E3G BELLONA

Carbon Capture and Storage Ladder

Assessing the Climate Value of CCS Applications in Europe

Briefing document

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About E3G

E3G is an independent climate change think tank with a global outlook. We work on the frontier of the climate landscape, tackling the barriers and advancing the solutions to a safe climate. Our goal is to translate climate politics, economics and policies into action.

E3G builds broad-based coalitions to deliver a safe climate, working closely with like-minded partners in government, politics, civil society, science, the media, public interest foundations and elsewhere to leverage change.

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About Bellona Foundation

The Bellona Foundation is an independent non-profit organisation that aims to meet and fight the climate challenges, by identifying and implementing sustainable environmental solutions. We work towards reaching a greater ecological understanding, protection of nature, the environment and health. Bellona is engaged in a broad range of current national and international environmental questions and issues around the world.

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The concepts developed here draw on the thinking of E3G and Bellona colleagues over the past decade, particularly Chris Littlecott (E3G) and Jonas Helseth (Bellona).

Neil Grant and Samantha Tanzer (Bellona) provided important initial contributions to conceptualising the CCS ladder. A special thanks to Amrei Milch (Bellona), Dido Gompertz (E3G) and Daniele Gibney (E3G) for communications and copy-edit support.

The development of the CCS ladder was inspired by the clean Hydrogen ladder developed by Michael Liebreich / Liebreich Associates, building on a concept by Adrien Hiel/Energy Cities.

We intend that this report and the CCS ladder concept can stimulate further discussion as to the public policy prioritisation of CCS applications and their enabling infrastructures. We appreciate feedback and suggestions to to incorporate into further iterations of the CCS ladder.

Executive summary

Carbon Capture and Storage (CCS) policy frameworks are being rapidly developed across Europe as the continent moves into an era of deep decarbonisation to achieve climate neutrality by 2050. Most pathways agree that this transition will require at least some amount of CCS deployment. This is happening in a broader context of emerging green industrial policy approaches alongside increased state involvement in terms of market intervention, regulation, and subsidies.

At the same time, the carbon capture debate lacks nuance, with CCS often perceived as a single technology with clear supporters and opponents. In reality, some CCS applications can contribute to a shift towards a climate-neutral economy while other applications have a higher risk of delaying real progress. In this context, there is a need to identify where CCS may deliver the greatest climate value via a merit order of CCS applications to help determine where to target policy support.

This briefing proposes a methodological framework for assessing the climate value of different CCS applications in Europe through the creation of a '**CCS Ladder**'.

To construct the ladder, a range of CCS applications are ranked across four criteria:

1. competition from alternative technologies
2. mitigation potential
3. feasibility
4. CO_2 source

The resulting intertemporal 'CCS Ladder' for 2030 and 2050 conveys the relative added value of different CCS use cases for a variety of industrial processes.

This briefing does not assess whether CCS should – or should not – be applied on a project-by-project basis. Determining the value of CCS for individual installations is dependent on many factors, including regionally and nationally differing access to alternatives, proximity to other potential capture sites, a plant's specific characteristics such as age, fuel use, and geographical location, as well as achievable capture rates, energy use, upstream emissions and socio-economic considerations. Instead, our CCS Ladder examines the relative climate value of different applications at an aggregate, Europe-wide level.

This briefing and the proposed methodology is version 1 of this work and not meant to be ultimately conclusive. Rather, we hope to stimulate a more nuanced and broader debate on the climate value certain CCS applications may have while developing further iterations of this Ladder over the coming years.

DISCLAIMER – the do's and don'ts of the CCS ladder

The CCS Ladder proposes a methodology / tool to policymakers and stakeholders to assess the value of CCS. Its aim is to **bring nuance into the debate** and help break the dichotomy between CCS opponents and proponents.

It can be used to inform debate and support the creation of regulatory frameworks. This can help facilitate the deployment of CCS where it is most needed, while limiting it where it is not.

What the CCS ladder is **NOT** meant to do:

1. **Be conclusive** – value propositions vary and criteria, and their underlying assumptions, may change over time.
2. **Denounce the use of CCS anywhere** – from a pure climate action perspective, capturing and storing emissions is always better than emitting them.
3. **Judge whether CCS should or should not be applied** on a project-by-project basis.
    - The ladder looks at applications in the broad sense.
    - The actual value of CCS for individual plants is dependent on plants' characteristics (*age*, *fuel use*, *geography,* etc.).

In short, we argue CCS is most valuable for industrial processes which align with all of the following conditions, where:

- There are limited alternatives for deep decarbonisation/defossilisation
- CCS has a significant emissions reduction potential
- CCS has (relatively) limited feasibility challenges to scale and deliver emission reductions based on costs, location and/or size of individual CO_2 sources, and
- CCS has limited negative side effects such as fossil fuel lock-in.

CCS Ladder for 2030 and 2050 (Figure A) **— Key takeaways**

1. **The climate value of CCS is lowest in the power sector and is expected to diminish considerably over time.**
2. **CCS's climate value is greatest for industrial applications with significant process emissions, particularly in non-metallic mineral sectors such as cement and lime.** The climate value of CCS for these applications is expected to increase through to 2050 as the full potential of other emission reduction levers like electrification, efficiency improvements, demand reduction and substitution are maxed out.
3. **It is generally expected that the climate value of CCS for most applications will decrease over time, while becoming increasingly important for helping to achieve negative emissions** through direct air capture.

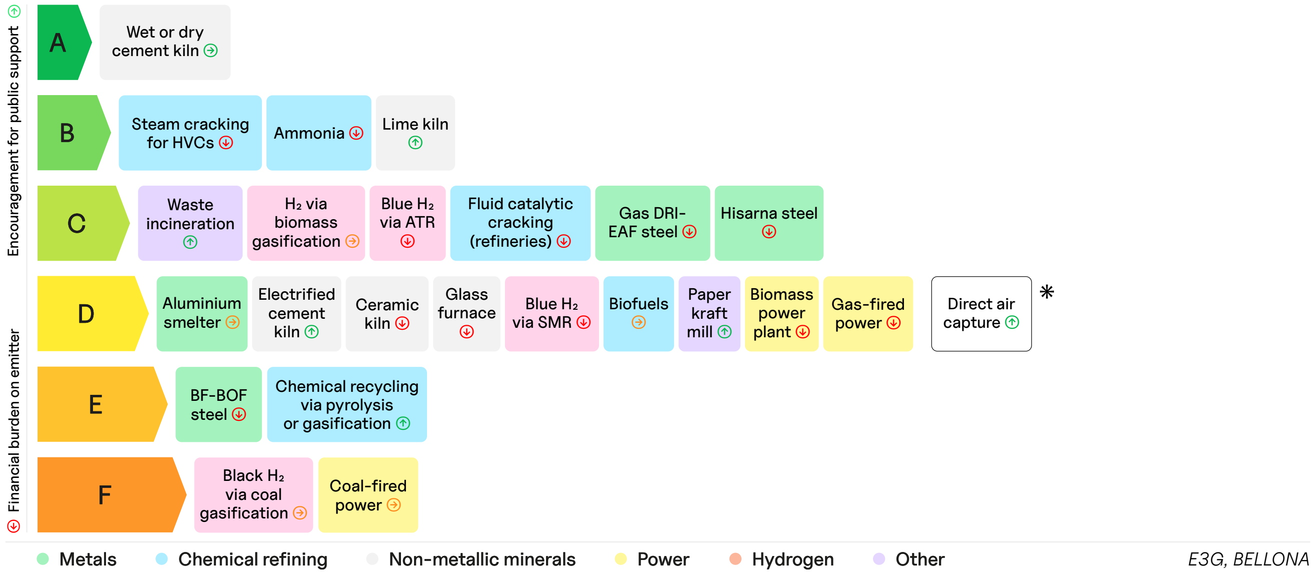
Recommendations

1. **When assessing the climate value of CCS applications, a holistic approach is required as not all CCS is the same.** In the context of deep decarbonisation, assessing the climate value of CCS applications must go beyond a simple 'emissions reduction to investment ratio' approach, and account for the whole host of environmental, ecological, financial, and technical feasibility factors.
2. **European policymakers need to undertake their own robust assessments to determine the climate value of different CCS applications.** These assessments should be based on objective and transparent criteria, established through input from all concerned stakeholders, and updated regularly considering the overall changing climate value that CCS deployment may have over time.
3. **European policymakers should target public support to CCS applications with the highest climate value, setting an example for others.** Limited public resources and restricted storage injection capacity, especially in the short- to medium-term, further support the logic of targeting public support– both financial and non-monetary – for those applications with the greatest climate value, particularly if their scale-up proves challenging due to technical and regulatory factors. In this context, the European Commission's proposal in the Net Zero Industry Act to obligate oil and gas producers to make storage injection capacity available should be welcomed, as it alleviates some of the pressure from public finances.
4. **Accelerated electrification, rapid scale-up of renewables, and increased deployment of energy efficiency and circular solutions are all needed.** Overall, the highest value of CCS for climate action can only be achieved if all other measures are deployed at the necessary scale and pace. Drastic reductions in fossil fuel usage, combined with a strong emphasis on energy efficiency and lowering primary energy demand, are necessary to reach climate targets and limit the risk of potential overreliance on CCS which could itself compromise climate objectives.

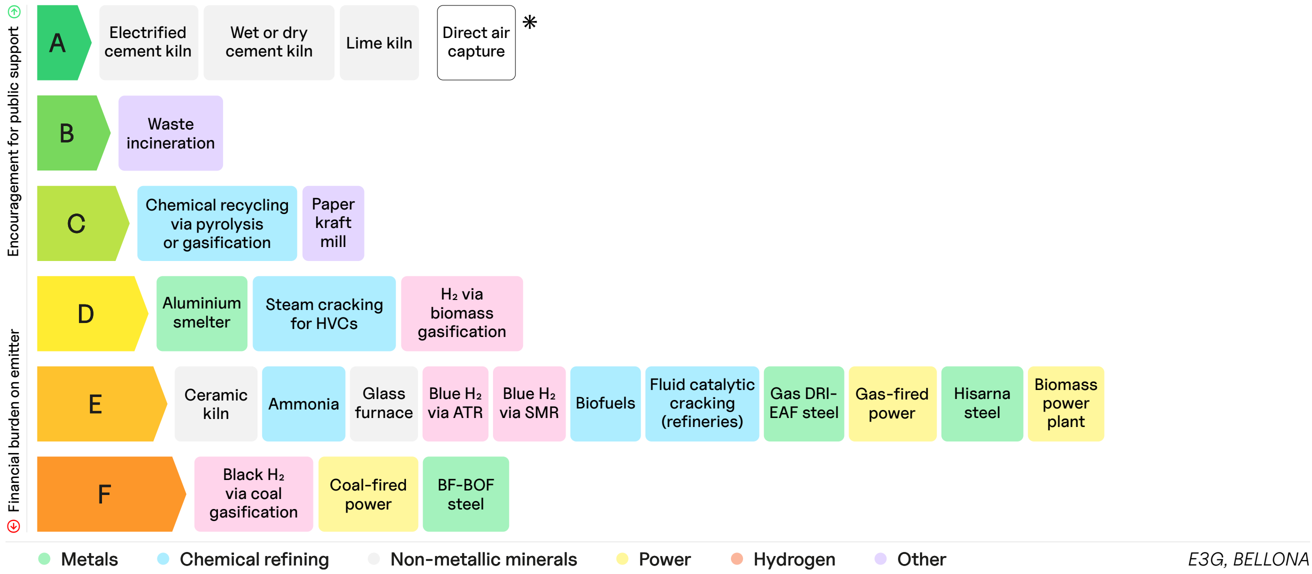
Figure A

CCS Ladder for 2030 and 2050[1]

Near-term 2030



Long-term 2050



Notes on diagrams:

* Please refer to page 8 in the 'Criteria and Methodology' document for our approach on DAC and other Carbon Dioxide Removals technologies in the ladder.

1 See Figure 3 in-text for a policy prioritisation variation of the above CCS Ladder for 2030 and 2050.

2030/2050 CCS ladder based on scoring of applications against four criteria. Applications are labelled by sector. Coloured arrows indicate the change in rank from 2030 to 2050 (up, down or stable). See Disclaimer on page 4 on how to interpret the CCS Ladder.

Introduction: carbon capture and storage – A debate lacking nuance

Carbon capture and storage (CCS) refers to an array of different technologies that can capture and permanently store emissions from different point sources to prevent them from reaching the atmosphere. Unlike carbon capture and usage (CCU), CCS can unequivocally reduce life-cycle emissions from industrial operations, delivering climate action through the permanent storage of CO_2 – understood as the long-term storage of CO_2 for centuries under normal practice.[2]

Most decarbonisation pathways compatible with 1.5°C require at least some level of CCS deployment to achieve the Paris Agreement goals, and many modelled pathways deploy large amounts of CCS across a range of different sectors and applications.[3] Despite the critical role of carbon capture in these pathways, there are many stakeholders in the climate space who are sceptical of its value as a climate solution. Indeed, while CCS enables the possible reduction of adverse CO_2-related climate impacts, it nevertheless addresses the symptom of our fossil-fuel powered economic system[4] rather than the source. Moreover, some stakeholders fear that deploying CCS risks crowding out investments in other decarbonisation options, thus constituting a 'moral hazard' against mitigation.[5]

Nuance is therefore lacking in the carbon capture debate, where CCS is often referred to as a single technology with clear proponents and opponents. In practice, CCS refers to a wide range of carbon capture technologies which can be applied to a variety of CO_2 sources that originate from a plethora of processes producing different goods and products. Instead of further polarisation, a more differentiated picture of the differing value propositions of this wide range of applications is needed. Some CCS applications can contribute to mitigation as part of a systemic and fundamental shift towards a more sustainable and climate-neutral economy. Other applications can come with a higher risk of delaying the transition.

What is critically lacking at present is the integration of CCS alongside other technologies within the broader decarbonisation landscape. CCS must be placed within the wider system of general climate action to help satisfy the decarbonisation needs of a diverse and complex set of emitters. Doing so requires considering the intricacies of CCS as both a technology and a form of infrastructure, as well as the specific contextual circumstances surrounding its deployment on a process-by-process basis.

Consequently, robust policy and regulatory frameworks are needed to govern the usage of CCS. These will need to follow clear principles that address concerns around the use of this technology while ensuring a responsible and objective-oriented deployment of CCS, through which trust in it as part of the toolbox of climate solutions can grow.

The case for a CCS Ladder: a tool to aid in targeting limited public resources

The CCS policy landscape is evolving rapidly in Europe. EU Member States such as the Netherlands[6] and Denmark[7] have started rolling out policy instruments to support CCS, including for developing CO_2 storage sites. France[8] and Germany[9] have both initiated national debates on the role CCS will play in the transition to climate neutrality. Meanwhile, the EU is increasing financial support for CCS projects – most notably through the Innovation Fund[10] – and the European Commission has recently proposed an obligation to EU oil an gas producers to make available 50 Mtpa CO_2 storage injection capacity as part of the Net Zero Industry Act.[11]

2 There is no absolute definition of permanence. The European Commission does not define permanence in the context of the 2009 CCS Directive but it has proposed a definition of permanence as "an activity that, under normal circumstances and using appropriate management practices, stores […] carbon for several centuries" in the context of carbon removals (European Commission, 2022, Proposal for a regulation establishing a Union certification framework for carbon removals).

3 IPCC scenarios that limit global warming to 1.5°C with limited or no overshoot rely on storing 100–1000 Gt ofcarbon dioxide throughout the 21st century (IPCC, 2018, Global Warming of 1.5 °C).

4 CCS also cannot address upstream emissions related to the extraction, processing and transport of fossil fuels.

5 Energy Transitions Commission, 2022, Carbon Capture, Utilisation & Storage in the Energy Transition: Vital but Limited.

6 Bellona, 2021, The Industrial CCS Support Framework in the Netherlands.

7 Danish Energy Agency, 2022, CCUS FUND.

8 Ministère de ,l'Economie des finances et de la souveraineté industrielle et numérique, 2023, Transition écologique : une planification pour accélérer la décarbonation des sites industriels.

9 BMWK, 2023, Beginn des Stakeholdersdialogs zur Carbon Management Strategie.

10 European Commission, 2022, Innovation Fund second call for large-scale projects.

11 European Commission, 2023, Proposal on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act).

This more active role of government in facilitating CCS deployment and wider decarbonisation efforts can be seen in the context of rapidly blurring lines between climate action and industrial policy. Green industrial policy packages are emerging across the world, including the US Inflation Reduction Act[12] and the EU's Green Deal Industrial Plan.[13] In this new policy landscape in which there is increased state involvement through a combination of intervention, regulation[14], and subsidies, there is a need to identify where policymakers can deliver the greatest climate value[15] for their deployment of scarce public resources when it comes to CCS vis-à-vis other emissions reduction options.

We argue that the deployment of CCS must be targeted due to limitations that affect its potential end use. Although CCS may help abate emissions in some sectors, certain technical and geographic limitations mean it is not an economy-wide solution for climate neutrality.

Indeed, policy frameworks for CCS deployment will require prioritisation for at least three reasons:

1. **Adverse impacts of CCS.** No technology has zero impacts, and the side-effects of all technologies must be considered during decision-making processes. CCS has adverse consequences specific to its deployment that should be considered. These include the local environmental impacts of CCS – from large-scale infrastructure deployment and continued fossil extraction – as well as increased energy use, the risk of locking-in fossil fuels, and the associated health impacts resulting from facilitating combustion-induced air pollution, including from biomass.
2. **Limited access to operational storage resources.** It is becoming clear that practical CO_2 storage availability may substantially limit CCS deployment, especially in the near- to medium-term. While there is sufficient theoretical CO_2 storage capacity, a range of technical, contractual, and regulatory barriers may constrain practical storage potential and feasible injection rates.[16] Moreover, the future demand for storage capacity will not only originate from emission mitigation via CCS – the focus of this briefing – but also from technological carbon dioxide removal (CDR). If CO_2 storage is scarce,[17] it is essential that it is used in an efficient way, while simultaneously scaling up available storage injection capacity. Here, the EU proposal for the Net Zero Industry Act goes in the right direction.
3. **Concerns around feasibility.** The track record for CCS deployment to date has been poor, with many projects being discontinued or not moving into their construction phases for a variety of reasons.[18] Therefore, there is a real possibility that large-scale CCS deployment may not be achieved if lessons are not learned from previous experiences.

In this context, a 'ladder' which can identify the value attached to different use cases of CCS across a variety of industrial processes can be a valuable tool for assisting policymakers and other stakeholders. While Liebreich Associates' Clean Hydrogen Ladder[19] has helped shape and inform the debate regarding the merit order of use cases for clean hydrogen, such a tool does not exist for CCS. Inspired by this work, our Ladder aims to encourage a similarly informed debate regarding where CCS can deliver the highest climate value. As such, this work brings together various ideas and concepts that have been part of E3G, Bellona and their partners' thinking for the past decade, unifying different elements of our work into a single, succinct framework.

As increasing attention is being devoted in Europe and elsewhere by both industry and policymakers to scaling up CCS, our Ladder can help illustrate where the greatest climate potential to investment ratio for CCS deployments could be achieved.

12 Senate Democrats, 2022, Summary: The Inflation Reduction Act of 2022.

13 European Commission, 2023, The Green Deal Industrial Plan.

14 The recently proposed greenhouse gas standards and guidelines for fossil fuel-fired power plants by the US Environmental Protection Agency are a good example of how regulation can drive (standards for) CCS deployment (EPA, 2023, Greenhouse Gas Standards and Guidelines for Fossil Fuel-Fired Power Plants).

15 The term 'climate value' is defined according to the methodological framework proposed in this work which conveys the impacts and relative added value of different CCS use cases for a range of industrial processes via the operationalisation of four criteria (competition from alternative technologies; mitigation potential; feasibility; CO_2 source).

16 Lane, J. et al., 2021, Uncertain storage prospects create a conundrum for carbon capture and storage ambitions.

17 In practice, the question of practical storage potential can only be answered through further exploration and limited yet substantial CCS deployment.

18 Wang et al., 2021, What went wrong? Learning from three decades of carbon capture, utilization and sequestration (CCUS) pilot and demonstration projects.

19 Liebreich Associates' Clean Hydrogen Ladder.

Goals and audience

By proposing a framework to assess the value of CCS in the context of deep decarbonisation, we hope to inform stakeholders that are engaging with the complex topic of CCS. Our primary target groups include policymakers who are assessing CCS policy framework designs, NGOs who are evaluating the role CCS can play in the climate transition, and industry representatives seeking to decarbonise their activities in line with climate neutrality goals.

The inherent value of this exercise lies in showcasing the different climate values of CCS applications for various industrial processes. Consequently, we highlight where it is most prudent to dedicate limited resources for scaling up necessary CO_2 transport and storage infrastructure. These resources can be measured in terms of both finance and time, and our work should help enable and empower stakeholders in making informed, climate-aligned decisions regarding CCS deployment.

This CCS Ladder is meant to be a conversation starter, rather than be ultimately conclusive. We fully acknowledge that there are different ways of thinking about CCS, and that some stakeholders' value propositions vary. Indeed, we encourage debate between all sides – industry, legislators, and civil society – concerning both the value of this exercise and, more significantly, on the climate value of certain CCS applications for effective decarbonisation.

The Ladder is not intended to prescribe whether, where or how much CCS should be undertaken. Rather, a set of criteria are proposed which we believe should be considered when trying to assess the climate value of possible CCS applications in Europe. As such, our argument is that in the context of limited public resources and competing climate solutions, public support – in a broad sense, ranging from infrastructure planning to policy frameworks or financial aid – should be targeted to those CCS applications that can facilitate the greatest climate value. In other words, access to (limited and) accessible CO_2 storage capacity, publicly funded CO_2 infrastructure or project support for applications that are lower down the Ladder should be secondary to that of high-priority applications.

However, it is important to note that being ranked lower in our illustrations does not necessarily imply that those processes should be restricted from deploying CCS altogether. **All other things being equal, capturing and permanently storing emissions is always better than simply continuing to emit - and ideally, all *unabated* fossil fuels should ultimately be subject to a ban.** Nevertheless, the pursuit of *alternative* mitigation strategies, particularly for those lower-ranking applications, should be emphasised due to the host of adverse impacts that can be incurred by deploying CCS.

Moreover, this exercise does not try to assess whether CCS should – or should not – be applied on a project-by-project basis. Determining the value of CCS for individual installations will depend on many factors, including a plant's specific characteristics – such as age, fuel use, and geographical location – as well as achievable capture rates, energy use, upstream emissions, and socio-economic considerations. Rather, the Ladder looks at applications in the broad sense from a Europe-wide perspective.

In summary, **the CCS Ladder can help calibrate expectations** around the contribution(s) that different CCS deployments can make for successful decarbonisation, and convey where limited public resources could be best targeted to maximise the climate value obtained by fitting CCS to certain industrial applications.

Methodology: four criteria to assess the climate value of CCS applications

We assess the climate value of CCS applications across four key criteria. These criteria, including the justifications for their selection and how the criteria are operationalised, are extensively detailed in the separate methodology document.[20]

In effect, these criteria aim to capture the various complexities and considerations that underpin CCS deployments across a wide variety of industrial processes. This set of criteria is not exhaustive but covers the most critical elements that can be robustly quantified in a consistent manner to help measure the climate value of different CCS applications.

20 See E3G and Bellona, 2023, Carbon Capture and Storage Ladder for Europe: Assessing the Climate Value of CCS Applications – Criteria and Methodology.

1. **Competition from alternative technologies** – *Are there alternative low-carbon technologies, currently or soon to be available, on a scale that could produce the same good/material in a manner compatible with climate neutrality and bring forward defossilisation, without reliance on CCS? Are related feed-stocks/resources such as clean energy available in sufficient quantities?*
2. **Mitigation potential** – *To what extent can CCS deployment reduce overall emissions and contribute to European climate goals? This covers both a system dimension (i.e., overall emission reductions potential) and single plant/good dimension (i.e., how much can the application of CCS lower its total life-cycle emissions?).*
3. **Feasibility of carbon capture** – *How feasible is CCS deployment in this sector? What is the techno-economic feasibility of upscaling its deployment? This considers spatial distribution and proximity to clusters (infrastructure needs), individual source sizes etc., which can all impact the system costs of CCS deployment.*
4. **CO_2 source** – *What is the source of CO_2 being captured? Is there a risk of lock-in to fossil fuels by deploying CCS or other negative side-effects such as from biomass production?*

A non-exhaustive list of 24 CCS applications[21] was compiled covering a wide range of sectors.[22] For some sectors (e.g., primary steel or hydrogen production) several production routes were incorporated to showcase that the climate value of CCS can differ within an individual sector. These applications were ranked across the four criteria on a scale of 1 (lowest) to 5 (highest) using quantitative data supplemented by qualitative assessments. This was conducted by the authors of this briefing and tested externally through several stakeholder workshops. The resulting multicriteria matrix can be seen in Figure 1.

Scores were then averaged into an overall ranking classification ranging from 'A' to 'F' and utilised to design a **CCS Ladder for 2030 and 2050**, in alignment with European climate targets.[23] The goal of this temporal differentiation is to assess the value of CCS while accounting for complementary emission reduction trends. We worked from the explicit assumption that other decarbonisation options[24] will develop and be deployed in parallel to CCS, in line with existing policy frameworks of the EU, Member States, and other neighbouring European countries.

The CCS Ladder for 2030 and 2050 is presented in Figure 2. Following this, further graphics are presented in Figure 3 that illustrate how groupings of different ranking classifications can be interpreted alongside the associated policy implications of doing so.

To preview our results, we argue that CCS is most valuable for industrial processes that meet all of the following conditions, where: i) there is limited alternatives for timely deep decarbonisation/defossilisation; ii) CCS has a significant emissions reduction potential; iii) CCS has (relatively) limited feasibility challenges to scale and deliver emission reductions based on costs, location and size of individual CO_2 sources, and; iv) CCS has limited negative side effects such as fossil fuel lock-in.

Results

Figure 1 shows a heatmap summarising the scores of the 24 industrial processes assessed in this work, from which a series of initial observations can be made.[25]

21 See E3G and Bellona, 2023, Carbon Capture and Storage Ladder for Europe: Assessing the Climate Value of CCS Applications – Criteria and Methodology (Annex).

22 A nuanced approach was taken to removals in this work since they cannot be a substitute for deep emissions reductions. Certain bioenergy with carbon capture and storage applications utilising only sustainable biomass are included in the Ladder. Direct air capture is treated separately within the Ladder visualisations to make clear that CDR should not be conflated with industrial CCS, nor distract from the need for CCS applications to facilitate ambitious emission reductions since CDR technology remains in its infancy.

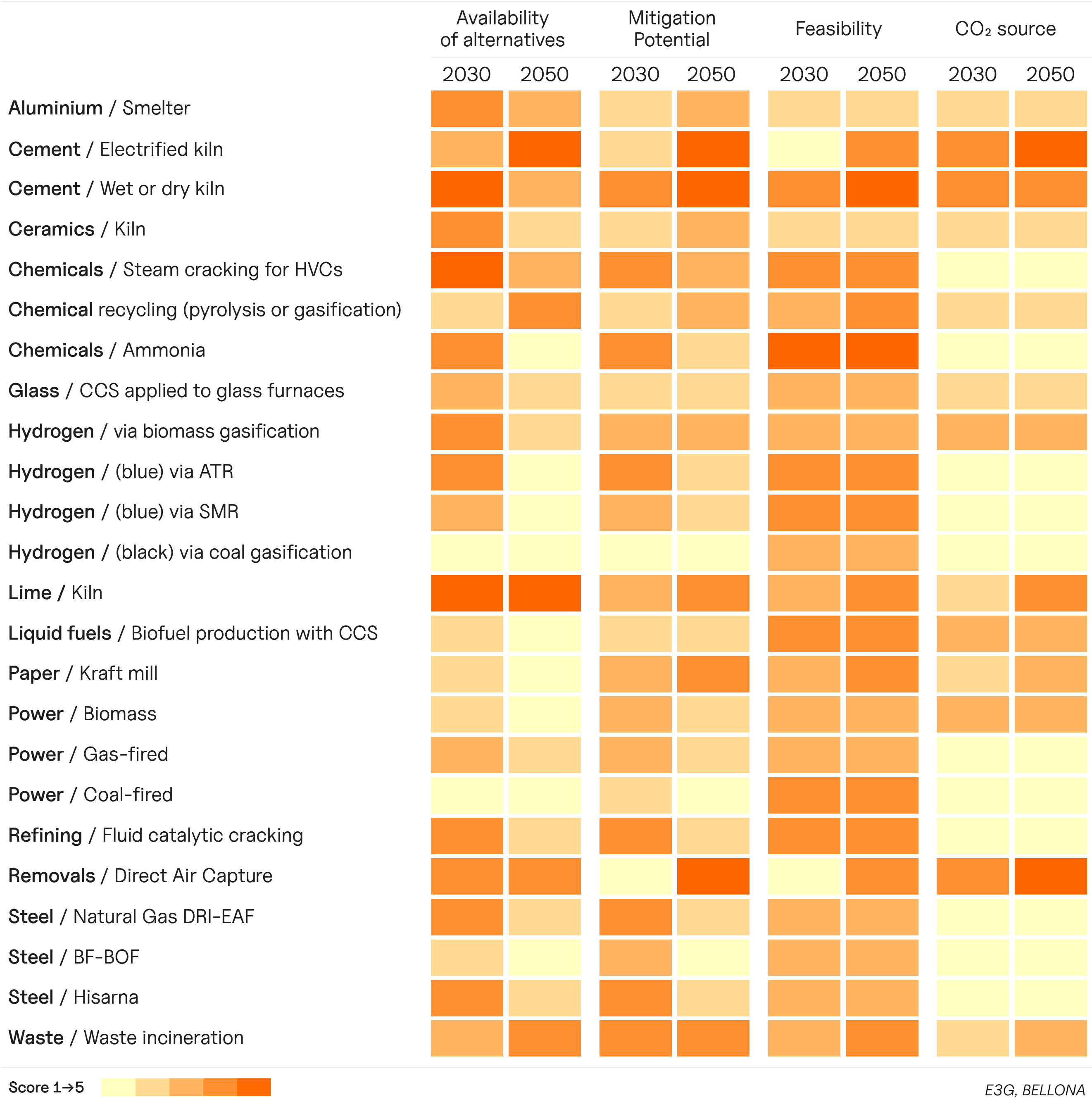
23 The rationale for designing the Ladder around two temporal anchors – 2030 and 2050 – can be found in the accompanying methodology document (E3G and Bellona, 2023, Carbon Capture and Storage Ladder for Europe: Assessing the Climate Value of CCS Applications – Criteria and Methodology).

24 For example, increased: energy efficiency; renewable energy deployment; electrification; circularity; substitution.

25 An interactive online version of the scoring matrix detailing the justification behind the criteria scoring for each individual CCS application – as well as downloadable Excel version – can be found on our publication page.

Figure 1

CSS applications heatmap (2030–2050)



Competition from alternative technologies

Broadly, scores change significantly between 2030 and 2050. This is due to the expected maturing of alternative technologies, lower costs facilitating increased deployment of renewable electricity, and associated increased scale-up and availability of green hydrogen. Moreover, due to imperfect capture rates and upstream emissions, the residual emissions associated with CCS will increasingly be punished through carbon pricing or other environmental regulation, in turn progressively improving the business case of alternative technologies vis-à-vis CCS. Notably, only a few applications still receive a score of 4 or higher in 2050 – by then, the highest scoring applications are often those which have considerable process emissions.[26]

It is worth highlighting that applications in the power sector generally score low on this criterion, a consequence of the falling cost of renewables. In other words, lower renewables costs and their wider deployment reduce the need for CCS in electricity generation. Additionally, the score for hydrogen-producing applications drops significantly between 2030 and 2050 as green hydrogen is expected to be scaled up and become increasingly cheap. The same holds true for applications that can utilise hydrogen, most notably steel and ammonia production.

Mitigation potential

Very few applications receive the highest score – perfect capture rates are deemed to be highly unlikely, if not impossible. Generally, applications which would continue to use fossil fuels receive a lower score. This is not only a result of imperfect capture rates but also due to continued (and considerable) upstream emissions which must be actively reduced in their own right. Fossil fuel applications with few existing emissions and lower feasible capture rates receive the lowest scores. In contrast, applications with large quantities of emissions in absolute terms and high feasible capture rates receive a higher score for this criterion, broadly speaking.

For some applications, scores change between 2030 and 2050 for several reasons.

1. As certain processes or associated products are expected to be progressively phased down over time in Europe, such as gas-fired power, the potential of reducing emissions through applying CCS decreases in tandem.
2. The mitigation potential for some nascent technologies, such as electrified kilns or direct air capture technologies, is expected to increase over time in line with their expected scale-up rate and greater clean electricity availability across Europe.
3. Upstream and residual emissions receive a higher penalty in 2050 vs. 2030 as the persistence of upstream and residual emissions associated with CCS applications would constitute a more significant problem in 2050 – the date by which the likes of the EU must meet its legal obligation to achieve climate neutrality.
4. The value of mitigating CO_2 from applications with relatively low emissions in absolute terms today will increase over time if activity levels are expected to remain relatively stable, few upstream emissions occur, and if high capture rates are feasible.

Feasibility of carbon capture

High scores are given to those applications which are usually located in industrial clusters with good access to infrastructure, and those industries which have large, concentrated CO_2 streams such as chemicals, refineries and steel. Sectors such as lime and ceramics receive lower scores due to high numbers of geographically dispersed plants, each of which typically have relatively small emissions.

Feasibility scores are expected to increase over time for most applications as CCS technologies further mature and infrastructure limitations diminish, overcoming a key bottleneck – subject to public support. Indeed, it is worth highlighting that there are several applications that score low on this criterion yet high on most others. This points to the fact that infrastructure availability (and associated costs) can be seen as a bottleneck for CCS to reach its theoretical climate value for certain applications. In this context, facilitating alternative CO_2 transport options such as rail and ships - rather than pipes - could help address locality issues for priority applications.

26 Defined as emissions resulting from chemical or physical transformations other than fuel combustion during the production process (IEA, 2020, The challenge of reaching zero emissions in heavy industry).

CO_2 source

Scoring for this criterion is relatively straightforward as the fuel mix considered for each application has been specified.[27] Scores for this criterion are relatively stable across the temporal dimension as many of the considered applications are dependent on specific fossil-fuel inputs. Evidently, those applications with considerable quantities of unavoidable process emissions receive the highest scores. Notably, for a few special cases, the score assigned to an individual industrial process changes between 2030 and 2050. For example, waste incineration is treated equal to sustainable biomass in 2050 as the share of biogenic waste is set to increase over time as better sorting and circularity measures are expected to reduce the amount of fossil waste.

It is interesting to observe that, especially in 2030, several applications with a low score on this category still have relatively high average scores – mainly chemicals and refineries. Despite the relatively high suitability of CCS in driving down emissions in these sectors in the short- to medium- term, targeting CCS deployments in these sectors could produce further lock-in of fossil fuel consumption.[28]

Constructing a ladder for CCS applications

By averaging the individual scores, a CCS Ladder is constructed identifying the value of CCS deployments on different industrial processes for 2030 and 2050. Figure 2 showcases the Ladder for 2030 and 2050 with an overall ranking classification ranging from 'A' to 'F'; each application is coloured by sector. An overview of how applications' ranking classifications change between the 2030 and 2050 CCS Ladder is presented in this briefing's Annex.

The purpose of this exercise is not to focus too much on the specific classifications for each individual application. Rather, the value of the Ladder is in conveying broad messaging about the overall placement of CCS applications for different industrial processes within the wider decarbonisation landscape. Consequently, several general observations can be made.

Firstly, the value of CCS is lowest in the power sector and is expected to diminish considerably over time. While in the past CCS was often associated solely with coal power generation,[29] the Ladder confirms that the discussion and policy focus should be more centred on the value CCS brings across a wide spectrum of industrial processes. Renewables have become such a viable and cheap alternative – and are expected to continue to drop in price – that CCS is now a relatively low-value option for decarbonising the power sector.

Secondly, the value of CCS will grow for specific industrial applications (including direct air capture) and is expected to increase through to 2050. This is especially true for the cement and lime industries, even when assuming significantly less production in 2050.[30] While the case for the deployment of CCS in energy-intensive sectors is a lot clearer than for the power sector, only a few applications rank at the top of the Ladder. CCS will be most pivotal for industrial sectors with a high share of unavoidable process emissions, particularly in several non-metallic mineral sectors. The overall score of these applications also improves over time as the potential of other decarbonisation levers is exhausted, and unavoidable process emissions become an increasingly greater share of total remaining emissions.

Lastly, it is generally expected that the climate value of CCS as a mitigation tool will decrease over time. This is due to commitments to drastically scale up renewables thereby also facilitating green hydrogen production, which will likely become increasingly cost-competitive and available in sufficiently large quantities. This is true for all industrial processes that can electrify directly and also for both hydrogen production and applications that compete with hydrogen-based technologies, most notably primary steel production. Nevertheless, CCS will remain key to mitigating unavoidable process emissions as well as become increasingly important for achieving negative emissions through direct air capture.

27 For the exact detail of the scores assigned to different fuel mixes, see E3G and Bellona, 2023, Carbon Capture and Storage Ladder for Europe: Assessing the Climate Value of CCS Applications – Criteria and Methodology, 'Methodology: operationalising the criteria – Criterion #4: CO_2 source'.

28 Also, especially within the chemical industry, a case can be made that this industry might need to internally recycle their (hot) CO_2 waste streams directly.

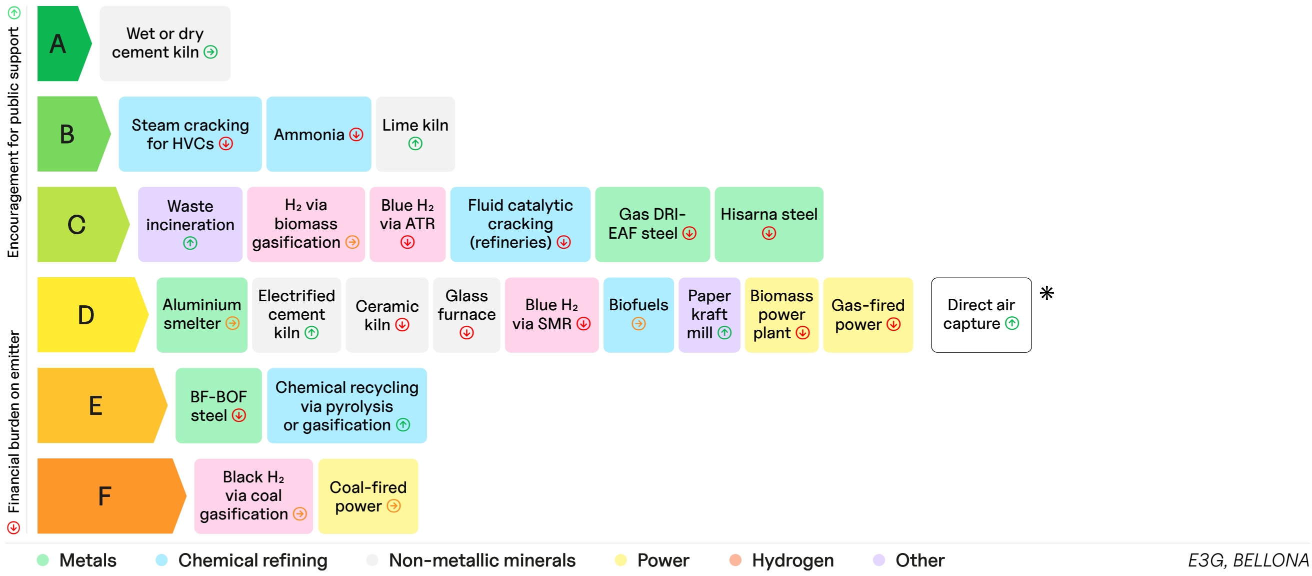
29 E3G, 2020, European CCS: leaning from failure or failing to learn?.

30 Fennel et al., 2022, Cement and steel – nine steps to net zero.

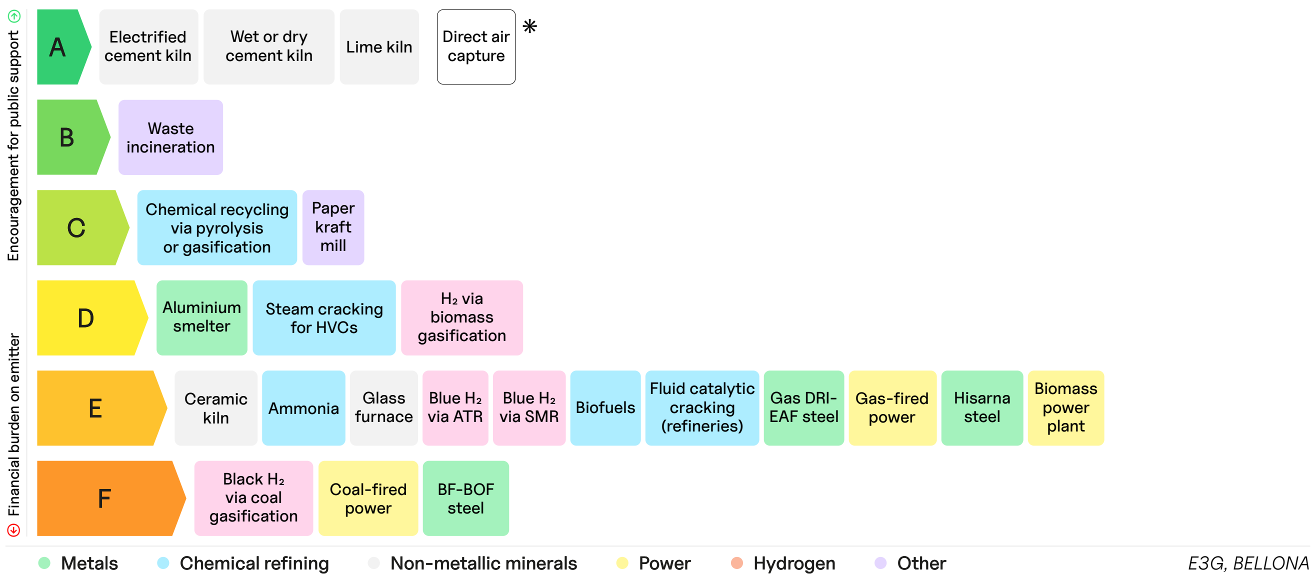
Figure 2

CCS Ladder for 2030 and 2050[31]

2030



2050



Notes on diagrams:

* Please refer to page 8 in the 'Criteria and Methodology' document for our approach on DAC and other Carbon Dioxide Removals technologies in the ladder.

31 2030/2050 CCS ladder based on scoring of applications against four criteria. Applications are labelled by sector. See Disclaimer on page 4 on how to interpret the CCS Ladder. Coloured arrows indicate the change in rank from 2030 to 2050 (up, down or stable).

Utilising the Ladder in policy frameworks for CCS

While a quantitative aggregation is useful to clearly rank CCS applications by their climate value and showcase temporal changes, for most categories the thresholds (based on small score intervals in our assessment) are too narrow to match strong value propositions or policy implications based on each application's individual ranking. This is because, except for the 'A' and 'F' classifications, relatively small changes in scoring can result in applications easily moving between levels.

As such, in designing CCS policy frameworks, it would be better to think in terms of a dual axis. This dual axis represents a bidirectional continuum showcasing growing CCS prioritisation for different industrial processes while concurrently illustrating where addressing emissions through other means should be preferred. This categorisation and bidirectional continuum is depicted in Figure 3], which groups applications into four broad divisions for both 2030 and 2050. This Ladder can help policymakers determine where limited public resources should be targeted.[32]

Top ranking applications (dark green category) can largely be considered impossible to fully decarbonise without the use of CCS technologies. In our policy prioritisation CCS Ladder, this level mainly includes those applications for which unavoidable process emissions make up a very large share of overall emissions, and where alternative production routes to achieve full decarbonisation are unclear at this stage. These sectors should be targeted for infrastructure planning and public support if possible. It goes without saying that any support should be combined with, and contingent on, measures being taken to maximise emissions reductions through other means, including through electrification, fuel substitution, energy and material efficiency, and circularity.

Bottom ranking applications (peach category) are those which typically have a plethora of alternative abatement options available. While there is little case to provide public (financial) support for these applications, policy frameworks should put the onus on emitters if they desire to address their emissions through CCS deployment, while focusing public support on alternative mitigation options. Banning the use of unabated fossil fuels in these processes could also be considered first for such applications.

For middle ranking applications, CCS policy framework design choices are less obvious thereby warranting a more cautious approach in terms of the policy support provided. For applications towards the upper end of the Ladder, the climate value of CCS deployments is relatively high, but the overall extent of deployment needs and/or feasibility is uncertain at present. For those applications towards the Ladder's bottom end, the case for CCS progressively becomes less evident – and with it the justification for public support. Here, local circumstances, and in particular plant characteristics (e.g., location, age, fuel use, negative emissions potential etc.), become increasingly important elements to consider when determining the climate value of potential CCS applications.[33]

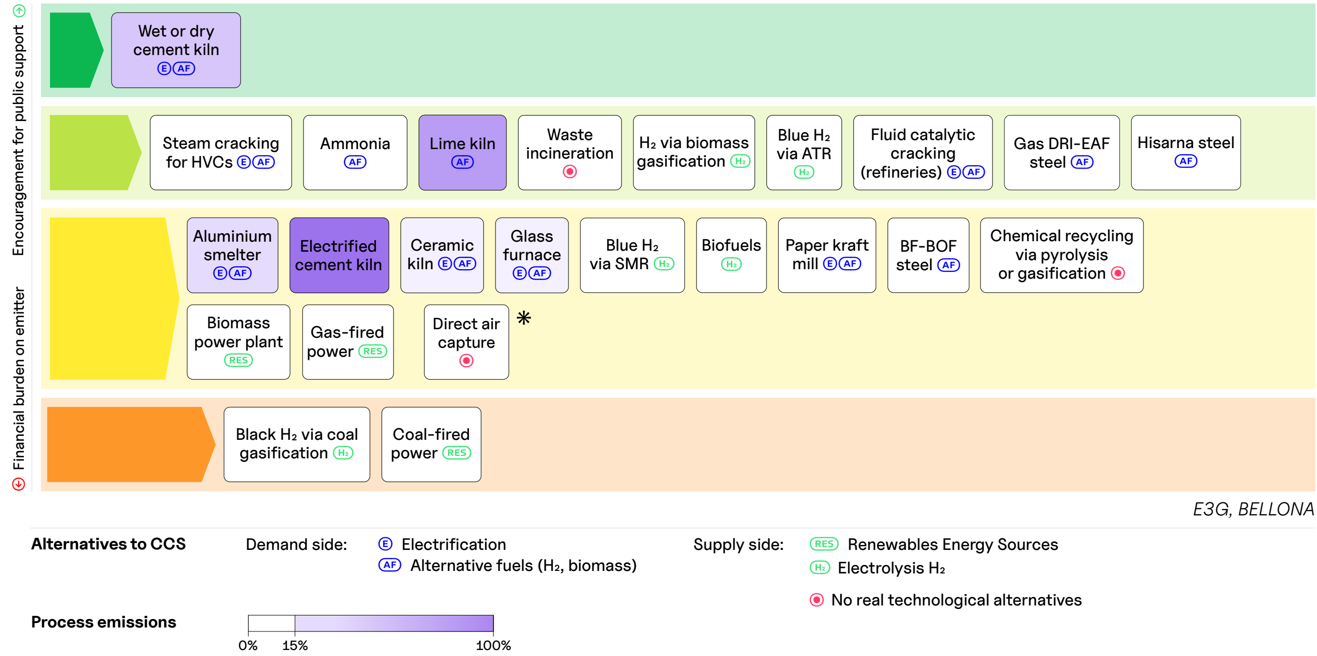
32 For information on how to design policy frameworks for high-value CCS applications see E3G, 2022, Making carbon capture work: a framework to facilitate high-value uses in Europe.

33 Take, for example, an old paper mill in Belgium which has access to cheap, renewable offshore wind. Since the temperature needs for the production process are relatively low, direct electrification will likely be the most suitable decarbonisation option. In contrast, consider the case of a relatively young paper mill in Sweden near existing transport and storage infrastructure which has access to locally sourced, sustainable biomass. For this case, even though direct electrification is technically possible, CCS might be a suitable decarbonisation option to help facilitate negative emissions.

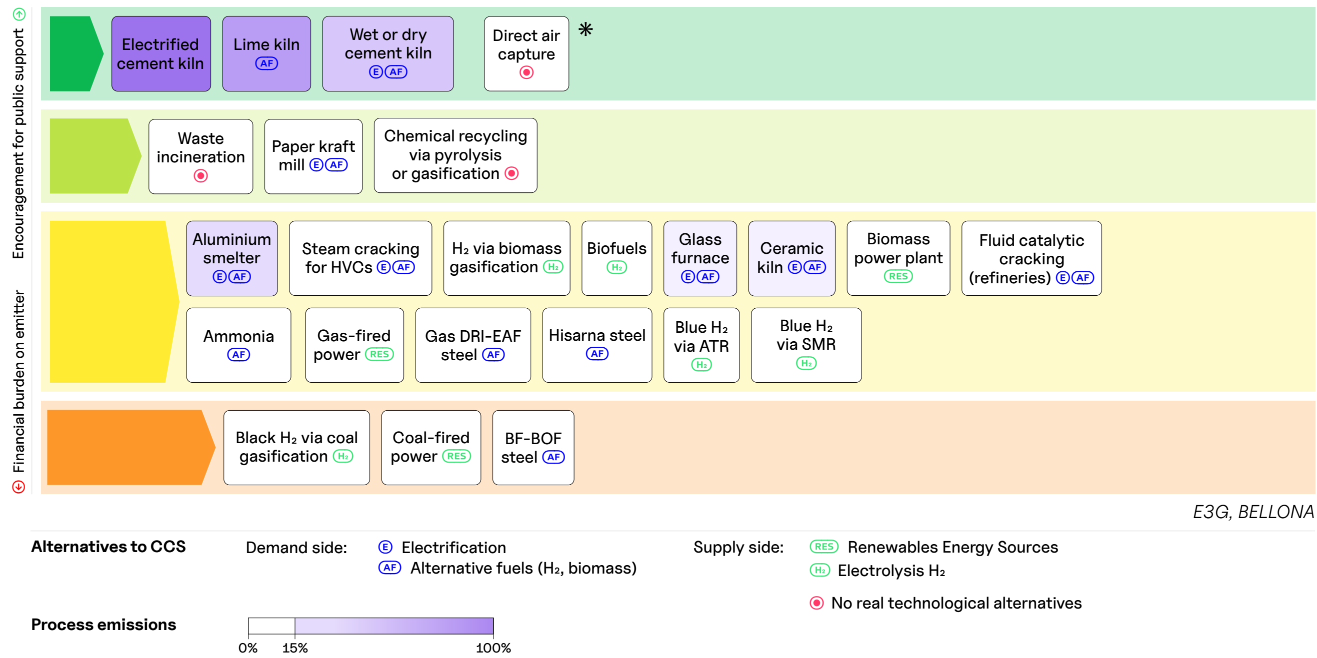
Figure 3

CCS Ladder for policy prioritisation, 2030 and 2050[34]

Near-term 2030



Long-term 2050



Notes on diagrams:

* Please refer to page 8 in the 'Criteria and Methodology' document for our approach on DAC and other Carbon Dioxide Removals technologies in the ladder.

34 2030/2050 CCS policy ladder based on scoring of applications against four criteria. Applications are coloured by percentage of process emissions in total emissions. Icons indicate the technological alternatives to CCS. See Disclaimer on page 4 on how to interpret the CCS Ladder.

Concluding recommendations

No 'one size fits all' approach can be adopted when it comes to determining the merit of CCS for a variety of industrial processes. Accordingly, this work proposes a tool to evaluate which industrial applications CCS should be targeted towards, illustrating where corresponding policy frameworks can enable the greatest climate value. By tying the various strands of this work together, we offer a series of final recommendations. These provide a framework for comprehending the value of CCS within the broader decarbonisation context and also provide suggestions regarding the design of corresponding policy frameworks to understand where support for scaling up CCS capacity might be best targeted.

1) When assessing the climate value of CCS applications, a holistic approach is required as not all CCS is the same.

1. Proponents of CCS typically highlight the absolute emissions reduction potential which can be achieved through CCS. Contrastingly, those opposing CCS deployments point out the technology's mixed track record as well as the wider adverse impacts it can have on the environment, including continued upstream emissions.
    - In the context of deep decarbonisation, assessing the climate value of CCS must go beyond a simple 'emissions reduction to investment ratio' approach.
    - Rather, determining the value of CCS applications requires understanding what is the greatest climate value that can be extracted from CCS deployments when the whole host of (potential) environmental, ecological, financial, and technical feasibility factors are accounted for.
2. Additionally, sectors need to be differentiated by location as different sites might require different solutions – for example, due to geographical or resource constraints.
    - In some scenarios, this can mean that CCS can be suitable in applications that theoretically have other decarbonisation options available or vice-versa.

2) European policymakers need to undertake their own robust assessments to determine the climate value of CCS applications.

1. These assessments should be based on objective and transparent criteria, established through input from all concerned stakeholders, including civil society – particularly environmental organisations – and citizens.
2. Moreover, in light of the changing climate value that CCS may have over time – as showcased by the temporal dimension in this work – assessments of the climate value of different CCS applications need to be updated regularly in line with developments in the wider decarbonisation landscape.
3. A stronger role for legislators – including the European Commission and relevant national authorities – is required.
    - These bodies need to have the capacity, technical expertise, and mandate to assess the climate value of CCS applications and regularly update their assessments.
    - The upcoming European Commission communication on a 'strategic vision' for carbon capture, usage, and storage needs to outline how to target support at the CCS applications with the highest climate value.

3) European policymakers should target public support to CCS applications with the highest climate value, setting an example for policymakers and stakeholders in other countries.

1. Considering the limitations that could impact CCS use, and the fossil fuel lock-in risk that exists through certain types of deployment – particularly in the short-term through to 2030 – public support for CCS should be focused where it provides the most climate value.
    - Limited public resources and constrained practical storage capacity, especially in the short- to medium-term, further support the logic to provide targeted support. The European Commission's proposal in the Net Zero Industry Act to obligate oil and gas producers to make storage injection capacity available should be welcomed in this context, as it alleviates some of the pressure from public finances while increasing available storage capacity.

2. Nonetheless, policy frameworks should not necessarily exclude the lowest priority emitters from deploying CCS.

    - On the contrary, a robust policy approach should put the onus on those lower priority emitters if they desire to address their emissions through CCS deployment, while focusing public support on alternative mitigation options. Banning the use of unabated fossil fuels should also be explored, possibly starting with lower priority emitters as they have plenty of alternatives available to them.

3. Emerging CCS policy frameworks – such as those in the EU – need to sufficiently disaggregate between different CCS use cases in their emerging CCS policy frameworks.

    - Ongoing legislative revisions and new proposals must help facilitate targeted public support towards high-value CCS applications, particularly if their scale-up proves challenging due to technical and regulatory factors.
    - At the EU level, this can include, for example, changing the award criteria for the Innovation Fund[35] or prioritising access to the CO_2 storage injection capacity facilitated via the Net-Zero Industry Act[36] to high-value CCS applications.

4. European policymakers targeting support for high-value CCS applications over those with limited value can also serve as international inspiration, helping to set an example for other countries who are thinking about the role CCS should play in their decarbonisation efforts.

    - While hurdles to developing and scaling CO_2 storage in the likes of the EU are small, barriers are much greater outside of Europe, particularly in emerging economies.
    - Therefore, if European countries can successfully target limited public resources and storage reserves for those applications with the greatest climate value – while effectively decarbonising the rest of their economies – the generated knowledge and expertise may be invaluable for external contexts.

4) Accelerated electrification, rapid scale-up of renewables, and increased deployment of energy efficiency and circular solutions is needed to limit the need for CCS and deliver European climate targets.

1. In terms of resilience, it is preferable to invest in a basket of technologies for reaching climate neutrality instead of over-relying on a single technology.

    - This is valid for CCS as one of a range of mitigation technologies as well as for potential CDR technologies.
    - Policy frameworks should enable and push those abatement solutions providing the largest climate value – which includes CCS deployment for certain applications.

2. Drastic reductions in fossil fuel usage, combined with a strong emphasis on energy efficiency and lowering primary energy demand, are necessary to reach climate neutrality, as illustrated by authoritative reports such as those from the IPCC[37] and IEA[38].

    - As such, emerging CCS policy frameworks must be accompanied by further scale-up of clean energy solutions such as increased electrification, efficiency, and renewable energy as well as demand reduction.
    - To avoid fossil fuel lock-in but also global temperature overshoot scenarios in the event of failure to deliver alternative means of decarbonisation, public support concerning the role of CCS to reduce emissions should be time-bound and regularly reassessed.

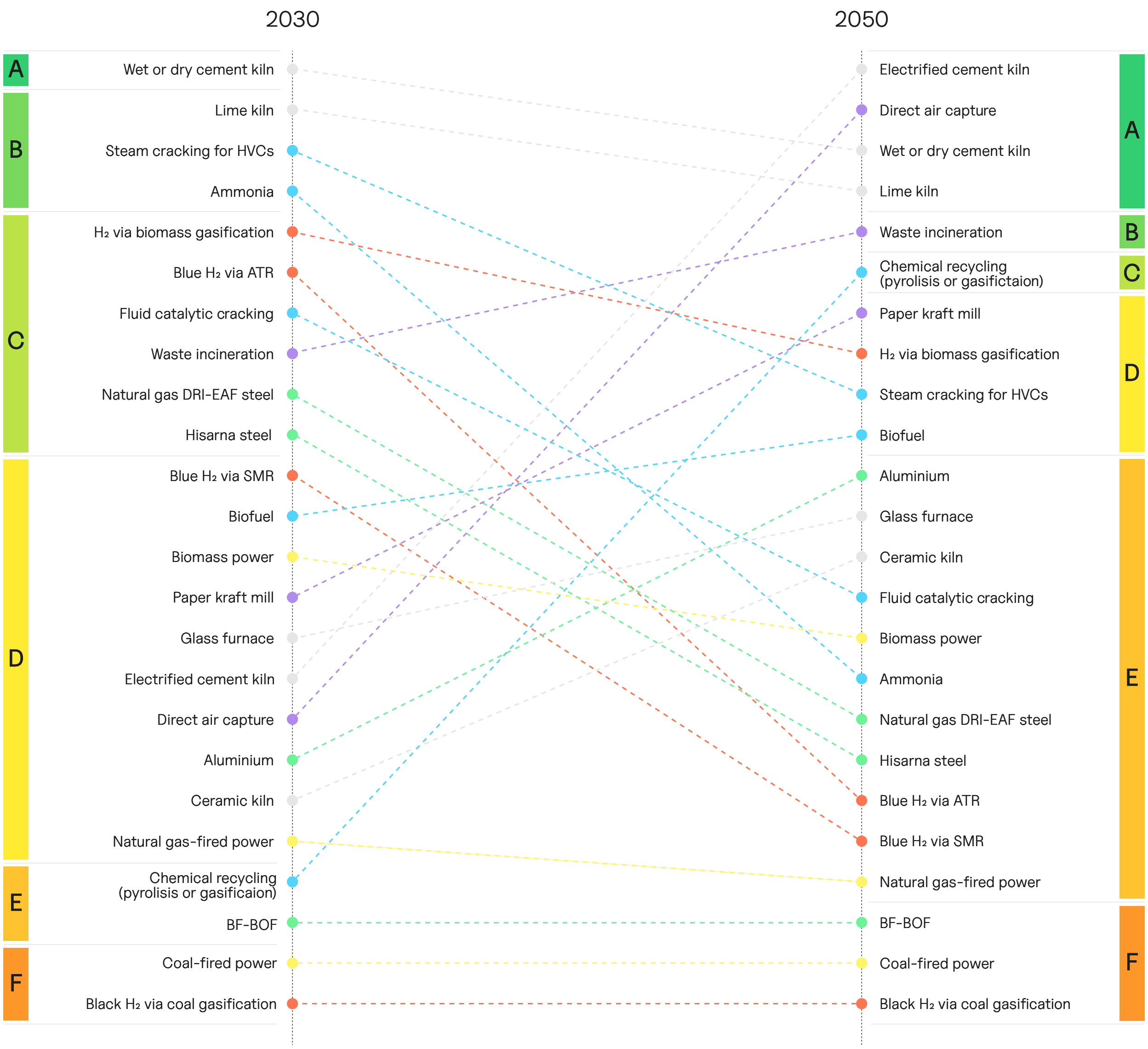
35 European Commission, 2019, Delegated regulation with regard to the operation of the Innovation Fund.

36 European Commission, 2023, Proposal on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act).

37 IPCC, 2018, Global Warming of 1.5°C.

38 IEA, 2021, Net Zero by 2050: A Roadmap for the Global Energy Sector.

CCS Ladder: application ranking changes 2030-2050[39]



39 This graph depicts the temporal evolution of CCS applications scores against our methodological framework. CCS applications are coloured by sector. Numbers indicate the relative ranking of each application, while A-F labelling corresponds applications' place in the ladder in 2030 and 2050, respectively. See Disclaimer on page 4 on how to interpret the CCS Ladder.