule for cooperation: any technological development or innovation aiming at avoiding CO_2 emissions that is specific to the steel production or the steel value chain will be within the scope of Clean Steel Partnership; technological developments or innovations that would be of cross-sectorial interest will be pursued under **Processes4Planet**. ESTEP and EUROFER have also signed a **similar letter with the Clean Hydrogen Partnership**. Formal mechanisms of consultation will be established with these two Partnerships to prepare the relevant Work Programmes. In addition, a coordination workshop will be arranged on a yearly basis to present and discuss completed, ongoing and planned activities of the Partnerships. The opportunity to create a common working group will be explored. Mechanisms of coordination may also be established with the **People-centric sustainable built environment (Built4People)**, **Made in Europe** and **Clean Energy Transition Partnerships**, limited to those parts of the Work Programmes that may affect the steel industry either upstream (renewable energy inputs) or downstream (steel construction materials, made in Europe products relying on steel inputs).

More generally, ESTEP and EUROFER will ensure alignment with other EU programmes affecting energy-intensive industries by relying on their participation and membership in relevant EU level working groups, such as the **High Level Expert Group on energy-intensive industries.**[102] Finally, synergies with other research initiatives may also be ensured through ESTEP and EUROFER membership in other research networks, such as the **Energy Materials Industrial Research Initiative** (EMIRI)[103] focus on R&I on advanced material.

With specific regard to **coordination with the Research Fund for Coal and Steel**, the ideal setting would feature one single funding mechanisms relying on both Horizon Europe funds as well as **ECSC assets**. In this respect, a revision of the legal framework of the Research Fund for Coal and Steel is underway. In case this will not be possible, the Partnership will work with separate and coordinated Calls for Proposals under the two funding programmes. Roughly half of the call will be issued under the Horizon Europe Programme, half under **the Research Fund for Coal and Steel** programme. The governance (see Section 0) of the Partnership will ensure full coordination among the different Calls for Proposals. The Clean Steel Partnership will mostly have projects in the range **EUR 10-100 million** to develop and test at large scale on higher TRL levels (TRL 6-8, starting TRL 5 may be accepted of the project achieves progress of at least TRL 7) in the period 2020-2030 the steelmaking technologies required to achieve a climate neutral EU steel industry by 2050.

The **COVID-19 pandemic** is likely to increase uncertainty in relation to the availability of funding and coordination mechanisms, from EU, national, and even private sources. A revision of the precise plans will be done once the health crisis will be over, to verify possible gaps. At the same time, the measures for economic recovery across the EU and their means of funding are being discussed. Should there appear shortages due to the COVID-19 crisis, the initial responses and instruments to be deployed to fight the crisis could provide forms of compensation for such shortages. The EU steel industry has reaffirmed its commitment to a **comprehensive plan towards achieving a clean steel industry** in the EU, even under the current circumstances.[104]

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[102] For further details, please see: ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3326

[103] For further details, please see: emiri.eu/

[104] For further details, please see by way of example: https://www.estep.eu/assets/CSP-letters/2020401-COVID19-Letter-Commission-President-Ursula-von-der-Leyen.pdf

3.1.3. Potential synergies with national programmes

The Clean Steel Partnership have started identified several national policies, programmes and activities that have high potential for synergies when it comes to R&D&I activities contributing to the decarbonisation of the steel industry. As explained in Section 2.3, list of countries and programmes summarised in only preliminary, as additional **inputs are expected from the 'Green Steel for Europe' Project**, and further opportunities of collaboration will be established through the SET plan and IPCEIs. Finally, **coordination mechanisms with Member States and regional authorities** established in the governance of the Partnership (see Section 3.3) and the consultation process to finalise the Roadmap (see Section 2.2.7) are expected to maximise synergies with national policies, programmes and activities.

Table 6: Examples of national policies and programmes generating synergies with the Clean Steel Partnership

Country	Programme/policy
Austria	**Austria** aims to achieve Climate Neutrality for 2040 and availability of 100% renewable electric energy in 2030. The **Austrian Climate and Energy Fund** supports three flagship initiatives (WIVA P&G, NEFI, and Green Energy Lab) to develop innovative energy technologies. Over 200 project partners from business, science and research are working together to achieve the targets set out by the Austrian authorities.
Belgium	The **Strategic Ecology Support**[105] (VLAIO) focuses on ecology investments that lead to environmental protection. The programme supports technologies aiming at preventing or remedying damage to the environment or the natural resources, including energy-saving measures and the use of renewable energy sources.
Belgium	The **Energy Transition Funds**[106] encourages and supports energy research, development and innovation, including the promotion of renewable energy.
Belgium	The **Flanders Industry Innovation Moonshot**[107] programme supports the decarbonisation of Flemish industries by 2050. More specifically, from 2020 to 2040, the Flemish Government will invest in innovative research in the circularity of carbon materials, electrification, radical process transformation and energy innovation.
Finland	The **Integrated National Energy and Climate Plan**[108] introduces financing measures in the area of R&I at national level, including Union support and the use of Union funds. Funding mechanisms place special emphasis on energy-intensive industry.
Finland	**Finland's innovation fund (SITRA)**[109] provides financial support for new operating models and stimulates business that aims at sustainable well-being. It particularly promotes activities supporting the National Road Map to a Circular Economy (2016–2025).[110]
France	The draft **National Energy and Climate Plan**[111] puts in place instruments to support industry with innovation-based solutions, which could be translated into energy-related competitiveness objectives.

[105] For further details, please see: vlaio.be/nl/subsidies-financiering/strategische-ecologiesteun
[106] For further details, please see: economie.fgov.be/nl/themas/energie/energietransitie/energietransitiefonds
[107] For further details, please see: moonshotflanders.be
[108] For further details, see: ec.europa.eu/energy/sites/ener/files/documents/finland_draftnecp.pdf
[109] For further details, see: sitra.fi/en
[110] For further details, see: toolbox.finland.fi/business-innovation/circular-economy/
[111] For further details, please see: ec.europa.eu/energy/sites/ener/files/documents/fr_swd_en.pdf, p.10; ec.europa.eu/energy/sites/ener/files/documents/necp_factsheet_fr_final.pdf

Country	Programme/policy
France	The **National Low-Carbon Strategy**[112] aims to reduce industry's emissions through using carbon-free resources, energy efficiency and technologies that capture, store, and reuse the carbon by industrial processes in order to offset residual emissions.
France	The **Investments for the Future Programme**[113] (PIA) finances innovations that contributes to the country's structural reforms and responds to major challenges for France, among which, carbon neutrality is one priority area.
Germany	The **Climate Action Programme**114 promotes measures to enhance energy and resource efficiency, to increase the use of renewables, and to support the decarbonisation in the production process in emission-intensive industries. The Programme particularly supports R&D into the storage and use of CO_2.
Germany	The **Hydrogen Strategy**,115 currently being developed by several ministries, envisages the promotion of research and use of carbon-free gas in industry and transport sector. Given Germany's leading role in the EU steel production and the importance of using hydrogen in decarbonising the steel sector, this collaboration will lead to remarkable benefits for the EU steel sector.
Germany	Under the **7th Energy Research Programme of the Federal Government** **Research for an environmentally friendly, reliable and affordable energy supply,**[116] research is supported regarding energy efficiency, reduction with hydrogen, flexibilisation, waste heat recovery and efficient steel products.
Germany	**Mitigation of climate-relevant process emissions in industry (KlimPro industry) Fund**[117] aims to enable the German raw materials industry to develop technologies and technology combinations that prevent GHG and to put them into practice in the medium to long term. The steel sector is one of the priority areas of funding under this programme.
Germany	Within the **Regulatory Sandboxes – Testing Environments for Innovation and Regulation**[118], infrastructural requirements can be tested within real conditions. Within the framework of the programme, a conceptual study regarding hydrogen infrastructure and a laboratory scale Direct Reduction plant will be supported. An existing hydrogen pipeline in the area will be extended to satisfy demand-driven hydrogen supply.
Germany	The **Environmental Innovation Programme**[119] focuses on projects that are well suited for demonstration purposes and hence for replication. These projects show how innovative technologies can be implemented to help reduce and prevent harm to the environment including the decarbonisation of the steel industry.
Italy	The **Integrated National Energy and Climate Plan** places strong emphasis on reducing carbon emission in energy-intensive industrial sector.[120] The draft Plan sets clear objectives and presents policies and measures on decarbonisation, energy efficiency, energy security and R&I.

[112] For further details, please see: ecologique-solidaire.gouv.fr/sites/default/files/Projet%20SNBC%20EN.pdf, p.86
[113] For further details, please see: gouvernement.fr/le-programme-d-investissements-d-avenir
[114] For further details, please see: bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Priority-Issues/Climate-Action/2019-09-19-climate-action-programm-download.pdf;jsessionid=88DF264E070912A0BCA6211C4EEA4DC7.delivery1-master?__blob=publicationFile&v=2
[115] For further details, please see: euractiv.com/section/energy-environment/news/germanys-steel-industry-in-transition/
[116] For further details, please see: bmwi.de/Redaktion/DE/Downloads/B/bekanntmachung-forschungsfoerderung-im-7-energieforschungsprogramm.pdf?__blob=publicationFile&v=3
[117] For further details, please see: bmbf.de/foerderungen/bekanntmachung-2565.html
[118] For further details, please see: bmwi.de/Redaktion/EN/Dossier/regulatory-test-beds-testing-environments-for-innovation-and-regulation.html
[119] For further details, please see: umweltinnovationsprogramm.de/
[120] For further details, please see: ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_it_necp.pdf

Country	Programme/policy
Italy	The **Programme Agreement**[121] (Accordo di Programma) provides funding for R&I in industrial sustainable growth through supporting innovation projects, technological clusters included.
Italy	The **Development Contract**[122] (Contratto di Sviluppo) provides financial support to R&D&I in industrial and environmental projects.
Italy	The **National Fund for Energy Efficiency**[123] (FNEE) supports the implementation of interventions aimed at ensuring the achievement of national energy efficiency targets. It particularly supports, among other issues, the reduction of energy consumption in industrial processes.
The Netherlands	**Climate Agreement ("Klimaatakkoord")**. The Netherlands signed the Paris Climate Convention in 2015 and put it into legislation: The Climate Act. This law states that by 2030 the Netherland must have reduced their CO_2 emissions by 49 percent and by 2050 by 95 percent, compared to the year 1990, as well as to increase the share of renewable energy to 100 percent by 2050. In 2019 the Dutch government organised thematic round tables with more than 100 parties/stakeholders to discuss measures for reducing GHG and generating clean energy. That resulted in the Climate Agreement. The plans are divided over five sectors, the so-called climate tables; the built environment, mobility, industry, the electricity sector and agriculture. The Climate Agreement will be implemented step by step. Next all the measures have yet to be precisely worked out and policies put into legislation through the Dutch parliament. Five regional geographical clusters will be in charge of the implementation of the measures arising from the Climate Agreement. In those regional clusters, government parties, industry parties, the communities and other stakeholders are represented.
The Netherlands	**Demonstration Energy and Climate Innovation (DEI+)**. In line with the objectives of the climate agreement, the Dutch government wants to support industry for investments aimed at innovative demonstration projects in the field of CO_2 reduction in industry and flexibilisation of the electricity system. Focus areas are amongst others: energy innovation and efficiency, renewable energy (including flexibilisation of the electricity system, including hydrogen and spatial integration), -CCUS (Carbon Capture, Utilisation and Storage), other CO_2 reduction measures in industry or electricity sector.
The Netherlands	**Public Private Partnership with Knowledge and Innovation Covenant**. In 2019 industry, universities and Dutch science foundation as well as the Dutch government signed an agreement to jointly invest 4.9 billion euros annually of which 2.85 billion from public funds. The focus of the cooperation is on four societal themes of the mission-driven knowledge and innovation policy: Energy Transition and Sustainability, Agriculture, Water and Food, Health and Care and Safety. The thematic missions and the Knowledge and Innovation Agendas shall pay particular attention to putting the expected results into practice.
The Netherlands	**Stimulating Sustainable Energy Production (SDE+)/ Sustainable Energy Transition Incentive Scheme (SDE++)**. The SDE+ scheme has been the main instrument for the development of a sustainable energy supply in the Netherlands since 2011. The focus areas are all forms of energy production by means of renewable sources. This scheme operates with a subsidy on the operational costs. In 2020, the existing SDE+ scheme will be broadened to SDE++. to other categories for the production of renewable energy and CO_2-reducing options. The focus will change from energy production towards energy transition. The scheme will support the transition by means of a subsidy compensating the unprofitable top of these techniques. The current technologies will continue to exist within the new SDE++, but will be supplemented with other techniques that save CO_2 such as CCS, waste heat utilisation, hydrogen production by

[121] For further details, please see: sviluppoeconomico.gov.it/index.php/it/incentivi/impresa/fondo-per-la-crescita-sostenibile/progetti-di-ricerca-e-sviluppo-accordi-di-programma
[122] For further details, please see: mise.gov.it/index.php/it/incentivi/impresa/contratti-di-sviluppo
[123] For further details, please see: invitalia.it/cosa-facciamo/rafforziamo-le-imprese/fnee

Country	Programme/policy
	electrolysis, electric boilers, heat pumps in industry. The list of techniques will be reviewed on a regular basis. If needed be, additional or new techniques can be added in the future.
Poland	The government has implemented several sectoral programmes targeting the decarbonisation of energy-intensive industries. By way of example, the **INNOSTAL programme**[124] aims at increasing R&D activities in the steel industry and decreasing negative impacts of the steel sector on the environment. These objectives are supported by investment in different research areas including: (i) new and improved steel products and their production technologies, (ii) new and improved feedstocks and alloys for metallurgical production, (iii) recovery and recycling of raw materials from metallurgical waste and scrap, (iv) optimization of energy, feedstock, media, tools and metallurgical equipment consumption, (v) innovative systems and technologies reducing harmful emissions to the environment, and (vi) innovative solutions to modernise and support technological processes in metallurgy.
Slovak Republic	The proposed **Integrated National Energy and Climate Plan**[125] also promotes the development of R&I that contributes to the decarbonisation of the industrial sector. The Plan places special emphasis on energy-intensive industries, in particular steel sectors as the largest industrial emitter of CO_2 in the country. The Plan emphasises the importance of developing technologies that enhance low-energy manufacturing processes in industry.
Spain	Spain has two organisations (one based on innovation, **the Centre for the Development of Industrial Technology** (CDTI) – and one on actual energy efficiency improvements, the **Institute for Diversification and Saving of Energy** (IDAE)), which may support decarbonisation projects. However, the scope of application is not specific to climate change transition and projects are limited in the size of the projects. There are several budget lines to finance innovation in the form of loans at low interest rates. Nevertheless, it is likely that the Spanish strategy on science and technology will set up a specific budget for decarbonisation projects, since this option is one of the tools considered in the **Integrated National Energy and Climate Plan**. It will include the use of alternative energetic vectors (such as electricity and hydrogen). Climate obligation and decarbonisation targets have been translated into diverse public funding lines and national plans in Spain.
Spain	The **State Plan for Scientific and Technical Research and Innovation**[126] sets the objective of promoting business leadership in R&D&I. The Plan puts special focus, among its eight priority areas, on R&D&I in (i) the design and development of efficient energy systems, especially in matters of industrial energy consumption, and (ii) the search for technologies in CDA and CCUS in industrial processes.
Sweden	**The Industriklivet initiative** (literal translation: industrial stride forward) was launched in August 2017 and is planned to run until 2040. The programme is directed by the Swedish Energy Agency and involves frequent calls for feasibility studies, pilot and demonstration projects and investment projects. HYBRIT is one of the projects receiving support.
Sweden	The **Integrated National Energy and Climate Plan**[127] highlights R&I in the areas of low carbon technologies as a crucial factor to achieve energy and climate targets. The Plan particularly supports breakthrough technologies in energy-intensive industry towards the objectives of higher energy and resource efficiency and elimination of CO_2 emissions in industry

Source: Authors' own elaboration on publicly available documents.

[124] For further details, please see: ncbr.gov.pl/fileadmin/user_upload/import/tt_content/files/zal_4__guidelines_for_evaluators_innostal.pdf
[125] For further details, see: ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_sk_necp.pdf
[126] For further details, see: ciencia.gob.es/stfls/MICINN/Prensa/FICHEROS/2018/PlanEstatalIDI.pdf
[127] For further details, see: ec.europa.eu/energy/sites/ener/files/documents/sweden_draftnecp.pdf

3.2. Resources (contribution from partners, other investments or framework conditions)

Summary

- Total assumed budget for R&D&I projects falling within the wider boundary of the Partnership is EUR 2.0 billion, out of which private sector is committed to make a major contribution.
- The resources deployed via the Partnership and the subsequent investments will ensure the delivery of demonstrators combining several building blocks of the technological pathways.
- A number of external conditions must be met for these investments to be realised:
  - *Policy*: EU continues considering low-carbon manufacturing industries – including the steel sector – a pillar of its industrial policy. EU and Member States continue their support towards the circular economy, and of the establishment of an appropriate regulatory framework.
  - *Economy*: state aid framework (IPCEIs), a stable financing flow from both public sources (e.g. ETS Innovation Fund, loans and guarantees from InvestEU) and private sources, availability of competitively-priced low CO_2 energy supply, common European hydrogen strategy, and consistent policies against carbon leakage.
  - *Societal*: availability of a highly skilled workforce and awareness of EU citizens for clean steel products.

The achievement of the objectives of the Partnership (i.e. substantially reducing CO_2 emissions from the steel industry while at the same time preserving its competitiveness), and the realisation of the opportunities of becoming a global leader in clean steel technologies require both a number of **external conditions** (discussed below) and the **strong effort of the sectoral players**.[128]

As described in Section 2.2.4 above, the total investments need to foster the decarbonisation of the steel industry are around EUR 2.55 billion for the whole decade, of which EUR 2 billion in the wider boundary of the partnership and at least **EUR 1.4 billion in the scope of the Partnership** for the 2021-2027 period. Private project investments will be taken in the form of in-kind or cash contributions, depending on the nature of the activities; for instance, financing of research projects will most likely display a large share of in-kind contributions, while financing of the Secretariat is more likely to be cash[129]. Furthermore, the Partnership's activities will mobilise **further resources from the Member States**, as several countries have expressed their expectation to orientate their national R&D&I programmes to ensure complementarity with the Partnership and to further increase leverage.

Private side´s contribution.

Resources contributed by the private side will consist of:

[128] This was repeatedly expressed in numerous commitments, the latest of which was the letter to President Juncker, in which CEOs of major EU steel producers showed their support to the Clean Steel Partnership (letter available at: https://www.estep.eu/assets/CSP-letters/20180925-Letter-to-Pres.-Juncker-and-College-of-Commissioners-on-Low-Carbon-Steel.pdf)

[129] Besides financial support for these above activities, members of the Partnership will also provide resources to ensure proper staffing of the Secretariat of the Partnership, as well as the various bodies of the Governance structure as indicated in section 3.3 of the Template

1. **In-kind contributions** to the projects funded by the Union (on the basis of non-reimbursed eligible costs, non-eligible costs and infrastructure costs)[130], with lower funding rates for high TRL[131];
2. **In-kind contributions** for additional activities foreseen in the Roadmap[132] not covered by Union funding such as:
   - Private company research funding linked to the Partnership on Clean Steel R&D&I framework;
   - Costs incurred by companies associated to the financing of demonstrators or pilot lines;
3. **Investments in operational activities**[133] that are spent beyond the work that is foreseen in the Roadmap such as additional investments by companies whose trigger will stem from technology improvements generated by projects within the Partnership for Clean Steel;

Public side´s contribution

The main contribution from the public side is to provide the support and means needed **for the steel sector to reach its ambitions** on climate neutrality, circular economy and zero-pollution for a toxic free environment, while at the same time improving its competitiveness. An open and transparent dialogue between the public and the private sides will be fundamental. As the promoters of the European Green Deal, the Circular Economy Package, the Industrial EU policy, the Skills Agenda and other relevant policies, the public side is in a unique position to provide the private side with relevant information in a timely manner so to achieve the objectives of the partnership.

As far as the **implementation of the Roadmap** is specifically concerned, the public side commitment consists in:

- **Setting up calls** for the Partnership on Clean Steel in the Union programmes based on the building blocks identified in the Roadmap of the Partnership on Clean Steel.
- **Facilitate the mobilisation of resources beyond the Union programmes,** through an optimal combination of funding and financing schemes, from Member States and regions to de-risk the innovations up to TRL9 so that developments also can be implemented.
- Provide inputs to **enable a regulatory framework** for the expected impacts of the partnership to be delivered based on the sustainability principles.

In addition, the Public side will facilitate an open and structured discussion to ensure the appropriate financing to de-risk investments up to TRL 9 and ensure internal coordination with complementary EU R&D&I programmes.

The resources deployed via the Partnership and the subsequent investments will **ensure the delivery of demonstrators** combining several building blocks of the technological pathways. The subsequent steps, i.e. the **upscaling to full industrial roll-out**, may be outlined as a follow-up activity of projects under the Clean Steel Partnership, but will not be realised within the scope of the Partnership. However, the plant builders, with their capability to participate in the engineering and technology commissioning phase of

[130] The private side committed to finance up to EUR 1 billion by matching public contributions (see letter from CEOs of major EU steel companies to President Juncker, available at: https://www.estep.eu/assets/CSP-letters/20180925-Letter-to-Pres.-Juncker-and-College-of-Commissioners-on-Low-Carbon-Steel.pdf)

[131] In principle the normal funding rates should apply. In special cases, a lower funding rate for high TRL is acceptable, but must be at least 50%.

[132] Information on additional activities can only be shared if it is not bound by confidentiality and it is compliant with national and EU competition law.

[133] Information on operational activities can only be shared if it is not bound by confidentiality and it is compliant with national and EU competition law.

the proposed solutions, are expected to take up the most promising technologies and bring these up to the market. These final steps, driven by the plant builders in collaboration with the steel producers and other stakeholders, will be decided case by case. Depending on the potential of the solutions, the industrial upscaling would normally require a budget of about 25 to 35% of the demonstration engineering budget. The upscaling can be jointly supported by in-kind participation, rolling up expenses or remuneration from selling fees and Intellectual Property (IP) shares of the technology.

Testing the breakthrough technologies at high TRL requires significant effort from the steel producers. For instance, processing high volumes of hydrogen requires a modification of the gas infrastructure. The change might negatively impact the productivity of these steel sites. The Partnership would therefore need to take into consideration this type of efforts borne by the steel producers, i.e. additional operating costs, as an in-kind contribution from their side. In addition, and most importantly, the investment for the demonstrators up to TRL 8 will be coordinated by the steel producers. The Clean Steel Partnership will compensate with depreciation rates during the project implementation.

As anticipated, for these investments to be realised, **a number of external conditions must also be met**:

- From a **policy** perspective, it is important that the EU continues considering low-carbon manufacturing industries – including the steel sector – a pillar of its industrial policy, as already acknowledged in the 'Strategic Value Chains' report.[134] This can only be achieved by considering a bundle of relevant policies, such as an EU Emission Trading System (ETS) accounting for the need of manufacturing industries at risk of carbon leakage, a trade policy strengthening the EU steel industry against dumping and unfair trade practices, the interventions to promote circular economy, and the broader EU energy policy. Furthermore, the success of the Clean Steel Partnership also relies on the EU and Member States' support towards the circular economy, and on the establishment of an appropriate regulatory framework. In particular, a contribution would come from:
    - the definition of a properly designed regulatory framework for the cross-border transport of CO_2;
    - the promotion of recycled carbon fuels; and
    - the setup of lead markets for low CO_2 and circular products, also by defining the appropriate standards and integrating them in green public procurement requirements.
- From an **economy perspective,** the framework conditions of state aid are of primary importance. In particular, the revamped attention to Important Projects of Common European Interest (IPCEI) would provide investors with a clear and stable framework in this respect.[135] In addition, a stable financing flow should also be maintained, both from public sources (e.g. ETS Innovation Fund, loans and guarantees from InvestEU), as well as private sources, which can be incentivised by ensuring that a framework for sustainable finance is in place. Availability of competitively-priced

[134] Cf. 'Strengthening Strategic Value Chains for a future-ready EU Industry', Report of the Strategic Forum for Important Projects of Common European Interest

[135] An aid that contributes to an IPCEI can be considered as compatible with the internal market if (i) it contributes to one or more EU objectives and has a significant impact on the competitiveness of the Union; (ii) it involves several Member States; (iii) it is co-financed by beneficiaries; (iv) the benefits spill over to other Member States and the rest of the EU economy. In case of R&D&I project, they must also be of a major innovative nature. For IPCEI, aid can cover up to 100% of the funding gap, based on a large set of eligible costs, and can also cover the industrial deployment phase. Cf. Communication from the Commission, Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest, (2014/C 188/02).

low CO_2 energy supply is also key for the success of the Partnership, together with a proper energy regulatory framework, including the possibility for energy intensive industry to benefit from low energy regulatory costs on a level-playing basis (both within the internal market and in consideration of international competition). Energy and energy-related infrastructures (e.g. for H_2, CO_2, CCS) should also be supported and deployed. A common European hydrogen strategy should also be adopted and implemented to ensure the availability for large scale H_2-based steelmaking operations and respectively support CO_2 re-use through industrial symbiosis and CO_2 storage. Finally, international competition needs to be preserved by consistent policies against carbon leakage, including the possibility to introduce a border carbon adjustment tax.

- From a **societal** perspective, action should focus on two aspects:
    - First, develop and ensure the availability of a highly skilled workforce that can handle the technological leap intrinsic in a low-carbon steel industry; and
    - Secondly, promote the awareness of EU citizens for clean steel products, thus kick-starting and supporting market demand.

3.3. Governance

Summary

- The Clean Steel Partnership will be established between the European Commission and the European Steel Technology Platform (ESTEP).
- Most of ESTEP members will be the initial members of the Clean Steel Partnership.
- The Partnership is open to the entire EU steel value chain community and Horizon Europe Associated Countries.
- The 'Partnership Board' (including representatives from both the public and private side) discuss and approve the periodic Work Programmes and ensure compliance with the vision, ambition, objectives, and research programme laid down in the multiannual Roadmap.
- The 'Implementation Group' is the general assembly of the Partnership. It discusses the technical needs and research progress, identify the R&D&I needs, discuss and propose the Work Programmes to the 'Partnership Board', coordinate revisions to the Roadmap, and share conclusions with Task Forces.
- The 'Task Forces' define future short- to mid-term R&D&I needs related to the different technological pathways and propose the content of the periodic Work Programmes to the Implementation Group.
- The 'Programme Office' supports coordination and communication activities, measures and reports on KPIs, organises events and promotes the Partnership.
- The 'Implementation Group' will be supported by two external bodies:
    - The 'Expert Advisory Group' advises on improvements on the current research development.
    - The 'Stakeholder Forum' provides feedback on potential revisions to the multiannual Roadmap and on the social and environmental impacts of activities under the Partnership.

The Clean Steel Partnership will be established between the **European Commission** (public side) and the **European Steel Technology Platform (ESTEP)** on behalf of the entire European steel value chain community (private side). ESTEP is a membership-based organisation, established as an international non-profit association under Belgian law (AISBL), with the role of representing its members concerning R&I strategies defined within its statutes.[136]

ESTEP and the Clean Steel Partnership are **open to the entire European steel value chain community**, i.e. to all EU based steel stakeholders comprising steel producers, steel processors, customers, suppliers, plant builders, research and academia, and civil society representatives. The Clean Steel Partnership will also be open to actors from Horizon Europe Associated Countries.[137] Any relevant stakeholder may participate in the Partnership by submitting an application form and paying a 'partnership fee', collected by ESTEP[138]. Upon approval of the Implementation Group (see below for further details), certain

[136] For further details see: estep.eu

[137] Their participation in Calls for Proposals funded via the Research Fund for Coal and Steel programme may be, however, limited by the relevant eligibility criteria.

[138] By becoming member of the Partnership, the organisation is obliged to fully adhere to the compliance rules within ESTEP according the constitution and internal rules. It is acknowledged that a member organisation may have stricter guidelines to

categories of stakeholders, such as representatives of national and regional authorities, civil society and reputable professionals may also participate in the Partnership as **observers**.[139] Membership in the Partnership does not automatically imply membership in ESTEP, and *vice versa*.[140]

The Clean Steel Partnership will benefit from **synergies of funds from two European research programmes**: Horizon Europe and the Research Fund for Coal and Steel.[141] Both programmes will coordinate efforts to achieve greater impact and efficiency. The ideal setting would feature a single funding mechanism (one stop shop). The research activities will be aligned with Horizon Europe Work Programme activities and with the objectives of the Research Fund for Coal and Steel.

- If a one stop shop cannot be realised, the Partnership may establish a governance structure to manage the implementation of the research activities under Horizon Europe and the Research Fund of Coal and Steel under differentiated and complementary calls.
- Each research programme (Horizon Europe and the Research Fund of Coal and Steel) will be bound by the obligation to inform the respective Programme Committee (Horizon Europe Programme Committee and COSCO, respectively) of the overall progress of the implementation of the actions of the specific programme.
- The Governance structure will take into consideration the legal basis for the implementation of the respective programmes, in particular as regards countries participating in the programmes, timing for alignment in calls for proposals and information to the European Commission and the respective Committees. The structure will aim at simplifying the procedures as much as possible.

The structure of the Governance is summarised in Figure 5**Error! Reference source not found.**.

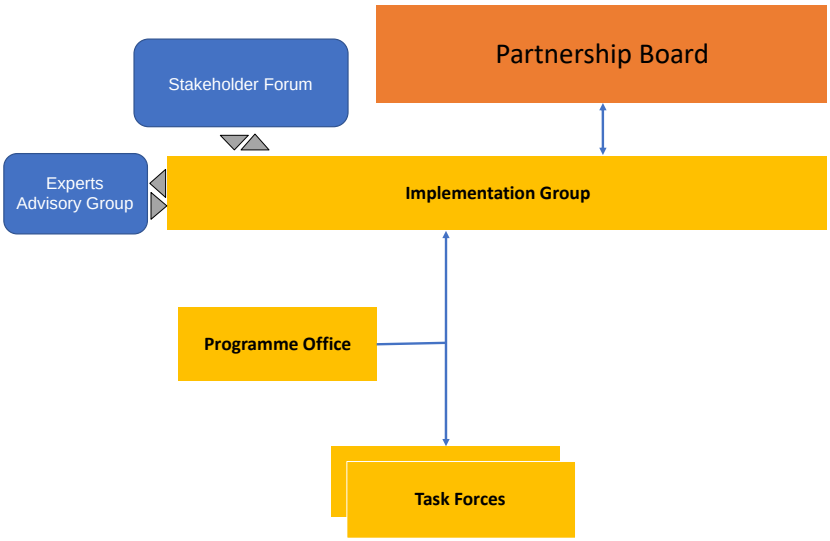
comply with national and EU competition law and exchange of information and experiences may be limited. Also there may be restrictions on sharing because of obligations on confidentiality.

[139] Observers will be invited to selected meetings of the Partnership only and will have the opportunity to review and provide comments on the draft multiannual Roadmap upon decision in the Implementation Group.

[140] The fact that ESTEP may nevertheless act on behalf of the members of the Partnership without them already being ESTEP members will be clarified in the statutes of ESTEP.

[141] Subject to the approval of the ongoing proposal for modification of RFCS Legal basis, establishing the rules of the research activities, part of the Research Programme may be implemented through co-programmed European Partnerships established in accordance with the rules set out in [Article 8 and Annex III to the Horizon Europe Regulation].

Figure 5: Governance structure of the Clean Steel Partnership



Source: Authors' own elaboration.

Partnership Board

The Clean Steel Partnership will be centred around the so-called '**Partnership Board**' (or 'the Board'). It will, among others, discuss and approve the periodic Work Programmes and ensure compliance with the vision, ambition, objectives and research programme laid down in the multiannual Roadmap, which will guide the work and decisions of the Board. The Board will consist of a public component, i.e. representatives of the European Commission services, and a private component, i.e. representatives of the Partnership members.

- On the **public side**, DG R&I, DG ENER, DG GROW, DG CLIMA, DG ENV and the Research Fund for Coal and Steel may be involved, thus fostering coherence and synergies with the EU R&I landscape relevant to the Partnership. The Commission will decide, however, on the final composition of the public side of the Board.
- On the **private side**, Board members will be proposed by ESTEP and appointed by the European Commission. Board members will be selected among the members of the so-called 'Implementation Group' (see below) in order to ensure **balanced representation of the different EU steel production routes and adequate experience of the relevant decarbonisation challenges** affecting the EU steel industry. The private component of the Partnership Board will present and discuss with the public component of the Board: (i) the decisions made by the Implementation Group with public members of the Board, such as the technical needs for the Partnership (which may evolve over time) and proposals for the Work Programme; (ii) the research progress of the Partnership demonstrating the progress of R&I activities and their alignment with mid- and long-term objectives of Clean Steel Partnership. The private side of the Board will also collect and report to the Implementation Group all feedback and suggestions put forward by the public side of the Board. Ideally, decisions in the Partnership Board, including those on the periodic Work Programmes, should be **based on consensus**.

Implementation Group

The **Implementation Group** is the general assembly of the Clean Steel Partnership, including all paying members. The voting rights of members will be decided at a later stage, by taking into account *inter alia* possible discounts on the partnership fee for specific categories of members, as further discussed in Section 3.4. Based on inputs from the Task Forces (see below) and after consulting the Stakeholder Forum and (where needed) the Experts Advisory Group (see below), the Implementation Group will:

- Discuss the technical needs and research progress of the Partnership by periodically analysing progress in R&D&I activities and their alignment with mid- and long-term objectives;[142]
- Share conclusions with specific Task Forces;
- Identify on yearly basis the overall R&D&I needs of the evolving Clean Steel Partnership to be shared with the public side of the Partnership Board;
- Discuss on Work Programme proposals coming from the Task Forces in order to balance the interest of the different Partnership members;
- Decide on how the private side of the Partnership Board will propose the content of the periodic Work Programme to the public side of the Board; and
- Discuss and coordinate any revisions needed to the multiannual Roadmap.

Decisions made by the Implementation Group will need to be discussed with the public side of the Partnership and finally approved by the Partnership Board. In case consensus is not reached within the Partnership Board (see above), the Implementation Group will **take into account the feedback and suggestions of the public components of the Board to reconsider its decisions** and contribute to achieve consensus.

Other components of the governance

The work of the Implementation Group will rely, among others, on the inputs of specific '**Task Forces**'. Different Task Forces will be established in order to cover all relevant technological pathways, such as CDA, SCU-carbon capture, SCU-process integration (PI), and circular economy. Based on the periodical assessment of research progress and the multiannual Roadmap, the Task Forces will **define future short- to mid-term R&D&I needs** related to the different pathways. In addition, in order to meet the detected needs, the Task Forces will **propose the content of the periodic Work Programmes**, which will be further discussed and decided upon by the Implementation Group. The Task Forces will include technology experts from organisations that are members of the Partnership as well as external experts, upon approval of the Implementation Group.

To ensure the smooth functioning of the Clean Steel Partnership, a **Programme Office** will be organised by ESTEP. The Programme Office will assist the Partnership when it comes to internal coordination, internal and external communications, support to the bodies of the Partnership, measuring and reporting on KPIs, organisation of events and promotion of the Partnership.

The work of the Implementation Group will be supported by **two external bodies**, thus ensuring openness as well as the opportunity to rely on expert opinions and views to take key decisions.

[142] All monitoring activities will be summarised in *ad hoc* 'monitoring reports', which will be reviewed and discussed at fixed intervals by both the Board of ESTEP as well as the Partnership Board.

- **Expert Advisory Group**. This body is composed of technical experts of steelmaking and related technologies, including, among others, academics and leading researchers not affiliated to organisations which are members of the Partnership. Under a strict confidentiality agreement, the Implementation Group provides information on the current research development and the Experts Advisory Group will advise the Implementation Group on improvements on the current research development.
- **Stakeholder Forum**. This body will include all relevant stakeholders that are not members of the Partnership and may contribute to the successful implementation of the Partnership. The Forum will be opened, among others, to stakeholders representing the civil society as well Member States and regional authorities in order to ensure coherence and synergies with national and regional R&I efforts. Non-technical experts from reputable research institutes may also be included. The Implementation Group will interact with the Stakeholder Forum in order to make sure that the Clean Steel Partnership will generate social and environmental impacts going beyond the steel industry and benefitting the EU as a whole. The Stakeholder Forum will play a central role to provide feedback on potential revisions to the multiannual Roadmap. In fact, to ensure an open and transparent approach, the preparation of the Roadmap (as further discussed in Section 2.2) as well as any major revisions of the document will undergo a public consultation.

Finally, it is important that the governance structure of the Partnership take into account the **synergies between Horizon Europe and the Research Fund for Coal and Steel** (funded by the ECSC assets in liquidation). In this respect, while it is not possible to transfer funds between the two programmes for the time being, the Research Fund for Coal and Steel financing scheme is moving closer to Horizon Europe through potential legal modification. The Partnership will closely follow the European Commission's guidance on harmonisation of these two programmes through e.g. establishing a number of evaluation criteria, technical project meetings and reports, and modifying Memoranda of Understanding with stakeholders to blend funds from different sources, different governance, calls and committees.

3.4. Openness and transparency

Summary

- The Partnership involves all relevant stakeholders and is constantly open to new partners.
- All Partnership members will have equal access to documents and information produced in the context of the Partnership.
- Information on key activities and projects will also be made available to the general public.
- Participation in Call for Proposals will be open to both members and non-members of the Partnership.
- Strategies to ensure easy and non-discriminatory access to information about the initiative and to stimulate the participation of new partners include: a dedicated website, LinkedIn and Twitter accounts, mailing lists, annual workshops, and thematic and networking events.
- *Ad hoc* membership campaigns may be implemented.
- A special 'partnership fee' will be applied to selected categories of participants such as governmental and non-governmental organisations and research institutes; these categories may also join the Clean Steel Partnership, free of charge, as observers.
- The Roadmap (and any update of the document) will undergo an open consultation process to collect feedback from Member States and all relevant stakeholders.

Openness

The decarbonisation of the steel industry requires a coordinated approach **across all countries, technologies and steel plants.** In fact, one of the operational objectives of the Clean Steel Partnership is about fostering R&D cooperation between all key actors of the steel value chain. Clean Steel will ensure openness by attracting new partners and players in this ecosystem, in particularly **SMEs**, **innovative companies and research institutes**. The impact of the Partnership will be, therefore, maximised by **involving all relevant stakeholders** and **remaining constantly open to new partners**.

Any relevant stakeholder may participate in the Partnership by submitting an application form (the form will be made publicly available on the Partnership website) and paying a 'partnership fee'. The full list of members will also be published on the website of the Partnership. Membership will be rejected only for exceptional reasons, such as lack of European added value or applications from countries outside the perimeter of the Horizon Europe (or Research Fund for Coal and Steel, depending on the applicable participation rules).

The Partnership will be established between the European Commission (public side of the Partnership) and the European Steel Technology Platform (ESTEP)[143] on behalf of the entire European steel community (private side of the Partnership). For further details on participation and governance see 2.4 and 0. Most of ESTEP members will be the initial members of the Clean Steel Partnership. ESTEP and the Clean Steel Partnership are open to the entire European steel community, e.g. to all EU based steel stakeholders, comprising steel producers, steel processing companies, customers, suppliers, plant builders, research and academia, and societal representatives.

[143] For further details, please see: https://www.estep.eu

Access to information

All members of the Clean Steel Partnership will have **equal access to documents and information produced in the context of the Partnership**. Openness should be the rule, and restriction due to confidentiality is the exception. However, to comply with EU and national competition law, company data and information necessary to be supplied by organisations that are members of the Partnership for reporting purposes will be handled in a secure and confidential way and only used for creating and presenting aggregated data and information. Information on key activities and projects will also be made available to the general public, via a dedicated website and other communication and dissemination tools (see below for further details).

Participation in Call for Proposals will be open, by definition, to both members and non-members of the Clean Steel Partnership, as long as they are eligible under the general conditions laid down in the Horizon Europe Regulation, specific conditions laid down in the Work Programmes and Calls for Proposals, and the legal framework of the Research fund for Coal and Steel, where applicable.

The Clean Steel Partnership will launch a **dedicated website** where the multiannual Roadmap and periodic Work Programmes, as well as non-confidential information about ongoing and finished projects, will be published. Access to results of specific projects will be granted in line with the general provisions of the Horizon Europe Regulation, the legal framework of the Research fund for Coal and Steel (where applicable) and specific provisions set out in the Grant Agreements. The website will have a 'private' section, accessible only to members of the Clean Steel Partnership, where any relevant working document will be made available. Confidentiality needs of the Partnership members will be met.

In addition to the website, the Partnership will create dedicated **LinkedIn and Twitter accounts** and a public **mailing list**, where any update published on the public part of the website as well as key consultation activities will be advertised. Any interested stakeholder will be able to follow the social media accounts as well as to register to the mailing list via the dedicated website, free of charge.

Finally, on a yearly basis, the Clean Steel Partnership will arrange a **workshop to present the main activities carried out and seek new partners**. The workshop will be arranged in Brussels or other suitable location. Participation will be open to the public, free of charge, upon registration. Interactive participation from remote will be allowed in order to overcome barriers linked to travel costs and maximise participation from stakeholders based in other Member States or outside the EU. The Clean Steel Partnership may also decide to arrange additional **thematic and networking events**, where participants will be requested to pay a fee.

Recruitment policy

ESTEP and the European Steel Association (EUROFER)[144] will invite all their members to join the Clean Steel Partnership. This will ensure **broad and representative participation of all the players of the EU steel value chain**, from technology providers to steelmakers and research organisations. EUROFER and ESTEP will ensure adequate information flow on the Partnership across their members, which also include companies operating on a global scale. In addition, to ensure outreach beyond the EU border and participation from Horizon Europe Associated Countries, EUROFER will establish a **formal mechanism of coordination with the worldsteel Association.** The mechanism will allow sharing basic information

[144] For further details, see: http://eurofer.be

regarding the Partnership and relevant projects and outcomes with worldsteel members (which represent about 85% of the global steel production), while ensuring full protection of confidentiality needs and intellectual property rights of Partnership members and grant beneficiaries.

When it comes to **recruiting new members**, rules and information on how to join the Clean Steel Partnership will be published on the dedicated website and circulated through the Partnership mailing list. *Ad hoc* **membership campaigns** may be implemented, based on needs for specific project partners emerging from any update to the multiannual Roadmap. New members will be accepted on an ongoing basis. In order to maximise participation from entities other than steelmakers and technology providers, **a special 'partnership fee' will be applied to specific categories of participants** such as governmental and non-governmental organisations and research institutes. These categories of participants may also decide to join the Clean Steel Partnership, free of charge, as **observers**, upon approval of the Implementation Group.[145]

Revising the Roadmap

The **multiannual Roadmap** will be updated by consulting all Partnership members, in close cooperation with the Commission services. In order to ensure an **open and participatory approach**, the Roadmap (and any update of the document) will undergo an **open consultation process** to collect feedback from Member States and all relevant stakeholders, further refine the identified priorities and design the key activities of the Clean Steel Partnership. Consultation activities will be based on an online survey, administered through the ESTEP website. The consultation will follow, to the extent possible, guidelines set out in Chapter VII of the Better Regulation Guidelines.[146] The updated Roadmap will serve as a basis for the Commission to draft and adopt annual or multiannual Work Programmes and, in turn, issue and manage Calls for Proposals.

[145] Observers will be invited to selected meetings of the Partnership and will have the opportunity to review and provide comments on the draft multiannual Roadmap.

[146] For further details, please see: ec.europa.eu/info/sites/info/files/better-regulation-guidelines-stakeholder-consultation.pdf

Annex 1. Steel Industry R&D&I programmes towards Climate Neutral Steelmaking

In the past many projects have been done with promising results to reduce CO_2 emissions. Due to the lack of further support to upscale and derisk these activities, the progress did not happen, or happened at moderate speed.

Table 7: Selected list of projects of the steel industry, which need follow-up for their deployment

No	Project name	Funding Instrument	Project period
1	ULCOS new BF process ULCOS NBF)	RFCS RFSR-CT-2004-00005	1/7/2004-30/6/2009
2	ULCOS Top gas recycling BF process (ULCOS TGRBF)	RFCS RFSR-CT-2009-00002	1/7/2009-30/6/2012
3	Iron production by electrochemical reduction of its oxide for high CO_2 mitigation (IERO)	RFCS RFSR-CT-2010-00002	1/7/2010-30/6/2013
4	Hisarna experimental campaigns B & C (Hisarna B&C)	RFCS RFSR-CT-2011-00002	1/7/2011-31/12/2014
5	Development of a Low CO_2 Iron and Steelmaking Integrated Process Route for a Sustainable European Steel Industry (LoCO2Fe)	H2020-SILCII 654013	1/5/2015-204/2018
6	Industrial Thermal Energy Recovery Conversion and Management (i-Therm)	H2020-EE-2015-1-PPP 680599	1/10/15-3/3/2019
7	From residual steel gases to methanol (FReSMe)	H2020-LCE-2016-RES-CCS-RIA 727504	1/11/2016-31/10/2020
8	ReclaMet - Reclaiming valuable metals from process residues with the Hisarna process	EIT Raw Materials 17209	01/08/2018-31/3/2021
9	Very efficient production of hydrogen using waste heat with the high-temperature electrolysis (GrInHy)	FCH-JU	From 2016
10	Scale-up of Calcium Carbonate Looping Technology for Efficient CO_2 Capture from Power and Industrial Plants (SCARLET)	FP7-ENERGY-2013-1	From 2014-04-01 to 2017-03-31
11	High performance MOF and IPOSS enhanced membrane systems as next generation CO_2 capture technologies (GENESIS)	NMBP-20-2017	From 2018-01-01 to 2021-12-31
12	BIOtechnological processes based on microbial platforms for the conversion of CO_2 from iron steel industry into commodities for chemicals and plastics (BIOCONCO2)	BIOTEC-05-2017 -	From 2018-01-01 to 2021-12-31
13	Turning waste from steel industry into a valuable low-cost feedstock for energy intensive industry (RESLAG)	WASTE-1-2014	From 2015-09-01 to 2019-02-28

14	Initiative to bring the 2nd generation of ThermoElectric Generators into industrial Reality (INTEGRAL)	PILOTS-01-2016 -	From 2016-12-01 to 2019-11-30
15	Enhanced energy and resource Efficiency and Performance in process industry Operations via onsite and cross-sectorial Symbiosis (EPOS)	SPIRE-06-2015 -	From 2015-10-01 to 2019-09-30
16	Development of a Low CO_2 Iron and Steelmaking Integrated Process Route for a Sustainable European Steel Industry (LoCO2Fe)	SILC-II-2014 - Sustainable Industry Low Carbon II	From 2015-05-01 to 2018-10-31
17	Industrial Thermal Energy Recovery Conversion and Management (I-ThERM)	EE-18-2015	From 2015-10-01 to 2019-03-31
18	Turning industrial waste gases (mixed CO/CO_2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings (Carbon4PUR)	SPIRE-08-2017 -	From 2017-10-01 to 2020-09-30
19	Integrated process control & diagnostics system for hot rolling mills based on comparison of physical data & mathematical process-models by using artificial intelligence (IPCDS)	RFCS RFSR-CT-2003-00038	01/07/2003 - 31/12/2006
20	TORrefying wood with Ethanol as a Renewable Output: large-scale demonstration (Torero)	LCE-19-2016-2017 -	From 2017-05-01 to 2020-04-30
21	CO2 reduction in reheating furnace-(CO2RED)	RFCS RFSR-CT-2006-00008	01/07/2006 - 31/12/2010
22	Production of sustainable, advanced bio-ethANOL through an innovative gas-fermentation process using exhaust gases emitted in the STEEL industry (STEELANOL)	LCE-12-2014 -	From 2015-05-01 to 2018-10-31
23	Development of new methodologies for industrial CO_2-free steel production by electrowinning (SIDERWIN)	SPIRE-10-2017 -	From 2017-10-01 to 2022-09-30
24	Fuels from electricity: de novo metabolic conversion of electrochemically produced formate into hydrocarbons (eForFuel)	LCE-06-2017 - New knowledge and technologies	From 2018-03-01 to 2022-02-28
25	Cost and energy-effective management of EAF with flexible charge material mix (FlexCharge)	RFCS RFSR-CT-2014-00007	01/07/2007 - 31/12/2010
26	(Carbon2Value)	Intereg 2 Seas (ERDF)	from 2017 to 2019
27	Direct electrocatalytic conversion of CO_2 into chemical energy carriers in a co-ionic membrane reactor (eCOCO2)	CE-SC3-NZE-2-2018 - Conversion of captured CO_2	from 01-05-2019 to 30-04-2023
28	DMX Demonstration in Dunkirk (3D)	LC-SC3-NZE-1-2018 - Advanced CO_2 capture technologies	from 01-05-2019 to 30-04-203
29	Market Uptake Support for Intermediate Bioenergy Carriers (MUSIC)	H2020-LC-SC3-2018-2019-2020	from 01-09-2019 to 31-08-2022
30	Sustainable EAF steel Production - GreenEAF1	RFSR-CT-2009-00004	1 July 2009 to 30 June 2012

31	Processes and technologies for environmentally friendly recovery and treatment of scrap - PROTECT	RFSR-CT-2010-00004	1/07/2010 - 31/12/2013
32	Biochar for a sustainable EAF steel production - GREENEAF2	RFSP-CT-2014-00003	1/07/2014 - 30/06/2016
33	H2Future - Hydrogen meeting future needs of low carbon manufacturing value chains	FCH JU 735503	01 Jan 2017- 30 Jun 2021
34	Control and optimisation of scrap charging strategies and melting operations to increase steel recycling ratio (ConoptScrap)	RFCS RFSR-CT-2005-00003	01/07/2005 - 31/12/2008
35	Optimization of scrap charge management and related process adaptation for performances improvement and cost reduction (OptiScrapManage)	RFCS RFSR-CT-2007-00008	01/07/2014 - 30/06/2017
36	Control of steel oxidation in reheating operations carried out with alternative fuels and new combustion technologies (CONSTOX)	RFCS RFSR-CT-2011-00007	01/07/2011 - 31/12/2014

Note: Many projects can be continued in the scope of the Clean Steel Partnership; some projects are in the scope of linked Partnerships or instruments.
Source: Authors' own elaboration.

Selected key breakthrough technologies for the BOF route

Process integration (to be combined with CCU and/or CCS):

- Top Gas Recycling-BF using plasma torch (project: **IGAR**)
- Carbon Valorisation/CCU (projects: **Steelanol**, **Carbon2Chem**, **FReSMe**)
- CDA via Hydrogen/Electricity
- CO_2 emission avoidance through direct reduction of iron ore using hydrogen and natural gas (projects: **HYBRIT**, **SALCOS**/**MACOR**, **H2Steel** (H2Future + SuSteel))
- Electrowinning of iron metal from iron oxides (**SIDERWIN**)

Other projects: Primary Energy Melter (PEM), Stepwise

Selected project descriptions

HYBRIT is a joint venture by three companies SSAB (steel), LKAB (iron ore) and Vattenfall (energy) which together have set out to eliminate CO_2-emissions in the ore-base steelmaking value chain. Efforts performed so far, and ongoing, have been co-sponsored by the Swedish Energy Agency. The project focuses on: (i) fossil free pelletizing; (ii) large scale H2 production using water electrolyser; (iii) large scale H2 storage; (iv) Inter-coupling between H2 production – storage – RES; (v) direct reduction of iron ore based on H2; (vi) electric steelmaking using carbon-free iron sources; (vii) integration of systems; and (viii) societal support activities, e.g. capacity building. Its timeline us as follows:

- Pre-feasibility study: 2016-2017
- Pilot phase: 2018-2024
- Demonstration phase: 2025-2035

SALCOS (Salzgitter Low CO_2 Steelmaking) is a direct reduction project, started in 2015, aimed at stepwise transformation of carbon based into hydrogen-based steelmaking, planned to be realized at the existing integrated steelworks facility in Salzgitter, Germany. The feasibility study of this project is called MACOR which will be completed by early 2020. The first steps of SALCOS could be implemented ((2023++), if the needed political regulations and economic feasibility are given. The first step would be the implementation of natural gas based direct reduction plant as a substitute for respective BF capacity, additionally offering the potential of integrating significant, variable shares of renewable energy via hydrogen produced through water electrolysis and an EAF using electricity from renewable sources for melting. Long-term steps include the successive change to electrical steelmaking, flanked by the built-up of further direct reduction plants and EAFs, until the contemporary BF/basic oxygen route could finally be completely shut down. Potential CO_2 emission reductions are estimated to increase stepwise from 26 % up to 95 % depending on political regulations and economic feasibility. Since the beginning of 2016, research has been conducted on the very efficient production of hydrogen using waste heat with the high-temperature electrolysis as part of an FCH-JU project GrInHy. The follow-up project GrInHy2.0 is underway.

H2Steel is an Austrian initiative by voestalpine and partners that aspires in the long term to successively substitute carbon in steelmaking by hydrogen. It currently consists of Hybrid Steelmaking as the first step (approx. one third CO_2 reduction in the final realization) for a deployment of low CO_2 steelmaking, as well as supportive projects like H2Future, an FCH-JU project launched in 2017, and SuSteel, a national Austrian project launched in 2016. Hybrid Steelmaking consists of the integration of an EAF, in combination with HBI, into a BF-BOF route with increasing Hydrogen and electricity in all process steps. H2Future produces H_2 by electrolysis based on PEM (Proton Exchange Membrane) cells and SuSteel uses Hydrogen in a H_2 plasma torch to reduce iron oxides. If successful, both projects need to be followed up after 2020 with upscaling projects. Additional development activities with regard to the raw material base need to be established as well.

SIDERWIN is the development of a fully electricity-based steel production route (steel production by direct electrowinning of iron ore) by a consortium including among others the company ArcelorMittal, EDF, Dynergie and Quantis, Mytilineos. The technology includes the ore purification, the alkali electrowinning cell and the melting of iron in an EAF. It has the potential to improve efficiency in direct (primary) energy use by 27% compared to non-electrochemical route. Based on the objectives set for the integration of RES in EU power grid in 2050, its potential reduction of specific CO_2 emissions is expected to lay by more than 70% (with 87% as objective). The technology can participate in the integration of renewable energy sources (RES) by interruptibility and presents an option to recycle iron oxide wastes. Timeline for development up to industrial scale is 2017-2022, and namely:

- 2017-2020: pilot phase (under SPIRE)
- After 2020: demonstration phase

tkH2Steel aims in a first step, CO_2 avoidance by converting the BF operation to hydrogen, i.e. instead of carbon (CO) in the form of injection coal, hydrogen (H_2) is used as a reducing agent in the existing BF process and water vapour instead of CO_2 is released.

The use of hydrogen instead of carbon in the BF process is an important step in reducing CO_2 emissions. However, to achieve higher CO_2 savings, further, more fundamental technological changes in steel production will be necessary. To this end Thyssenkrupp plans to build direct reduction plants (DR plants),

which operate on the basis of gases containing hydrogen. Rather than molten pig iron, DR plants produce solid sponge iron (DRI) which is in the longer term further processed into crude steel in EAFs. Subsequently, the BF route is gradually converted to direct reduction plants (DR plants) and EAFs by 2050. The direct reduction is to be achieved by gradually increasing the input of hydrogen for a sustainable climate neutral steel production.

The **HYFOR (Hydrogen Fine Ore Reduction)** technology is a new hydrogen based direct reduction process and the only one which allows the usage of any kind of iron ore fines without an additional step for pre-processing like pelletizing or sintering. The technology, which was invented by and developed under the leadership of Primetals Technologies, can be applied to all types of beneficiated ore and up to 100% of the particle sizes of the feed can be smaller than 150 µm. As primary reduction agent H_2 from renewable energy is targeted, but, depending on availability, H_2 rich gases from conventional steam reformers or H_2 rich waste gases can be used alternatively. This results in a low or even a zero CO_2 footprint when enough hydrogen can be supplied. The technology was proven at lab scale at the University of Leoben, Austria, over the past few years. Currently an industrial pilot plant, consisting of a preheating-oxidation unit, a gas treatment plant and the core reduction unit, will be installed in partnership with voestalpine and K1-MET. In the preheating-oxidation unit, fine ore concentrate is heated to approx. 900 °C and fed to the reduction unit. The reduction gas H_2 is supplied over the fence from a gas supplier. A waste heat recovery system from the off-gas ensures optimal energy use and a dry de-dusting system takes care of dust emissions from the processes involved. The hot direct reduced iron (HDRI) leaves the reduction unit at a temperature of approx. 600 °C, which can be subsequently used in an EAF or to produce HBI. The aim of the testing facility, which is due to be commissioned in the third quarter of 2020, is to verify and optimize this break-through process and to provide the data basis for setting up a First Industry Demonstrator (FID) in the coming years.

Hisarna project is an innovative smelting reduction technology combining both the Cyclone Converter Furnace (CCF) and HIsmelt© technologies to produce liquid iron (hot metal). The HIsarna development started with the ULCOS consortium and has been continued with major European steelmakers ArcelorMittal, voestalpine, thyssenkrupp Steel and Tata Steel. HIsarna could readily reduce up to 20% of emissions as compared to the emissions from the average European steel production via BF-BOF route. Basically, this could be achieved by eliminating the ore agglomeration and coking steps. It could also be demonstrated that up to 40% of CO_2 reduction could be realized if HIsarna is fed with 50% scrap input and biomass. An important intrinsic advantage to HIsarna is being a "CO_2 Capture Ready Ironmaking Process". With CO_2 Capture and Storage (CCS), up to 80+% of the emissions reduction from the steel production could be reached. If CCS is combined with (partial) use of sustainable biomass instead of coal in HIsarna, negative emissions can be realised, providing a more cost-effective way to compensate for many small stack emissions on integrated sites. CCU and CCS technologies are instrumental in realising HIsarna's full potential. Essential to note that HIsarna has been demonstrated in large scale pilot plant at Tata Steel's site in the Netherlands with a capacity of 60,000 t/y hot metal production. As such, the Technology Readiness Level of 7 has been achieved. Tata Steel in Europe aims to reduce its CO_2 emissions with 30% by 2030. The company is looking at a combination of CCS and CCU including a full scale HIsarna plant. In that respect, the next step, the pilot plant should be equipped with CO_2 capture plant to de-risk the HIsarna Demonstration Plant. Other supporting developments in the Netherlands are ongoing amongst others the ReclaMet project supported by EIT Raw Materials. Further collaborative R&D projects are being pursued such as HISlag-Utilisation of HIsarna Slag in Building Materials.

CCU Projects

- Gas fermentation processes to reduce CO_2 emissions and produce low carbon liquid fuels and chemicals (project: **Steelanol**).
- Use gases from steel production processes, including CO_2, as a starting material for chemical products and use surplus energy from renewable source in the process (project: **Carbon2Chem**).
- EAF steelmaking projects, using EAF as a breakthrough technology for CDA BOF, by direct reduction of iron ore using hydrogen and natural gas (project examples: **GreenEAF2**, **OSCANEAF**, **OXYMON**, **SuperChargeEAF**, **Fines2EAF**, and **RINFOAM**).

Selected project descriptions

The **Steelanol** gas fermentation process is a new approach to reduce CO_2 emissions while producing low carbon liquid fuels and chemicals, which captures and recycles carbon-rich industrial process gases of the global steel and ferro-alloy industry. Carbon-rich industrial gases such as process gases produced during steel manufacture are transformed into commodity fuel and chemical products in a continuous process. Instead of sending a process gas stream to a thermal energy or electrical power generation unit, the gas, which is cooled and pre-treated by gas handling technologies, is then injected into a fermentation vessel containing proprietary microbes and liquid media. The microbes convert the CO, CO_2, and H_2 into ethanol and chemicals that can be recovered from the fermentation broth. While both CO/CO_2 and H_2 are utilized in the process the proprietary microbes are also able to consume hydrogen-free CO-only gas streams, due to a highly efficient biological water gas shift reaction that occurs within the microbe. The main research objective is the validation of the fermentation technology from pilot to demonstration scale. The technology also has a significant impact on the carbon footprint of steelmaking facilities and their products. Separate lifecycle analyses (LCAs) have shown that producing bioethanol from steel mill process gas results in a product with lifecycle carbon emissions 50-87% lower than conventional gasoline depending on the carbon intensity of the local electrical grid. Globally, up to 150 million tonnes of CO_2 emissions could potentially be avoided by re-using available process gases through this process. Gas fermentation also avoids combustion of the process gas stream being converted, resulting in a substantial reduction in Particulate Matter (PM), SO_x and NO_x emissions up to 85% and higher. All by-products are internally or externally recycled, which leads to reductions of fresh imported raw materials. In the longer term, it can be anticipated commercial production plants to deliver even greater GHG reductions than those presented here. If or when credits for these reductions are included, the economic value of using this type of technology will be further enhanced. The 64,000 tonnes/year (or 80 million litres of ethanol) for the project at ArcelorMittal Gent -sufficient to fuel 100,000 cars with ethanol blended gasoline-, will demonstrate the added value of recycling waste streams, not only by reducing emissions, but by keeping fossil fuels in the ground through the production of commodity chemicals and fuels that would otherwise be made from oil. If all process gases of the EU conventional steel plants (BF-BOF route) are converted into ethanol the yearly production potential of app. 14.5 million tonnes/year of ethanol will reduce CO_2 emissions from industry by 33.3 million tonnes/year. The construction of a demonstration plant takes place in 2017-2019, the commissioning and trial operation are foreseen for 2019-2021, further development and rolling out the technology are planned for after 2022, further development of process and products are scheduled for 2020-2030.

The **Carbon2Chem®** initiative of Thyssenkrupp Steel aims to use process gases, including the CO_2, from steel production as a starting material for chemical products. Surplus energy from renewable sources will

be used in the process. Thus, the project is an essential contribution to climate protection as well as energy transition. Carbon2Chem® concept needs hydrogen for the chemical processes involved in e. g. ammonia and methanol production. While the hydrogen, already present in the process gases, is sufficient for ammonia synthesis, additional hydrogen is to be produced to make methanol. Hydrogen is produced by water electrolysis, which uses electricity to separate water into oxygen and hydrogen. For the hydrogen production energy from renewable sources will be used. Carbon2Chem's prospects of success are good because the basic chemical processes and required technologies are largely known. It is already technically possible to convert process gases from steel production into ammonia as a starting product for fertilizers, though not yet cost-efficiently. Another possibility would be to produce methanol from process gases. Carbon2Chem is characterised by broad-based, cross-industrial cooperation. It will create a new network of steel production, electricity generation and chemical production. The main research objectives are the purification and conditioning of the process gases, the Hydrogen production (e. g. by water electrolysis), the adaptation of the chemical processes to the new synthesis gas composition, the performance increase of catalysts for adapted chemical processes and the system integration. The estimated saving potential is about 50% of CO_2 emissions from process gases. If all process gases of German conventional steel plants (BF-BOF route) are used by Carbon2Chem for chemical bulk products, it will reduce CO_2 emissions from industry by 20 million tonnes/year in Germany. The first phase of project (Phase 1-Laboratory scale) will run until 2020, the second phase (Phase 2-Technical scale) is foreseen for 2020-2024 with a first demonstration plant in 2024, the third phase (Phase 3-industrial phase) is scheduled for 2025-2030 with a first world scale plant to be available in 2030.

The possible expected impact is shown in Table 8.

Table 8: Projected industrial demonstration of 7 projects and roll-out

Period	Smart Carbon Use (SCU) Carbon Direct Avoidance (CDA)		CO_2 reduction potential* (up to…)
2018-2021	SCU	CCU (ethanol)	80% with CCS and H_2
2021-2025	SCU	CCU (methanol)	80% with CCS and H_2
2022-2027	SCU	Process Integration	80% with CCUS
2025-2030	CDA	Hydrogen based steelmaking	95%
2025-2030	CDA	Hydrogen based steelmaking	95%
2025-2035	CDA	Hydrogen based steelmaking	95%
2025-2035	CDA	Iron ore electrolysis	95%
2022, 2026, 2031, 2036	Start of **market roll-outs** if CAPEX & OPEX are competitive at demonstration phase, & regulatory framework conditions and infrastructures beyond site borders are in place		
2050	**Carbon-neutral steel industry in Europe (80-95% CO_2 reduction)**		

*Potential CO_2 reduction compared to Blast Furnace route in case of full scale implementation. CO_2 reduction of the entire steel industry depends on the combination of production technologies.

Selected key breakthrough technologies for the EAF route

The Scrap route will be fundamental in Clean Steel Partnership to reinforce the position in the CE of EU steel industry. In this contest both Iron Ore and Scrap routes must be in symbiosis: the main % of C steel long products in EU (79%) is produced by EAF, while 91% of flat is product by BOF. Moreover, the EAF is

an important element in the mentioned breakthrough technologies for CDA BOF: steel production by direct reduction of iron ore using hydrogen and natural gas. EAF steelmaking projects in the RFCS framework like GreenEAF2, OSCANEAF, OXYMON, SuperChargeEAF, Fines2EAF, and RINFOAM posed the base for scaling up of the process and generate new framework for development of the future strategies/plane from EAF route. Just started the H2020 Retrofeed project which includes the development of tools and equipment to allow the use of renewable feedstock and industrial residues in the steel sector.

Key breakthrough technologies for the Scrap/DRI-HBI/Pig Iron EAF route, such as listed below but not limited to, are:

- Process integration with reduced use of Carbon
    - Lump and injected coal substitution with alternative carbon-based material with low CO_2 emission (bio-char, plastics, rubber, etc.)
- CDA via Hydrogen/Electricity
    - Advanced smelting processes using electricity and H2
    - Design of new burners to use increasing quantities of H2
    - Oxygen from in situ electrolysis injection in EAF
- Integration of process steps and internal use of process gases
    - Scrap pre-heating technologies (using melter off-gas, external gas such as NG, biogas, H2…)
    - Low CAPEX / High efficiency technologies for heat recovery at high temperature (>600°C) from off-gas and slags maintaining the potential for residual valorisation
    - High temperature materials for new sensors and tools for real time measurement of liquid metal and slag temperature;
- Circular Economy
    - Scrap cleaning technologies (removal of Zn & metallic coatings, paints & organic coatings, non-ferrous scrap, mixed waste materials, etc.)
    - Scrap yard management by metal scrap classification and tracking
    - Dedicated electrical/H2 based pyro-metallurgic process to improve the yield of the EAF route recovering the metals by residues
    - Recovery of valuable material from internal and external residue

Selected project descriptions.

The "**Dalmine 0 emissions**" plan of TenarisDalmine aims to replace natural gas currently used in Dalmine site with hydrogen obtained by electrolysis and powered by electricity from renewable sources. The main objectives are:

- Production of green H_2 from renewable energy and use of H_2 in the production processes: steel-shop and seamless pipe rolling mill;
- Installation of a hydrogen storage buffer in large capacity cylinders to compensate for changes in consumption by users and reducing the risk of electric grid unbalance;
- Reutilization inside the melting process of the Oxygen produced by on site electrolysis.

Removing the existing technological gaps and demonstrating the feasibility of the complete decarbonisation of the EAF process is the goal of the "**Dalmine 0 Emissions**" project and it is closely linked with the European projects related of integral cycle steel (**HYBRIT, SALCOS, H2Steel**). Its main advantage is the structure of the EAF process that, being highly modular, allows to approach the transformation directly at full scale in a timeframe of about 7-10 years. The first phase (Replacement of natural gas in the EAF) could be completed within 2-3 years, without requiring prohibitive infrastructure investments, both in renewable energy production plants and on the existing distribution network. The preliminary CO_2 reduction estimates compared to the current situation are the following:

- for steel-shop 10% reduction. Furthermore, considering the complete supply of electricity from renewable sources, reduction can reach 75%;
- total conversion of Dalmine plant from natural gas to H2 and the total supply of renewable electricity would lead to about 90%.

The investment costs for the first phase are around 15-20 Million EUR while the costs for the whole project is in the range of 250-300 Million EUR. The overall costs (CAPEX + OPEX) for the first phase of the project can be estimated, over a period of 10 years, between 135 and 170 Million EUR, while the implementation of the whole project will require between 1.050 to 1.300 Million EUR (including the higher operating costs for a period of 10 years). The project could clearly be extended to EU level. Contacts are currently underway with various Italian companies able to supply electricity and leading European companies able to provide efficient systems for the production of hydrogen. To overcome technological challenges, the involvement of primary research bodies is already underway.

The **Sustainable Process for metal and Energy Recovery from steelmaking EAF process gases (SUPEREAF)** aims to implement CE and industrial symbiosis concepts at industrial scale. This will be achieved through the integration of different technologies at industrial scale plant in the TenarisDalmine facility in Italy where it will be possible to develop, erect and operate the innovative integrated system allowing sustainable improvements in line with EU policies:

- production of steam and electricity from waste heat contained in the exhaust gases of the EAF steel plant;
- elimination of toxic compounds (i.e. dioxin and furans) potentially contained both in the off gas and in the dusts;
- direct recovery of the iron contained in the hazardous waste (EAF dust) increasing the yield of the melting process;
- conversion of steel mill dust into a valuable by-product (high concentrated Zn oxide -Waelz Oxide);
- direct use of the concentrated Zn oxide in zinc smelters without any pre-processing;
- drastic reduction of the amount of the landfilled EAF dust.

The integration of these technologies and the development work during the project will allow for moving from an overall Technology Readiness Level (TRL) 6[147] at the beginning of the project to a TRL 8 at the end of the project. Moreover, the integration of the process in the value chain upstream (power production) and downstream (material recovery) will activate the benefits of the industrial symbiosis and of the CE.

[147] Starting TRL 5 may be accepted of the project achieves progress of at least TRL 7

Taking as reference an annual European production of EAF steel of 67,5 Mt, this project is expected to have the following major impacts:

- ~ 2.100 GWhe/y of energy recovered in off gas, which means 121,7 MEUR/y;
- ~ 270.000 t ZnO/y and ~ 300.000 t Fe/y, which means ~450 MEUR/y including waste management;
- ~ 3 time less dust in landfills, equal to about 400 Mt/y;
- > 900.000 t/y CO_2 avoided, from the generation of 2.100 GWh/y by waste heat recovery;
- ~ 12% reduction of the Zn imported in the EU;

A precursory business plan has been prepared based on the knowledge and experience in the steel industry of the technology providers and end-user partners. The expected cost of the whole project is about 30 mln EUR. The potential benefits can be achieved in terms of savings and CE is 4,5 mln EUR/y. The project partnership includes EAF plants from Germany and Spain, RTOs, technology providers together with a leading EU zinc supplier.

Pittini Group "sustainable production" represents a strong commitment towards steel sustainability. The following actions are to be undertaken, with an expected investment of about EUR 10 million:

- energy recovery, in harsh environments, buffering of energy recovered to overcame fluctuation due to batch EAF process,
- use of Syngas / H_2 /Biomass as substitute of fossil fuels (CH_4, Natural Gas, Carbon) for reaching decarbonisation of EAF process; this would consequently forterbiomass collection and production value chains, syngas production and/or H_2 production, modification and management of gas network dedicated to EAF
- zinc recovery from EAF Dust: recovery processes exist so far but with low environmental efficiency (high waste/product quantity ratio). New processes are thus necessary to enable EAF plants recovering of zinc and other metals in an efficient and environmentally safe way (zero-waste principle).
- increase use of DRI produced nearby EAF. Pig iron, DRI, HBI are important input materials in production of EAF steels particularly when low tramp elements are requested. Therefore, increasing the use of DRI produced near the EAF plant gives the opportunity to increase energy efficiency of the process. Pig iron can be replaced by DRI or HBI, which processes can be associated with the production of H_2, thus generating significant synergies with other European projects related to BF-BOF cycle (HYBRIT, SALCOS, H2Steel).

Arvedi "zero impact project" intended to develop, upscale and roll out new technologies that could reduce CO_2 emissions by 2050 by at least 80 to 95% compared to 1990 levels, following the Commission's Strategic Vision "A Clean Planet for all" concerning CO_2 emission reduction. This project combines technological solutions as steel recycling, carbon capture utilisation and storage (CCUS), process integration and electricity/hydrogen-based metallurgy. It aims at designing a 'zero impact project' to achieve these goals within five years. More in detail, it is intended to achieve:

- **Climate neutrality** by reducing direct emissions, feeding EAF exclusively with power from renewable sources, off-setting all CO_2 produced from production and transport of materials;

- **CE/Zero waste** by the use all slag (recovery up to 99%), recovery of spent refractories, re-use of ferrous by-products, the recovery of sludge from water treatment plant and hydrochloric acid from pickling lines for the chemical industry, involving up to 10 million Euro investment.

Arvedi's target in the **Arvedi Circular Economy project (ACE)** is the reduction of the CO2 of the EAF plant following two main pathways in the frame of Circular Economy: increase the POST CONSUMER SCRAP reducing the PIG IRON presently used in the melting process and segregate the CO2 from the off-gases in by-products (slags).

The two pathways require industrial demonstration activities before to be integrated at industrial scale to reach the final target of about 173,000/tons of CO2 per year.

The target of the POST CONSUMER SCRAP demonstration is reaching the goals defined by UN 2030 (approved on 2579/2015) as far as Sustainability Development Goal target 12 (responsible consumption and production) and target 13 (act for climate change). The final objective is a reduction of CO2 directly generated in Arvedi EAF plant up to 143.000/tons per year in respect to present emissions by totally review of the scrap mix and consequently reducing the today pig iron utilization from 25% to ZERO. This target requires research of technologies to favour the selection of scrap. The starting point of envisioned technology has a Technology Readiness Level 6. During the project the technological framework will allows to reach high level of TRL, between 7 and 9. The estimated cost is between 27 and 29 million in a time frame of three years. An international partnership including technology suppliers, RTO has been already identified.

The **pathway for CO2 sequestration** is based on the recovery of inert materials to be used in the construction industry and utilize the characteristics of the waste to capture CO2 The required activities include preliminary experimental laboratory tests to identify and verify materials that can be used for CO2 sequestration/absorption, the set-up of a pilot plant as well as a verification protocol to certify the quality of the material generated and its environmental impact. Expected impact of is 30.000 tons of CO2/year.

The initial part of the study has an estimated cost of 2 million EUR. The demonstration phase requires a pilot plan with a cost estimated in additional 9 million EUR to reach TRL 8 starting from present TRL 6. Total cost is 11 million EUR in a time frame of 3 years.

Feralpi's LowCarbonCharge aims at reducing carbon usage in steelmaking production - both those generated directly and indirectly from other energy sources. This will be monitored through variation of quantity of Anthracite, Coal, or CH_4 used in EAF and BF-BOF steelmaking. This project concerns the management, treatment, and processing of materials used and deals with the following aspects:

- Improved management of materials in charge and scraps to enable the optimal charging procedures and mix.
- Management of the handling of all solids materials to select the different types to enable the optimal destination in charge or recovery.
- Substitution of whole quantity of carbon charged in each form with alternative materials also as recovery of other sectors.
- Recovery of metal fractions from waste materials with recovery on devoted plants.

This project will allow avoiding the use of new carbon sources in charge (as anthracite, coal, or gas) and it will enable the optimization of the metallic yield and energy consumption thus lowering CO_2 emissions. It

would require a budget of about 20 MEUR to set up a demonstrator plant, hence passing from TRL 5 to TRL8.

The **CO2Reduction** project aims at reducing CO_2 emissions from production furnaces to zero and as measured by the % of CO_2 and Flow rates in off gas plant emissions. The focus point of this project is the activities aimed at sequestering the CO_2 emitted during the steelmaking process, both by the heating furnaces and by the electric arc furnaces, and at finding a kind of its internal and external usage. This can be achieved by several actions, including: This needs for several actions including:

- Collection of emissions from all heating furnaces
- Collection of emissions from electric arc furnaces
- Fume treatment
- Implementation of systems for CO2 internal usage
- Implementation of systems for CO2 external usage also through the algae cultivation in different forms.

This activity will lead to the CO2 emissions elimination in all the Feralpi Group's production sites. This project would require a budget of about 40 MEUR to set up a demonstrator plant (as new pilot plants and demonstrator of CO_2 extraction and concentration and new pilot plants and demonstrator for Algae growing), hence passing from TRL 5 to TRL8.

With the project **Energy Conversion**, the target is to significantly reduce methane gas quantity used in the production plant, as measured looking at variation of quantity of CH_4 yearly used as flow rate and volume per year. This project would thus lower the amount of CH_4 used to supply energy to the heating furnaces through the usage of different types of input fuels or of different forms of energy and production layout. This project would require a total budget of about 25 MEUR to obtain new pilot plants for alternating heating tests and demonstrator plant with alternative heating sources passing from TRL 5 to TRL8.

ORI-DEC project targets a 30% CO_2 reduction respect to present level for the EAF steel plant of ORI Martin through the demonstration and integration of different pathways:

- Energy recovery : +15%
- Energy supply reduction: -50%
- Reduction of fossil raw material in the EAF: -20%
- Materials supply

To reach these goals ORI Martin Group woks on a several technology Building Blocks:

- a precise control of the loaded scrap, with intelligent management of the CaO and CaOMgO, an intelligent control and management of the slag.
- reduction of electricity consumption by an innovative melting furnace capable of maximizing the electrical efficiency in the melting process with the use of electromagnetic stirrer (reduced electric energy consumption, eliminating argon consumption), the reduction of the use of fossil coal through the use of alternative materials polymers (bio char, materials innovative derivatives from reworked industrial waste), for the deoxidation of steel, for the formation of foamy slag for the stabilization of the electric arc;
- reduction of materials currently sent to landfills by recovering raw materials (e.g. metals, CaO, CaOMgO);

- capture and reuse of CO^2 from heating systems;
- recovery and reuse of the waste heat in the melting and heating systems;

These objectives are reflected in a series of demonstration stage (3-5 years) necessary to select the most effective technologies moving from TRL 5 to 8 and reduce the risk to the industrial implementation that is envisioned in a time frame of 8-10 years. Sub-projects can be set up by combining the 4 issues above listed (each of them can be approached standalone) for a total investment between 15-20 MEuro in the first demonstration stage The final of demonstration step will also enable the possibility to symbiosis between industry and territory (district heating, greenhouse heating).

Annex 2: Joint Declaration from A.SPIRE, EUROFER and ESTEP

SPIRE Sustainable Process Industry through Resource and Energy Efficiency

EUROFER The European Steel Association

ESTEP

JOINT DECLARATION FROM A.SPIRE, EUROFER AND ESTEP ON:
"Circular and Carbon Neutral Industry" and "Clean Steel-Low Carbon Steelmaking"
proposed partnerships for Horizon Europe

The emerging partnership portfolio proposed by the EC in the *Digital, Industry and Space* area of Horizon Europe, includes a partnership referred to as "Circular and Carbon Neutral Industry" (hereinafter "SPIRE-CCNI"), as a reformed continuation of SPIRE, together with a new partnership, focused on steel and referred to as "Clean Steel – Low Carbon Steelmaking" (hereinafter "CS-LCS"), the latter being partly funded by the assets of the European Coal and Steel Community (ECSC). Although SPIRE-CCNI has a broader roadmap, both partnerships have a common interest towards the major challenge of avoiding CO2 emissions from industry in Europe, with a focus on respectively the Process Industries – currently including eight sectors (cement, ceramics, chemicals, engineering, minerals, non-ferrous, steel and water) - at cross-sectorial level for the former, and on the Steel Value chain specifically for the latter.

Both A.SPIRE and the Steel Sector (represented by EUROFER and ESTEP) confirm their willingness to ensure that both partnerships can be developed in an efficient and complementary manner. EUROFER and ESTEP also confirmed in this regard their interest to remain part of the Future SPIRE-CCNI Partnership for the cross-sectorial level.

In this spirit, A.SPIRE and ESTEP/EUROFER have had constructive conversations and exchange of views with the purpose of ensuring that complementarity and synergies can be built between the two partnerships while avoiding duplications, and came subsequently to the recommendations below.

As major and general guideline, it is suggested that any technological development or innovation aiming at avoiding CO2 emissions that is specific to the Steel production or the steel Value chain, be within the scope of CS-LCS, while those technological developments or innovations that would be of cross-sectorial interest be pursued under SPIRE-CCNI. Specifically, this would translate into the following cooperation scenarios:

- When a technological development or innovation specific to the Steel sector (project addressing a challenge specific to the steel sector) would require a contribution from partners from other sectors, the project will be entirely financed by CS-LCS.
- Conversely a technological development or innovation of cross-sectorial interest and not specific to Steel will be entirely financed by SPIRE-CCNI.
- If cases arise that a technological development or innovation cannot be clearly assigned to CS-LCS or SPIRE-CCNI, both partnerships will investigate the possibility to have "aligned/complementary" calls.
- Finally, it is also recommended that if difference in priorities exists between the vision of the process industries at large and the steel sector specifically, for some topics of common interest, each Partnership could launch a topic according to its roadmap prioritization while the other could complement in subsequent calls either at cross-sectorial level (SPIRE-CCNI) or at steel value chain specific focus level (CS-LCS).

Both A.SPIRE and ESTEP/EUROFER are determined to ensure a smooth development of the two partnerships based on these initial recommendations and on further conversations and agreements in line with the above recommendations.

Further aspects that could be tackled in future:

- Review the list of topics and projects that are envisioned in each partnership and identify the synergies and areas to be addressed by the respective partnerships;
- Exchange information on events and calls, and learning and success stories of each partnership in their areas of complementarity so as to avoid overlaps; and
- Ensure that there is a harmonious allocation of projects to generate synergies and maximise impacts.

Pierre Joris **Chairman** A.SPIRE	**Axel Eggert** **Director General** EUROFER	**Klaus Peters** **Secretary General** ESTEP

Brussels
23 September 2019

Annex 3: Joint Declaration from Hydrogen Europe, Hydrogen Europe Research & EUROFER and ESTEP

JOINT DECLARATION FROM HYDROGEN EUROPE, HYDROGEN EUROPE RESEARCH & EUROFER AND ESTEP ON:
"Clean Hydrogen for Europe" and "Clean Steel-Low Carbon Steelmaking"
proposed partnerships for Horizon Europe

The emerging partnership portfolio proposed by the EC includes a partnership focused on steel and referred to as "Clean Steel – Low Carbon Steelmaking" (hereinafter "CS-LCS"), being partly funded by the assets of the European Coal and Steel Community (ECSC), together with the renewal of an existing partnership on Hydrogen, referred to as "Clean Hydrogen for Europe" (hereinafter CHE) as a reformed continuation of the FCH2-JU.

Both partnerships have a common interest towards the major challenge of avoiding CO2 emissions from industry in Europe, with a focus respectively on the Steel Value chain specifically for the former, and hydrogen production, distribution and end-uses at cross-sectorial level for the latter.

Both the hydrogen sector (represented by Hydrogen Europe (HE) and Hydrogen Europe Research (HER) and the Steel Sector (represented by EUROFER and ESTEP) confirm their willingness to ensure that both partnerships can be developed in an efficient and complementary manner.

In this spirit, HE/HER and ESTEP/EUROFER have had constructive conversations and exchange of views with the purpose of ensuring that complementarity and synergies can be built between the two partnerships while avoiding duplications, and came subsequently to the recommendations below.

As a major and general guideline, it is suggested that

1. any technological development or innovation dealing with clean hydrogen production, distribution and storage be within the scope of CHE,
2. any development of a new steel production plant or process will be within the scope of CS-LCS
3. the integration of the production, distribution and storage of hydrogen in the steel making process is <u>an area for cooperation</u> between the 2 partnerships.

In the area of cooperation, the following cooperation scenario are envisaged:

- When a pure process-related development or innovation specific to the Steel sector (project addressing a challenge specific to the steel sector) would require a contribution from a partner of another sector (such as integration of means of producing, storing and dispensing hydrogen), the project will be entirely financed by CS-LCS and this upon invitation by the steel sector of the identified partner of another sector.

- Conversely a technological development or innovation of technology bricks not specific to Steel will be entirely financed by CHE. This would also include aspects such as safety and regulations codes and standards.

- If cases arise that a technological development or innovation cannot be clearly assigned to CS-LCS or CHE, both partnerships will investigate the possibility to have "aligned/complementary" calls. This could be the case especially in the integration of hydrogen technologies where the know-how might be equally split between stakeholders of both partnerships.

- Finally, it is also recommended that if difference in priorities exists between the vision of sectoral integration through hydrogen technologies and the steel sector specifically, for some topics of common interest, each Partnership could launch a topic according to its roadmap prioritization while the other could complement in subsequent calls either at cross-sectorial level (CHE) or at steel value chain specific focus level (CS-LCS).

Both HE/HER and ESTEP/EUROFER are determined to ensure a smooth development of the two partnerships based on these initial recommendations and on further conversations and agreements in line with the above recommendations.

Further aspects that could be tackled in future:

- Review the list of topics and projects that are envisioned in each partnership and identify the synergies and areas to be addressed by the respective partnerships;
- Exchange information on events and calls, and learning and success stories of each partnership in their areas of complementarity so as to avoid overlaps; and
- Ensure that there is a harmonious allocation of projects to generate synergies and maximise impacts.

Since many industrials are involved in both CHE and CS-LCS, it is envisioned to create a "bridging" function fulfilled by relevant stakeholders to ensure the aspects aforementioned are effectively achieved.

Valérie Bouillon-Delporte	**Laurent Antoni**	**Axel Eggert**	**Klaus Peters**
President Hydrogen Europe	**President** Hydrogen Europe Research	**Director General** EUROFER	**Secretary General** ESTEP

05 May 2020

Annex 4: Preliminary list of expected members of the Partnership (*to be updated after the open public consultation*)

Country	Category	Name
European	Association	ESTEP – European Steel Technology Platform
European	Association	EUROFER - European Steel Producers Association
European	Plant builder	Primetals Technologies Austria GmbH
Austria	Plant builder	Primetals Technologies Austria GmbH
Austria	RTO	K1-Met
Austria	Producer	Voestalpine Stahl GmbH
Belgium	Producer	ArcelorMittal
Belgium	Producer	NLMK Verona SpA
Belgium	RTO	Centre for Research in Metallurgy (CRM)
Croatia	Producer	Acciaierie Bertoli Safau SpA
Denmark	Producer	NLMK Verona SpA
Denmark	RTO	Swerim AB
Finland	Producer	Outokumpu Oyj
Finland	RTO	Centre of Advanced Steels Research (CASR) - University of Oulu
Finland	RTO	Swerim AB
France	Producer	ArcelorMittal
France	Producer	Acciaierie Bertoli Safau SpA
France	Producer	Feralpi Siderurgica
France	Producer	NLMK Verona SpA
France	RTO	Institut Jean Lamour (IJL) - Université Lorraine
Germany	Producer	Acciaierie Bertoli Safau SpA
Germany	Producer	Alfa Acciai SpA
Germany	Producer	AG der Dillinger Hüttenwerke
Germany	Producer	ArcelorMittal
Germany	Producer	Feralpi Siderurgica
Germany	Producer	Hüttenwerke Krupp Mannesmann GmbH
Germany	Producer	Outokumpu Oyj
Germany	Producer	ORI Martin SpA
Germany	Producer	Salzgitter AG
Germany	Producer	thyssenKrupp Steel Europe AG
Germany	Plant builder	Tenova SpA
Germany	RTO	FEhS- Institute for Building Materials Research e.V.
Germany	RTO	Sieć Badawcza Łukasiewicz – Instytut Metalurgii Żelaza (IMZ)
Germany	RTO	VDEh-Betriebsforschungsinstitut GmbH (BFI)
Germany	RTO	Sozialforschungsstelle Dortmund - Technische Universität Dortmund
Italy	Association	Federacciai
Italy	Plant builder	Tenova SpA

Country	Category	Name
Italy	Producer	Acciaieria Arvedi SpA
Italy	Producer	AFV Acciaierie Beltrame
Italy	Producer	Acciaierie Bertoli Safau SpA
Italy	Producer	Acciaierie Venete
Italy	Producer	Alfa Acciai SpA
Italy	Producer	CB Trafilati Acciai SpA
Italy	Producer	Dalmine SpA, part of Tenaris SA
Italy	Producer	ArcelorMittal
Italy	Producer	Feralpi Siderurgica
Italy	Producer	Marcegaglia Steel
Italy	Producer	NLMK Verona SpA
Italy	Producer	ORI Martin SpA
Italy	RTO	RINA Consulting - Centro Sviluppo Materiali SpA
Italy	RTO	Sieć Badawcza Łukasiewicz – Instytut Metalurgii Żelaza (IMZ)
Italy	Plant builder	Danieli Automation
Italy	Producer	Lucchini Industries SRL
Luxembourg	Producer	ArcelorMittal
The Netherlands	Producer	ArcelorMittal
The Netherlands	Producer	Tata Steel
Poland	Producer	ArcelorMittal
Poland	RTO	Sieć Badawcza Łukasiewicz – Instytut Metalurgii Żelaza (IMZ)
Romania	Producer	Acciaierie Bertoli Safau SpA
Romania	Producer	Dalmine SpA, part of Tenaris SA (Silcotub SA)
Spain	Producer	ArcelorMittal
Spain	Producer	Sidenor Aceros Especiales S.L.U.
Sweden	Association	Jernkontoret (Swedish steel producers' association)
Sweden	Producer	Outokumpu Oyj
Sweden	RTO	Swerim AB