SYNOPSIS REPORT OF CONSULTATION ACTIVITIES

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Table of contents

List of figures

List of tables

List of symbols, indices, acronyms and abbreviations

CAPEX	Capital expenditure
CCU	Carbon capture and usage
CO_2	Carbon dioxide
DRI	Direct reduced iron
ER	Energy recovery
ETS	EU Emission Trading System
EU	European Union
GREENSTEEL	Green Steel for Europe
H_2-DR	Hydrogen-based direct reduction
HPSR	Hydrogen plasma smelting reduction
IBRSR	Iron bath reactor smelting reduction
IPCEI	Important projects of common European interest
MOE	Molten oxide electrolysis
OPEX	Operational expenditure
PI	Process integration
R&D&I	Research, development and innovation
RFCS	Research Fund for Coal and Steel
SOEC	Solid oxide electrolyser cell
TGR-BF	Top gas recycling – blast furnace
TRL	Technology readiness level
WP	Work package

1 Introduction

This report shows data and information on investment needs and funding programmes relevant to the development and deployment of technologies enabling climate-neutral steel production. The information collected were gained from key players in the steel industry (steel producers and technology providers) located in the European Union (EU).

The consultation phase entailed a scoping questionnaire and in-depth interviews. They were part of the Green Steel for Europe (GREENSTEEL) project, had a general approach but they also included issues concerning technology, drivers and barriers. These issues will be treated in separate reports.

This report shows data collected from the start of the project (January 2020) to February 2021. The results presented, as well as any additional information provided by the consulted stakeholders, provide relevant information on the following deliverables (either pending or already released) that are part of the GREENSTEEL project:

D1.1. Draft assessment and roadmapping of technologies;

D1.2. Assessment and roadmapping of technologies;

D1.4 Draft collection of possible decarbonisation barriers;

D1.5 Collection of possible decarbonisation barriers;

D2.1 Draft investment needs report;

D2.2. Investment needs report;

D2.3 Draft report on funding opportunities;

D2.4 Report on funding opportunities;

The remainder of this report is divided into five main sections:

- Methodology (questionnaires rationale, data collection methods and respondents' sample);
- scoping questionnaire findings highlighting the financial needs to develop, demonstrate and deploy the decarbonisation technologies as well as the increase in capital expenditures (CAPEX) and operating costs (OPEX) stemming from the industrial deployment of the identified technologies;
    - funding opportunities, summarising the available financial support programmes to decarbonise the EU steel industry used by the consulted stakeholders, as well as barriers to exploit such opportunities;
- in-depth consultation findings, with the feedback from stakeholders and technology providers;
- 'success stories', and
- concluding remarks.

2 Methodology

The consultation phase entailed a scoping questionnaire and in-depth interviews to stakeholders available to provide further information in a subsequent step.

The scoping questionnaire is divided into four parts:

1. the first part aims to collect basic information on the company and person answering the questionnaire;
2. the second part focuses on innovative decarbonisation technologies and their maturity progress, from the expected period for demonstration (technology readiness level, TRL = 8) to the deployment as first-of-a-kind at industrial level (TRL = 9). In addition, the second part focuses also on the investment and funding needed to develop and uptake such technologies for the periods 2020-2030 and 2030-2050;
3. the third part focuses on drivers and barriers affecting the decarbonisation of the steel industry. The assessment was carried out based on a scale from 1 to 5, as follows: (1) not at all; (2) to a limited extent; (3) to some extent; (4) to a high extent; or (5) to the fullest extent; and
4. the fourth part gathers data and information from the stakeholders on their awareness of funding opportunities to support the required technologies and the experience achieved with them, if any, including possible barriers or experience in funding blending and/or sequencing.

A total of 34 stakeholders, both producers and technology providers, were consulted in this phase. They are located all over Europe: Austria, Belgium, the Czech Republic, Finland, Germany, Italy, the Netherlands, Poland, Slovakia, Spain, and Sweden. Table 1 shows the corresponding carbon dioxide (CO_2) emission share in Europe from the steel industry (more than 80% as claimed in the project's Technical Annex).

Table 1: Overall scoping interview statistics

Status	Total	CO_2 share (of EU steel production)	Share (of contacted)
Contacted	34	83.5%	NA
Replied to contact (in any form)	26	83.1%	76.5%
Still ongoing	5	11.0%	14.7%
Sent filled questionnaire	15	71.1%	44.1%

Source: authors' own composition based on interview data.

The shares of CO_2 emissions of stakeholders involved in the consultations were calculated based on the 2020 allocations within the EU Emission Trading System (EU ETS).[1]

[1] Data on CO_2 emission were achieved by performing a data analysis of the publicly available 2020 EU ETS allocations (via EU Transaction Log https://ec.europa.eu/clima/ets/) and subsequent extraction of

Such an analysis is based on the assumption that the allocated CO_2 allowances reflect the current CO_2 emissions more accurately than the stakeholders' production capacity, as it is likely that they are operating at varying (not full) capacity. A more detailed approach, taking into account the reported verified emissions over multiple years, is being developed and is going to be used in a subsequent evaluation process, as well as in the synopsis reports of consultation activities (Hauck & Kempken, 2021), (Simonelli, 2021).

For the aggregate data analysis, the following approach has been used:

- if the producers gave multiple answers, the most frequent answer was generally taken as representative. In other cases, a time range or an average was provided; and
- if the producers gave multiple answers to single technologies, each information (TRL, investment needs, CAPEX, OPEX…) was allocated to each technology.

In other cases, when the answers referred directly to a combination of technologies along the production chain, the information gained was correlated to said combinations.

The responses to this scoping questionnaire were the basis for more detailed, in-depth interviews with the stakeholders who were willing to participate. The contact people of these companies (10) were consulted to gather a more detailed insight on some aspects concerning technology, investment needs and funding issues (statistics in Table 2 below).

The in-depth consultation questions were general, in order to favour a broader discussion during the interviews. Said interviews, to a great extent, were conducted by phone.

60% of the respondents provided information on work package (WP) 2 topics, reported below, whereas all of them gave further details on WP1 issues, which are discussed in a separate report. The data collected, nonetheless, are of particular significance because two in-depth interviews were conducted with technology providers. Their contribution is clearly of the outmost importance in identifying relevant R&D and funding-related issues in the path towards a carbon neutral steel production. In addition, they can provide valuable information on the feasibility and maturity of the technologies that are being developed and implemented. In this regard, the share of covered CO_2 emissions as shown in Table 2 is of less importance for the significance of the data.

Table 2: In-depth overall statistics

	Number	Share	CO_2 Share
Contacted for in-depth interviews	10		35.2%
Replied and answered questionnaire (to some extent)	10	100.0%	35.2%
Answered questionnaire (to funding questions)	6	60.0%	11.5%

Source: authors' own composition based on interview data.

In brief, the questions involved:

- the financial framework conditions with indication of possible barriers;

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the allocated CO_2 emissions for iron and steel industry stakeholders. Thus, the specific share of the EU's steel industry CO_2 emissions was calculated for each stakeholder.

- the market scenario; and
- the experience in funding programmes and their use, with evidence of 'success stories'.

The recording of each interview, as well as the scoping questionnaires' forms, are stored in the GREENSTEEL project database managed by the Project Leader (CEPS).

3 Scoping interviews

3.1 Technology assessment and investment needs

In the first part of the questionnaire, stakeholders were asked to assess various alternatives of selected decarbonisation technologies, in line with the classification adopted in the reports concerning Technological Assessment (Hauck, et al., 2021) and Investment Needs (De Santis, et al., 2021).

This list comprised:

1. hydrogen-direct reduction (H_2-DR);
2. chemical/biological carbon capture and usage/storage (chem./biol. CCU);
3. increased substitution of fossil fuels by biomass (incr. biomass);
4. increased scrap input (incr. scrap);
5. energy recovery and re-use (energy rec. / ER);
6. processing of steel plant slags (slag processing);
7. hydrogen plasma smelting reduction (HPSR);
8. alkaline iron ore electrolysis (alkaline electrolysis, AE)
9. molten oxide electrolysis (MOE);
10. iron bath reactor smelting reduction (IBRSR); and
11. other technologies specified by the stakeholders (e.g., top gas recycling blast furnace (TGR-BF); BF injection of H_2 rich gases, etc.).

In the questionnaire several combinations of technologies, listed below, were also presented. For each technology the same acronyms and abbreviations of the previous list and report's tables were used.

12. H_2-DR + chem. CCU + alkaline electrolysis + increased biomass + increased scrap + ER;
13. H_2-DR + chem. CCU + HPSR + ER + SP + solid oxide electrolyser cell (SOEC);
14. chem. CCU + hot charging;
15. BF injection of H_2-rich gases,
16. EAF in BOF route;
17. increased biomass + ER + slag processing;
18. natural gas replacement with green hydrogen;
19. H_2-DR + chem. CCU + bio. CCU + increased biomass + ER + slag processing;
20. H_2-DR + alkaline electrolysis;
21. multifuel combined with H_2;
22. increased biomass + increased scrap + ER + slag processing in EAF;
23. chem. CCU + increased scrap + increased biomass;
24. TGR-BF + chem./bio CCU + increased biomass + ER + H_2 use;
25. H_2-DR + slag processing + alkaline electrolysis.
26. H_2DR + increased biomass + ER;
27. natural gas replacement with green hydrogen + ER;
28. bio. CCU + increased biomass + ER + slag processing + metal oxides electrolysis + alkaline electrolysis;

29. H_2-DR + chem. CCU + alkaline electrolysis; and
30. H_2-DR + slag processing + alkaline electrolysis.

The stakeholders were asked to assess one or more technologies relevant for their company and to express their views on how to achieve their industrial deployment, in terms of technology readiness level (TRL), time and financial resources needed. Information was also asked on the expected share of production for the corresponding technology alternative and the cost effects (influence on CAPEX and OPEX as well as investment and funding needs).

This report focuses exclusively on the aspects concerning investment needs and/or funding issues. Data on barriers and relevant factors that could enable the technologies' development up to industrial deployment are going to be treated in a separate analysis.

Table 3 shows an overview of the issues for the period 2020-2030, whereas Table 4 gives an overview of combinations of technologies for the same period. The corresponding information for the period 2030-2050 is given in Table 5 and Table 6. In some cases, different answers for the same technology were given and all of them are reported.

The legends are similar for all four tables and are described as follows. The column headers represent the questions asked in the questionnaire for the related content. They are indicated in a shortened form as explained hereafter:

TRL 2019

TRL achieved for the technology in 2019.

TRL 8 year

Expected year when demonstration state at TRL 8 will be achieved.

TRL 9 year

Expected year of first industrial deployment at TRL 9.

Full deployment year

Expected year of full industrial deployment.

Share of production to 2030

Expected share (%) of production out of total production of each company in 2030 (as a best estimate). Included in this analysis as a framework reference.

Foreseen CO_2 reduction

Expected CO_2 reduction per tonne of crude steel (decrease ratio compared to 1990 emission levels, reference in the questionnaire). This information is included in this analysis for completeness, as it is relevant to the main issue behind the project scope.

Investment needs TRL 7

Investment needs (include CAPEX + OPEX) for pilot scale tests at TRL 6-7.

% needs (for TRL 7, 8 and 9)

Share of external financial support needed (%) (e.g. by public funding programmes).

Investment needs TRL 8

Investment needs for demonstration plants at TRL 8.

Investment needs TRL 9

Investment needs for first industrial deployment at TRL 9.

% CAPEX

Expected increase in annual CAPEX (% increase/decrease for the technology or combination thereof selected above, compared to current CAPEX per tonne of steel).

% OPEX

Expected increase in OPEX after industrial deployment (% increase/decrease for the technology or combination thereof selected above, compared to current OPEX per tonne of crude steel).

The row headers represent the technology, or the combination of technologies, indicated in the table for the corresponding period. Such information is schematised with a number: in the tables' legends each type of technology and/or the combination of technologies is explained, using the shortened form/acronym indicated in the list in the initial part of the section.

The relevant data are referred to plants whose reference size is 1 million tonnes of crude steel/year, and can be summed up as follows:

- in Table 3, no information is needed on TRL 9 (assumed to be achieved within 2030) and on CAPEX for the technologies, only in two cases for OPEX;
- in general, the most relevant technologies (CCU, H_2-DR) are indicated as not yet mature at a demo scale (TRL = 7). Only for technologies generally embedded in the pathway process integration (PI), such as 'increased scrap' and 'energy recovery', the reported TRL is higher and a start of industrial deployment within 2030 is expected;
- overall, a reduction of CO_2 emission of at least 50% is foreseen by 2030 compared to 1990 emission levels;
- the investment needs for the considered technologies can reach values as high as 5 million Euros for the achievement of TRL 7 and 25 million Euros for TRL 8 for the period 2020-2030, while for the period 2030-2050 upper limits of 25 million Euros for TRL 7, 1.4 billion Euros for TRL 8, and 5 billion Euros for TRL 9 are expected;
- with regard to the period 2020-2030, the information on the combination of technologies is scarce and the most recurring technologies involve increased use of biomass and scrap as well as ER;
- for the period 2030-2050, from the questionnaires' answers more ambitious targets for the various technologies emerge: in several cases a CO_2 reduction greater than 90% is expected as a result of the deployment of some technologies or combinations of technologies (see the corresponding columns 'Foreseen CO_2 reduction' in Table 4 and Table 5). More details on the mostly envisaged combinations of technologies are shown in the Technology assessment Report[2]. In parallel, for the period 2030-2050, the investment costs claimed for deployment at industrial level can reach an order of magnitude of 4-5 billion Euros and a CAPEX increase of 100% in some cases.

[2] GREENSTEEL project, Grant Agreement no. 882151, Technology roadmapping, forthcoming report.

Table 3: Overview of issues concerning technologies to reduce emissions from consulted EU producers' plants between 2020 and 2030 – Part 1

Technology	TRL 2019	TRL 8 year	TRL 9 year	Full deployment year	Share of production to 2030	Foreseen CO_2 reduction (%)	Investment needs TRL 7 - k€	% needs	Investment needs TRL 8 - M€	% needs	% OPEX
1	7	2028	2030	2035		80					
	4	2025	2026	2030	20	100	120				
	5	2026	2030	2035	1	90	110	100	25	100	60
2	5	2030	2032	2035		80	1000	60		60	
3	2	2025	2030	2035	3	60					
	6	2022	2025	2028	10	50	100	0			
	7	2023	2024	2025		20					
	7	2023	2025	2035		60	500	75	15	50	
4	8	2020	2021	2025	30	50					
	7	2023	2025	2035		60	1000	75	2	50	
5	8	2020	2021	2022	5						
	7	2030	2040								
	7	2025	2026	2030	100						20
	7	2023	2027	2035		60	5000	75	15	50	
6	7	2023	2025	2035		60					

Note: legend for the technologies (acronyms in the text of Section 3.1):
1 = H_2-DR, 2 = chem./biol. CCU, 3 = increased biomass, 4 = increased scrap, 5 = ER, 6 = slag processing
(1) CI= availability of clean hydrogen, RE = availability of renewable energy, CCS = availability of CCS, F = availability of public funding opportunities, SYM = availability of industrial symbiosis synergies, DRI = availability of DRI.

Table 4: Overview of issues concerning combinations of technologies to reduce emissions from consulted EU producers' plants between 2020 - 2030 – Part 2

Combination of technology	TRL 2019	TRL 8 year	TRL 9 year	Full deployment year	Share of production to 2030	Foreseen CO_2 reduction (%)	Investment needs TRL 7 - M€	% needs	Investment needs TRL 8 - M€	% needs	% OPEX
12	6	2025	2026	2027	30		Received questionnaires contained no information on these issues				
13	3	2026	2029	2035		30					
14	7	2020	2021	2021	100						
15	9	2028	2030	2035	40	10					
16	9		2030	2035	20	30					
17						30					
18	6	2025	2030	2040	50	60					
19	3	2023	2024	2025	50	30					
20	7	2022	2029	2035		60					
21	7	2023	2025	2035		60					
22	5	2024	2026	2028	100	95					
23	5	2025	2028	2030	80	35					
24	6	2025	2030	2035	25	40					
25	8	2019	2030	2050	40						

Note: legend for the combination of technologies (acronyms in the text of Section 3.1):
12 = H_2-DR + chem. CCU + alkaline electrolysis + increased biomass + increased scrap + energy recovery; 13 = H_2-DR + chem. CCU + HPSR + ER + SP + SOEC; 14 = chem. CCU + hot charging; 15 = BF injection of H_2-rich gases; 16 = EAF in BOF route; 17 = increased biomass + energy recovery + slag processing; 18 = natural gas replacement with green hydrogen; 19 = H_2-DR + ch.CCU + bio. CCU + increased biomass + energy recovery + slag processing; 20 = H_2-DR + alkaline electrolysis; 21 = multifuel comb. with H_2; 22 = increased biomass + increased scrap + energy recovery + slag processing in EAF; 23 = chem. CCU + increased scrap + increased biomass; 24 = TGR-BF + chem./bio CCU + increased biomass + energy recovery +H_2 use; 25 = H_2-DR + slag processing + alkaline electrolysis
(1) CI= availability of clean hydrogen, RE = availability of renewable energy, CCS = availability of CCS, F = availability of public funding opportunities, SYM = availability of industrial symbiosis synergies, DRI = availability of DRI.

Table 5: Overview of issues concerning technologies to reduce emissions from consulted EU producers' plants between 2030 and 2050 – part 1

Tech.	TRL 2019	TRL 8 year	TRL 9 year	Full depl. year	Share of prod. to 2030	Foreseen CO_2 reduction (%)	Inv. needs TRL 7 - k€	% needs	Inv. needs TRL 8 - M€	% needs	Inv. needs TRL 9 - M€	% needs	% CAP EX	% OPEX
1	7	2028	2033	2035		90					2000		100	60
	4	2025	2026	2030	20	100	12000							
	6	2030	2040	2050	100	95			100	60	5000	60	15	80
	8	2023	2030	2045	100	70								
3	6	2028	2033	2035		90					1200		100	60
4	7	2028	2033	2035		90					2000		1	1
5	7	2028	2033	2035		90					200		20	2
6	7	2028	2033	2035		90					350		2	0
7	5	2030	2050	2070	100	100			100	100	5000	60	15	80
8	2	2045	2050		30	95	25000	100	70	100	500			
9	5	2030	2035	2050	30	95	2700		50	100	500		80	20

Note: legend for the technologies (acronyms in the text of Section 3.1):
1 = H_2-DR, 3 = increased biomass, 4 = increased scrap, 5 = ER 6 = slag processing, 7 = HPSR 8 = MOE, 9 = alkaline electrolysis
(1) CI= availability of clean hydrogen, RE = availability of renewable energy, CCS = availability of CCS, F= availability of public funding opportunities, SYM = availability of industrial symbiosis synergies, DRI = availability of DRI.

Table 6: Overview of issues concerning combinations of technologies to reduce emissions from consulted EU producers' plants between 2030 and 2050 – part 2

Comb. of tech.	TRL 2019	TRL 8 year	TRL 9 year	Full depl. year	Share of prod. to 2030	Foreseen CO2 reduction (%)	Inv. needs TRL 7 -k€	% needs	Inv. needs TRL 8 - M€	% needs	Inv. needs TRL 9 - M€	% needs	% CAPEX	% OPEX
21	7	2025	2030	2040	100	95					10		10	100
22						70								
24	6	2035	2040	2050	70	95	20000	100	1400	100	4000	100	50	50
26	1	2037	2045	2050	25	50		50		60		60		
27	6	2025	2030	2040	50	*60*	10000	100	100	70	150	30	15	10
28	2	2035	2042	2050		80	15000	100	250	85	45	65	10	
29	6	2025	2026	2027	100	70								
30	9	2019	2030	2050	100	70								

Note: legend for the combination of technologies (acronyms in the text of Section 3.1):
21 = multifuel comb. with H_2; 22 = increased biomass + increased scrap + energy recovery + slag processing in EAF route; 24 = TGR-BF + chem/bio CCU + increased biomass + energy recovery + H_2 use; 26 = H_2DR + increased biomass + energy recovery; 27 = nat. gas replacement with green hydrogen + energy recovery; 28 = bio. CCU + increased biomass + energy recovery + slag processing + metal oxides electrolysis +alkaline electrolysis; 29 = H_2-DR + chem. CCU + alkaline electrolysis; increased biomass + increased scrap + energy recovery, 30 = H_2-DR + slag processing + alkaline electrolysis

(1) CI = availability of clean hydrogen, RE = availability of renewable energy, CCS = availability of CCS, F = availability of public funding opportunities, SYM = availability of industrial symbiosis synergies, DRI = availability of DRI.

3.2 Funding opportunities

This section is focused on evaluating the stakeholders' answers to the scoping questionnaire's questions on the existing funding opportunities to decarbonise the steel industry.

The results from the questionnaire's questions referring to the investment needs were divided in:

- stakeholders' experience with funding mechanisms, and
- barriers in making use of the available funding opportunities.

At this stage, the consultation aimed to identify possible improvements in the existing programmes and/or to suggest possible new approaches to funding the decarbonisation of the steel industry.

A short overview over the results is shown in Table 7 below. The data reported refer to the most frequent answers provided in the forms received. Public funding (primarily at national/local level, and subsequently at EU level) broadly represents the most widespread option. The typical TRL step of the R&D activities addressed varies from 5 to 7.

The average duration of a project is 3 years; in most cases (75%) participants are organised in consortiums and the typical funding rate is of 60% (as occurs, for example, in RFCS projects).

Based on the indications of Section 3 of the questionnaire, where a funding rate of up to 100% in some cases is envisaged, stakeholders expect much stronger aids to support their decarbonisation investments related to the most challenging steps forward in technology readiness levels (from TRL 7 onwards).

Table 7: Overall data on the stakeholders' awareness of the main available EU funding programmes related to decarbonisation technologies, and their application.

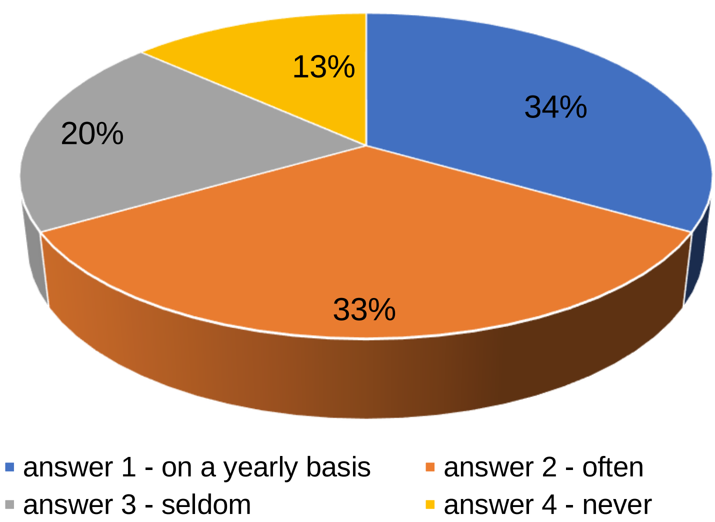
Main funding programmes (used or aware of) in the EU for R&D&I or activities related to decarbonisation technologies	
Public, national	83% of the answers
Public, EU level	83% of the answers
Public, regional	75% of the answers
Starting TRL	5 (50% of the answers)
Final TRL	7 (50% of the answers)
Duration (years)	3 (75% of the answers)
Consortium?	Yes (75% of the answers)
Overall co-financing rate (%)	60 (75% of the answers)
Specific co-financing rate (if any) for purchasing assets (%)	60 % (60% of the answers)
Specific co-financing rate (if any) for R&D expenditures (%)	60% (90% of the answers)

Source: Authors' aggregation of the consultation data.

3.3 Experience with funding mechanisms

Figure 1 shows how much stakeholders are familiar with relevant EU funding programmes, which is quite high: “often” means experience in more than 3 projects in the last 10 years, while “seldom” means less than 4 projects in the last 10 years. By summing up those making use of these opportunities on a yearly basis with those making use of them very often, a share of 67% is reached. Only 13% of the respondents answered they have never used such funding opportunities. This definitively shows that producers consider funding programmes to be a sound basis for their research, development and innovation (R&D&I) actions.

Figure 1: Frequency of EU financial support to R&D&I decarbonisation technologies projects.



Source: Authors’ aggregation of the consultation data.

In Table 8, the typical TRL step accompanying the project development is shown. It was rated to range from 5 to 7, up to just before the demonstration level. This has once again highlighted that funding plays an enabling role for producers to carry out innovation, which is of the outmost importance particularly for new technologies.

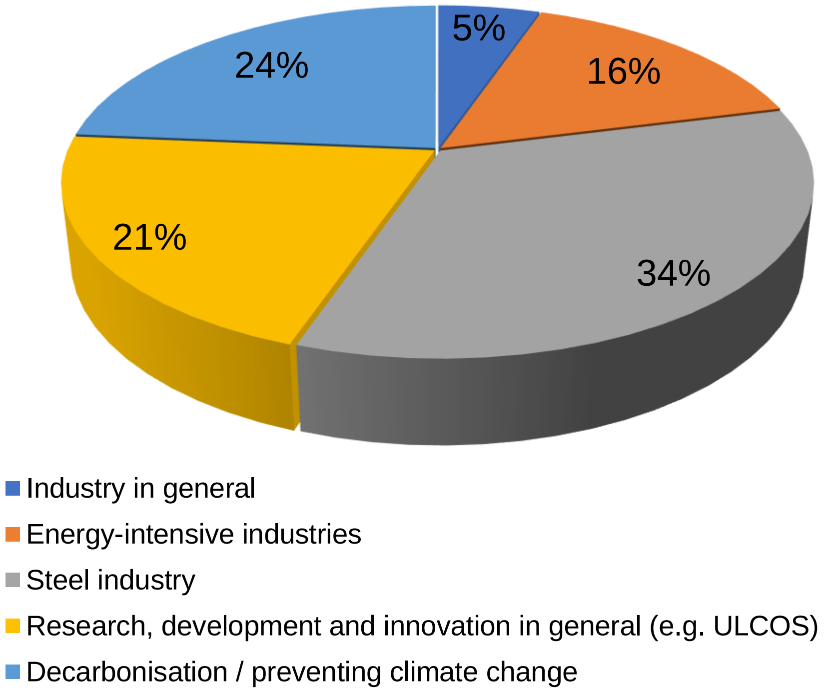
Table 8: Typical technology readiness levels and production range in projects approached.

Typical starting TRL	5 (33% of the answers)
Typical target TRL	7 (40% of the answers)
Typical target production (t crude steel/hour)	150 (average among the answers collected)

Source: Authors’ aggregation of the consultation data.

In Figure 2 the share of the main funding programmes mentioned is shown. The most frequently used ones (34%) are those directly relevant for steel industries. Moreover, general programmes for industries, addressed by producers on special R&D&I issues (21%), or aimed at decarbonisation (24%), are used. This is an indicator of the effort stakeholders make to benefit at the greatest extent possible from the opportunities offered by funding on issues of general interest.

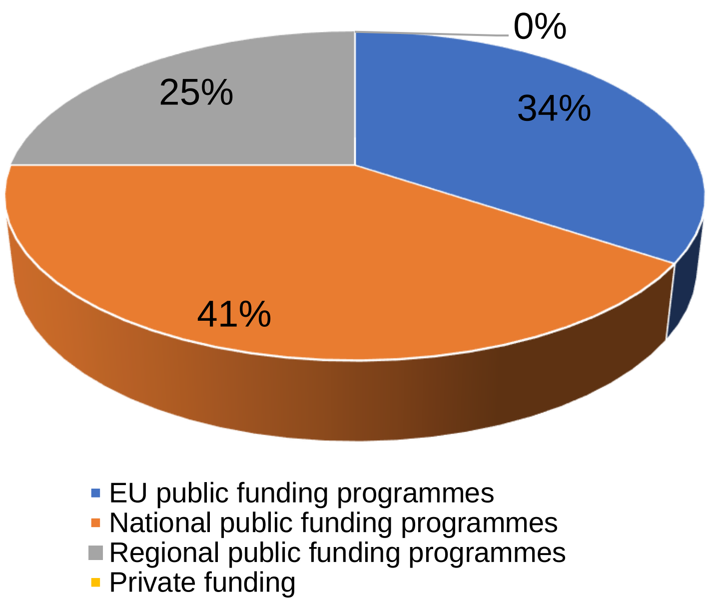
Figure 2: Main programmes used by the stakeholders consulted.



Source: Authors' aggregation of the consultation data.

Figure 3 shows the share among the geographic source of the funding programmes. The majority of programmes used are national ones (41%)[3]. Besides, also regional public funding programmes are used (25%). This shows, on the one hand, the broad effort companies make to benefit from funding opportunities at any level, on the other hand that support from national States still represents the most powerful lever the producers rely on in this field.

Figure 3: Funding programmes used by the stakeholders consulted



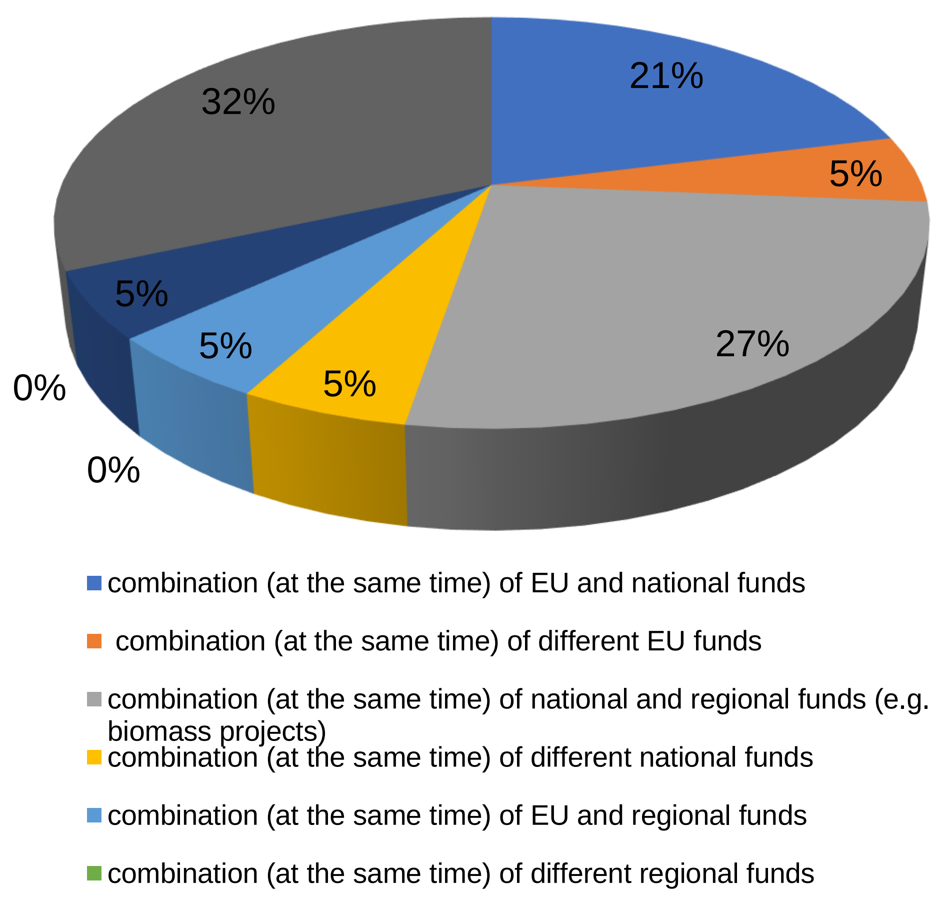
Source: Authors' aggregation of the consultation data.

[3] Related to the EU Countries of the stakeholders involved in the consultation: France, Spain, Italy, Germany, Belgium, Sweden, Poland.

Figure 4 shows data from the stakeholders on their experience in blending funding programmes, while in Figure 5 their experience on sequencing the funding opportunities is shown.

As Figure 4 highlights, the most frequent scenario is that stakeholders did not have any experience in blending of funding opportunities. When it did happen, it usually entailed blending of national and regional funds (27%) or EU and national funds (21%), with national support schemes still representing a sound backbone.

Figure 4: Stakeholders' experience in blending of funding programmes.



Source: Authors' aggregation of the consultation data.

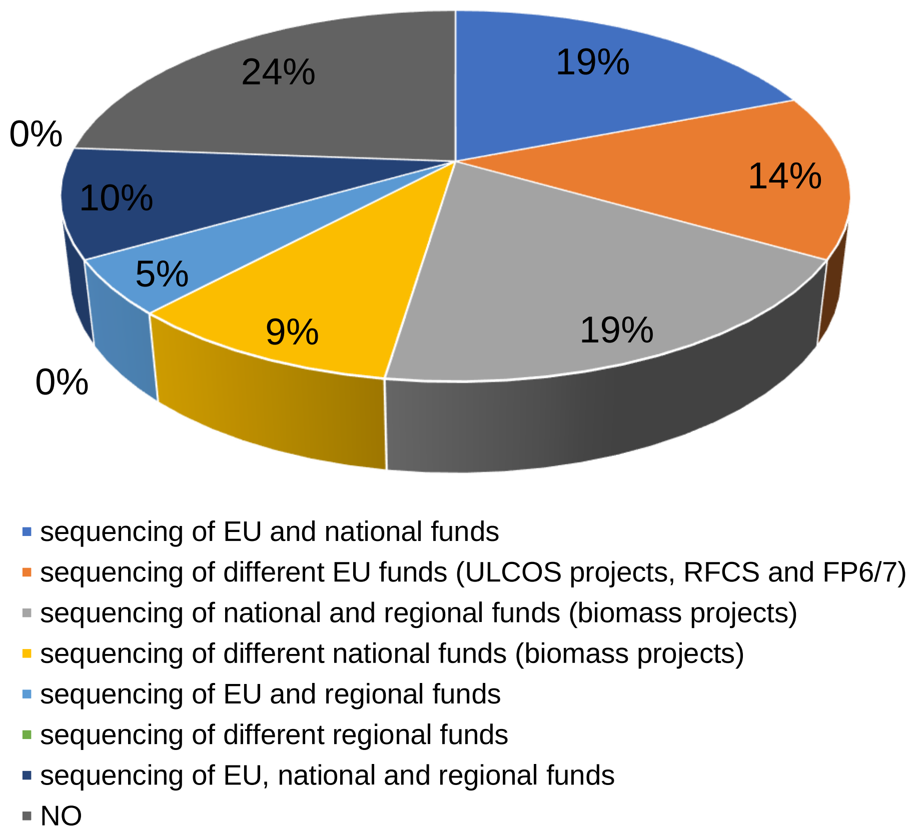
The blending experiences mentioned in the questionnaires are:

- RFCS (Research Fund for Coal and Steel) + LIFE (L'Instrument Financier pour l'Environnement) programme;
- IPCEI (important projects of common European interest) + national funds; and
- RFCS/HorizonEurope + Innovation Funding and IPCEI, also blended with national Governments' initiatives.

Figure 5 shows the results on sequencing (i.e. using one fund after the other). As for blending, the option of "no sequencing" is the most frequent one (24%). The sequential use of different EU funding programmes is reported in 14% of the answers. Again, for sequencing experiences too, the most widespread ones (19%) involve EU plus national funds, and national plus regional funds. This shows once again the paramount role of local support schemes. In particular, the sequencing experiences reported involve:

- RFCS + H2020; and
- regional/national programmes + Horizon Europe.

Figure 5: Stakeholders' experiences in sequencing of funding programmes.



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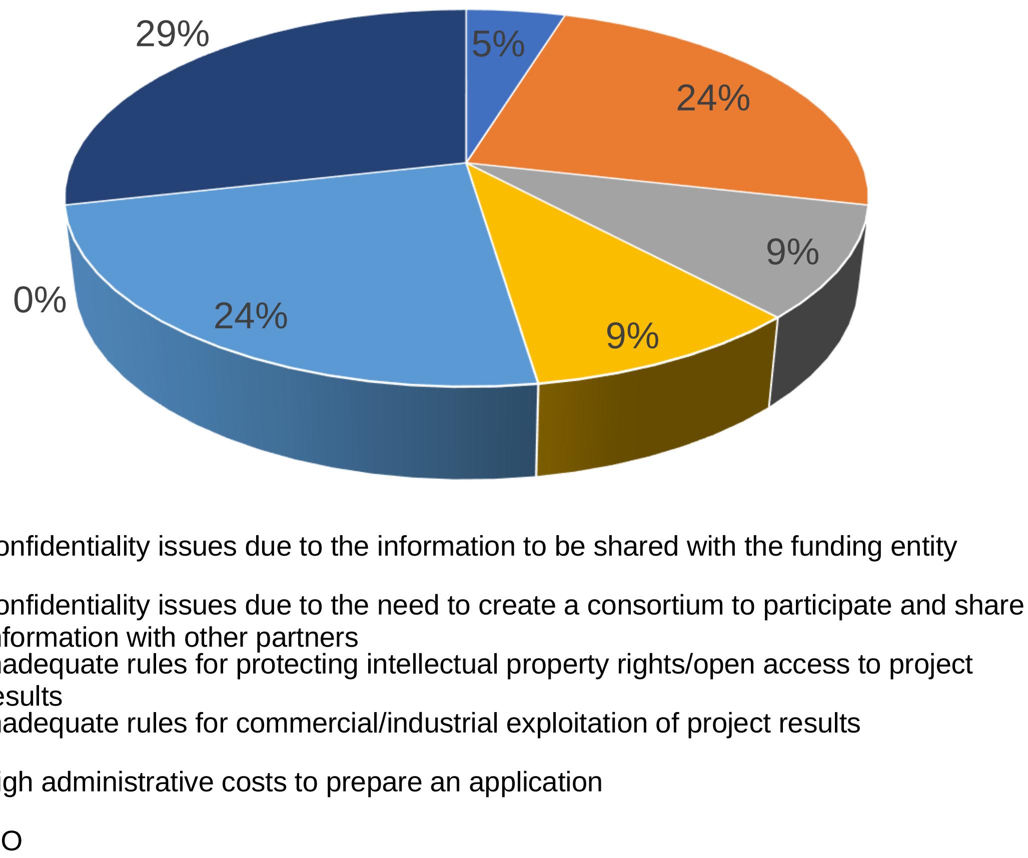
Source: Authors' aggregation of the consultation data.

Finally, an overview of the barriers found in accessing funding opportunities is shown in Figure 6. Only 29% of the consulted stakeholders declared they did not find any issues in one or more of the existing funding programmes. The vast majority (71%) highlighted having some concerns. A significant part (30% of the total cases) is ascribed to confidentiality issues, due to the information to be shared with the funding entity and the consortium. In some cases, these confidentiality issues also hindered the formation of a suitable consortium for the project. Relevant concerns are also related to the high administrative burden entailed by preparing the application (24%). Other relatively minor causes of concern are: (i) inadequate rules on how the project findings will be exploited; and (ii) how the intellectual property of the findings will be protected (9% in both cases). Most of these concerns are, at least partially, related to market issues and strategies (confidentiality, intellectual property, etc.), nevertheless the administrative burden entailed by applying to funding programmes is definitively an issue that might be improved.

Figure 6: Main financial barriers found in using funding programmes.



Source: Authors' aggregation of the consultation data.

4 In depth interviews

The low number of companies (10) willing to take part to the second round of consultations makes it pointless to summarise the results using statistical charts. The relative basic questionnaire is reported in the Appendix.

The relevant findings are listed below:

- the expected increase in OPEX related to energy/renewable energy consumption, as well as for its relevant infrastructure (e.g. CO_2 storage, H_2 distribution grid, etc.), is the most relevant barrier, in terms of financial framework conditions, hindering the development of decarbonisation technologies at demonstration/industrial level. A comprehensive overview on the barriers claimed by the stakeholders will be given in a dedicated GREENSTEEL project report;
- as regard to the market scenario, the Asian competition is a strong cause for concern. Institutional support is envisaged both in protecting in some way the EU's production and in providing adequate funding support to face the expected strong investment needs;
- concerning the funding experience, a general positive feedback is reported, as funding support programmes are paramount for the companies' innovation strategies. Most of the consulted stakeholders appreciated especially the local (national, regional) opportunities allowing them to make steps forward in the deployment of technologies. Technology providers, in particular, expressed a completely positive feedback on this aspect;
- concerning the weaknesses of the existing funding opportunities, stakeholders expressed their wish for wider blending and/or sequencing opportunities. Moreover, the only financial support for industrial scale equipment via depreciation is considered to be too weak. The current range of funding opportunities is, so far, considered to be not fitted to the real investment needs, especially in enhancing the technology readiness level from 6 (technology demonstration in industrially-relevant environment) to 8 (pre-deployment). In this sense, there are great expectations for the scenario opened by the Clean Steel Partnership as being a more adequate instrument to support both carbon-neutral steel production and technology players; and
- concerning 'success stories' in projects with funding support programmes at Institutional level (from the EU to local one), several examples were given. They range from well-known breakthrough developments of technologies (HYFOR, HYBRIT, H2Future, SuSteel – see also (Hauck, et al., 2021) to the so-called 'Process Integration' approaches (e.g. suitable burners), including also energy saving and reuse (e.g. district heating networks in Northern Italy). Also carbon direct avoidance projects in Germany, such as H2BF (Hauck, et al., 2021), are examples of sequencing of funding (from TRL = 6 to TRL = 7 with 40% regional public funding support, from TRL = 7 to TRL = 9 with 40% national funding). Finally, it is worth mentioning that the consortium in Hybrit receives 40% of funding support from a National Swedish programme[4], and the other 60% from three private companies (SSAB, LKAB and Vattenfall, 20% from each partner), and agrees to share the licenses and technologies developed in Hybrit.

[4] Energimyndigheten, https://www.energimyndigheten.se/, Swedish Energy Agency.

4.1 Feedback on success stories

Finally, success stories are presented after further consultation with stakeholders wishing to provide their positive feedback in projects aimed at carbon-neutral steel production and supported by funding programmes at Institutional (from EU to local) level. As a general comment, proof of the successful role of such support schemes comes directly form the fact that in the last ten years the number of projects has been increasing continuously, and this occurred especially thanks to the funding opportunities.

So far, the relatively low TRLs allowed the funding programmes to be reasonably in line with the investment needs. Nowadays there is a huge momentum towards the achievement of the Green Deal climate targets; in addition to that, most of the decarbonisation technologies are in the final levels of the TRL ranking (from 6 to 8 and higher). Therefore, the crucial step forward will be to keep on ensuring adequate support, considering that in order to reach the industrial deployment phase much higher investments are needed. More on this can be found in the GREENSTEEL reports on Investment needs (De Santis, et al., 2021) and funding (Gimondo, et al., 2021).

The filled-in forms are reported in the Annex as Tables (Table 9, Table 10, Table 11).

The questions covered general aspects of the projects(s) and of the funding programmes used (type, blending/sequencing, etc.), together with some questions on the financial support and, in particular, on issues such as:

- rationale: why were those specific funding programmes chosen (were they easier to get, most familiar, most appropriate in terms of type and amount…)?
- key role: did the institutional funding support scheme play a key role in the decision to take up the development of new decarbonisation technologies?
- most relevant goal(s) achieved;
- envisaged step(s) forward: are stakeholders considering going ahead on their project(s) based on institutional funding?
- adequateness of funding programme(s): are the current funding opportunities appropriate for the envisaged next steps? and
- current funding 'offer': are stakeholders considering using other private funding for the next steps?

The first success story (details in Table 9) refers to the experience of a technology provider (Tenova). The targeted and strategic funding support used allowed the company to develop technologies specific to a production step (hot rolling mill) aimed at reducing CO_2 emission in a 'smart carbon usage' pathway scenario. It also allowed the company to improve the technology, starting from TRL 4 and ending at TRL 9. The funding programmes used were both at EU (RFCS) and national level (from the Italian Ministry of Industrial Development), with grants accounting for 60% in the RFCS projects and 38% for the Italian programme.

Apart from the advantage of working in an end-user network and favouring the development from plant suppliers up to deployment, the project's use of institutional funding was reported to reduce the risk of applying new technologies and materials. Moreover, next steps are foreseen to further develop the technology at large scale demonstration, but, due to the much higher costs foreseen, it is envisaged that other funding schemes too will be used, such as the Innovation Fund and IPCEI.

The second success story (details in Table 10) refers to the Austrian experience in the SuSteel project, involving the HPSR technology in a carbon direct avoidance pathway frame. The technology reached the pilot scale level thanks to the collaboration between a technology provider, a steel producer and a University with very sound reputation in the steelmaking R&D scenario. The financial engine is national, i.e. the Austrian research promotion agency[5], which is also used as an example of funding sequencing in the already started follow up project.

The third success story refers to the Swedish Hybrit project (see also Table 11), where a totally industrial and heterogeneous consortium (SSAB, LKAB and Vattenfall) has been created. The related technology is the H_2-DR-EAF route and the achievement of a TRL 9 is envisaged within 2030. Concerning how the funding is organised, 40% of funding comes from the Swedish Energy Agency, and the rest comes from three private companies: SSAB, LKAB and Vattenfall (20% from each partner). Apart from the skills each company brings into play, the success is also favoured by the fact that such technological development is a strong priority at national level. Another key factor is the effort made by industries. Indeed, the project is generally considered to be an example of a virtuous combination between the industrial commitment to a climate-neutral industrial steel production and the effort made by national entities to favour such 'green' transition – as requested by the Green Deal Strategy.

These examples provided by the stakeholders are not exhaustive, but they can give a picture of the potential success the synergy among Institutions and stakeholders can bring in achieving the Green Deal targets.

[5] Förderagentur für die unternehmensnahe Forschung und Entwicklung in Österreich (FFG).

5 Concluding remarks

This report showed the findings from the scoping questionnaires and the in-depth consultations. The former was focussed on the main steel producers, covering more than 80% of European CO_2 emissions, while the latter provided with more details. Moreover, the scoping questionnaires were a rich source of information for the investment needs report in the frame of this project.

The main outcomes from the scoping questionnaires are the following:

- the level of technical readiness of the decarbonisation technologies is assessed to be around TRL 5-7. Therefore, it is paramount to start closing the technology gap towards demonstration level right now;
- this step forward is expected to generate major costs, calling for significant public support to cover investment needs. As highlighted in Section 3, for the period 2030-2050 the investment costs for deployment at industrial level can allegedly reach an order of magnitude of 4-5 billion Euros and a CAPEX increase that in some cases can reach 100%;
- correspondingly, stakeholders clearly deem financial obstacles to be the most severe barriers hindering decarbonisation. They are assessed with ratings between “relevant to a high extent” and “relevant to the fullest extent”;
- high financial barriers are in particular linked to increases in CAPEX and OPEX and to the unknown market conditions for clean steel, given strong competition on the global steel markets;
- the stakeholders’ replies concerning funding opportunities show that they already are quite highly aware of the available funding programmes. The most important ones are national programmes and EU programmes (covering 75% of the replies);
- from the stakeholders’ replies on issues related to the blending and sequencing of funding programmes, it can be concluded that a great margin of improvement exists in order to make blending and sequencing of funding programmes more effective; and
- the most important barriers in funding mentioned in the questionnaires were the high administrative costs and confidentiality issues. This is highly relevant as innovation in breakthrough technologies at high TRLs risks to fail without an appropriate innovation framework.

From the in-depth interviews, the main outcomes were the following:

- the most relevant financial framework condition to be tackled to deploy decarbonisation technologies up to the industrial level is the expected increase in OPEX related to energy/renewable energy use;
- the most relevant concern regarding the market scenario is the competition with non-EU (especially Asian) producers. Institutional ‘protective’ support is needed, as well as significant funding support, to cope with the expected strong investment needs;

- concerning the existing funding opportunities, the feedback is generally positive – even if, in some cases, bureaucracy concerns are raised. This happens not only at EU level but also at local (national, regional) one, and is true also for technology providers;
- concerning the weaknesses of the existing funding opportunities, stakeholders expressed their wish for wider blending and/or sequencing opportunities. Moreover, the only financial support for industrial scale equipment via depreciation is considered to be too weak. The current range of funding opportunities is, so far, considered to be not fitted to the real investment needs, especially in enhancing the TRL from 6 (technology demonstration in industrially relevant environment) to 8 (pre-deployment); and
- concerning 'success stories' in projects with funding support at Institutional (from EU to local) level, examples were given referring to well-known breakthrough developments of technologies. In addition, funding programmes play a key role in 'climbing' the TRL steps up to industrial deployment.

The overall feedback is that Institutional funding at any level is going to be decisive in allowing all the players to carry out all the steps needed to achieve the carbon-neutral objectives for the steel production scenario. To this end, there are great expectations for the scenario opened by the Clean Steel Partnership as it is considered to be a very adequate instrument to support carbon-neutral steel producers and technology players to master the transformation challenge.

6 Bibliography

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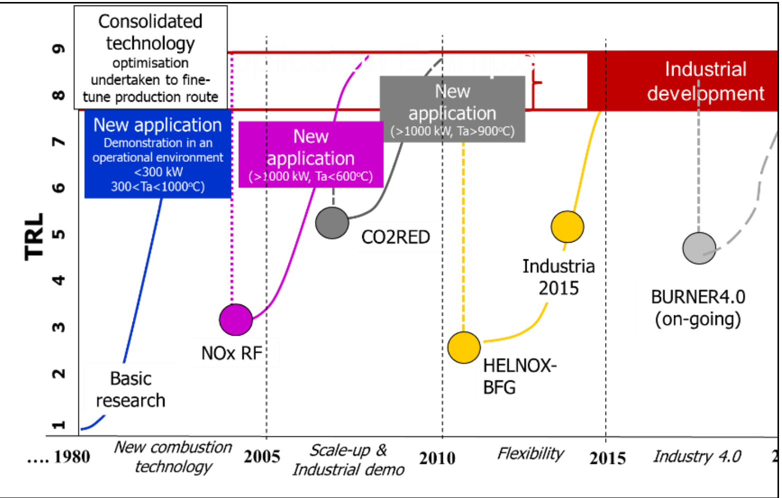
Annex

Table 9: Example of 'success stories'. The Tenova experience

SUCCESS STORIES – TEMPLATE – CO_2 reduction in hot rolling mills	
1. Country/Project	Europe ***NOxRF - Minimising NOx emissions from reheating furnaces (2003-07)*** - *RFSR-CT-2003-00005:* test of combustion systems after numerical modelling (single burner) ***CO_2RED - CO_2 reduction in reheating furnaces (2006-10)***- *RFSR-CT-2006-00008:* reduction of CO_2 emissions by regenerative and oxy-fuel burners after complete furnace modelling ***HELNO$_X$-BFG* - High Efficiency Low NOx BFG Based Combustion Systems in Steel Reheating Furnaces *(2012-16*)** - RFSR-CT-2012-00010: combustion system for an efficient utilization of blast furnace gas and fuel preheating (gas-gas heat exchangers or regenerators) Italy In parallel to EU projects, a national-funded, environmentally-friendly dedicated programme[6] was implemented. The funding entity was the Italian Ministry of Industrial Development (MISE).
2. Was there a Consortium or Leader (optional)?	The three EU projects had a common core partnership composed by: - AGA Aktiebolag (SE) - Arcelor Mittal España AS (ES) - Tenova S.p.A. (IT) - VDEH – Betriebsforschungsinstitut GMBH-BFI (DE) - Centro Sviluppo Materiali S.p.A. (currently Rina-CSM) (IT) - formerly Mefos AB, now SWERIM (SE)
3. Which decarbonisation technologies or pathways were involved?	Recuperative and regenerative (TENOVA) / oxy fuels (AGA) combustion system Smart Carbon Usage
4. Which TRL step forward has been achieved? (from…to)	From 4 to 9

[6] Industria 2015- Efficienza "Integrazione della Tecnologia MILD in sistemi innovativi di combustione a basso impatto ambientale", http://www.irc.cnr.it/progetti/nazionali/conclusi

	
5. What types of funding have been used?	EU RFCS. National fund from the Italian Ministry of Industrial Development (MISE). Both programmes include grants.
6. Have you used any form of blending and/or sequencing? How? (e.g., %,)	Sequence of RFCS projects with 60% grant (R&D projects), blended with national funding from the Italian Ministry of Industrial Development (grant 38%) and TENOVA internal resources for final industrialization and development of the complete portfolio of combustion systems.
7. Why have you chosen these funding programme(s)? (easier to access, most familiar, most appropriate in terms of type and amount…)	It was the most appropriate in terms of type, as it consisted in R&D funds dedicated to the steel sector, and also amount, due to the focus on component's development (burners) and industrial scale pilot testing. In addition, the RFCS programme has a clear structure for the submission of the project proposals and certainty of approval and starting times.
8. Did the institutional funding support scheme play a key role in the decision to take up the development of new decarbonisation technologies?	The institutional funding reduced the risk of applying a new combustion technology (low NOx flameless combustion) and materials (ceramic heat exchangers). Moreover, the nature of the collaboration and partnership with the end user of the technologies and RTOs sped up the development from plant suppliers (TENOVA and AGA).
9. Which have been the most relevant goals achieved?	Furnace efficiency increased by 10-15% compared to the state of the art at the beginning of the projects. Reduction in NOx emissions by one order of magnitude compared to the technology's state of the art at the beginning of the projects (from 200 ppm to 40 ppm @ 3% O_2 with a furnace temperature of 1250°C and air temperature >500°C) and possibility to couple high temperature air preheating (or air enrichment with oxygen up to 100%) to improve furnace efficiency without increasing NOx emissions.

	The developed technology has been progressively introduced in the product portfolio of TENOVA with the trade-mark of Flexytech® as Low NOX flame/flameless highly efficient burners family as lateral and roof burners. After the development of the technology carried out in the above mentioned R&D projects, and as a confirmation of the successful results achieved, more than 2500 burners of the Flexytech® family have been equipped the in the furnaces sold by Tenova worldwide.
10. Are you considering going ahead on this project(s) based on institutional funding support schemes?	Presently, a project is running with institutional funding support schemes in the framework of RFCS named ***BURNER 4.0 - Development of a new burner concept: Industry 4.0 technologies applied to the best available combustion system for the Steel Industry*** - RFCS-02-2018. The aim is to go beyond the current technological limitations of combustion systems in different areas (design, manufacturing, control & process optimization, operating life & maintenance) through the combined application of Industry 4.0 technologies. Besides, according to Tenova, the inherent flexibility of the flameless combustion technology developed in the steel sector has a great potential in speeding up the carbon direct avoidance pathway envisioned in the Clean Steel Partnership Strategic Research Agenda, as it has already proven for the combustion of hydrogen rich by-product gaseous. Therefore, collaborative projects in this combustion area are needed to transform the entire steelmaking process from the liquid production process (upstream) to the rolling and finishing line (downstream).
11. Are the current funding opportunities appropriate for the envisaged next steps?	Both process steps, upstream & downstream, need to be carried out through a stepwise adaptation or replacement of present technologies. For example, the installation of efficient electrolyser plants, gas distribution networks and sophisticated logistics are needed to reach a competitive cost of steel production based on hydrogen and the carbon neutrality goal fixed by the European Green Deal. R&D funding (RFCS, Horizon Europe) are appropriate for the component's development (testing and modelling of combustion systems) and industrial pilots (i.e. the installation of some burners on industrial furnaces for prolonged testing, eventually integrated with small size on-site hydrogen production). This step is necessary to verify the technology itself both at component level (i.e. electrolyser stack optimisation, extension of the combustion capability at multi-

	fuel operation), and at system level, to develop a modular approach and to reduce the risks entailed by scaling up. Due to the current higher cost of hydrogen compared to fossil fuels, the first industrial deployment of the technology as large scale demonstration requires, in addition to CAPEX, considerable OPEX – that could be covered by other funding schemes such as the Innovation Fund or IPCEI.
12. Are you considering using other private funding initiatives for the next steps?	Tenova is already investing relevant part of its R&D funding in the energy transition, with particular attention to the use of hydrogen produced by RES ('green hydrogen') and is also collaborating in important demo projects for the direct reduced iron (DRI) production, such as Hybrit in Sweden and Salcos (Salzgitter) in Germany. The Techint Group (to which Tenova belongs) is also carrying out an on-going project on the decarbonisation of the hot rolling mill area. The goal is to investigate the integration at industrial scale of enabling technologies for green hydrogen production and combustion. The installation of a 0.5MW electrolyser allows for the generation of the hydrogen to be used in a single 200kW$_{th}$ burner at the furnace in TenarisDalmine site. This is part of the more general decarbonisation pathway for project proposals for the Innovation Fund in the framework of liquid steel production and in the IPCEI framework to integrate the two production steps.

Table 10: Example of 'success stories'. The voestalpine/K1-MET experience

SUCCESS STORIES – TEMPLATE - SuSteel	
1. Country/Project	Austria / SuSteel
2. Was there a Consortium or Leader (optional)?	Montanuniversität Leoben (coordinator), voestalpine and K1-MET.
3. Which decarbonisation technologies or pathways were involved?	CDA (HPSR).
4. Which TRL step forward has been achieved? (from…to)	Reactor scale up (pilot scale) with about 90kg melt capability (within the project duration 01.09.2016 to 29.02.2020).
5. What types of funding have been used?	National funding: FFG (the Austrian research promotion Agency).
6. Have you used any form of	Sequencing: Follow up project already started (same

blending and/or sequencing? How? (e.g., %,)	funding programme).
7. Why have you chosen these funding programme(s)? (easier to access, most familiar, most appropriate in terms of type and amount…)	Most familiar.
8. Did the institutional funding support scheme play a key role in the decision to take up the development of new decarbonisation technologies?	Yes.
9. Which have been the most relevant goals achieved?	Construction of an experimental plant (testing facility) and implementation of test campaigns.
10. Are you considering going ahead on this project(s) based on institutional funding support schemes?	Follow up already started.
11. Are the current funding opportunities appropriate for the envisaged next steps?	Yes.
12. Are you considering using other private funding initiatives for the next steps?	Yes.

Table 11: Example of 'success stories. The Swedish experience (Hybrit project.

SUCCESS STORIES – TEMPLATE - Hybrit	
1. Country/Project	Sweden/HYBRIT
2. Was there a Consortium or Leader (optional)?	SSAB, LKAB and Vattenfall (HYBRIT company).
3. Which decarbonisation technologies or pathways were involved?	H_2-DR-EAF technology route.
4. Which TRL step forward has been achieved? (from…to)	TRL will become 9 in 2030.
5. What types of funding have been used?	National funding and own investments.

6. Have you used any form of blending and/or sequencing? How? (e.g., %,)	40% of funding support is from Swedish Energy Agency, and the rest comes from three private companies (SSAB, LKAB and Vattenfall, 20% from each partner).
7. Why have you chosen these funding programme(s)? (easier to access, most familiar, most appropriate in terms of type and amount…)	It is quite natural to start the project in such way which is financed by both the government and the industry.
8. Did the institutional funding support scheme play a key role in the decision to take up the development of new decarbonisation technologies?	Yes. It shows that the project activity is highly prioritized at national level, followed by the engagement from the industries.
9. Which have been the most relevant goals achieved?	Running Hybrit pilot plant.
10. Are you considering going ahead on this project(s) based on institutional funding support schemes?	Yes, for Hybrit in general we will go ahead.
11. Are the current funding opportunities appropriate for the envisaged next steps?	Yes.
12. Are you considering using other private funding initiatives for the next steps?	Yes, we will make use of financing supports from companies involved in Hybrit.