CLIMATE CHANGE
06/2018

The Innovation Fund: How can it support low-carbon industry in Europe?

Design recommendations for the successor instrument to the NER 300 in Phase 4 of the EU ETS

Working Paper

For our Environment

Umwelt Bundesamt

CLIMATE CHANGE 06/2018

Environmental Research of the
Federal Ministry for the
Environment, Nature Conservation,
Building and Nuclear Safety

Project No. (FKZ) 3715 42 5010

The Innovation Fund: How can it support low-carbon industry in Europe?

Design recommendations for the successor instrument to the NER 300 in Phase 4 of the EU ETS

Working Paper arising from project no. (FKZ) 3715 42 5010

by

Matthias Duwe, Robert Ostwald
Ecologic Institute, Berlin

On behalf of the German Environment Agency

Imprint

Publisher:
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
info@umweltbundesamt.de
Internet: www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt

Study performed by:
Ecologic Institute
Pfalzburger Strasse 43/44
10717 Berlin

Study completed in:
November 2017

Edited by:
Section E 2.3 Economic Aspects of Emissions Trading, Monitoring, Evaluation
Frank Gagelmann, Alexandra Zirkel

Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4359

Dessau-Roßlau, February 2018

The project underlying this report was financed by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear safety under project number FKZ 3715 42 5010. The responsibility for the content of this publication lies with the author(s).

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BAT	Best Available Technology
BF	Blast Furnace
BOF	Basic Oxygen Furnace
Capex	Capital expenditure
CC	Carbon Capture
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CEPI	Confederation of European Paper Industries
CEF	Connecting Europe Facility
CHP	Combined Heat and Power
CO	Carbon oxide
CO_2	Carbon dioxide
DRF	Direct Reduction Furnace
DRI	Direct-Reduced Iron
EAF	Electric Arc Furnace
ECRA	European Cement Research Academy
EDP	Energy Demo Projects
ETS	Emission Trading System
EU	European Union
EUA	EU Allowance
HLG	High Level Group
IF	Innovation Fund
KETs	Key Enabling Technologies
MF	Modernisation Fund
MS	Member States
NER	New Entrance Reserve
PCI	Project of Common Interest
R&D	Research and Development
R&D&I	Research, Development and Innovation
RES	Renewable Energy Sources
TRL	Technology Readiness Level
UK	United Kingdom
ULCOS	Ultra-Low Carbon CO_2 Steelmaking
USA	United States of America

Executive summary

This report analyses a range of options for designing the EU Innovation Fund (IF), a financing instrument created under the EU Emissions Trading System (ETS) to support technological breakthrough for low-carbon innovations in the power sector and industry. The report combines a look at lessons learned from the IF's predecessor mechanism "NER 300" with insights from the respective emission reduction technology options in three key industry sectors (steel, cement, pulp & paper) based on a literature review and interviews: on this basis, the paper concludes with recommendations for the IF's design.

The NER 300 experience: lessons to be learnt on risk reduction and political commitment

Lack of a business case is a fundamental barrier to investment in untested technology. Spending money on such projects creates risk without obvious rewards and can make it difficult to attract financing, which is why companies may be right to look for public support for such initiatives. The design of the NER 300 (which addressed only the energy sector: carbon capture and storage (CCS) and innovative renewable energy technologies) had a variety of shortcomings, including regarding **risk sharing**, as a result of which high risk technology projects (such as CCS) did not materialise. Higher co-financing rates may be one solution going forward, as well as a more nuanced set of conditions for payments. Another shortcoming exists in terms of **political/public support**, the lack of which led to individual projects being withdrawn. It is apparent that more factors than merely access to finance are creating barriers to investments in low-carbon innovation.

Industrial players display an "incumbent's bias", need a pro-business decarbonisation perspective

The **industry perspective** of the opportunities and threats of the decarbonisation challenge is **rather defensive** (especially for steel and cement). The interviews and the industry roadmap documents exhibited a tendency to be pessimistic about novel technologies and various products which would have the potential to bring about a more fundamental change to the traditional way of doing business. This traditional perspective is understandable, but also limits the possibility to see what other alternative futures may be possible, and what one might call the "Elon Musk approach" to industrial manufacturing.

To decarbonise the European economy and maintain a strong industrial base in Europe may, however, require more fundamental changes in the way businesses organise themselves, what products they decide to create to satisfy customer needs as well as a more service-oriented perspective (moving away from a simplified focus on product sales figures) – in addition to a reduction in direct emissions from manufacturing. Allwood (2016) and Wyns and Axelson (2016) point out examples of how such **new visions of a low-carbon business model** could look like, e.g. for the UK steel sector, and the long-term outlook for the pulp & paper sector goes in that direction, restyling itself in the 2050 roadmaps as the "forest fibre industry" (CEPI 2011) that could strive in a bio-economy.

The IF should focus on facilitating breakthrough technologies, not rolling out existing ones

The analysis of the technology options for the three sectors and the perspectives of the existing players shows that currently available technologies in industrial sectors for emissions reductions are largely focused on the existing technology stock and marginal improvements and do not include more novel approaches and new business options. However, the summary report from the European Commission's 2017 consultation process with industry stakeholders (European Commission 2017a) concludes that the IF should include support not just for projects featuring technologies that are at pilot demonstration stage (Technology Readiness Levels (TRLs) 6 to 7), but also those closer to the commercial environment (TRLs 8-9). Directing policy support to such more proven technologies may turn out not to be sufficient to deliver the magnitude of emissions reductions required. Or, if such an approach does achieve the needed mitigation potential, it runs the risk of doing so only in a structurally conservative form that may not be cost-competitive in a low-carbon world (because it centres around marginal improvements to existing facilities). It could also create a new set of risks (such as strong reliance on end-of-pipe capture technology). A focus on more proven technologies could thereby jeopardise the originally stated objective of the IF – to support the development of breakthrough technologies, needed for further substantial CO_2 reductions - **with no other instrument in sight that would fulfil this important function**.

We contend that both breakthrough development and support for market entry are needed, but that the **primary function of the IF must be to help deliver breakthroughs** to enable decarbonisation, and not to focus on marginal gains or more proven technologies. However, there is **potential to do both under the IF**, for example via the use of loans (rather than grants) to more mature technology projects (which would mean the money is paid back over time – and thus not diverted away from breakthrough financing). Qualitative and quantitative restrictions should be applied to such funding for technologies closer to the market, to ensure that the most value added is created in terms of emissions reductions.

Mind the policy gap – additional support is needed to bridge the gap between the IF and the ETS

The debate on the focus of the IF's financing highlights that additional measures may be required to help some of the technologies emerge from the "valley of death" of technological innovation and help them cross from demonstration level to market entry. Existing policies such as the EU ETS are most adept at driving technology deployment between options with a low-cost differential and thus play a role mainly further down the technology deployment curve. In the context of the debate about the impacts of climate policy on the competitive position of European industry and possible carbon leakage, the Fund itself must be seen in an **integrated perspective for a low-carbon industrial policy**. The existing regulatory landscape must be corrected for its occasional bias in favour of carbon-intensive incumbents and the focus on existing products and processes, and complemented to create an environment that truly incentivises investment in innovative low-carbon technology, both in development and later deployment. Without a long-term perspective for how to make a business case for low-carbon industrial production, the IF in itself cannot succeed.

Bringing such a change about requires both a **commitment from political decision-makers** as well as a change in perspective across industrial sectors and closer sector integration, in order to arrive at new ways of doing business and give assurance to innovators that they will be rewarded. The upcoming decisions on the design parameters of the Innovation Fund need to be seen in this general spirit and be shaped to fit with a new perspective, one that is serious about realising a future for industry in a low-carbon world.

Specific recommendations for future design of the Innovation Fund[1]

On the basis of the considerations summarised above, the analysis has concluded with the following policy recommendations, focusing on financing conditions and project eligibility.

- Guarantee a minimum amount of funding for the IF as a whole.
- Provide higher co-financing rates for high-risk projects and for small ones.

1 These recommendations need to be seen in the following context: the underlying research was limited in terms of the level of detail it was able to consider (e.g. a limited set of industrial sectors, limited number of dedicated expert interviews) and, in some instances, the conclusions are not unequivocal in the case of e.g. static vs. dynamic choice of eligible technologies.

- Avoid reliance on strict performance-based criteria as payment conditions; use milestones.
- Establish maximum funding per project as absolute amounts.
- Focus on breakthrough technologies for the eligibility of projects and provide funding for technologies that are already closer to market introduction via loans instead of grants (and with a limited share of the IF's volume).
- Earmark minimum shares of funding per main category (CCS, industry, renewables) but be flexible about them if unused.
- Set ambitious criteria for selection of projects (specific to each main category), addressing inter alia the emission reduction potential. These could be combined with criteria that take into account possible long-term business opportunities, to increase the likelihood that the technology is indeed commercialised after the successful demonstration project.
- Build in incentives to support product substitution innovations.

Table 1: Overview of recommendations for the design of the Innovation Fund per element

	Design Elements	Recommended design
Financing conditions	Total budget of the IF	Set minimum amount floor, with mechanism to guarantee it in case the monetising of the 450 million EUAs is not sufficient
	Co-financing rate	Provide higher co-financing rates for high-risk projects and smaller projects
	Conditionality	Avoid strict performance-based criteria as conditions for payment, use milestones (in combination with mitigation performance)
	Allocation of funds per project	Establish maximum funding per project as absolute amounts
Project eligibility	Eligibility criteria for projects	Focus on breakthrough technologies for the eligibility of projects – potential to support more "market-ready" technologies with other financial instruments
	Category specific quotas	Specific minimum quotas per category to ensure that non-CCS industrial projects, as well as small projects, will be able to receive funding (with spill over possibility)
	Technology	Set ambitious emission reduction based thresholds for selection of projects underneath the main technology categories - but combine with criteria measuring co-benefits that hint at business opportunities (where possible). Install a dedicated incentive for low-carbon substitutes
Additional points	Start and end dates	Flexibility to synchronise with investment cycles
	Facilitate collaboration	Encourage collaboration inside and across sectors through more favourable conditions for integrated consortia

1 Funding innovation with ETS revenues

In July 2015, the European Commission (hereafter "the Commission") presented its proposal for the fourth trading period (2021 - 2030) of the EU emission trading system (EU ETS) (European Commission 2015a). With the Innovation Fund (IF) and the Modernisation Fund (MF), the legislative proposal includes two instruments additional to the carbon pricing element of the EU ETS that aim to support the shift of the EU's power and industry sectors towards a low-carbon economy. Implementing the European Council conclusions on the EU's 2030 energy and climate policy from October 2014 (European Council 2014; p. 3), the Commission proposes that the IF shall support demonstration projects of innovative technologies in the fields of carbon capture and storage (CCS), renewables and – in contrast to its predecessor, the so-called NER 300 – for the first time also low-carbon technologies and processes in industrial sectors. The European Parliament has backed this idea in a resolution on industrial development (European Parliament 2015; p. 8). By early 2017, both institutions adopted their respective position on the legislative proposal of the Commission and subsequently opened inter-institutional negotiations to reach an agreement – a process still ongoing at the time of writing. It can be expected that the negotiations will come to a close by the end of the year (European Parliament 2017, Council of the European Union 2017; pp. 24).

In addition to the EU institutions, stakeholders from European industrial sectors have signalled support for the IF – as evidenced by their answers to a public consultation on the ETS reform that the Commission had opened in 2015. The results of the consultation were published in early 2016 and show that most stakeholders are in favour of making innovative industrial projects eligible for funding under the IF. Stakeholders also welcomed higher co-financing rates, as proposed by the Commission in its legislative proposal (European Commission 2016; p. 3). Between January and June 2017, the Commission has carried out a consultation on the design of the IF to stakeholders and organised additional events on more concrete questions related to the design of the IF with stakeholders from various industrial sectors (European Commission 2017a).

Although the negotiations about the features of the IF have begun via the ETS Directive, the final form will be settled in a separate format, via a decision of the European Commission, which is still under development. The decision will establish the main design features, which will determine whether the IF can successfully attract private companies to invest in and implement innovative demonstration projects in the EU. This question is highly relevant for the energy-intensive industry in Europe. European industry representatives contend that their competitive position has come under considerable pressure from producers in developing countries that compete with them on the global market (see, for example, Gabrizova and Dupáková 2015). In the context of the EU ETS, they warn of an increasing potential for "carbon leakage", with industrial production capacity moving out of Europe to places without or with lower carbon prices. The question can thus be extended to whether the IF can help secure the competitiveness of the European industries, but in a climate-friendly manner.

This report aims to address these issues, by looking at the following questions:

- In what respect should the IF differ from its predecessor, the NER 300?
- Which low-carbon technologies for industrial processes should receive funding under the IF?
- Is a "one size fits all" approach suitable for all industrial sectors or should the rules allow for differentiation?

To answer these questions, this report is structured as follows:

Chapter 2 discusses the context of support for industrial innovations in the EU and then analyses whether public support for investments and/or innovation implies trade-offs or synergies.

Chapter 3 provides a list of key features for the design of the IF and an overview of the existing provisions for the NER 300. Subsequently, the existing scientific literature on the NER 300 is reviewed to establish what lessons from its experience can be drawn from its implementation so far. This allows for an identification of the shortcomings of the existing framework.

Chapter 4 provides information on the characteristics of three energy-intensive industrial sectors and their innovation potential (for mitigation options specific to their processes and products) and explores to what extent these specific features could and should inform the design of key features of the IF. The chapter relies on recent literature on innovation and decarbonisation options and incorporates insights gained from interviews with experts from different industrial sectors, including iron and steel, cement, and pulp and paper industry.

Finally, chapter 5 of the report is based on the knowledge gained from the previous chapters and presents recommendations for the design of the IF.

2 The policy landscape for climate friendly innovation in Europe's industrial sectors

Recent assessments on potential emission pathways for halting global climate change to an increase of maximum 1.5°C compared to preindustrial levels (as per the Paris Agreement) indicate that global emission of CO_2 from electricity and industrial production will need to reach zero by 2050 if the goal is to stay within reach (Rogelj 2015), implying an even faster trajectory for Europe. The EU is still in the process of developing its post-2020 policy framework, which should facilitate the transformation towards such a low-carbon economy (Oberthür 2016; p. 3). While significant advances have been made in emissions reductions from the power sector, due to progress in the deployment and further development of renewable energy technology, the solutions for decarbonising manufacturing are less prominently visible. How can low-carbon industry technology be advanced, and what policies are best suited for the task?

In EU climate policy, the main instrument addressing greenhouse gas emissions from industrial sectors is the EU ETS. However, the current design of the system dims the potential effect of the carbon price signal because of a low price induced by structural oversupply and continued free allocation. Irrespective of the current shortcomings of the EU ETS, research conducted by a range of different academic and governmental institutions in recent years has questioned the general suitability of a trading system alone to facilitate the development of fundamentally new technologies and finds it better suited to helping optimise the use of competing technologies that are not far apart in terms of economic viability (see among others Görlach (2014), Grubb et al (2013)). While some evidence exists (e.g. from the power sector (Rogge 2010, 2011)) that the EU ETS has influenced corporate research and development (R&D), the European Commission itself has started questioning its effectiveness as a sole driver for innovation, stating that the "ETS by itself may be insufficient to drive investment in R&D and trigger pre-commercial demonstration phase of new low-carbon technologies" (European Commission 2015b; p. 55). Additional measures may thus be required to fully realise the ETS's impact on low-carbon innovation.

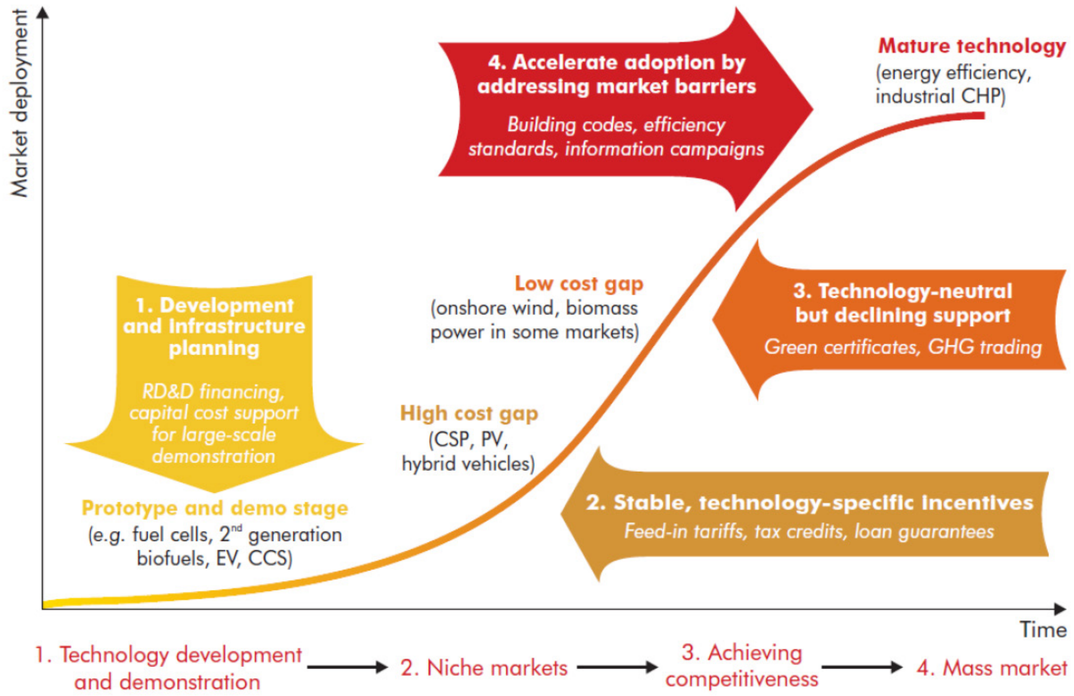
The key take-away message for the context of industrial innovation is that different policy instruments are better suited for overcoming certain stages of technology development. This understanding is also illustrated by Figure 1, taken from a 2011 IEA report on the effective combination of different policy instruments. Market-based policies such as cap-and-trade systems are seen to be well suited to support deployment of established technologies (Stage 3) – whereas the initial development stage requires, for example, financing.

This perspective is emphasised through the findings of economist Mariana Mazzucato (2014) on the historical developments leading to key technological breakthroughs. Her findings underline the fundamentally important role of the state in facilitating such advances.

These analyses thus combine to form a strong argument in favour of using an instrument like the IF to foster low-carbon technology development, especially helping promising technologies to prove themselves in a demonstration environment that can make them become potentially viable candidates for future deployment in real production environments.

However, the recent work on the specific suitability of different policy instruments, which has, among other fields of study, looked at the successful cost reductions in renewable energy technology over the past decade, points to a potential gap between the demonstration stage of new technologies (where for the latter the Innovation Fund may be suitable) and the wide-spread diffusion/ "mass market" (where the EU ETS may be supportive). Again, Figure 1 illustrates this issue, indicating the need for "stable, technology-specific incentives" to help bridge the "high cost gap" that proven technologies often experience as a key barrier to market entry before a wide-spread deployment helps reach economies of scale and a decline in prices.

Figure 1: Policy support appropriate to different stages in technology development



Source: Hood (2011; p. 29).

Additional instruments may thus indeed be required to connect the IF's push and the ETS' pull factor. Having this perspective of a potential "policy gap" in the EU policy landscape for the decarbonisation of industrial sectors in mind may help understand what the potential role of the IF can be, and what its likely limitations are. This perspective will support the analysis of the potential design elements of the Fund and helps identifying suitable choices for the specific context of industrial emissions reduction options.

3 Designing an effective Innovation Fund

This chapter moves from the general considerations on how to spur industrial innovation in Europe towards considerations on how the IF should be best-designed to contribute to this objective. It looks at the various options for influencing the design of the IF and discusses the ways in which their use affects the working of the Fund. This metric is then applied to present the design options chosen for the NER 300 as the current predecessor of the IF. Lastly, the chapter looks at the results of the NER 300 and lessons that can be drawn from the achievements and outputs of the process so far.

3.1 Key elements for Fund design

This section presents a list of key design elements that can be taken into consideration for the design of the IF. For each element a number of implementation options is possible.

Table 2 presents an overview of the key individual elements and groups them.

Table 2: Main design elements for the Innovation Fund

Element grouping	Individual element
Financing conditions	Total budget of the IF
	Financial instrument types
	Co-financing rate (rate provided by the Fund)
	Upfront funding
	Conditionality
	Allocation of funds per project
Project eligibility	Selection process
	Eligibility criteria for projects
	Technologies eligible for funding
Administrative aspects	Management structure of the fund
	Timing and frequency of call announcements
	Geographical distribution and balance

Source: own compilation.

Below, we describe ways in which the respective options influence the Fund's ability to create an impact.

Financing conditions

- **Total budget of the IF:** The budget of the Fund defines how much support for projects is available – the higher the budget the more funding can be disbursed. The total volume is currently expressed in the form of millions of EU allowances (EUAs) available for auction. The revenues resulting from the auctioning of these EUAs define the actual amount of money available for financing projects. This creates an inherent uncertainty over the actual budget available for disbursement, because the market carbon price fluctuates. One problem resulting from this uncertainty is that if the carbon price realised in the auctions continues to stay low, the total budget of the Fund may fall short of expectations (as experienced under the NER 300), reducing the number of projects that can be supported. Two options are available to decrease the uncertainty of the size of the overall available budget: 1) adjusting (increasing or reducing) the number of EUAs available for auctioning in order to provide stable revenues and 2) alternatively expressing the funding directly in Euros and building in a maximum or a minimum amount available (this would provide higher certainty on the number of projects which may expect to receive funding and would enhance planning security for potential investors).

- **Financial instruments:** The financial support made available under the Fund can be disbursed in different ways. Classical instruments include 1) grants (the money is paid out to the project operator – without having to be returned), 2) loans (lending money under certain conditions – to be paid back at a later date) and 3) loan guarantees (meaning the provision of a guarantee to cover risks of failure – assuring banks to make a loan available for a specific project). Different options exist for the use of grants (such as equity participation). Combinations of the different instruments are possible (e.g. partial grants with loan guarantees). The difference for both the Fund and the project backers are straightforward – only the grants (and loan guarantees in case of failure) imply an actual expenditure from the Fund's resources, whereas loans are only a temporary payment and require the project investors to cover the expenditure eventually. Higher risk projects would thus be likely to be in need of grants (and possibly loan guarantees for bank loans), whereas loans could be appropriate for projects with low risk and higher likelihood of economic returns being generated.
- **Co-financing rate:** meaning the rate of funding that is provided by the Fund (as a grant) as a contribution to the overall financing required. The higher the co-financing rate the less funding the project developer needs to bring to the table. A high rate could help to get projects that are less economical / further from market maturity (= carry a higher risk) off the ground. The low level of own finance required by companies in those instances could, however, also imply a low commitment to the success of the project. Projects that are viable with only low co-financing rates on the other hand could be indicative of situations where additional funding may not have been necessary in the first place. In such a case, financial instruments other than grants are more suitable.
- **Allocation of funds per project:** an allocation limit restricts the funding that a project can receive out of the total budget of the fund. The higher the limit, the more funds can be distributed to a project. Thus, a high limit could possibly lead to funding being provided to only a few large projects, whereas a low limit could spread the funds to a larger number of projects.
- **Upfront funding:** The timing of a payment can make a difference for many business transactions and this also applies here. Upfront funding allows projects to receive funds at the start of the project, before actual results about their performance are available. If upfront funding is not implemented, projects may only receive financial support once they have reached certain milestones or results (see Conditionality below). Having access to upfront funding can make certain projects easier to start (largely a matter of liquidity), depending on what other means of financing are available to the investors concerned. Upfront funding may be made available for only parts of the overall sum and not the total amount.
- **Conditionality:** the use of conditionality links the disbursement of funds awarded to the performance of projects and not simply to the start and end date of a project. This can be done in several ways: a) simple project management conditionality (project receives funding if operation is proceeding largely as planned) or b) performance related conditionality (in which a project only receives funding if a goal (e.g. CO_2 avoidance) is realised) or c) a dynamic performance reward. In the latter case the disbursement of funds could be higher the more successful the project is, e.g. the more CO_2 is stored or the more electricity is generated in a certain time interval (e.g. one year). This could create an incentive for high performance, but could also lead to manipulation in the application phase (underestimation of likely performance to lower benchmarks). Creating a performance conditionality (b) would mean that a project may not receive funding if the targeted technology fails. This approach creates a high risk for projects with less proven technologies and establishes a disincentive for highly innovative projects. Combinations of different types of conditions are possible (for example a and b).

Project eligibility

- **Selection process:** The implementation of a programme like the IF that needs to award funding requires a clear selection procedure. A sound selection procedure needs to define the process to be followed and the institutions involved (and their respective mandates and responsibilities), but it also needs to establish how applications for funding will be evaluated and selected. For this purpose, the process itself will require criteria on the basis of which applications can be distinguished (see below). Since too many possible ways of designing the procedure and the respective organisational setup exist, these are not further explored here.
- **Eligibility criteria for projects:** a broad or narrow definition of eligibility criteria can increase / decrease the type of projects that can receive financial support from the Fund. A narrow definition can restrict funding to a small number of projects (which may also limit the effect to a small list of possible innovation advances). A broad definition would increase the likely list of eligible projects and applications. Eligibility criteria would certainly include the technologies eligible (see below), but could also include additional considerations, such as: a) size and duration of the project, b) financial and technical credibility of the main operating company c) likely impact in terms of creating an innovation breakthrough (operating conditions, proximity to market operations), d) financing requirements (overall request, total project size and financing from other sources), etc. The respective choices will influence the types of projects being selected and thus determine the Fund's overall impact on innovation.
- **Technologies eligible for funding:** A key element to decide for the IF will be whether and how it specifies what types of technologies may be funded. The two main options for expressing this choice are 1) static, technology specific and 2), dynamic, technology neutral. The former may use a set of criteria to take this decision (such as technology readiness, CO_2 reduction potential, etc.) but could simply spell out a list of technologies; the latter must be criteria based, as it applies them on an ongoing basis. The choice of criteria being applied in either option will influence where the Fund seeks to create impact (in which stage of the technological development) and whether the Fund focuses support on breakthroughs for high mitigation potential technologies over more incremental improvements. Choosing low threshold criteria (which would create a long list of eligible technologies) leaves more choice to the sectors and companies involved, but may create a less targeted impact. An explicit means of implementing a technology-specific approach on a more general level would be the establishment of quotas for certain technology types (e.g. CCS and renewables and industrial sector projects), defining a share of the total funds for each category. Such earmarking of funding for individual categories could be used to place an emphasis on a certain group of technologies to prioritise their advancement over others. To avoid a situation in which this earmarking leads to inflexibilities in spending, the respective shares could set a minimum and would not need to lead to a fully specified allocation amounting to 100%.

Administrative aspects

- **Management structure of the Fund:** the management structure of the Fund defines the responsibilities of the different institutions involved at the EU and national level with regard to the implementation of the funding programme. Such responsibilities include, among others, issuing calls for proposals, monetising ETS emission allowances, and assessing the technical and financial viability of projects (due diligence assessment). The degree to which EU-level institutions are involved in the structure, and to which the legislation defines the process to be followed and the criteria to be applied, will define the extent to which common standards will be applied to the projects supported by the Fund. A more bottom-up structure, with Member States left to decide significant elements by themselves, would be the alternative – with more ownership by Member States but less certainty on the impact of the Fund.

- **Timing and frequency of call announcements:** a key consideration in terms of impact is the lead time needed for projects to get off the ground and start to show results. The timing of calls can have an impact in this regard and what the limitations for these the Fund would find permissible. More frequent calls could allow projects taking longer to prepare to find a window later in the Fund's operation. Another timing related issue is the creation of the revenues through the auctioning of EUAs – and the prices expected to be realised (as this influences the budget available for the Fund), where a later auction may yield higher prices.
- **Geographical distribution and balance:** As an EU instrument the IF is a priori meant to be benefitting all EU Member States. In terms of impact it is worth considering a balance between the need for an equal distribution with the possible location of desirable projects, which may not be equally spread throughout the EU, but slightly more concentrated in key (industrial) hubs.

Although all of these criteria are vital for the functioning of the IF, **not all of them are equally important for the implementation of industrial projects**. Industrial sector breakthrough technologies may carry a higher risk of failure than those in the power sector, meaning that these technologies are likely to require significant **co-financing** – and strict conditionality may make high-risk projects less attractive. The process chosen to decide which **types of technologies** may receive funding is key for all potential applicants – and has the most direct impact on the innovation effect of the IF. Accordingly, features that influence the "financing conditions" (such as the co-financing rate, choice of financial instrument, conditionality (for the disbursement of funds)) and "technology eligibility" are of particular importance for industrial sector projects. Therefore, the following analysis will focus on these two main design element groupings and will consider additional points, related to "administrative aspects" only insofar as they directly relate to the specific needs of support for technological innovation in industry.

3.2 The design chosen for the NER 300

This section presents the design of the NER 300 (as the IF's predecessor) against the elements presented in section 3.1 above. The legal basis of the NER 300 is the EU ETS Directive (2009/29/EC) and the NER 300 Decision (2010/670/EU). The EU ETS Directive (European Union 2009) defines that projects in the field of CCS and renewable energy sources (RES) are eligible for funding. The NER 300 Decision (European Union 2010) provides a more detailed account of the different technologies that can be funded under the NER 300. It lists four CCS technologies and eight RES, with the latter being further divided into 34 subcategories (see Table 3). The NER 300 thus applied a technology-specific approach.

Before a project could receive funding under the NER 300, it had to undergo a selection process, as defined in Article 5 of the NER 300 Decision. In the first stage of this process the Commission had to publish a call for proposals. Subsequently, the Member States had to assess whether a project meets the eligibility criteria laid out in Article 6 and the Annex of the Commission Decision. If a Member State (or more in the case of trans-boundary projects) supported a project, the Member State had to submit the proposal to the EIB (European Union 2010; pp. 41).

Table 3: Technologies funded under the NER 300

Technology	Subcategories
CCS	Power generation (pre-combustion)
	Power generation (post-combustion)
	Power generation (oxyfuel)
	Industrial applications (refineries, cement kiln, iron and steel production, aluminium production)

Technology	Subcategories
RES	Bioenergy
	Concentrated solar power
	Photovoltaic
	Geothermal
	Wind
	Ocean
	Hydropower
	Distributed Renewable Management (smart grids)

Source: European Union (2010; pp. 45).

According to the rules of the NER 300 Decision, the award choice was made by ranking the projects on the basis of comparing their Cost-Per-Unit Performance (CPUP). CCS demonstration projects are ranked as a single, separate group. The ranking of the RES demonstration projects was conducted within each of the 34 subcategories. To be eligible for funding, projects had to fall under the aforementioned (sub)categories and comply with a number of requirements. According to Art. 6(1)(c). of the NER 300 Decision, RES projects must "be innovative in nature [while] [e]xisting, proven technologies are ineligible".

The CPUP for CCS projects is calculated as follows:

$$\frac{\text{total request for public funding + (estimated) additional benefits resulting from support schemes}}{\text{total projected amount of } CO_2 \text{ stored in the first 10 years of operation}}$$

The CPUP for RES projects is calculated as follows:

$$\frac{\text{total request for public funding + (estimated) additional benefits resulting from support schemes}}{\text{amount of energy produced in the first 5 years of operation}}$$

Before funds were granted, the EIB performed an assessment of the financial and technical viability (financial and technical due diligence) of the proposed projects (Art. 5 and 7). The assessment covered at least seven aspects:

- technical scope;
- costs;
- financing;
- implementation;
- operation;
- environmental impact;
- procurement procedures.

In the final stage of the selection process, the EU Member States had to confirm that sufficient funding was secured for the CCS demonstration projects. At least one, but not more than three projects could be funded within one Member State (Art. 8).

The following table summarises the design options chosen for the NER 300.

Table 4: Design choices in the NER 300

Design Element	Legal reference	Concrete design of the NER 300
Total budget	2009/29/EC, 10a (8); 2010/670/EU, Art. 2 (1)	Determined by the revenues generated via the auctioning of 300 million allowances from the new entrants reserve.
	2009/29/EC, 10a (8)	Co-financing is possible by Member States and other EU instruments.
	2010/670/EU, recital (5)	Budget of the NER 300 is not part of the general budget of the EU and can therefore be combined with financial means from other instruments.
Co-financing rate	2009/29/EC, Art. 10a (8)	Substantial co-financing must be provided by the operator of the installation.
	2010/670/EU, recital (6)	Amounts to 50 % of the relevant costs.
Upfront funding	2010/670/EU, Art. 11 (5)	Funds may be disbursed prior to the entry into operation of a project if Member States issue a guarantee that the funds will be returned to the EIB.
Conditionality	2010/670/EU, Art. 11 (2)	The disbursement depends on the verified avoidance of CO_2 emissions.
	2010/670/EU, Art 12	Knowledge-sharing on an annual basis is required in order to receive funding. Annex II specifies that this includes the following aspects of projects: technical set-up and performance, cost level, project management, environmental impact, health and safety, and CCS storage site performance.
	2010/670/EU, Art. 9	Limit for final investment decisions: 24 months[2].
	2010/670/EU, Art. 11 (1)	Entry into operation of projects: 31 December 2015 for projects from the first funding round and 4 years for projects adopted after 31 December 2011.
	2010/670/EU, Art. 11 (4)	For CCS and RES projects, disbursement of funds is limited to a period of 10 and 5 years respectively, ensuing from the date of entry into operation.
Allocation of funds per project	2009/29/EC; 2010/670/EU, recital (6)	No project shall receive more than 15 % of the total number of allowances available under the NER 300 (equal to 45 million EUA).
Selection process	2010/670/EU, Art. 8 (2)	The projects are selected on the basis of comparing their Cost-Per-Unit Performance (CPUP).
Eligibility criteria for projects	2009/29/EC, 10a (8)	CCS and RES demonstration projects are only supported if they are not yet commercially viable; CCS project must be on a commercial scale in order to receive funding.

2 36 months for CCS demonstration projects, with saline aquifer storage.

Design Element	Legal reference	Concrete design of the NER 300
	2010/670/EU, Art. 6	Projects must be innovative in nature. Existing, proven technologies are ineligible. Projects must meet the project requirements and use technologies specified in Annex I of the decision.
List of (industrial) technologies eligible for funding	2009/29/EC, 10a (8)	A wide range of innovative technologies in the field of CCS and RES.
	2010/670/EU, Annex I	List of CCS and RES project categories with minimum thresholds.
	2010/670/EU, Art. 8	8 CCS projects, 34 RES projects.
	C(2014) 4493 final, recital (8)	Flexibility of shifting funds between categories.
Timing of call announcements	2010/670/EU, Art. 2 (2)	Two calls organized by the Commission (no dates specified).
Geographical distribution and balance	2009/29/EC, 10a (8)	Projects must be geographically well balanced within the territory of the EU.

Source: own compilation based on legal references

3.3 Results and lessons of the NER 300

3.3.1 Outcomes in terms of projects funded

The total budget available under the NER 300 was determined on the basis of the revenue generated through the auctioning of the 300 million allowances, which took place in two steps (first 200 million, then 100 million). The average sales price per EUA was € 7.19. However, the sales prices had dropped from € 8.05 per EUA in the first monetisation round (December 2011-September 2012) to € 5.48 per EUA in the second round (November 2013 – April 2014) (EIB, 2014; p. 1). In total, over EUR 2 billion were generated in this process – and the European Commission estimates that this funding attracted EUR 700 million in other public funding and EUR 2.7 billion from private sources – resulting in a leveraging factor of 1.6.

In 2010, the European Commission launched the first of two calls for proposals for innovative demonstration projects under the NER 300. In this first round, eight CCS projects and 20 renewable energy projects should receive funding from the NER 300. Of the initially 22 CCS project applications that were submitted to the Member States until May 2011, 13 were supported and forwarded by Member States to the EIB for the assessment of their financial and technical viability. Although the CCS projects passed the assessment of the EIB, only one project was finally confirmed by Member States. On the contrary, almost all RES projects were confirmed. The last CCS project (in Florange, France) was finally withdrawn, due to technical problems. Thus, in the first funding round only RES projects were able to secure funds from the NER 300, with a total of € 1.1 billion.

In the second NER 300 funding round, some of the funds (€ 275 million) were earmarked for CCS projects (Lupion and Herzog 2013; pp. 21). In April 2013, the Commission launched a second call for proposals. Thirty-three project proposals were submitted during this round, of which only one was a CCS project. From the initial list, 18 renewable energy projects and the one CCS project were awarded funds from the NER 300 (Ibid.; p. 24). For this second round, € 1.0 billion was made available for the support of demonstration projects under the NER 300. The amount consisted of unspent funds from the first funding round and from the monetisation of the remaining 100 million EUAs (European Commission 2014; p. 3) – see also Table 5.

For a number of reasons, it is not clear how much of the NER 300's funds will remain unspent and thus will potentially be available for the IF. The first reason is project failure. The only CCS project in the UK, which was awarded EUR 300 million during the second funding round, will be closed down. The project website states that "the consortium partners in White Rose have begun the process of winding down the operations of Capture Power Limited with an eventual closing of the business" (Capture Power Limited 2016). This makes EUR 300 million available for other demonstration projects. In 2017, three more projects were officially withdrawn by EU Member States (UPM Stracel, Woodspirit, Gobi-gas phase 2). In total, € 436 million were earmarked for these projects (NER300.com 2017). However, more projects could eventually fail. Projects that received a positive funding decision in the first round of calls had to reach their final investment decision in December 2016. The European Commission has confirmed in May 2017 that 16 projects have reached their final investment decision (Uihlein 2017; p. 3). This includes both projects from the first and the second call. This means that more projects from the first round could be withdrawn and that more funds could be freed up.

Table 5: Overview of NER300 funds for both rounds[3]

NER 300 first funding round			NER 300 second funding round	
Sale of 200 million EUAs (about 20 million EUAs per month between 5 December 2011 – 28 December 2012 with an average sales price of € 8.05 per EUA for a total value of € 1,609,125,460 ~ € 1.6 billion			Sale of 100 million EUAs (about 10 to 20 million EUAs per month between 14 November 2013 – 11 April 2014) with an average sales price of € 5.48 per EUA for a total value of € 547,705,340 ~ € 0.55 billion	
Awarded to projects ~ € 1.1 billion		Unspent funds of the first NER 300 funding round ~ € 0.5 billion	Awarded to projects ~ € 1 billion	
Actually spent and remaining awarded funding as of June 2017 ~ € 0.7 billion	Unspent funds from failed RES projects (info as of June 2017) ~ € 0.436 billion		Remaining awarded funding as of June 2017 ~ € 0.7 billion	Unspent funds likely to be withdrawn from CCS project (info as of June 2017) ~ € 0.3 billion
	To be transferred to EIB's Innovfin EDP and CEF Debt for projects from the first and second call If unspent			Potentially available for the Innovation Fund

Source; own calculations based on EIB, 2014 and NER300.com.

[3] Approximate values – data not fully public.

Among the Member States there was no consent about how to use the unspent funds. During the Council meeting of the environmental ministers in October 2016, the Cyprus delegation "suggested using these unspent funds to provide additional support to projects already awarded funding to help them overcome financing problems" (Council of the European Union 2016; p. 28). Although the idea was at first rejected by some of the Member States (who preferred moving the unspent funds into the IF) (Ibid.; p. 28), Member States present in the Climate Change Committee amended the NER 300 Decision on May 19, 2017 (Lichtenvort and Gagliardi 2017; p. 10) and agreed to transfer the unspent funds to the InnovFin EDP (Energy Demo Projects) Facility and the debt instrument of the Connecting Europe Facility (EDF) that offer loans and loan guarantees to first-of-a-kind demonstration projects. The Climate Committee decided that NER 300 projects that participated in the first and second call and have reached their final investment decision will be eligible for financial support under these financial instruments (European Commission 2017b). In its draft for a council position, the presidency of the Council of the EU proposed that "remaining revenues from the 300 million allowances available in the period 2013-2020 under the Commission Decision 2010/670/EU" should be used under the IF (NER400.com 2017).

3.3.2 Insights from the implementation so far

Drawing lessons from the implementation of the NER 300 is not easy. Relevant information is scarce, as several important sources are not accessible to the public. Accordingly, the existing literature is relatively thin – there are few studies that focus exclusively on the NER 300. The study by Lupion and Herzog (2013) seems to be the most comprehensive one to date. It focuses on the first round of proposals under the NER 300 and analyses the factors that led to the decision of the Commission not to fund any CCS projects. These factors include: lack of flexibility of the legal framework (Lupion and Herzog state that these rules largely remained the same in the second round of calls), the complexity and costs of CCS projects, a low carbon price, and the lack of national funding / commitments (Ibid.; pp. 22). Lupion and Herzog conclude that the "tight specifications in relation to technological and geographical representation have constrained the funding programme implementation, especially relevant for CCS projects" (Ibid.; p. 22). Most of the other studies available cite the work of Lupion and Herzog, and focus more on CCS deployment in general than on the NER 300.

Piria (2016a) differentiates between exogenous and endogenous factors that led to the low approval rate of CCS projects. He argues that the exogenous factors played a more important role than the endogenous factors. As exogenous factors he lists overoptimistic cost calculations of CCS projects, technical issues, and the low public acceptance of CCS (and connected to this, the problem of securing permits to implement CCS projects). Due to the latter, investors also perceived CCS as a solution that had more financial risks than other options to reduce CO_2 emissions (i.e. energy efficiency). Finally, the low carbon price during the funding period made CCS projects uneconomical, irrespective of the funding provided by the NER 300. With regard to the endogenous factors, Piria (2016a) finds that the 15% cap on allowances per project was the main obstacle for the implementation of more CCS projects, because the low carbon price reduced the financial value of the allowances and thus lowered the overall budget (Piria 2016a; p. 4).

Neuhoff et al. (2014) argue that the provision that the funding needs to be paid back in case of failure (e.g. not enough CO_2 was stored / electricity generated) is a flaw in the design of the NER 300 regulation. With regard to the steel sector, the authors point out that the risk of failure acts as a barrier for investments in innovative projects: "[b]ased on these conditions, if a project were to fail to deliver the capture rates, funding would need to be paid back. For innovative projects this makes little sense: the risk of failure was the very reason steel companies were looking for public funding" (Ibid.; p. 31). Also in the pulp and paper sector this provision acted as a barrier for investment decisions and funding applications under the NER 300 (Roth et al. 2016; p. 29).

Especially for CCS projects, the time given under the rules of the NER 300 programme to reach a financial investment decision for a project were deemed to be too short. BusinessEurope argues that these projects face certain hurdles (e.g. obtaining licensing approvals and permits) that require more time than the 24 months given under the NER 300 provisions. Business Europe argues that these deadlines should be extended to at least five years (BusinessEurope 2016; p. 8).

4 Design options for industrial demonstration projects

4.1 Beyond the NER 300 - considerations for industry

Although it is possible to derive insights for the overall design of the IF from the experiences made with the NER 300, these experiences provide only limited guidance for the specific design regarding industrial sector projects, as these had previously only been allowed under one sub-category of the CCS technology funding stream. With regard to public support for innovations in the private sector, Martin and Scott have pointed out that “[t]he forces leading to private underinvestment in innovation differ from sector to sector across the economy, and policy design should take these differences into account” (Martin and Scott 2000; p. 439). It is therefore necessary to assess the needs and differences of the industrial sectors when it comes to financial support from the IF.

In order to understand these needs, the next section will look at three industrial sectors in more detail. The sectors included in the analysis are the iron and steel, the cement, and the pulp and paper sector. In section 4.2, the general characteristics that these industrial sectors share with regard to innovation are explored. Section 4.3 then provides a profile of each sector and presents sector-specific lists of low-carbon technologies. Information on potential decarbonisation options were derived from three so-called Decarbonisation and Energy Efficiency Roadmaps to 2050 that were released in 2015 (DECC and BIS 2015). These sector-specific roadmaps provide an extensive list of technologies, which was elaborated on the basis of expert interviews and a literature review. In addition to this, a number of other recent studies were taken into account, which present options and venues for reducing the emissions in the respective sectors. In addition, the authors conducted several interviews with sector specialists, who wish to remain anonymous. The insights generated from these interviews have been woven into the sectoral analysis but also provide input to the definition of the recommendations in Chapter 5.

4.2 Innovation characteristics of industrial sectors

In order to assess which technologies should be eligible for funding, the state of development and the mitigation potential of individual technologies (specific per sector) need to be assessed. In the UK, eight Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 were released in 2015 (DECC and BIS 2015). The roadmaps cover the energy intensive industries (iron and steel, chemicals, oil refining, food and drink, pulp and paper, cement, glass, and ceramics). Moreover, the roadmaps contain each a list of technology options for decarbonising the respective sector. Among other things, information is provided for the Technology Readiness Level (TRL) of each technology and estimates on the upfront capital expenditure (CAPEX) for its implementation[4]. See Figure 2 below for an example from the cement sector).

[4] The information on the TRL and the capex is seen as valuable addition for the assessment of the IF’s design options. The authors are aware that the lists of technologies in these sector roadmaps are not exhaustive and that other technologies exist that are not included in these roadmaps. For the sake of completeness, other low-carbon approaches and technologies were included in chapter 4.3, which provides an overview of the characteristics of the steel, cement and paper sector. See European Commission (2017; pp. 11) for an alternative list of technologies.

Figure 2: Example of technology options in a TRL scale – from UK industrial technology roadmap (here two entries for the cement sector)

Name / Description	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex (per site)	Capex data source[7]	CO_2 reduction	Electricity reduction	Carbon Dioxide Reduction Data Source
Carbon capture[8]	6[9]	0%	50%	£100,000,000	Adapted for this project based on the following references (Ricardo AEA, 2013; International Energy Agency & World Business Council for Sustainable Development, 2009; Cement Sustainability Initiative, 2009) and review by sector team	90%	-100%	Adapted for this project based on the following references (Ricardo AEA, 2013; International Energy Agency & World Business Council for Sustainable Development, 2009) and review by sector team
Oxygen enrichment technology	7	0%	75%	£6,000,000	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team	3%	-50%	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team

Source: WSP | Parsons Brinckerhoff and DNV GL, 2015d; p. 88. Explicatory note: adoption rate refers to the estimated use of the respective technology by the industry in the year 2012; practical applicability: refers to the degree a technology option can be applied to the respective production process of a sector; capex (short for capital expenditure) refers to financial sum needed for the implementation of the technology on an industrial site; CO_2 reductions: estimated direct CO2 reduction potential.

TRL metrics are based on an assessment scale, generally ranging from 1 to 9, that allows its users to compare the maturity level of different technologies. TRLs were first developed for NASA (Mankins 1995), but are now also used in other contexts (i.e. in the EU also for innovation funding specification, such as for the Horizon 2020 programme). They can serve as approximations for categorising technologies, but any such categorisation should not be seen as definite or static.

Table 6: Technology Readiness Levels

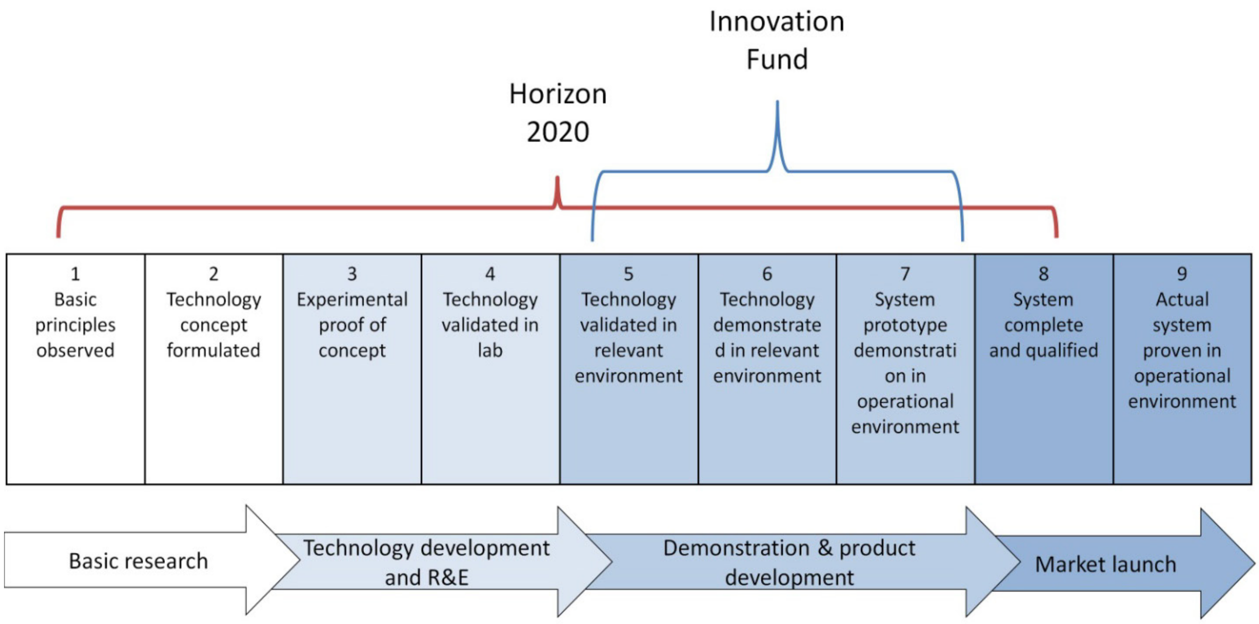
Column heading	Column heading
TRL 9	actual system proven in operational environment
TRL 8	system complete and qualified
TRL 7	system prototype demonstration in operational environment
TRL 6	technology demonstrated in relevant environment
TRL 5	technology validated in relevant environment
TRL 4	technology validated in lab
TRL 3	experimental proof of concept
TRL 2	technology concept formulated
TRL 1	basic principles observed

Source: own illustration based on European Commission (2011; p. 31).

Table 7: "Adaptation of the TRL scale for the process industries“ (see next page) provides an example of a slightly modified TRL scale that the High Level Group for Key Enabling Technologies (HLG KET) of the European Commission used in its final report. Klar et al. (2016) have pointed out that innovation procedures in process industries (such as the iron and steel industry) differ from other industries. Therefore, the authors recommend sector-specific TRL scales. Klar et al have developed a TRL scale for the iron and steel industry that could also be applied to other process industries with similar innovation stages, such as the cement industry (see Table 6).

For the purposes of analysing innovation potential in the three sectors chosen for inclusion in this report, we used the TRL scale approach to narrow down the search. By zooming in on specific scale levels, we tried to generate a (not necessarily fully comprehensive) list of technologies that could potentially be eligible for funding under the IF and to derive the average amount of funding likely needed per project. We interpreted the formulation in the Commission's proposal for the ETS Directive, the funding provided under the IF would be restricted to "demonstration projects" to imply that the selection of technologies should be focused on technologies with a TRL between 5 and 7 (moving them towards levels 8 and 9) (see Figure 3 and Table 7 below).[5] We discuss this focus and its interpretation again in the respective sections 4.3 and 5 below.

Figure 3: Visualisation of focus of the Innovation Fund on the TRL scale



Source: adapted from Diekmann (2014).

[5] We chose the focus on technologies with a TRL between 5 and 7 for the purposes of the analysis as a starting point, without wanting to imply that the decision to include/exclude technologies from funding should be strictly *categorical* and dependent on the TRL (as the definition of these scales is not finite). The use of the scales has limitations and based on feedback from experts we expanded the analysis in certain instances to technology options outside of the 5-7 scales to provide a more complete picture.

Table 7: Adaptation of the TRL scale for the process industries

EU HLG KETs	TRL		Allowable location for trial	Product dimension	Manufacturing process dimension
Actual system proven in operational environment	9	Full-scale testing	Proposed working environment	Customers have modified their buying behaviour and now buy the new product	New manufacturing process integrated in full-scale production
System complete and qualified	8		Proposed working environment	Full-scale testing of product with customers to validate the product in full batches	Validation of the new process at full scale in its proposed working environment
System prototype demonstration in operational environment	7		Proposed working environment	Full-scale testing of the new product technology that validates the concept in its proposed firm-internal working environment, as well as validation of the concept at customers' facilities with smaller batches	Full-scale testing of the new process technology that validates the concept in its proposed firm internal working environment
Technology demonstrated in relevant environment	6	Pilot-scale testing	Pilot facility	Large batch size and/or high rate production validated in pilot facility	Process concept validated in a pilot facility
Technology validated in relevant environment	5		Pilot facility	Small batch sizes and/or low rate production validated through tests in pilot facility	Process concept tested in a pilot facility
Technology validated in lab	4	Laboratory scale testing	Laboratory	Validating experiments fully supporting the applicability of the product concept	Validating experiments fully supporting the applicability of the process concept
Experimental proof of concept	3		Laboratory	The product concept and its applicability can be proven in preliminary laboratory tests	The process concept's applicability and functionality can be proven in preliminary laboratory tests
Technology concept formulated	2	Concept creation	No restriction of location	An initial product concept has been formulated, and its potential applicability in a future new or improved product has been documented	An initial process technology or process concept has been formulated, and its potential applicability in a future new or improved manufacturing process has been documented

EU HLG KETs	TRL		Allowable location for trial	Product dimension	Manufacturing process dimension
Basic principles observed	1	Concept identification	No restriction of location	Basic research (internal or external) that could influence a product concept	Basic research (internal or external) that could influence a process concept

Source: own illustration based on European Commission (2011; p. 31) and Klar et al. (2016; p 4-5).

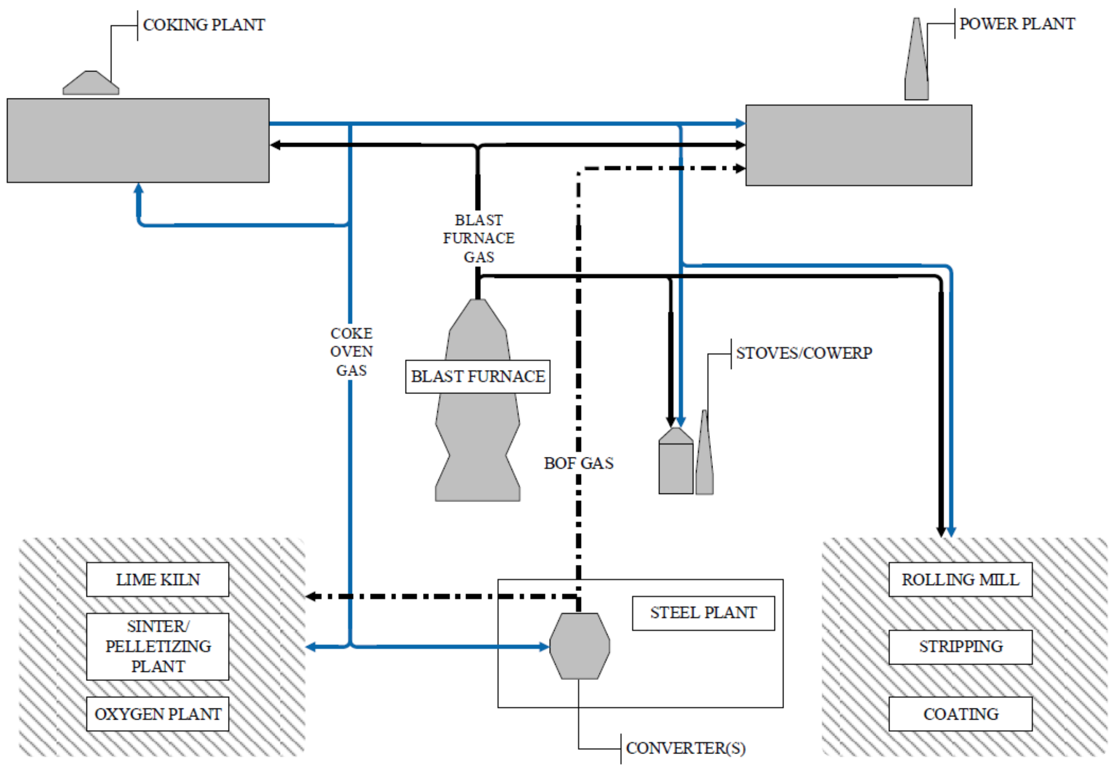
4.3 Characteristics of the three industrial sectors – insights for the design of the Innovation Fund

4.3.1 The iron and steel sector

Despite the impact of the economic and financial crises, the European iron and steel industry remains the second largest steel-producer worldwide. More than half of its production comes from four EU Member States (Germany, Italy, France and Spain). In the EU, steel is mostly produced in integrated steel plants (Blast Furnace - Basic Oxygen Furnace (BF-BOF) route) (see Figure 4) as well as in mini-mills with electric arc furnaces (EAF) (largely secondary steel-making that makes use of scrap materials). These two types account for approximately 60% and 40% of total production, respectively (Rootzén 2015; p. 7).

In the steel sector, a blast furnace (BF) can be in operation for several decades (60 to 70 years), if it is being retrofitted and upgraded over the course of its lifetime (WSP | Parsons Brinckerhoff and DNV GL, 2015a, p. 38). Most of the blast furnaces in the EU (80%) were built in the 1970s and 1980s (Allwood 2016; p. 4, Rootzén 2015; p. 7).

Figure 4: Production process of an integrated steel plant



Source: Adapted from Rootzén, 2015, p. 7.

The process equipment for primary steel production is estimated to have a lifespan of 50 years. The lifetime of utility equipment is shorter, ranging from 20 to 25 years (CHP, turbines, and vacuum pumps) to approximately 15 years (smaller utilities such as heating, ventilation, air conditioning, and lighting). Therefore, it is estimated that there is only one, at maximum two, investment cycles until 2050 (WSP | Parsons Brinckerhoff and DNV GL, 2015a, p. 38).

Decarbonisation options for the iron and steel sector include improvements in energy efficiency, alternative low-carbon steel production routes that use a shift to different existing technologies (e.g. recycling of secondary steel, Direct Reduction, and Smelting Reduction), new steel making processes (e.g. advanced electrolytic processes), alternative fuels and solutions based on carbon sequestration (CCS and CCU) (Rootzén 2015; pp. 8).

Neuhoff et al. (2014; p. 3) state that energy efficiency measures have the potential to reduce emissions by 10-20%. With regard to secondary steel production, Allwood (2016) notes that electrification in combination with improved steel recycling could in fact result in high emission reductions. He states that the recycling of steel is much less energy intensive than the production of new steel products. Moreover, EAF without a DRF could be used for the recycling; coupled with a further decarbonisation of the electricity sector, "the emissions with recycled steel could drop further, and in the limit, could approach zero" (Ibid.; p. 5). Discussing the situation in the UK, Allwood points out that current steel plants, which are designed for processing iron ore, would need to be reconfigured to process scrap (Ibid., p. 4) and that innovative recycling processes, such as up-cycling instead of current down-cycling procedures, would need to be (further) developed (e.g. novel sorting technologies, alternative purifying approaches for molten scrap, belt casting for obtaining higher value products) (Ibid.; p. 6). For Allwood, the crucial factor for steel makers would be the development of electricity prices, as the cost of an electric arc furnace itself is estimated to be a quarter of the total costs of a regular steel plant (Ibid.; pp. 8). However, it has been questioned whether the amounts of scrap available will suffice for a steel industry that relies on recycling on a large scale (UBA 2014; p. 146). It seems more likely that, in the future, primary steel production from iron ore will still be required to partially cover steel demand. In this case, technologies other than the conventional BF-BOF production process could be used to reduce CO_2 emissions from primary steel production.

The DRI-EAF process route is an established production route that offers an alternative to the BF-BOF route. In this alternative route, direct-reduced iron (DRI) (also called sponge iron) is produced in a Direct Reduction Furnace (DRF) by using a reducing agent (i.e. coal and natural gas) and further processed in an Electric Arc Furnace (EAF). The emissions of the DRI-EAF route are 20-40% below the BF-BOF route if natural gas is used as a reducing agent instead of coal (Neuhoff et al. 2015; pp. 389). Steel produced from a DRI-EAF route could be used to bridge shortages of steel scrap (which would allow an EAF-only application). In India, DRI has been increasingly produced since the 1990s to combat scrap shortages (Singh 2015; p 3).

The direct reduction of iron can also be achieved by using hydrogen. Hydrogen can be produced from fossil fuels (mostly natural gas) and via electrolysis. If electrolysis is used, electricity is generated to split water into hydrogen and oxygen (water electrolysis). Otto et al. (2017) show for the case of Germany that the direct reduction of iron with hydrogen as a reduction agent has the potential to reduce CO_2 emissions by 95% (compared to 1990 levels). A prerequisite for this significant emission reduction is that electricity is fully produced from renewable energy sources (Ibid., p. 12). This fuel shift ("Power to Steel") comes at a cost of higher energy demand and would require the expansion of electricity production (Ibid., p. 18). In 2016, Swedish steelmaker SSAB, the mining company LKAB and Vattenfall announced a joint project (HYBRIT - Hydrogen Breakthrough Ironmaking Technology) that would apply the hydrogen-based approach for producing CO_2-free sponge iron (SSAB et al. 2016). The project partners state that the project will require an enormous amount of electricity (15-20 TW) and public support (Garside 2016).

Remus, et al. (2013) point out that the DRI that is produced in a DRF does not necessarily have the same quality as iron produced in a BF: the “[p]roduct [is] prone to reoxidation unless passivated or briquetted. Quality [is] highly dependent on feed quality” (Ibid.; p. 534). Advanced smelting technologies such as HIsarna, Corex and Finex produce hot metal that is similar in quality to iron produced in a BF and can be feed to an EAF. Moreover, these advanced smelting reduction technologies require less coal (HIsarna) and allow for the use of non-coking coal (Corex, Finex), which makes coking and sintering unnecessary (WSP | Parsons Brinckerhoff, DNV GL 2015a; p. 54; Posco and Primetals Technologies 2015; p. 2). Wyns and Axelson state that alternative fuels, hydrogen, and carbon capture technologies can be applied to the HIsarna steelmaking process (Wyns and Axelson 2016; p. 36).

The use of alternative fuels offers the option of replacing fossil fuels during the production process and hence reducing CO_2 emissions from steelmaking even further. In addition to biomethane, liquid and solid bio-based reduction agents can be used directly instead of fossil coal for producing steel with a lower CO_2 footprint (Suopajärvi et al. 2017; p. 729). Suopajärvi et al. argue that “[f]rom the CO_2 emission reduction perspective, the measure that has potential to drastically decrease the CO_2 emissions in current processes, is the injection of biomass-based reducing agents into the BF [and that] other biomass use scenarios in iron and steelmaking applications are also worth of further research and development” (Ibid.; p. 729). Biomass can, for example, be used in coking, iron ore sintering, carbon composite agglomerates, BF injection, and EAFs (Ibid.; p. 729). Although part of the equipment and storage infrastructure of a steel plant would need to be adapted for using bio-based products, the main obstacle for their application is not of a technical nature; rather, it is the price difference between bio-based products and comparatively cheap fossil fuels (Suopajärvi et al. 2017).

Advanced electrolytic processes (such as molten oxide electrolysis) are described as another option for the decarbonisation of primary steel production (Ibid.; p. 149). Electrolysis is characterised as a “high-risk-high-reward technology” with a high CO_2 reduction potential, but presently only available at laboratory scale (Wyns and Axelson 2016; p. 35).

Other breakthrough technologies with high CO_2 reduction potentials such as CCU (which at least offers capture and a temporary storage) and CCS have been explored by the industry but are not commercially viable (yet)[6]. They would require financial support if they were to be scaled up to higher production levels (Neuhoff et al. 2015; pp. 389).

A CCU option that could use the CO_2 emissions of both steel and cement plants is catalytic methanation (DENA, 2015, p. 8). In this case, CO_2 and hydrogen (which is produced via water electrolysis) can be used to produce synthetic natural gas (SNG). SNG has properties similar to fossil fuels and can be used for electricity generation, heating, industrial processes, and as transportation fuel (Ibid.; pp. 8). This CCU option would allow the temporarily storage and reuse of CO_2 from industrial processes in other sectors; however, it would not reduce steel (or cement) sector emissions per se (UBA 2016; p. 15). It has been suggested to use Life Cycle Assessments (LCA) to determine the CO_2 savings of CCU products compared to conventional fossil energy sources (Piria et al. 2016; p. 18). This would help take into account increases in fossil fuel-based production processes due to higher energy demand from CCU (or CCS) (UBA 2016; p. 20).

See Table 8 below for a list of breakthrough technologies derived from the UK’s Industrial Decarbonisation and Energy Efficiency Roadmap for the steel sector.

6 In contrast to CCS, which does not result in a new product, CCU can potentially offer a business case for companies to engage in carbon capture technology - or at least provide partial financial compensation. In the steel sector, a number of CCU pilot projects exist. ArcelorMittal is currently constructing a biofuel production facility in Gent that will even be able to function at commercial-scale production levels (ArcelorMittal 2015).

Table 8: Examples of technology options for the iron and steel sector[7]

Option	TRL	Adoption rate	Practical Applicability	Capex (per applicable site)	CO_2 (C) or Electricity (E) Reduction
All Plants					
Heat recovery and re-use: innovative options	5-7	0%	88%	€750.000	1% (C)
Technologies based on continued use of Blast Furnace and Basic Oxygen Furnace					
Pulverised coal injection with use of biomass (bio-PCI) (for Blast Furnace only)	5-7	0%	85%	-	29% (C)
Stove flue gas recycling with CC	6	0%	100%	€12.750.000	27% (C)
Retrofit solution[8] with CC[9]	6	0%	100%	€97.500.000	50% (C)
Advanced technologies without CC and rebuild	6	0%	100%	€525.000.000	25% (C)
Advanced technologies with CC and rebuild	5	0%	100%	€1.020.000.000	80% (C)
Technologies replacing Blast Furnace and Basic Oxygen Furnace					
Advanced electrolysis techniques	4	0%	-	Not part of any pathway	80% (switch to Elec)
DRI-EAF with natural gas	8-9 1)	-	100% 2)	-	20 - 40% (C) 2)
DRI-EAF with hydrogen (water electrolysis)	3 3)	-	-	-	95% (C) 4)

Source: own illustration based on (WSP | Parsons Brinckerhoff and DNV GL 2015b; pp. 67). Explanatory note: adoption rate refers to the estimated use of the technology by the industry in the year 2012; practical applicability: refers to the degree a technology option can be applied to the respective production process of a sector; capex (short for capital expenditures) refers to financial sum needed for the implementation of the technology on an industrial site; CO_2 reductions: estimated direct CO_2 reduction potential. Advanced technologies refers to "HIsarna, Corex and Finex and process CC in the case with CC" (WSP | Parsons Brinckerhoff, DNV GL, 2015a, p. 54). The information on the DRI-EAF route was added by the authors. 1) is based on Wyns and Axelson and refers to currently available DRI-EAF technologies; 2) estimates regarding the CO_2 reduction potential are based on Neuhoff et al. 2014; p. 4); 3) based on UBA 2014, p. 63; 4) the reduction potential for advanced DRI-EAF steelmaking (with water electrolysis) is based on Otto et al. 2017; p. 18).

This portfolio of technologies shows that a variety of options exists for decarbonising iron- and steelmaking in the EU. As pointed out, the technologies that are applicable today can only reduce sectoral CO_2 emissions to a certain extent; breakthrough innovations will be needed to deliver deep emission reductions. The European Commission also noted in its Action Plan for the European steel sector that significant CO_2 emission reductions in the sector can only be achieved with new breakthrough

7 The information displayed in this table was taken directly from WSP | Parsons Brinckerhoff and DNV GL. Even though the information was collected from various sources, the assumptions about the listed technology options (e.g. the practical applicability) may be subject to (technological) change and should not be regarded as absolute.

8 Post combustion capture including power plant

9 All costs are for CO2 capture alone, including CO2 purification and compression. Costs associated with transport and storage/utilisation are excluded

technologies, but it focused notably on CCS. Moreover, the Commission highlighted the fact that an "industrial-scale demonstration project of producing steel with CCS will be required, and the likely financial envelope will fall beyond the typical size of an R&D&I project" (European Commission, 2013, p. 19). Such a project at industrial scale would surpass the HIsarna Pilot Plant Project and require 500 Million Euro (Ibid., p. 19). The HIsarna pilot plant with a nominal production capacity of 60.000 t/a is the result of an EU-wide R&D initiative of the iron and steel sector with the name ULCOS (Ultra Low CO_2 Steelmaking).

In the 2050 roadmap of the European steel sector (EUROFER 2013), the downsides of CCS are also described openly: it is an end-of-pipe technology that will increase the cost of production. Moreover, the lack of public support for the technology in some EU Member States is seen as a barrier for investments in CCS projects. Energy efficiency measures, on the other hand, are regarded as an innovation option that offers "co-benefits", as it reduces the energy costs of a company (Ibid; p. 56). With regard to CCS, the roadmap further points out that the technology will require a massive amount of financial capital – not only during the research and development and demonstration phases, but also during the deployment phase. The roadmap states that "the first NER 300 funding round shows clearly that investors are not willing to bear the majority of the costs of such high risk investments" and that CCS projects will only be implemented once public authorities provide sufficient funds and planning certainty (Ibid.; p. 57).

The strong focus on CCS in the steel sector reflects the dominant BF-BOS production route, considering the current technology as the basis for a prioritisation of mitigation options – a potential bias. In its 2050 roadmap, EUROFER describes steel recycling with EAF and the shift to the DRI-EAF route as too costly – even under favourable conditions (i.e. low prices for natural gas and electricity)(Ibid.; p. 10, p. 35). A shift from BF-BOS to DRI-EAF is only seen as an option if it is backed by support policies. Interestingly, the steel sector considers DRI with hydrogen (via water electrolysis) as a potential decarbonisation option, which would, however, depend on developments in electricity production (carbon intensity and prices), which the sector otherwise often considers a cost concern (EUROFER 2013; pp. 10).

The need for public support for innovative low-carbon measures is also reflected in the study conducted by WSP | Parsons Brinckerhoff and DNV GL. One of the experts from the steel sector interviewed during the course of the study explained: "Decarbonisation is not a business goal. Decarbonisation is not the first priority amongst equals to the CEO. At the moment, the steel sector is struggling with profitability, getting into the black out of the red. Once this improves, then there will be time to look at energy efficiency, and other initiatives linked to sustainability […]" (WSP | Parsons Brinckerhoff and DNV GL 2015b; p. 64).

Insights – Steel Sector

The steel sector in Europe, in its own perception, is "struggling for survival" (personal communication) given the impacts of the global economic crisis and increased competition from developing countries. While the sector has continuously made incremental productivity improvements and many (of the, by now, rather old) plants are constantly having parts upgraded, there is no sense yet of a business case for developing breakthrough technology options. The sector is largely focused on options for the dominant BF-BOF production route and CCS technology and does not consider electrification via DRI-EAF or EAF as promising alternatives. The sector's experience with developing CCS under the NER 300 (as with the project in Florange, France) has, however, not been positive; it has created a sense of disappointment over the lack of governmental support (personal communication). Demonstration projects in this sector are likely to need a high level of financial support and, at the same time, long-term commitments to the development of key breakthrough technologies. Higher prices of ETS allowances and fossil fuels could induce the development of alternative production processes and technologies. In that case, bio-fuels could become more attractive to the industry.

4.3.2 The cement sector

Like the iron and steel industry, the cement industry was heavily affected by the economic crisis. The average production level fell from 230-270 Mt cement/yr (prior to 2009) to 150-200 Mt cement/yr (2010-2014). Cement production in the EU is dominated by a small number of companies (the five largest firms produce approximately 60% of the total output). Most of the production sites use dry process kilns (90%) and are located in Italy, Spain, Germany, France, Greece and Poland. Semi-dry/semi-wet process kilns and wet process kilns make up the rest of the production (7,5% and 2,5% respectively) (Rootzén 2015; p. 8).

During the cement production process, considerable amounts of CO_2 are generated. About two-thirds of the total CO_2 emissions are process-related and mainly generated when the limestone is transformed into lime and the clinker is produced in the kiln. The remaining third of the CO_2 emissions is energy-related and generated during the combustion of fossil fuels (Neuhoff et al. 2015; p. 390; CEMBUREAU 2017; p. 2). Neuhoff et al. point out that the development of low-carbon innovations that specifically target process-related CO_2 emissions is needed. This is due to the fact that these emissions cannot simply be offset by switching to low-carbon fuels or by introducing energy efficiency measures (Neuhoff et al. 2015; p. 390).

The technical equipment of a cement plant can be continuously modernised, and this may lead to small and medium improvements in terms of CO_2 reductions (Cement Sustainability Initiative 2009; p. 8). To a limited extent, replacements or adjustments of technologies and processes can be done annually during winter down-time without significant production losses (CemWeek 2013; pp. 5, CEMEX 2017). Large-scale modernisation activities involving the kiln of a cement plant, such as switching to a new production process, would lead to larger CO_2 reductions but cannot be implemented during winter down-time because they would require a longer shut-down period (Ibid.; p. 8). In OECD countries retrofitting is less cost-intensive than building a completely new plant (Cook 2011; p. 9) and is usually preferred to the latter. It should be noted that cement companies handle the specific dates for the replacement of kilns confidentially (WSP | Parsons Brinckerhoff and DNV GL 2015d; pp. 26). The kilns of cement plants have a lifespan of at least 30 to 40 years (WSP | Parsons Brinckerhoff and DNV GL 2015c; p. 26).

The production process of a cement plant (see Figure 5) requires high amounts of electricity and fuel. As stated above, CO_2 is produced almost exclusively during the clinker burning process. However, the "levels of energy use and related CO_2 emissions vary depending on the choice of production route and kiln technology […] the efficiency of the process, the mix of fuels used, and the specifications of the cement" (Rootzén 2015; p. 10). Some of the options for reducing CO_2 emissions during the production process are similar to those of the iron and steel industry. This includes improvements in energy efficiency (e.g. via alternative raw materials (calcined)), the use of alternative fuels (such as natural gas and hydrogen) and CCS. Other options are the use of alternative materials (e.g. substituting clinker with by-products from other industrial processes such as blast furnace slag or fly ash) and the development of novel low-carbon cements (e.g. Celitement) (Ibid.; p. 11, UBA 2014; p. 186).

To date, fuel switching is increasingly considered as an option by cement companies, but the use of this mitigation option is structurally limited as fuel combustion only accounts for around a third of overall emissions. Fuels that are used instead of coal and pet-coke include industrial and municipal waste and biomass (Rootzén 2015; p. 10). Neuhoff et al. note that while the use of alternative fuels has contributed to reducing the sectors CO_2 emissions, breakthrough technologies that reduce process emissions are needed to achieve further significant emission reductions (Neuhoff et al. 2015; p. 390). This is reflected in the technology options listed in Table 9 (see below).

Thus, compared to the use of CCS, fuel switching to natural gas or hydrogen alone can achieve only minor CO_2 and electricity reductions. The application of CCS in the cement sector is, however, also still in the early development phase. Three options for carbon capture exist that could be applied in a cement plant: post combustion capture, oxy-fuel combustion with carbon capture and calcium looping (Wyns and Axelson 2016; p. 46). WSP | Parsons Brinckerhoff and DNV GL argue that oxy-fuel combustion is the most appropriate carbon capture technology[10] (see Table 9). Oxy-fuel combustion could be applied in the precalciner and in the kiln at the same time, but this could increase the wear processes in the latter due to the higher temperatures reached (Wyns and Axelson 2016; p. 46). Rootzén states that if this option would be only applied in the precalciner, CO_2 emissions could be reduced by 50%. While this would reduce the CO_2 reduction potential of the technology, it would have the advantage of diminishing its impact on the kiln and the clinker process (Rootzén et al. 2011; p. 9). Post combustion capture could reduce 95% of the emissions (with the drawback that the process leads to the additional generation of steam and thus “slightly”[11] higher CO_2 emissions in total) (Rootzén 2015; p. 11). A number of sources mention calcium looping as the “most promising” technological approach to applying carbon capture in the short and medium term (Chemical Engineering & Technology 2013; p. 1450, Romano et al. 2014; p. 500, Wyns and Axelson 2016; p. 46). In this approach, calcium oxide-based sorbents and flue gases are injected in a carbonator. In an exothermic reaction, the CO_2 is removed from the flue gases and calcium carbonate is formed ($CaO + CO_2 \rightarrow CaCO_3$). In a calcinator, the calcium carbonate is then split into calcium oxide and highly concentrated CO_2, which can be stored and used at a later stage. Approximately 50% of the calcined material (CaO) can be used in the kiln for cement production, whereas the rest of the CaO is sent back to the carbonator (Romano et al. 2014; p. 501). Romano et al. (2014) estimate that calcium looping could reduce the CO_2 emissions of a cement plant by 94% (Ibid.; p. 502). So far, test facilities in Taiwan and Germany were able to reduce CO_2 emissions by 85% and 90%, respectively (Chemical Engineering & Technology 2013; p. 1450; Wyns and Axelson 2016; p. 47). In addition to this high CO_2 reduction potential, carbon looping is also a relatively cheap carbon capture option (approximately US $40 per tonne of CO_2 captured) due to “the cheap sorbent (limestone) and the low energy penalty” (Ibid.; p. 46).

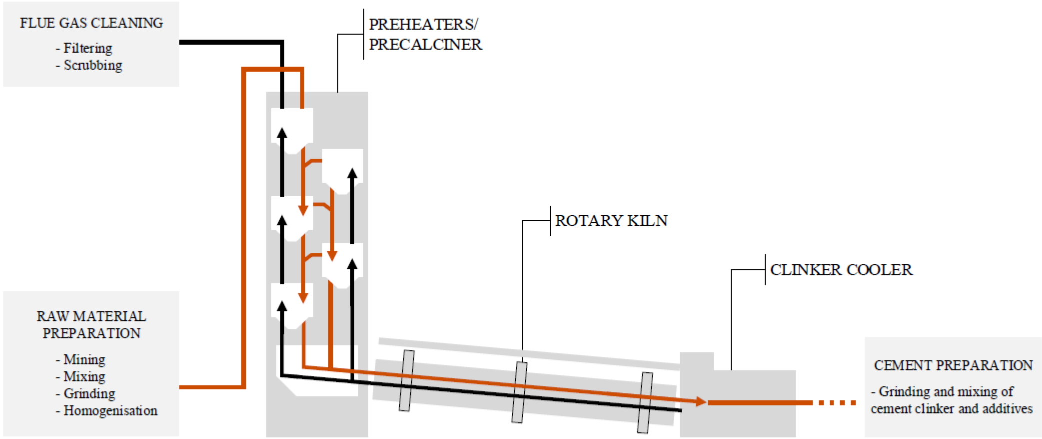
As stated in the previous section, emissions from steel and cement plants could be used for various CCU options, e.g. producing synthetic natural gas (SNG). Another CCU option for the cement sector could be the production of building materials via the mineralisation of CO_2 (Calera 2017). This technique is seen as a way to store the greenhouse gas permanently (without any leakage) in materials that could be used in the construction industry (CO2Chem 2012; p. 23). During the process, the CO_2 reacts with minerals (calcium or magnesium silicates) and forms carbonates. This reaction is exothermic and could be a source to produce additional energy (heat). In theory, the earth’s mineral deposits are sufficient to fix all the CO_2 that is emitted via the combustion of fossil fuels (Ibid., p. 23). However, there are also technical challenges and environmental aspects that need to be taken into account. Regarding the latter, Styring et al. state that the “mineral sequestration of carbon dioxide present[s] significant potential for adverse environmental impacts, which are comparable with the issues faced by similar sized modern quarrying/mining operations” (Styring et al. 2011; p. 32). A major technical challenge that still needs to be overcome is the acceleration of the reaction process (CO2Chem, 2012, p. 23).

A technology option that has currently only been tested at laboratory scale is limestone reduction through electrolysis. During the transition of limestone to lime, carbon monoxide (CO) instead of CO_2 is derived as a by-product. CO could be used in the chemical industry, and electrolysis could therefore offer a business case for the cement industry (Wyns and Axelson 2016; p. 47).

[10] WSP | Parsons Brinckerhoff and DNV GL (2015d): “We have assumed oxy-combustion capture as the most appropriate technology for use in the cement sector, on the basis of cost and efficiency. Oxygen enrichment is a separate option, which uses oxy-combustion to improve efficiency, but without carbon capture. All costs are for CO_2 capture alone, including CO_2 purification and compression. Costs associated with transport and storage/utilisation are excluded.”

[11] Unfortunately, no further information was given by Rootzén on this matter.

Figure 5: Production process of a cement plant



Source: Rootzén, 2015, p. 10.

Table 9 Examples of technology options for the cement sector[12]

Option	TRL	Adoption rate	Practical Applicability	Capex (per applicable site)	CO_2 (C) or Electricity (E) Reduction
Alternative raw materials (calcined)	7	1%	2%	0	67% (C); -0% (E)
Fuel switching to natural gas	5	0%	25%	€5.625.000	7% (C); -10% (E)
Hydrogen fuel	4	0%	0%	-	10% (C); -20% (E)
Fluidised bed kiln	4	0%	100%	-	3% (C); -5% (E)
Carbon capture (oxy-fuel combustion)	6	0%	50%	€75.000.000	90% (C); -100% (E)
Oxygen enrichment technology (without CCS)	7	0%	75%	€4.500.000	3% (C); -50% (E)
Calcium looping 1)	-	-	-	-	94% (C)
Celitement 2)	-	-	-	-	50% (C); 50% (energy) 2)
Limestone reduction through electrolysis 3)	3	-	-	-	-

Source: own illustration based on (WSP | Parsons Brinckerhoff and DNV GL 2015d; pp. 84). Explanatory note: adoption rate refers to the estimated use of the technology by the industry in the year 2012; practical applicability: refers to the degree a technology option can be applied to the respective production process of a sector; capex (short for capital expenditures) refers to financial sum needed for the implementation of the technology on an industrial site; CO_2 reductions: estimated direct CO_2 reduction potential. The information on calcium looping, Celitement and limestone

12 The information displayed in this table was taken directly from WSP | Parsons Brinckerhoff and DNV GL. Even though the information was collected from various sources, the assumptions about the listed technology options (e.g. the practical applicability) may be subject to (technological) change and should not be regarded as absolute.

reduction was added by the authors. 1) is based on Romano et al. 2014; p. 502, 2) is based on UBA 2014; p. 186, and 3) is based on Wyns and Axelson 2016; p. 47).

WSP | Parsons Brinckerhoff and DNV GL also conducted interviews with experts from the cement sector. The analysis of the interviews revealed that the potential installation of new low-carbon technologies is in competition with other investment options. If the latter provides a better return on investments, decarbonisation measures are likely to be postponed or discarded (WSP | Parsons Brinckerhoff and DNV GL, 2015d; pp. 32). In addition, the interviews showed that the interviewees were highly sceptical with regard to the commercial viability of CCS in the cement sector (Ibid.; p. 81).

Insights – Cement Sector

Under the current economic and regulatory circumstances, it seems unlikely that CCS demonstration projects in the cement sector would be realised without significant public financial commitments. The sector does, however, seem ready to embark on a demonstration plant in a multi-company collaboration under the European Cement Research Academy (ECRA) (personal communication). There is also no appetite in the sector for the introduction of measures that could create additional technology pull, such as a higher carbon price or carbon product standards. Overall, sentiments echo those in the steel sector: there is no vision for a low-carbon business case, and thus little willingness to invest money into high-risk projects. CCS dominates the thinking about deep emission reduction options; alternatives (incl. product substitutes or novel cements) are not considered significant. The IF design could help to change that perspective by providing incentives for alternatives.

4.3.3 The pulp and paper sector

The Confederation of European Paper Industries (CEPI) was the first of the European industry sectors to produce a sector-specific 2050 technology roadmap. It states the sector's expectations that there will be only two investment cycles in the paper industry until the year 2050 (CEPI 2011; p. 2). Similar to the other two industrial sectors reviewed above, the lifetime of the technologies and equipment in the paper industry stretches over several decades (25 to 40 years) (WSP | Parsons Brinckerhoff and DNV GL 2015e; p. 28). Paper machines, which require high investment sums, may have a lifespan of 60 years. WSP | Parsons Brinckerhoff and DNV GL conclude that if deep cuts in carbon emissions are to be achieved, such a machine must potentially be replaced before reaching its end-of-life (WSP | Parsons Brinckerhoff and DNV GL 2015f; p. 42).

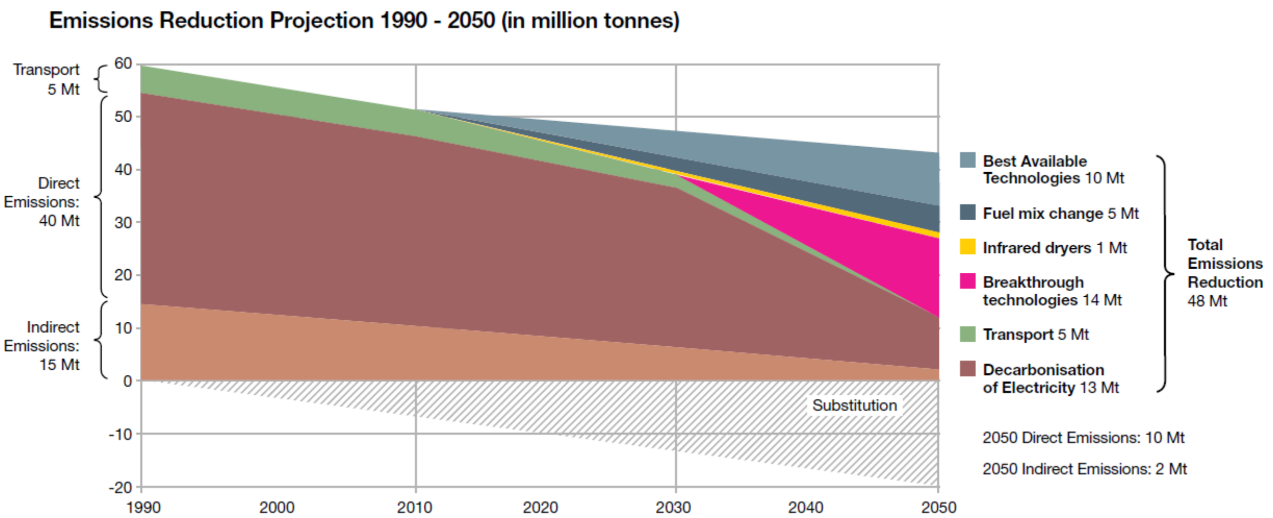
The 2050 decarbonisation roadmap further indicates that the pulp and paper industry prefers to use proven technologies that have already been tested by competitors. Moreover, return on investment cycles (optimally with payback times between one and four years) are the most important factor for companies in this sector when it comes to investment decisions. Companies are also reluctant to use new technologies because these could have negative impacts on product quality. Another barrier that is mentioned with regard to innovation in the pulp and paper sector is the lack of knowledge sharing between companies of this sector (WSP | Parsons Brinckerhoff and DNV GL 2015f; pp. 41).

A study conducted by Roth et al. (2016) confirms these findings. Best available technologies (BAT), such as more energy efficient machineries with short return-on-investment cycles that require only medium or low investment costs are preferred by the sector because new technologies could have a negative impact on machine operability and interlinked production processes. The authors also point out that the relative neglect of R&D has resulted in limited knowledge about new technologies and that a shortage of skilled labour has acted as a barrier even for the adoption of BATs (Ibid.; pp. 19). Thus, breakthrough technologies will likely be an even greater challenge for the sector, but they are a necessity in order to achieve emission reductions of 80% by 2050 (Ibid.; p. 30).

CEPI states that 50% of the emissions from the pulp and paper sector can be reduced with technologies that are known today. The list of these options includes the purchase and production of renewable electricity for production processes, a fuel mix change from fossil fuels to biomass, biogas, and biocoal, the use of biofuels to offset the transport-related emissions of the sector, and the use of bio-based chemicals (see Figure 6). For the remaining CO_2 emissions, breakthrough technologies are needed (CEPI 2011; p. 23).

With regard to breakthrough technologies, CEPI argues that "Paper drying accounts for up to 70% of fossil fuel energy consumption in the pulp and paper sector alone. In the broader sector, it represents the largest source of non-biological CO_2 emissions. It offers a great potential for energy saving". However, CEPI emphasises that the development of such breakthrough technologies is slow and will need at least a decade: "However, technological development in this area is slow, with little chance of a large-scale improvement in the coming two decades" (CEPI 2011; p. 22). Figure 6 displays the estimated CO_2 emission reduction potential of available technologies. In order to present these decarbonisation options, Table 10 also displays technologies with a TRL level below 5).

Figure 6: Estimated emission reduction potential of available technologies in the pulp and paper sector



Source: CEPI, 2011, p. 23.

Table 10 Examples of technology options for the paper sector[13]

Option	TRL	Adoption rate	Practical Applicability	Capex (per applicable site)	CO_2 (C) or Electricity (E) Reduction
Organic rankine cycles, heat pumps and similar heat recovery technology	7-9	8%	80%	€375.000 - €750.000	3% (C)
Dry sheet forming	7	0%	0%	€1.500.000 - €5.250.000	42% (C)
Heat recovery on hoods (future)	1-4	0%	98%	€375.000 - €750.000	40% (C)
High consistency forming	7	15%	50%	€1.500.000 - €5.250.000	3% (C)

13 The information displayed in this table was taken directly from WSP | Parsons Brinckerhoff and DNV GL. Even though the information was collected from various sources, the assumptions about the listed technology options (e.g. the practical applicability) may be subject to (technological) change and should not be regarded as absolute.

Option	TRL	Adoption rate	Practical Applicability	Capex (per applicable site)	CO_2 (C) or Electricity (E) Reduction
Hot pressing	7-8	1%	50%	€375.000 - €750.000	8% (C)
Improved dewatering in press section beyond shoe press	1-4	5%	60%	€1.500.000 - €5.250.000	8% (C)
100% electricity (heat saving)	7-9	0%	100%	€1.500.000 - €5.250.000	100% (C)
100% electricity (electricity increase)	7-9	0%	100%	€1.500.000 - €5.250.000	-304% (E)
Deep eutectic solvents	3	0%	100%	-	20% (C)
Dry pulp for cure-formed paper	3	0%	100%	-	55% (C)
Flash condensing with steam	3-5	0%	100%	-	50% (C)
Supercritical CO_2	3	0%	100%	-	15% (C)
Superheated steam drying	3-5	0%	100%	-	50% (C)
Toolbox	5	0%	100%	-	40% (C)

Source: own illustration based on (WSP | Parsons Brinckerhoff and DNV GL 2015d; p. 84). Explanatory note: adoption rate refers to the estimated use of the technology by the industry in the year 2012; practical applicability: refers to the degree a technology option can be applied to the respective production process of a sector; capex (short for capital expenditures) refers to financial sum needed for the implementation of the technology on an industrial site; CO_2 reductions: estimated direct CO_2 reduction potential.

Insights – Pulp and paper sector

In the case of the pulp and paper industry, a number of BAT and decarbonisation options exist to date that are able to reduce approximately a third[14] of the sectors emissions (Roth et al. 2016; p. 30). However, these technologies are unable to reach the deep emission reductions needed by 2050. Therefore, it is imperative that breakthrough technologies be developed in time to be demonstrated and applied. Given the fact that the sector has neglected the R&D of breakthrough technologies, parts of the IF's funds should be reserved for a later funding round to support technologies that are not ready for demonstration by 2020. Moreover, it seems important that R&D activities in the pulp and paper sector should be encouraged. The overall outlook in a low-carbon future is more positive in this sector, which sees opportunities and is willing to redefine itself. Technology platforms that bring together representatives from different companies could be a means of encouraging the exchange of ideas and knowledge sharing.

4.3.4 Insights across the sectors – inputs from sector experts

The analysis of the overall context in the three sectors demonstrates that there are several barriers to investment in innovative industrial technology options. Intervening in existing operations to introduce upgrades is costly. Especially the steel and cement sectors do not perceive their economic position as particularly positive and see no business case for technologies that will make operations more expensive. The experts interviewed were generally confident about the existence of technological options for reductions in principle, but were worried about the economics – which are seen to be in a "different

[14] As stated above, CEPI estimates that all BAT will suffice to reduce 50% of the CO_2 emissions from the pulp and paper sector.

galaxy" from the current environment (personal communication). None of the experts gave the impression of being opposed to pursuing innovation and investing in related projects, but they were clearly pessimistic about the funding possibilities and the political support for high-risk technologies. In their view, the current regulatory framework is not particularly supportive.

IF design features from the industry perspective

Several interviewees did not express very detailed positions on specific aspects of the design of the IF (at the time of the conversations in late September/early October 2016) – and some indeed took the interview as a pointer that they should consider specifying their own interests more explicitly.[15] In the meantime, BusinessEurope (2016), an overarching corporate umbrella organisation, has published a position paper with considerable specification. Since then, expert representatives from a range of relevant sectors (including specific industries) were invited to join a series of stakeholder workshops on the design of the Innovation Fund that were organised by the European Commission in the first half of 2017. In these fora, they voiced their opinions, which were then captured by a summary report (European Commission 2017a).

In the context of discussing the possible value of the IF, industrial sector representatives are asking for high shares of direct support to overcome barriers to investment. BusinessEurope (2016) has published a position requesting 75% of the total project costs and one sector expert mentioned 85-90%. Industry experts are clearly critical of the design of the NER 300 and its performance based conditions that made high risk technologies unattractive and in essence skewed the system towards "proven technology" (personal communication). Also, the selection choices based on a ranking by relative carbon cost were deemed nonconductive to supporting high-risk (and thus currently expensive) technology.

Access to capital was mentioned by some experts as an issue for companies otherwise short of cash. It was also claimed that it is hard to get third party investors involved because they want guarantees of future reward of their investment, which cannot be guaranteed for many such projects. Different types of financial support or their combinations are seen as possible but in principle these companies are looking for grants ("loans do not look good on balance sheets" (personal communication)). Some experts expressed interest in an early start to the IF and one expert explicitly requested the left over NER 300 funding to be transferred to the IF.

The analysis of the three sectors (see Sections 4.3.1 to 4.3.3) and the following Table 11 show that the support needs depend on sector and technology, which vary with respect to level of risk and size. This suggests that the IF's rules should reflect this – and the interviews supported this impression. Indeed, the situation in the pulp & paper sector is clearly different from that of the iron and steel and the cement sector. Many smaller companies exist with smaller overall operations and smaller innovation projects with added value may thus be possible. Special (meaning: simpler) rules should possibly apply to such smaller projects (European Commission 2017a; pp. 15).

In terms of project size, the interviewed experts suggested that most industrial projects need EUR 100 million at least (pilots), but that some projects could require up to EUR 500 million and large ones up to EUR 1 billion. The data extracted from the technology roadmaps (see Table 11 below) indicates that much smaller projects might also be relevant, especially non-CCS projects. Based on the three sector-specific technology lists (see previous sections), the financial resources needed for the realisation show CCS projects worth up to EUR 1 billion and non-CCS up to EUR 500 million – starting from as low

[15] This may in part be explained by the fact that the focus was on the negotiations on the EU ETS Directive, whereas the technical details on the Innovation Fund are expected to be adopted separately.

as around half a million[16]. The sectoral expert workshops summary lists a range of €5-200 million covering the majority of projects (European Commission 2017a; p. 16).

Table 11: Capex per sector and technology category

Sector	CCS / non-CCS	Capex minimum	Capex maximum	Capex average
Iron and Steel	CCS	€12.750.000	€1.020.000.000	€376.750.000
Cement		€75.000.000	€75.000.000	€75.000.000
Pulp and Paper		-	-	-
Iron and Steel	non-CCS	€750.000	€525.000.000	€262.875.000
Cement		€4.500.000	€135.000.000	€48.375.000
Pulp and Paper		€375.000	€5.250.000	€2.320.313

Source: own calculations based on the capex-information available for technologies with a TRL between 5 and 7 from the tables with the technology options in chapter 4, based on WSP | Parsons Brinckerhoff and DNV GL (respective documents). Caveat: the soundness of the results is limited due to the small number of technologies available for the calculation and the lack of additional sources.

Technology choices

Few sector experts had strong opinions on the process or criteria for choosing technologies but some mentioned that the IF should focus on real breakthrough technologies. BusinessEurope (2016) has come out in favour of a technology neutral approach. CCS clearly features strongly among the possible mitigation options considered by BusinessEurope and this is evident also in the sector-specific 2050 roadmaps that all three analysed sectors have published. However, interviewees denied that CCS was necessarily the only option. The relationship to CCS technology seemed indeed somewhat ambivalent: on the one hand it was identified as a key mitigation option (e.g. in the sector roadmaps), but on the other hand, several sector experts remarked that they "know about capture" (personal communication) but their current operations gave them no expertise in transport and especially storage of carbon ("we are not geologists, we are engineers" (personal communication)) and requested additional specific support for those elements, also from governments. Several experts expressed an interest in CCU technology, which could provide opportunities for the creation of a new business model. However, the current policy framework was designed against this, one expert said (e.g. treatment of transferred emissions under the EU ETS).

Alternative or novel products featured hardly or only very low on the list of technologies in the interviews and the sector roadmaps, maybe unfairly so (see for example Wyns and Axelson 2016). A representative of the cement sector described his sector to be in competition with other building products and did not, for example, voice the option of becoming "building material company" rather than being merely a "cement company".

An important obstacle to some technology options and possible business models mentioned in both literature and interviews is the availability of the respective cleaner raw materials (biomass or recycled paper/steel etc.) which can be a limiting factor. Improving access to such raw materials and improving recycling rates may be a kind of flanking policy that may make alternative products and processes more attractive.

A specific obstacle was mentioned for the pulp and paper sector, which does rely on a few specific manufacturers for its machinery. These external suppliers of machinery can be a bottleneck for the adoption of possible emission reduction options, as they are required to redesign machines. This begs

[16] However, in some categories only one technology option was available.

the question whether a greater scope for collaboration can be achieved through targeted outreach activities in this regard and through the inclusion of such manufacturers in low-carbon innovation support programmes.

Lastly, the issue of requiring political support and a steadfast commitment to individual projects and innovative technologies from EU institutions and host country governments at Member State level was a concern mentioned by several experts, certainly around CCS (including reference to the Florange example). One interviewee specifically demanded a new EU-wide Industrial Policy approach and asked for a public declaration (by governments) of a partnership with industry in the development of low-carbon technologies. More than one expert cited the ETS as an example of policy uncertainty for industrial sectors, which was not conducive to investment decisions.

Support beyond the IF

A topic that several experts raised and returned to and that is also highlighted in recent papers on the topic (Allwood 2016, Wyns and Axelson 2016) is the need to find a long-term business case. As one sector representative put it: even if, for example in the case of CCS, a funding scheme for a project may allow it to operate for ten years, this very same project may simply be turned off from one day to the next once the financial support is gone – if there is no business case. Without demand for low-carbon products, the IF itself is clearly insufficient.

To have a chance of companies realising the benefits of innovative technology commercialisation, there needs to be the prospect of a future market. In the opinion of several sector experts this may require additional support mechanisms (e.g. public procurement and product performance standards were mentioned) including those with a long-term perspective. The BusinessEurope (2016) position paper reiterates this request (Ibid.; p. 11). Concerns over having a "first mover disadvantage" (making the investment to develop technology but then others commercialising it) and the need for some form of policy support to protect against it were also mentioned in this regard.

These concerns point to a potential "policy gap" between the IF and the EU ETS (as identified in Section 2 at the start of this paper). However, as one innovation expert remarked, the successful example of bridging such a gap in the power sector via renewable energy support may not be applicable in the context of industrial manufacturing, which has much fewer individual operations and less potential to achieve economies of scale fast. In his opinion, the likely answer for industry may lie in combining low-carbon technology with innovations in both business operations and business model – and for this to work, flanking policy may indeed be required.[17]

The gap to the market also appears in some form in the Commission's workshop series summary report (European Commission 2017a), which notes as relative consensus among experts the need for funding to be directed at technologies up to a readiness level of 9 (with the range being TRL 6-9, in contrast to the 5-7 proposed here). As justification it cites the need for financial instruments to support investments into more proven technologies, as banks and other lenders attach too high a risk to the commercial viability of such projects. However, such a focus on more mature technologies may change the nature of the Fund and shift support from clear breakthrough innovation to more proven technologies (or even to early deployment), for which the likely size of the Fund may be ill equipped (as more mature projects are likely to be larger and more plentiful). This poses a rather fundamental question about what the actual needs for low-carbon technology development in Europe are. Is the main need the demonstration of potential breakthrough technology or support for entry into the market for largely developed (and proven) options?

[17] What types of incentives such flanking policy would need to provide and how they could work is beyond the scope of this paper and merits further research and analysis.

The authors contend that the answer to the question is: both are needed, but that the primary function of the IF should be to help deliver breakthroughs to enable deep decarbonisation because there is no other instrument currently in place in the EU to do it. Focusing the IF on bringing more proven technologies to the market (some of which may not deliver fundamental changes in emissions, but only marginal ones), carries the risk that a mitigation gap remains as less developed technology options with potential for deeper reductions are being neglected. However, the two functions do not necessarily need to be exclusive of each other – the IF could do both to some extent, with specific requirements for the market entry support function. Financial support could be limited to technologies with high CO_2 reduction potentials and the type of support could be different (in terms of the IF provisions being applied) and work through loans (rather than grants), for example.

This question over the focus of the IF serves to illustrate the inadequacy of the current setup of policy instruments and the lack of focus in the related political dialogue to formulate a credible pathway for the long-term transformation towards a decarbonised industry sector. While the Innovation Fund can play a vital role in this regard as a stepping stone for developing technology, it cannot be successful on its own but will require additional changes to be brought about by other processes and policies in order for industry to adjust to the low-carbon future. In the context of the debate about the impacts of GHG emission regulation in Europe on the competitive position of European industry and possible carbon leakage, the Fund itself can thus support the development of a new technological base which can make decarbonisation possible – but it cannot provide the necessary deployment at scale.

A new vision for what future industrial operations might look like

While the engagement with individual sector experts has clearly enriched the authors' understanding of the sector-specific circumstances and generated additional insights for this report, there are also obvious limitations to this approach. For example, we are unable to independently verify statements about the state of technology development or their suitability as a major mitigation option (apart from consulting additional literature) and thus we need to assume a certain bias in the experts' responses.

One of these understandable biases in the industry perspective is created by their perception of opportunities and threats of the decarbonisation challenge, which is rather defensive (especially for steel and cement). The interviews and the industry roadmaps also exhibited a tendency to be pessimistic about novel technologies and very different products that would have the potential to bring about a more fundamental change to the traditional way of doing business. With many existing installations now in operation for decades, this traditional perspective is understandable. However, it also limits the possibility to see what other alternative scenarios may be possible and what one might call the "Elon Musk approach" to industrial manufacturing. This is compounded by the singular focus on production process innovations, which is currently dominant in the design of the NER 300 and the EU ETS, and a lack of leadership from governments to engage proactively in a joint undertaking to decarbonise industry.

However, in addition to a reduction in emissions from production processes, decarbonising the European economy and maintaining a strong industrial base in Europe may require more fundamental changes in the way businesses organise themselves, in what products they decide to create to satisfy customer needs and a stronger service-oriented perspective (moving away from sales figures). Examples for what such new visions of a low-carbon business model could look like are pointed out by Allwood (2016) for the UK steel sector and by Wyns and Axelson (2016) for energy intensive industries. The long-term outlook by the pulp & paper sector presents an example of such a different vision, restyling itself in the 2050 roadmaps as the "forest fibre industry" (CEPI 2011) that could strive in a bioeconomy. Alternatives are possible.

5 Policy recommendations

5.1 Summary of main insights

What are the implications for the IF's design elements distilled from the attempt to analyse the characteristics of a three essential industrial sectors and their respective context and mitigation options in detail? The following key conclusions can be drawn.

- It seems sensible to apply an ambitious and dynamic approach to choosing which technologies may be supported, to **create a focus on real breakthroughs** and to allow possible new options to come into play over time, as perceptions of their suitability change.
- The IF needs to **provide opportunities for high-risk projects** to be funded – to also allow a high reward in terms of deep CO_2 reductions. The NER 300 had clear deficiencies in this regard.
- To the extent possible, the IF should focus on supporting technologies that may also create **new business opportunities** and possibly new business models by supporting project designs that take this into account, so as to facilitate future uptake in the sector and sustainability of the project beyond the lifetime of the support by the IF. This implies also moving beyond the sole focus on production process technologies to decarbonise the existing set of products – but to allow for alternative routes.

Beyond that, there are additional insights that cannot be easily and directly addressed via design elements of the IF but that are nevertheless crucial to successful technological innovation in Europe.

- The financial support that the IF provides to demonstration projects should be sustained in some form to allow promising technologies to cross the final part of "the valley of death" between demonstration and full, large-scale commercialisation and to help them enter the market. For this, the IF may need to be **complemented by additional policy measures** (the specifics of which require further investigation).
- There may need to be a **political commitment** to the development of certain types of technology (e.g. CCU, CCS) or a conscious decision against them to create some certainty to base investment decisions on. High-risk projects cannot take place without support from governmental agencies.

5.2 Specific design options for an effective IF

On the basis of the conducted analysis and the review of the existing literature, we have generated recommendations for most of the main design elements. In case of some design elements the scope of the research done for this report had clear limitations. For example, the role of different financial products (see chapter 3.1) could not be explored in more detail but it is a topic worthy of further analysis. Also, the potential combination with other EU funding programmes, e.g., Horizon2020 (SILC Sustainable Industry Low Carbon II – 20 million launched in 2014), LIFE, or activities under the SET-Plan, could not be further explored. For some design elements (e.g. administrative set-up of the Fund), there is no obvious preferred choice from the authors' perspective with regard to the impact for industrial sector innovation.

5.2.1 Financing conditions – enabling high risk breakthrough technologies

Summary of the main points:

- Guarantee a minimum amount of funding for the IF as a whole.
- Provide higher co-financing rates for high-risk projects and smaller entities.
- Avoid relying only on strict performance based criteria as conditions for payment.
- Establish maximum funding per project as absolute amounts.

Total budget of the Innovation Fund

The current setup of monetising a fixed amount of EU Allowances (EUAs) creates uncertainty over the total amount of funding available, especially in the face of low-carbon prices. Estimates about the overall volume range from EUR 2 to 11 billion (for carbon prices of 5€ to 25€ per ton of CO_2) for the Commission proposal of 450 million allowances (BusinessEurope 2016) and could go up to EUR 17 billion if a higher set-aside was created, as is discussed in the European Parliament (up to 650 million allowances). Unspent funds from the second call of the NER 300 could eventually increase the total budget of the IF or partly offset reduced revenues from a low carbon price. The IF would substantially benefit from more certainty about the funding available to enhance investor confidence and planning stability (which is particularly important for industrial sector projects). One way to improve the situation would be to establish a minimum guaranteed level which would secure a certain number of projects and enhance planning security. Such a solution was implemented in the case of the German Energy and Climate Fund (Energie und Klimafonds (EKF)). In 2013, the fund faced similar problems due to declining revenues from emission trading and was thus supported with money from the state budget (Federal Ministry of Finance 2013). For the IF, a minimum amount could be ensured by drawing on other EU funds as a means of making up for any shortcomings from EUA auctioning.

Co-financing rate

High-risk[18] projects (including but not limited to CCS or CCU) are particularly economically unattractive for any party involved. One way to enhance high-risk projects' viability is through higher co-financing rates. The European Commission ETS proposal (2015a) has already suggested increasing the co-financing rate from 50% to 60%.

Whether it would be possible to establish the project risk on a case-by-case basis is a question that requires further investigation. One simplified way of implementing a differentiated treatment on the basis of risk could be through distinguishing between main project categories (based on their inherent characteristics (incl. risk)). This differentiation could, in theory, be broken down to the level of individual industrial sectors or technologies but would then likely imply that a static ex-ante technology choice approach is used, meaning that the level of risk (and thus co-financing) is decided upfront down to the level of individual technology options (see respective section below). For example, considering risk only at the level of the three main categories (CCS, industrial projects, renewables) would likely be too simplified an approach (as certainly for the latter two categories a more nuanced option would be more effective).

Smaller entities (e.g. in industrial sectors with a higher share of SMEs) and smaller projects may also be in need of higher co-financing in general, as they tend to have fewer opportunities for bank loans (European Commission 2017a; p. 16).

There is a drawback to increasing the co-financing rates: fewer projects can be funded in total. Combining funds from the IF with other national and EU funds should therefore be permitted so that private investors can have access to various public sources and increase the non-corporate funding share. This should be reflected in state aid guidelines and respective decisions. In addition, a combination of different financial instrument types may be advisable to overcome hurdles for high-risk projects (see also BusinessEurope 2016; p. 10) – e.g., combining grants with loan guarantees for the remaining (non-IF financed) part of the required investment, so as to facilitate bank loans for those amounts.

[18] Risk meaning in this case, for example, the overall level of investment required (= risk of losing that amount of money) or the likelihood of a business case being created for this technology later on (= risk of investment with no returns), or risk of technology failure (= risk of not reducing carbon emissions) which may also create a risk of awarded IF funding not materializing (depending on the rules).

Conditionality

Applying certain types of conditionality for financial support is good practice for any type of public support to private entities. In fact, eligibility criteria (for application) already provide an initial screen for the types of projects to be supported. Conditional payments are thus more linked to monitoring actual progress in implementation. Linking payments directly to the real-world success in reducing CO_2 emissions helps bringing the ultimate goal of the IF into strong focus but may have undesirable repercussions. Strict performance-based conditionality such as the one used under the NER 300 acts as an active barrier towards particularly innovative (and/or high-risk) projects. To reduce this effect, payments should be coupled to the achievement of certain project milestones instead and not be solely oriented towards the realised emission reductions. The introduction of a CO_2 performance-based element could act as an additional incentive towards the end of the project. A combination of both seems to be the most sensible approach. The IF related provisions in the European Commission proposal for the ETS Review already move in this direction.

Allocation of funds per project

The analysis of the potential project sizes (CAPEX only) in chapter 4 has shown that these could range from EUR 100 million to EUR 1 billion – a difference of a factor of ten. With the IF's overall volume somewhere between EUR 2 and 11 billion, a cap on the funding per individual project makes sense. However, the approach chosen under the NER 300 to use a relative share of the fund's total (15%, see Table 4) can lead to too strict a limitation particularly if the Fund's monetisation only comes to a total volume at the lower end of the above-mentioned range. Absolute amounts are thus more suitable. They provide certainty to potential project developers and investors and allow for more control over the type and number of projects being funded. These limits could be set to suit the respective characteristics of the technologies in question as a means of differentiating appropriately between their respective needs.

Based on the range of broadly identified overall project sizes (see Table 11), an upper threshold equivalent to 60% of the maximum capex (assuming a 60% co-financing rate), which is expected for projects in those categories, would imply absolute limits of EUR 612 million and EUR 315 million financial support for industrial demonstration projects with and without CCS respectively. Piria (2016b) arrives at the same ballpark (EUR 600 million and EUR 300 million). If the requests from industry for even higher co-financing rates should be applied, e.g. 75% (BusinessEurope 2016), this could require a further increase of the total amount, based on the largest project size (CCS in the steel sector – as per the information contained in the table above). However, for such particularly large projects, which could take up significant shares of the overall funding available, additional sources of funding could be sought.[19]

The setting of absolute limits per project is complicated, however, when operating expenditures (OPEX) are also taken into account. After all, a project developer would need to pay for both the upfront installation of the technology and its operation during the project's lifetime. OPEX should be included in the financial support (to an extent) – and any upper limits should take this into account. Either an additional amount is added to maximum absolute funding limits per project or OPEX are subject to a separate limitation (relative or absolute).[20]

To keep administrative efforts low, minimum thresholds for project size could also be considered – especially in coordination with other possible funding schemes such as Horizon2020 (which had the

[19] A relaxation of the total maximum amounts could be considered under specific circumstances that increase the size of the project (and make it thus particularly interesting), such as cross-sectoral multi-company collaborations – possibly also bringing together multiple Member States.

[20] Exploring specific data for operating cost levels was beyond the scope of this report – which is why no specific recommendations can be made on the subject.

Sustainable Industry Low Carbon Funding Stream) that might be able to cover even smaller projects. However, for industrial sectors with a higher share of SMEs, small projects may be an important segment that should not be missed out of innovative projects.

5.2.2 Project eligibility – focusing on high potential innovation with a business opportunity

Summary of the main points:

- Focus on **breakthrough technologies** for the eligibility of projects. Some potential to also support market entry of more mature technologies, but rather via loans and under qualitative and quantitative limitations.
- Earmark **minimum shares of funding per main category** (CCS, industry, renewables) but be flexible about them if unused and allow for different project sizes also.
- Set **ambitious criteria** for selection of projects underneath the categories in terms of emission reduction potential, but combine with criteria measuring co-benefits that hint at business opportunities and new business models where possible.
- Provide **incentives for projects focusing on substitution** of high-carbon products.

Eligibility criteria for projects

The eligibility criteria are key to deciding what the focus of the IF should be. Two options are possible: 1) support of first-of-a-kind projects only or 2) support of first-of-a-kind projects combined with support of proven technologies with an unused carbon-reduction potential. In the first case, projects are only supported if they deploy a cost-effective low-carbon technology that has so far not been sufficiently demonstrated at pilot scale (technologies with a Technology Readiness Level (TRL) between 5 and 7 and a significant CO_2 reduction potential)[21]. In the second case, projects would be supported that implement technologies that are already (largely) proven but largely not in commercial application yet (TRL 8-9), and can bring about additional CO_2 reductions. This approach may allow exploiting the potential of more proven technologies, whilst supporting companies in their efforts to reduce CO_2 emissions.

While the first option will spur innovation in breakthrough technologies, the second option could be selected to attract more private investments (possibly with less money per project).

As noted at the end of Chapter 4, the summary report from the European Commission's consultation process with industry stakeholders (European Commission 2017a) stated that the debates had concluded that the IF should support projects with TRL from 6 to 9, thus clearly including the second option (market entry for more mature technologies), and with a lesser focus on early demonstration (TRLs 5-7). If the design followed this advice, the original objective of the IF to support the development of breakthrough technologies, which is needed for further substantial CO_2 reductions, might be jeopardised, with no other instrument in sight that would fulfil this much needed function. Incumbent industrial corporations already signal little appetite to invest in technologies with an unlikely economic reward. The existing set of available technologies in industrial sectors is largely focused on the existing technology stock and marginal improvements, and does not include more novel approaches

[21] Technologies presently below these levels (TRLs 1 to 4) could be supported at a later stage (if they have been advanced in the meantime through other means). This would require that the list of eligible technologies would be updated during the lifetime of the IF – or be based on dynamically applied criteria, used in later calls for funding. This approach would allow for taking technological developments into account over time. Another option would be to continue funding low-carbon technologies that have received financial support from other funds (i.e. Horizon 2020) that support lower TRL levels (and higher ones) – to create continuity in innovation support across EU funding instruments. Choosing a smaller segment of potential technology readiness levels would simplify the Fund's design and operating rules and concentrate its impact so it can serve more specific purposes – but could also narrow its functionality.

and new business options. Limiting policy support to the more mature technologies may not be sufficient to deliver the magnitude of emissions reductions required or do so only in a structurally conservative form that may not be cost-competitive in a low-carbon world or come with new sets of risks (such as strong reliance on end-of-pipe capture technology).

With a long-term view to decarbonising the industrial sector and to avoid such structural lock-in, we therefore recommend to keep the IF's focus on the development of new breakthrough technologies. That does not need to be the only function of the IF. It could also support more proven technologies' roll-out (TRL 8-9) through the use of loans rather than grants, which would allow the use of IF resources to enable projects in a way that the money is paid back and is not lost for supporting breakthrough projects. Criteria should apply that focus such support on projects with high emission reduction potential – and the overall share of the IF's financing that is available for such support should be limited, to ensure that most of the resources are directed at supporting breakthrough technology development.[22]

Windows for main project categories and flexibility of Fund allocation

The NER 300 established a detailed ex-ante list of eligible technologies – which has proven to entail important drawbacks. It did so under the two main technology types – CCS and renewables – and aimed to keep a minimum of funding for either category. Despite the fact that this did not work out as planned due to the withdrawal of all CCS projects, the approach of earmarking certain minimum amounts per project category makes even more sense with the introduction of industrial projects, since earmarking for categories provides certainty that also non-CCS industrial sector technologies are funded. This implies the use of at least three main separate project type categories: CCS&CCU industry, non-CCS/CCU industry, and renewables. Such a "general project type" differentiation should then be combined with criteria for actual choice underneath the categories (see the following section). Moreover, the IF should support different project sizes and should guarantee especially the funding of some smaller projects by creating specific windows (certainly in the non-CC industry and the renewables categories).

In addition, the lessons from the NER 300 show that it was essential to have the option that funds can be **transferred from one category to another**. This option should be maintained. Through this mechanism, funds that are not fully used in one category can be used for projects from the other two categories (see also Piria 2016b; p. 14) in later calls.

Criteria for project selection – technologies and future commercial use

Two of the key insights from the analysis done for this report can be captured in the setting of criteria for the decision on what projects may receive funding. With regards to **technology**, a dynamic approach based on specific criteria should be applied (possibly slightly differentiated within with each of the three main categories). To ensure that the process focuses on technologies with a high mitigation impact, one of the criteria should establish a minimum GHG emission reduction over state of the art technology, at the order of 20-25% (see also Wyns and Axelson 2016; p. 57). This reference state of the art technology in general must refer to the dominant technology in application, also for demonstration projects covering other production approaches. For instance, innovative direct reduction approaches in the iron and steel industry have to be compared to the emissions from the currently dominant blast furnace route (and not to the efficiency of state of the art DRI technology).

[22] In line with the recommendations/discussions in the stakeholder consultation report (European Commission 2017a, p. 9 and p. 20), also 'intermediate forms' such as partial grants, de-risked loans or equity could be considered, but which ones may be particularly suitable for what sector and technology as well as the general feasibility of the idea to simultaneously apply several different financial instruments go beyond the scope of this study.

Considering that demonstration projects' energy and emission efficiency often fall short of their technologies' potential efficiency in larger scale (and in the market diffusion process), we strongly suggest that the figures to be expected at large scale and after significant diffusion should be used for determining this threshold. We propose this even though we acknowledge that these estimates can contain a relevant predictive uncertainty.

Furthermore, it is important that eligible demonstration projects can also comprise innovative solutions for critical process components (and do not necessarily have to comprise entire processes), so that essential elements of new approaches can receive support as well.

With regard to incentivising the **connection to business opportunities**, Wyns and Axelson (2016) introduce the idea of adding criteria that may "increase the likelihood of future deployment and commercialization" and list for example increased productivity, other cost savings and business model innovation. Adding this dimension to the selection process would facilitate the development of a new vision for industrial business operation in a low-carbon world.

Shift the focus – support product substitution in a dedicated fashion

The NER 300 as the predecessor to the IF has a sole focus on innovation within the boundaries of the existing product segment. In the power sector (which is the main target of the NER 300), the product (electricity) is the same and it is only the change in production process that matters – substitution in the form of energy savings is not addressed. Moreover, (zero carbon) electricity itself is seen as a means to enable other sectors to decarbonise (e.g. in the electrification of transport) and thus carries particular weight. Energy efficiency and energy savings are, however, addressed through a range of other policies.

The IF could change this paradigm. Especially for industrial products, a comprehensive perspective must include a look at substitution of existing products with high carbon intensity through low-carbon alternatives (e.g. in steel or cement as building materials or components for, say, cars). In principle, this can be addressed via the project criteria (see previous segment) e.g. through high eligibility thresholds on the greenhouse gas emission reduction potential, for example. However, it may be useful to put an emphasis on substitution projects by creating more favourable conditions for them or by establishing a separate funding window for related applications.

Support for carbon intensive product substitution is also made more difficult by biases in the existing regulatory framework. Under the EU ETS for example, free allocation of allowances in the cement sector is based on the clinker component. Low clinker or clinker free products thus receive less to no free allocation, which creates a potential (economic) disadvantage. Such barriers should be reduced as part of an effective low-carbon innovation policy of which the IF forms an important element.

5.2.3 Additional observations for IF design

Besides the key design elements elaborated upon above, there are a few distinct pointers to other issues specific to industrial sector innovation that have come up through our analysis that should be taken on-board for the design of the IF.

- Flexibility to synchronise with investment cycles

As building / retrofitting of a sole unit or a whole plant can only be undertaken economically at certain intervals, the allocation of funding and the start date of a project could remain flexible to account for this (e.g. individual project start dates could be agreed with the respective company, not set as fixed for all projects to apply equally) (see also BusinessEurope 2016; p. 6).

- Offer funding also for operating expenses.

As mentioned under the section on support limits per project, operating expenses (OPEX) can make up significant portion of project costs and thus contribute to the need for finance from the IF. Since this was not part of the rules under the NER300, we specifically highlight the recommendation to include support for OPEX in this section on additional observations.

► Encourage collaboration inside and across sectors

Knowledge sharing should be encouraged to accelerate the diffusion of innovative technologies. The ULCOS consortium in the steel industry may serve as a positive example in this regard. This knowledge sharing could be encouraged by offering more favourable conditions for such collaborative applications. This idea was also echoed by participants in the Commission's expert consultations (see European Commission 2017a). Intersectoral integration could also support unlocking new business models (see previous section).

5.3 Conclusion and outlook

Over the course of research done for this paper and analysing the available material on lessons from the NER 300 and the needs of a selected group of industrial sectors for the development of low-carbon technology, the debate on the design of the Innovation Fund has advanced. General interest in the topic and the level of the debate and participation in it has increased significantly, owed in no small part to the engagement process organised by the European Commission. Industrial sectors are more aware now of the new instrument and have developed more refined positions on their preferences for the design.

Our analysis has arrived at specific recommendations for the design of the Innovation Fund that would, from the perspective of the authors, enable an effective IF working towards the goal of developing low-carbon technology to transform industry in time to meet Europe's climate objectives. These recommendations are summarised in Table 12. They focus mainly on the types of projects chosen for funding, as well as on how and in what intensity the funding would be made available.

However, the analysis (including insights from the conversations with industry representatives) also underlined that the IF must be seen in an integrated perspective for a low-carbon industrial policy. The existing regulatory landscape must be corrected (for its occasional bias in favour of high carbon intensive incumbents and the focus on existing products and processes) and complemented to create an environment that truly incentivises investment in innovative low-carbon technology, both in development and later deployment. Without a long-term perspective for how to make a business case for low-carbon industrial production, the IF in itself cannot succeed.

Bringing such a change about requires both a commitment from political decision-makers as well as a change in perspective in industrial sectors and closer sector integration to arrive at new ways of doing business and to give assurance to innovators that they will be rewarded. The upcoming decisions on the design parameters of the Innovation Fund need to be seen in this general spirit and be shaped to fit with a new perspective that is serious about realising a future for industry in a low-carbon world.

Table 12: Overview of recommendations for the design of the Innovation Fund

	Design Elements	Recommended design
Financing conditions	Total budget of the IF	Set minimum amount floor, with mechanism to guarantee it in case the monetising of the 450 million EUAs is not sufficient
	Co-financing rate	Provide higher co-financing rates for high-risk projects and smaller projects

	Design Elements	Recommended design
	Conditionality	Avoid strict performance-based criteria as conditions for payment, use milestones (in combination with mitigation performance)
	Allocation of funds per project	Establish maximum funding per project as absolute amounts
Project eligibility	Eligibility criteria for projects	Focus on breakthrough technologies for the eligibility of projects – potential to support more mature technologies with other financial instruments
	Category specific quotas	Set specific minimum quotas per category to ensure that non-CCS industrial projects will be able to receive funding (with spill-over possibility) and small projects also
	Technology	Set ambitious emission reduction based thresholds for selection of projects underneath the main technology categories - but combine with criteria measuring co-benefits that hint at business opportunities (where possible). Install a dedicated incentive for low-carbon substitutes.
Additional points	Start and end dates	Provide flexibility to synchronise with investment cycles
	Facilitate collaboration	Encourage collaboration inside and across sectors through more favourable conditions for integrated consortia

References

Allwood, J.M. (2016): A bright future for UK steel. A strategy for innovation and leadership through up-cycling and integration. Cambridge, UK. Available online at: http://www.uselessgroup.org/files/a_bright_future_for_uk_steel.pdf. Date accessed 30.11.2016.

ArcelorMittal (2015): ArcelorMittal, LanzaTech and Primetals Technologies announce partnership to construct breakthrough €87m biofuel production facility. Available online at: http://corporate.arcelormittal.com/news-and-media/news/2015/july/13-07-2015.Date accessed 27.06.2016.

BusinessEurope (2016): EU ETS reform: making the Innovation Fund fit-for-purpose. Brussels.

Capture Power Limited (2016): Statement. Available online at: http://www.whiteroseccs.co.uk/

Calera (2017): Products. Available online at: http://www.calera.com/beneficial-reuse-of-co2/products.html.Date accessed 21.09.2017.

CEMBUREAU (2017): The Story of Cement Manufacture, Brussels.

Cement Sustainability Initiative (2009): Development of State of the Art-Techniques in Cement Manufacturing: Trying to Look Ahead, Duesseldorf, Geneva.

CEMEX (2017): Planned Plant Shutdown. Available online at: http://www.cemexcommunities.co.uk/planned-plant-shutdown.aspx. Date accessed 29.06.2017.

CemWeek Magazine (2013): The New Regenerative Thermal Oxidation (RTO) with integrated NOx Reduction at the Cement Plant Wopfing, Austria, in: CemWeek Magazine, October - November 2013, Issue 17, pp. 5-10.

CEPI (2011): The Forest Fibre Industry 2050 Roadmap to a low-carbon bio-economy. Brussels.

Chemical Engineering & Technology (2013): Carbonate Looping Technology, in: Chemical Engineering & Technology, Special Issue: Carbonate Looping, September 2013, Vol. 36(9), p. 1450.

CO2Chem (2012): Roadmap for the future of CO2Chem and CCU, Sheffield.

Cook, G. (2011): Investment, Carbon Pricing and Leakage. Cambridge.

Council of the European Union (2016): Outcome of the Council Meeting. Luxembourg.

Council of the European Union (2017): Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments - General approach, Brussels.

DECC, BIS (2015): Research and analysis: Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050. Available online at: https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050. Date accessed 20.04.2016.

DENA (2015): Power to Gas system solution. Opportunities, challenges and parameters on the way to marketability, Berlin.

Diekmann, W. (2014): Struktur von Horizont 2020 & Orientierungshilfe. Trier.

EIB (2014): NER300 Monetisation. Summary report on the monetisation of 300 million EU allowances (EUAs). Luxembourg. Available online at: http://www.eib.org/attachments/ner_summary_report_en.pdf. Date accessed 30.11.2016.

EUROFER, T.E.S.A. (2013): A Steel Roadmap for a low carbon Europe 2050. Brussels.

European Commission (2011) High-Level Expert Group on Key Enabling Technologies. Brussels.

European Commission (2013): Action Plan for a competitive and sustainable steel industry in Europe. COM(2013) 407 final. Brussels.

European Commission (2014): Commission Implementing Decision of 8.7.2014. Award Decision under the second call for proposals of the NER 300 funding programme. C(2014) 4493 final. Brussels.

European Commission (2015a): Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low carbon investments. COM(2015) 337 final. Brussels.

European Commission (2015b): Commission Staff Working Document: Impact Assessment. Accompanying the document Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low carbon investments. SWD(2015) 135 final. Brussels.

European Commission (2016): Commission Staff Working Document, Stakeholder Feedback on the Proposal for a Directive on the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low carbon investments (COM(2015)337 final). SWD(2015) 297 final. Brussels.

European Commission (2017a): Summary Report of Expert Consultations for Finance for Innovation: Towards the ETS Innovation Fund; Brussels.

European Commission (2017b): Commission Decision of XXX amending Commission Decision 2010/670/EU as regards the deployment of non-disbursed revenues from the first round of calls for proposals, Brussels. Available online at https://ec.europa.eu/clima/sites/clima/files/lowcarbon/ner300/docs/2017_draft_amendment_post_ccc_en.pdf. Date accessed: 14.11.2017.

European Council (2014): European Council (23 and 24 October 2014) Conclusions. Brussels.

European Parliament (2015): Developing a sustainable European industry of base metals. European Parliament resolution of 16 December 2015 on developing a sustainable European industry of base metals (2014/2211(INI)). P8_TA-PROV(2015)0460. Strasbourg.

European Parliament (2017): Cost-effective emission reductions and low-carbon investments ***I. Amendments adopted by the European Parliament on 15 February 2017 on the proposal for a directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments (COM(2015)0337 – C8-0190/2015 – 2015/0148(COD)), Strasbourg.

European Union (2009): Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. Brussels.

European Union (2010): Commission Decision of 3 November 2010 laying down criteria and measures for the financing of commercial demonstration projects that aim at the environmentally safe capture and geological storage of CO 2 as well as demonstration projects of innovative renewable energy technologies under the scheme for greenhouse gas emission allowance trading within the Community established by Directive 2003/87/EC of the European Parliament and of the Council. Brussels.

Federal Ministry of Finance (2013): BMF schafft Planungssicherheit beim Energie- und Klimafonds (EKF). Available online at: http://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Oeffentliche_Finanzen/Bundeshaushalt/2013-04-25-ekf.html. Date accessed 05.11.2016.

Gabrizova, Z., Dupáková, M. (2015): Eurofer boss: Europe’s steel industry needs modern trade defence instruments.

Garside, Ben (2016): Swedish firms launch initiative to decarbonise steelmaking, in: Carbon Pulse, April 4, 2016, Available online at: http://carbon-pulse.com/17894/ Date accessed 21.09.2016.

Grubb, M.; Hourcade, J.-C.; Neuhoff, K. (2013): Planetary Economics: Energy, climate change and the three domains of sustainable development, London

Hood, C. (2011): Summing up the Parts: Combining Policy Instruments for Least-Cost Climate Mitigation Strategies. International Energy Agency Information Paper. Paris.

Klar, D., Frishammar, J., Roman, V., Hallberg, D. (2016): A Technology Readiness Level scale for iron and steel industries, in: Ironmaking & Steelmaking, pp. 1–6.

Lichtenvort, K. Gagliardi F. (2017): European Leadership in Renewables – Funding Innovation. Sustainable Energy Week, 22 June 2017, Brussels. Available online at: https://setis.ec.europa.eu/system/files/eusew_ner300.pdf. Date accessed 27.06.2017.

Lupion, M., Herzog, H.J. (2013): NER300: Lessons learnt in attempting to secure CCS projects in Europe. International Journal of Greenhouse Gas Control, Vol. 19, pp. 19–25.

Mankins, J.C. (1995): Technology Readiness Levels: A White Paper.

Martin, S., Scott, J.T. (2000): The nature of innovation market failure and the design of public support for private innovation, in: Research Policy, Vol. 29, pp. 437–447.

Mazzucato, M. (2014): The Entrepreneurial States. London.

NER300.com (2017): Three further projects withdrawn from NER300. Total unspent awards: 436 M EUR, 16 May 2017, Available online at: http://www.ner300.com/?p=441. Date accessed 27.06.2017.

NER400.com (2017): ETS Trilogue: agreement within sight on ETS Innovation Fund. Available online at: http://ner400.com/2017/10/08/ets-trilogue-agreement-within-sight-on-ets-innovation-fund/ and: ner400.com/wp-content/uploads/2017/10/Amdt77_4col_Sept2017.docx. Date accessed 14.11.2017.

Neuhoff, K., Acworth, W., Ancygier, A., Branger, F., Christmas, I., Haussner, M., Ismer, R., Rooij, A. van, Sartor, O., Sato, M., Schopp, A. (2014): Carbon Control and Competitiveness Post 2020: The Steel Report. Final Report. Berlin.

Neuhoff, K., Ancygier, A., Ponssard, J.-P., Quirion, P., Sabio, N., Sartor, O., Sato, M., Schopp, A., (2015): Modernization and innovation in the materials sector: Lessons from steel and cement, Berlin.

Oberthür, S. (2016): The European Union in Crisis: What Future for the EU in International Climate Policy?, Policy brief Issue 2016/18, Brussels.

Otto, A.; Robinius, M.; Grube, T.; Schiebahn S., Praktiknjo, A.; Stolten, D. (2017): Power-to-Steel: Reducing CO_2 through the Integration of Renewable Energy and Hydrogen into the German Steel Industry, in: Energies, Vol. 10(451), pp. 1-21. doi:10.3390/en10040451

Piria, R. (2016a): Analyse der Erfahrungen mit NER300 in Blick auf die Gestaltung von NER400/Innovationsfonds. Berlin.

Piria, R. (2016b): Project volumes and co-financing rates for the industrial sector in the Innovation Fund. Berlin.

Piria, Raffaele; Naims, Henriette; Lorente Lafuente, Ana Maria (2016): Carbon Capture and Utilization (CCU): Klimapolitische Einordnung und innovationspolitische Bewertung. Berlin / Potsdam.

Posco and Primetals Technologies (2015): The Finex® Process. Economical and environmentally save ironmaking, Linz.

Remus, R; Aguado-Monsonet, M.A.; Roudier, S.; Sancho, L. D. (2013): Best Available Techniques (BAT) Reference Document for Iron and Steel Production, Luxembourg.

Rogge K.S. and Hoffmann V.H. (2010): The impact of the EU ETS on the sectoral innovation system for power generation technologies - Findings for Germany, in: Energy Policy, Vol. 38 (12), pp. 7639-7652.

Rogge K.S., Schneider M. and Hoffmann V.H. (2011): The innovation impact of the EU Emission Trading System - Findings of company case studies in the German Power Sector, in: Ecological Economics, Vol. 70 (3), pp. 513-523.

Romano, Matteo C.; Spinelli, Maurizio; Campanari, Stefano; Marchi, Stefano Consonni Maurizio; Pimpinelli, Natale; Cinti, Giovanni, (2014): The Calcium looping process for low CO2 emission cement plants, in: Energy Procedia, 2014, Vol. 61, pp. 500 – 503.

Rootzén, J. (2015): Pathways to deep decarbonisation of carbon-intensive industry in the European Union. Techno-economic assessments of key technologies and measures. Gothenburg.

Rootzén, J.; Kjärstad, J.; Johnsson, F. (2011): Prospects for CO2 capture in European industry, in: Management of Environmental Quality: An International Journal, Vol. 22(1), pp. 18-32.

Roth, S., Zetterberg, L., Acworth, W., Kangas, H.-L., Neuhoff, K., Zipperer, V. (2016): The pulp and paper overview paper. Sector analysis for the Climate Strategies Project on Inclusion of Consumption in Carbon Pricing. London.

Singh, J. (2015): Sponge Iron Consumption against Metallic Steel Scrap In Secondary Steel Making, Mumbai. Available online at: https://www.mrai.org.in/site/assets/files/5261/presentation_by_jitendra_singh_isc_udyog.pdf. Date accessed 27.06.2017.

SSAB; LKAB; Vattenfall (2016): HYBRIT – A Swedish prefeasibility study project for hydrogen based CO_2-free ironmaking. Enhancing the EU's industrial competitiveness through the EU ETS innovation fund. Available online at: http://carbonmarketwatch.org/wp-content/uploads/2016/04/SSAB-HYBRIT-A-Swedish-prefeasibility-study-project-for-hydrogen-based-CO2-free-ironmaking.pdf. Date accessed 21.09.2017.

Suopajärvi, H.; Kemppainen, A.; Haapakangas, J, Timo Fabritius (2017): Extensive review of the opportunities to use biomass-based fuels in iron and steelmaking processes, in: Journal of Cleaner Production, Vol. 148, pp. 709-734. http://dx.doi.org/10.1016/j.jclepro.2017.02.029.

UBA (2014): Treibhausgasneutrales Deutschland im Jahr 2050. Dessau-Roßlau.

UBA (2016): Integration von Power to Gas/Power to Liquid in den laufenden Transformationsprozess, Dessau-Roßlau.

Uihlein, A. (2017): The NER 300 Programme: Bringing low-carbon technologies to the market. EU Green Week 2017 (31 May 2017), Brussels.

WSP | Parsons Brinckerhoff, DNV GL (2015a): Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Iron and Steel. London.

WSP | Parsons Brinckerhoff, DNV GL (2015b): Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Iron and Steel Appendices. London.

WSP | Parsons Brinckerhoff, DNV GL (2015c): Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cement. London.

WSP | Parsons Brinckerhoff, DNV GL (2015d): Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cement Appendices. London.

WSP | Parsons Brinckerhoff, DNV GL (2015e): Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Pulp and Paper. London.

WSP | Parsons Brinckerhoff, DNV GL (2015f): Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Pulp and Paper Appendices. London.

Wyns, T., Axelson, M. (2016): The Final Frontier – Decarbonising Europe's energy intensive industries. Brussels.