Reaching Climate Objectives – The Role of Carbon Dioxide Removals

Insights briefing

Energy Transitions Commission

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Insights Briefing

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C.

Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. The ETC is chaired by Lord Adair Turner who works with the ETC team, led by Faustine Delasalle. Our Commissioners are listed on the next page.

During 2021 the Energy Transitions Commission has sought to better understand the role of carbon dioxide removals in meeting emissions reduction and climate objectives. The ETC's work began with a consultation paper published in May 2021, followed by a series of stakeholder workshops undertaken throughout the year, and will culminate with the publication of a report.

This ETC Insights Briefing is a summary of key insights from our upcoming report. The goal is to provide a concise reference document on this nuanced subject prior to UNFCCC COP26. Ultimately, it aims to inform the way net-zero targets are set by countries and corporates. One of the underlying assumptions is that emission reduction targets are essential to get to net-zero in 2050 and that carbon dioxide removals should complement, not replace, emission reduction measures.

This insights briefing is based upon analyses carried out by ETC knowledge partner SYSTEMIQ, with the financial support from We Mean Business. It builds upon prior ETC reports, especially *Making Mission Possible (2020)*, *Making Clean Electrification Possible (2021)*, *Making the Hydrogen Economy Possible (2021)*, *Making a Sustainable Bioresources Economy Possible (2021)*, and *Keeping 1.5°C Alive (2021)*. It also draws upon past analyses carried out by ETC knowledge partners BloombergNEF, alongside analyses developed by Climate Policy Initiative, Material Economics, McKinsey & Company, Rocky Mountain Institute, The Energy and Resources Institute, and Vivid Economics for and in partnership with the ETC. We also reference analyses from the International Energy Agency and IRENA. We warmly thank We Mean Business, our knowledge partners, and other contributors for their inputs.

This briefing constitutes a collective view of the Energy Transitions Commission. A full-length report will be published in the coming months expanding on the insights presented here. Members of the ETC endorse the general thrust of the arguments made in this publication but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse this briefing paper.

The ETC Commissioners not only agree on the importance of reaching net-zero carbon emissions from the energy and industrial systems by mid-century, but also share a broad vision of how the transition can be achieved. The fact that this agreement is possible between leaders from companies and organisations with different perspectives on and interests in the energy system should give decision makers across the world confidence that it is possible simultaneously to grow the global economy and to limit global warming to well below 2°C. Many of the key actions to achieve these goals are clear and can be pursued without delay.

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Introduction

To have a fifty-fifty chance of limiting global heating to 1.5°C, the world must reduce CO_2 emissions to around net-zero by mid-century, with a decline of around 40-50% achieved by 2030.[1] Understanding this, many countries and companies are now committed to achieving net-zero by either 2050 or 2060. But even in the most ambitious reduction scenarios, cumulative greenhouse gas emissions over the next 30 years are likely to overshoot a carbon budget consistent with limiting global heating to 1.5°C. A significant volume of carbon dioxide removals (CDR) is therefore required to meet the 1.5°C climate objective.

During 2021 the ETC has therefore sought to understand the potential for different forms of carbon dioxide removal and will produce a comprehensive report on their role in climate mitigation strategies early in 2022. This briefing document sets out key emerging conclusions from the analysis to help inform debate on these issues at COP26, following a consultation process that started in May 2021.[2] Ultimately, through this work the ETC aims to inform how CDR is considered in the net-zero strategies set by countries and corporates.

The central message is that carbon removals must play a role in climate change mitigation strategies, but this must be in addition to, not instead of, rapid decarbonisation efforts. In this insight briefing we cover in turn.

- The scale of carbon dioxide removals required.
- Types of carbon dioxide removal and their feasible scale by 2050.
- The risks involved in different types of CDR and how to manage them.
- Who should pay for removals: countries and/or companies?
- The actions needed in the 2020s to ensure subsequent removals occur at sufficient scale.

1. We will need carbon dioxide removals

- **Decarbonisation to reach net-zero by 2050 is technically and economically feasible in all sectors of the economy.[3]**
- **Yet even ambitious decarbonisation pathways which reach net-zero by 2050 are likely to overshoot the carbon budget compatible with a fifty-fifty chance of limiting warming to 1.5°C.**
- **Carbon dioxide removals, will be required to compensate for that overshoot as well as neutralising residual emissions from mid-century onwards.**

1 IPCC (2018) *Special Report for 1.5°C*
2 ETC(2021), *Consultation Paper: Reaching climate objectives: the role of carbon dioxide removals*
3 ETC (2020), *Making Mission Possible*

The International Panel on Climate Change (IPCC) indicates that if we are to have a 50% chance of limiting global warming to 1.5°C and a 90% chance of limiting it to 2°C,[4] cumulative CO_2 emissions between now and mid-century must be limited to a "carbon budget" of 500 gigatons (Gt) CO_2.[5] This budget assumes a concurrent reduction of around 50% in annual methane (CH_4) emissions and 30% in annual nitrous oxide (N_2O) emissions by mid-century.[6]

Previous work of the Energy Transitions Commission,[7] (Scenario A, see Box A) suggests that CO_2 emissions from the Energy, Building, Industry, & Transport (EBIT) sectors could be reduced from today's 34 GtCO_2 per annum to around 2 Gt by mid-century through a combination of energy productivity improvements, clean electrification, and the wide-scale deployment of other zero-carbon technologies (hydrogen, sustainable bio-energy, CCS/U). Halting deforestation and changing agricultural practices could reduce CO_2 emissions from Agriculture, Forestry, and Other Land-use (AFOLU) from today's net 6-7 Gt CO_2 to about <1 Gt CO_2, and N_2O emissions could be cut by 40%. Total CH_4 emissions across all sectors could be reduced by around 40% (see Scenario A in Box A).

Achieving these reductions will require forceful policies. But even if achieved they will still be insufficient to give a 50% chance of limiting warming to 1.5°C. Comparing Scenario A with the IPCC's carbon budget shows an overshoot of 220 Gt CO_2 over the next 30 years.[8] EBIT emissions do not fall fast enough in the 2020s to keep cumulative emissions within budget – IPCC pathways to meet a 1.5°C climate objective require around a ~50% reduction of emissions by 2030, our illustrative Scenario A would result in only a ~25% reduction.

However faster emission reductions could be possible. The recent ETC report on "Keeping 1.5°C alive"[9] sets out six categories of actions which could bring emissions closer to the 1.5°C pathway.[10] These actions deliver significant emissions cuts by 2030; methane by ~40% and carbon dioxide by ~45%. Actions include accelerated closure of existing coal power generation, significantly reduced deforestation, and accelerated progress on road transport electrification, alongside decarbonisation of heavy industry and energy efficiency improvements. Yet even in this case, if these actions could be agreed and implemented, cumulative CO_2 emissions between now and 2050 would likely exceed the 1.5°C budget by around 70 Gt CO_2 (see Scenario B in Box A).

While the precise scale of removals required will depend on future success with emissions reduction, it is clear that carbon dioxide removals at significant scale are essential – at least in a range of 70-220 Gt CO_2 and still more if action to reduce gross emissions falls short of our Scenario A.

These negative emissions will be required:

- To compensate after mid-century for continual residual emissions (e.g. around 2 GtCO_2 per annum), which the EBIT sectors will produce even in the most ambitious reduction scenario (Scenario B).

- To compensate before mid-century for a potential carbon budget overshoot resulting from not reducing emissions fast enough in the initial stages of the path to net-zero (the difference between a "concave curve" of required reductions and a "convex curve" of maximum possible progress).

- To potentially, though ideally not, generate sufficient net negative emissions in the second half of the 21st-century to reverse the climate-warming effect of an overshoot of the cumulative budget. Any strategy which relies on removing CO_2 after the carbon budget has already been overshot carries a danger of triggering earth system tipping points and reinforcing feedback loops that are potentially irreversible, and should be avoided.[11]

If large-scale carbon removals are to be achieved within the next 30 years it is essential to take action now, in particular since a) nature-based carbon sequestration requires action in the 2020s to plant trees that will gradually sequester carbon over multiple decades and b) it will take time to develop and bring down the cost of engineered technologies and monitoring.

The next section describes different carbon removal solutions, and the role that they might play over time.

4 Estimate. Derived by approximating the probability distribution for a carbon budget which would limit warming to below 2°C using a normal distribution.
5 IPCC, (2021), *Climate Change 2021: The Physical Science Basis;* carbon budget estimated from 2020.
6 Carbon Budgets provide directional insight only and remain highly uncertain. They relate only to anthropogenic emissions or emissions from natural sources arising because of human activity (e.g., land use change), and already allow for the significant carbon sequestration which naturally occurs in forests and oceans. This implies that (i) if standing natural sinks got smaller over time, the overall carbon budget would reduce; and (ii) that any carbon removals to close the gap between future anthropogenic emissions and the carbon budget must be in excess of the terrestrial sequestration already assumed.
7 ETC (2018), *Mission Possible ; ETC (2020), Making Mission Possible.*
8 In addition to on-going residual emissions of 2-3 GtCO2 from 2050 onwards.
9 ETC (2021), *Keeping 1.5°C Alive: Closing the gap in the 2020s.*
10 The 'low or no overshoot' illustrative pathways described in the IPCC (2021) *Climate Change 2021: The Physical Science Basis.*
11 It is possible that, beyond some thresholds or "tipping points" positive climate feedback loops could become so strong as to trigger highly non-linear and irreversible climate change. How near we are to such "tipping points" is debated, and the IPCC carbon budgets do not explicitly model their potential impact. IPCC (2018), *Global warming of 1.5°C. An IPCC Special Report.*

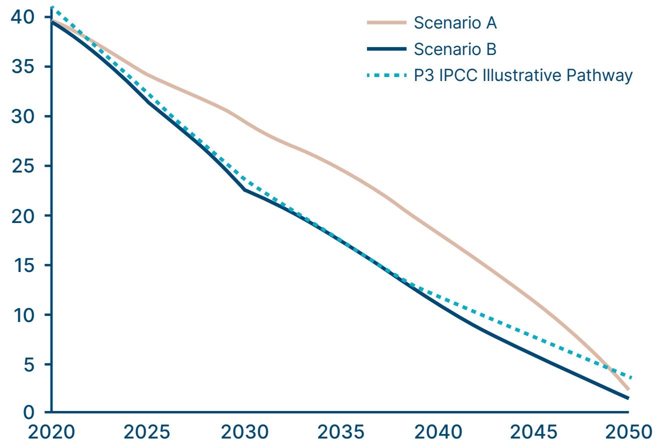
Exhibit 1

In Scenario B, cumulative emissions overshoot the carbon budget by 70 $GtCO_2$

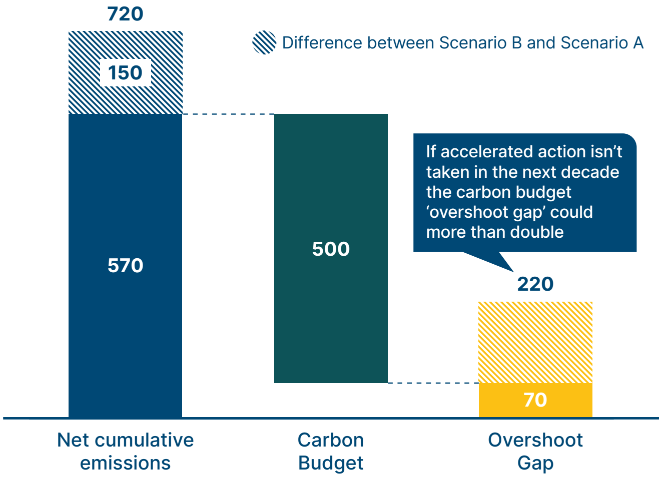
Gt CO_2/year, Global, Scenario A & B

PRELIMINARY; YET TO BE FINALISED

Total annual gross emissions in two ETC scenarios for a transition to net zero by mid-century[1], shown in contrast IPCC limited overshoot 1.5°C pathway[2]



Cumulative emissions across sectors and compared with the carbon budget



NOTE: [1] Point-source CCS assumed as part of within-sector decarbonization for EBIT sectors. ; [2] P3 = A middle of the road scenario which assumes societal and technological development roughly follow historical patterns and drive net emissions reduction by changing the way energy and products are produced. IPCC Integrated Assessment Models modelled 42 scenarios for >1.5°C, typically drawing on multiple data sources and forward projections, meaning that some variation in starting points is expected.

SOURCES: SYSTEMIQ analysis for the ETC based on: IEA (2017), Energy Technology Perspectives; IEA (2020), Energy Technology Perspectives; Previous analyses of the Energy Transitions Commission; IPCC (2018) *Special Report for 1.5°C*; IPCC (2021) *Climate Change 2021: The Physical Science Basis*

BOX A

***Making Mission Possible Report* 'Scenario A'** *Supply-Side Decarbonisation*		**'Scenario B'– aligned to ETC *Keeping 1.5°C Alive*** *Supply and Demand Side Decarbonisation, alongside early action in the 2020s*
• No new coal. Coal fully phased out by 2045/50 • Developed economies achieve almost complete decarbonisation by mid-2030s, developing economies by mid-2040s • 2030 mix: ~**60% renewable electricity**, ~20% gas, ~5% coal	**POWER**	• No new coal. Phase-out of coal in OECD countries by 2030 • Global power decarbonisation by 2040, including full unabated coal phase-out • Faster shift to renewables: **70% renewable electricity in 2030**
• Full electrification of building non-heating by 2030 • Building heating fully electrified by 2050 driven by increased adoption of heat pumps	**BUILDINGS**	• More rapid improvements in building efficiency and appliance standards from the 2020s (~20% compared with scenario A), reducing total buildings power demand
• **Cement:** Direct electrification kilns, some biofuels and hydrogen but significant fossil fuel consumption in 2050, paired with CCS. • **Iron & Steel:** Shift to hydrogen, alongside CCS (~85% fossil energy demand in 2030, ~25% in 2050, with CCS). Secondary production electrified. • **Chemicals & petrochemicals:** Shift to electrification and hydrogen. Significant energy demand and feedstock still fossil-fuel (with some CCS). • **CCS ramp up:** Up to 4% of total emissions in 2030, increasing to 62% in 2050	**INDUSTRY**	• Increased energy productivity in industry (reducing energy consumption by ~10% compared to scenario A) • **Cement:** aligned to latest Mission Possible Partnership outputs, implying faster adoption rates of new technologies. • **Iron & Steel:** aligned to latest Mission Possible Partnership outputs • **Chemicals & petrochemicals:** Fossil share of energy mix for other sectors is same as Scenario A • **CCS ramp up:** Same percentage removal as for Scenario A, less in absolute terms.
• **Road:** Rapid growth in the share of new auto sales accounted for by battery EVs. Some developed countries plan to ban ICE sales from 2030. Continued fuel economy improvements in light and heavy duty vehicles. • **Shipping & Aviation:** near complete decarbonisation by 2045/2050 (shipping primarily via ammonia; aviation using biofuels or synthetic fuels). • **Rail:** increased electrification, completely electrified by 2040	**TRANSPORT**	• **Road:** Global ban on light vehicle ICE sales by mid-2030s at latest. Continued fuel economy improvements. Lower travel demand (e.g. via shared use models). • **Shipping & Aviation:** aligned with Scenario A and slightly increased efficiency • **Rail:** aligned with Scenario A
• Reduced emissions from deforestation and degradation **(70% in 2030, 95% in 2050)** • Reduced process emissions from agriculture up to 66% in 2030 • Shift to plant-based diets reducing emissions up to 50% in 2050	**AFOLU**	• Reduced emissions from deforestation and degradation **(90% in 2030, 95% in 2050)** • Reduced process emissions from agriculture up to 66% in 2030 • Shift to plant-based diets reducing emissions up to 50% in 2050

2. Potential scale of carbon dioxide removals

- **We describe two broad categories of carbon dioxide removals: Natural Climate Solutions (NCS[12]) and engineered or hybrid solutions such as Direct Air Carbon Capture and Storage (DACCS), and Bio-Energy with Carbon Capture and Storage (BECCS).**
- **Combined we estimate they could cumulatively deliver ~220 Gt CO_2 of CDR by 2050, a supply-side estimate constrained by cost-effective and sustainability criteria.[13]**

Natural Climate Solutions deliver sequestration either through the restoration of nature or improved management of existing land uses. These solutions apply natural biogeochemical processes such as photosynthesis and, in some cases, leverage technology to further enhance sequestration and long-term or permanent storage. Examples include afforestation and reforestation (including commercial forestry), improved natural forest management and agroforestry, improved agricultural practices to enhance soil carbon sequestration in grasslands and croplands, and marine ecosystem restoration. The largest opportunity for NCS is in the tropical and sub-tropical belt, where substantial co-benefits in terms of positive community and biodiversity impact can be expected. Natural climate solutions store carbon in live biomass (for example, trees) and in soils.

Three considerations are important in assessing the potential scale of NCS removals:

- **Restoration of degraded land into forest or wetlands is a simple concept but challenging to execute** due to the high risk of reversal, limits to available land, and political uncertainty. As a result the feasbile cost effective potential may be considerably less than estimates of maximum technical potential. Efforts should be focused on geographic areas such as the tropics, which have high sequestration density and low risk of wildfire, and where innovative technology, governance and financing can be used to reduce reversal risks.[14]
- **Improved management of existing land uses such as forestry or farming can lead to enhanced soil and biomass sequestration.** Here the cost-effective potential tends to be a higher proportion of the maximum technical potential since these approaches build on existing uses of the land rather than requiring land-use change.
- **Achieving the full potential of NCS requires early action.** Our supply-side estimate of CDR potential presented in Exhibit 2 suggests that carbon removal via restoration of forests, peatlands and wetlands could grow to reach ~2 Gt CO_2/year by 2030 (increasing slightly to <3 Gt CO_2/year by 2050), while improved management solutions could in principle deliver a larger ~3.5 Gt CO_2/year by 2030.[15] It is important to note however that to achieve the ~2 Gt CO_2/year of restoration removals by 2030 would require much earlier action and massive scale up in stable financial support, given the inherently gradual growth rate of any nature-based sequestration.

It is also important to note that NCS sequestration must be in addition to reducing annual net AFOLU emissions by around 6 $GtCO_2$ by 2050 - primarily achieved via avoided deforestation (noting these are considered emission reductions, not removals).[16]

Engineered solutions rely on technology, particularly carbon capture & storage (CCS), to artificially capture and store CO_2. Typical 'hybrid' solutions combine nature-based 'capture' (e.g. biomass growth) with storage technology.[17]

- **Direct Air Capture (DAC)** is a chemical process that can capture CO_2 from ambient air, with the CO_2 then stored in products or geological formation **(DACCS)**. In principle the technical potential scale of DACCS sequestration is almost limitless, but DACCS will always entail significant costs and DAC technologies are currently at an early stage of development and only demonstrated at very small scales (4000 tCO_2/year[18]). Nevertheless one or more variants of DAC are likely to become commercially viable by 2030, with large-scale application thereafter.[19] Future sequestration potential from DACCS is highly dependent on the pace of cost reduction and the resulting industry growth rate. Assuming a 25% annual industry growth rate from 2025, DACCS capacity could reach ~4.5 Gt CO_2/year by 2050.[20]

12 Nature-based Solutions (NBS) are activities that harness the power of nature to deliver services for adaptation, resilience, biodiversity, and human well-being, including reducing the accumulation of greenhouse gases (GHGs) in the atmosphere. Natural Climate Solutions (NCS) can be considered as a subset of NBS with a specific focus on addressing climate change. NCS has been defined as 'conservation, restoration, and/or improved land management actions to increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, agricultural lands, and oceans' (Griscom et al. (2017), *Natural Climate Solutions*).
13 Cost-effective is defined as mitigation solutions up to a carbon price of \$100/tCO_2eq as it is in the middle of the range for carbon prices in 2030 for a 1.5°C pathway, and at the low end of the range in 2050 (Rogelj et al., (2018); Roe et al. (2021)).
14 Van Lierop et al., (2015), *Global forest area disturbance from fire, insect pests, diseases and severe weather events.* Between 2003 and 2012 approximately 38 mha of forests were disturbed due to extreme weather, mostly in Asia.
15 Roe et al., (2021), *Land-based measures to mitigate climate change: potential and feasibility by country:* Note based on analysis from average annualised estimates of sequestration potential 2020-2050.
16 Deforestation is the main source of CO_2 emissions from the Agriculture, Forestry & other Land Use (AFOLU) sector (not including other greenhouse gasses). Paying to 'avoid deforestation' from occuring is therefore the main CO_2 emissions reduction lever for that sector.
17 Further solutions for carbon dioxide removal not discussed here include ocean alkalinization, enhanced weathering, ocean fertilization and farming of seaweed sequestration. They represent significant uncertainties of potential impacts and ability to scale commercially.
18 Climeworks' recently opened 'Orca' facility in Iceland is estimated to capture around 4000 tonnes of CO_2 per year.
19 The Royal Society & Royal Academy of Engineering (2018), *Greenhouse Gas Removal.* DACCS demand for clean power is likely to be around 6-8% of final energy demand in 2050 (ETC Analysis, Scenario A). While significant, this demand could be met alongside in conjunction with energy efficiency strategies. Other resource demands such as for land, materials and water represent a modest increase relative to estimated 2050 demand.
20 Hannah et al. (2021) *Emergency deployment of direct air capture as a response to the climate crisis.*

Hybrid solutions include Biochar and BECCS, both of which are constrained by sustainable biomass supply. These solutions exist to some extent today but not at a commercial scale.

- **Biochar**[21] is charcoal produced by pyrolysis of biomass (in a low-oxygen environment), which makes biomass more resistant to decay, and which can then be buried to store carbon long-term in soils or, potentially, in geological storage (e.g., placed in abandoned mines).[22] It can also provide soil quality co-benefits.[23] It is an established process, but is not widely applied today due to costs versus other energy solutions and low availablity of pyrolysis facilities. The potential capacity for carbon removal is still widely debated, but could be potentially feasible at a commercial scale within a decade.[24]

- **Bio-Energy with Carbon Capture and Storage (BECCS)** is a technology in which CO_2 is initially sequestered via photosynthesis (a version of NCS), the biomass subsequently converted to energy (e.g. via combustion or gasification), and the majority of the CO_2 is then captured and placed in geological storage. BECCS can undoubtedly play a role in carbon dioxide removal: the crucial questions are the scale of sustainable supply of biomass and the optimal use of land.[25]

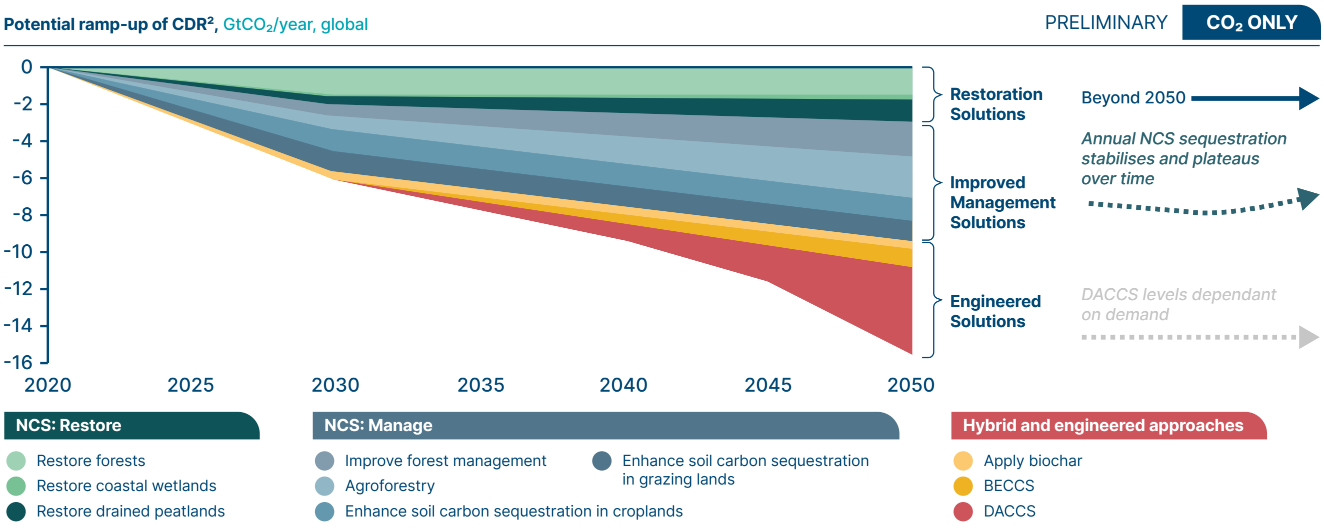
Our illustrative supply-side CDR estimate assumes 1 Gt CO_2/year is sequestered by BECCS in 2050, delivered through an even split of dedicated energy crops and forestry residues. Biochar, in this assessment, is assumed to rely primarily on crop residues as a feedstock. These estimates consider the constraints on sustainale biomass supply assessed in the ETC report Making a Sustainable Bioeconomy Possible (2021). In theory, the biomass feedstocks utilized by biochar or BECCS could be used for carbon removal without energy production via BiCRS (Biomass with Carbon Removal Storage).[26]

The total estimated potential for CDR in 2050, illustrated in Exhibit 2 at around 15 Gt per annum, considerably exceeds what will be required beyond 2050 to offset residual emissions (assuming net-zero successfully reached). But it is important to recognise that the potential annual sequestration from NCS would plateau in the long-term, from decades to centuries, as reforestation projects reach maturity (and if no further land freed up for restoration). The 220 Gt CO_2 of cumulative removals required for Scenario A (demonstrated in Exhibit 1) would be required to ensure no overshoot of the carbon budget, avoiding having to rely on retroactive removals and risking the dangers of such an approach.[27]

It is therefore prudent to develop strategies that could ensure a significant share of the removal potential to be exploited if needed, and to identify the risks which need to be managed to ensure that those CDR solutions are effective and permanent. Section 3 considers the risk management challenge.

Exhibit 2

Supply-constrained estimate of CDR Trajectory over time for cost effective and sustainability criteria could provide cumulative removal potential of ~220 $GtCO_2$



NOTES: The analysis was designed to avoid potential double-counting of emissions reductions, and is adjusted from annualised average potential estimates for 2020-2050 period. The models reflect land management changes, yet in some instances can also reflect demand-side effects from carbon prices, so may not be defined exclusively as 'supply-side'.

SOURCE: ETC Analysis, based on Roe et al. (2021), Hannah et al. (2021), Griscom (2017)

21 The Royal Society & Royal Academy of Engineering (2018), *Greenhouse Gas Removal*
22 Thengane et al. (2019), *Biochar Mines: Panacea to climate change and energy crisis?*
23 The Royal Society & Royal Academy of Engineering (2018), Greenhouse Gas Removal; Biochar is shown to improve soil water and nutrient retention and reduce erosion.
24 National Academies (2019), *Negative Emissions Technologies and Reliable Sequestration;* Vivid Economics analysis based on Fuss et al. (2018), *Negative emissions—Part 2: Costs, potentials, and side effects.*
25 See extended discussion of the trade-offs in ETC (2021) *Making a Sustainable Bioeconomy Possible:* The location and condition of the land and the desired outcomes – be they carbon sequestration, energy, materials, or benefits for biodiversity and nature – determine the most appropriate use of land. In a hypothetical analysis comparing possible uses for freed-up former agricultural land (i.e. no emissions from land use change), BECCS from energy crops resulted in the greatest carbon storage and energy generation, but without biodiversity benefits. Significant carbon will also be held reforested land and managed forests, with managed commercial forests having lesser outcomes for biodiversity than natural forest. Where collection is economically feasible, wastes and residues from other uses of land (e.g. forestry, agriculture, municipal waste) can provide a source of biomass for hybrid CDR technologies.
26 Innovation for Cool Earth Forum (2021), *Biomass Carbon Removal and Storage Roadmap;* Another term for the hybrid use of biomass combined with CCS is 'BiCRS' (Biomass with Carbon Removal Storage), that does not prioritise energy generation, but describes a range of processes that use plants and algae to remove carbon dioxide (CO_2) from the atmosphere and store that CO_2 underground or in long-lived products. In theory, by excluding the energy generation step, a more efficient and effective processing of biomass and underground storage is possible, making it cost-effective and allowing for other applications of biomass. One such example is 'bio-oil'.
27 It is purely a coincidence that this supply-side analysis for CDR potential exactly matches the carbon budget overshoot gap estimated by the ETC's decarbonisation pathway Scenario A.

3. Risks in different types of CDR solutions and how to manage them

Natural Climate Solutions and engineered or hybrid solutions are inherently different in terms of costs, co-benefits, sequestration profile and risks around permanence

- **Managing these risks will require robust monitoring and verification systems**
- **Risks in NCS projects can be addressed in several ways, including by making conservative assumptions about sequestration quantities achieved**
- **Investing in a portfolio of different removal types can reduce the overall risk**

Natural Climate Solutions typically entail lower estimated costs of abatement (e.g., USD$10-$100 per tonne) than the Engineered and Hybrid solutions and in addition provide improved outcomes for biodiversity, water supply, food security, and income to local communities. They are therefore essential to achieving the wider Sustainable Development Goals. However, NCS assets sequester carbon over a period of decades, during which time they are vulnerable to reversal (e.g., via forest fires or the return of deforestation drivers) and have inherent challenges with respect to:

- Accurate estimates of sequestration volumes.
- The permanence of sequestration, given the potential risks of sequestration being reversed e.g. through forest fires, insecure finance and the return of deforestation drivers.

In addition, restoration projects such as reforestation have an inherently S-shaped profile of sequestration over time, making it essential to take action early to deliver future removals.

Engineered solutions such as DACCS, BECCS and Biochar tend to have higher costs (particularly so in the case of DACCS), and do not typically deliver as many co-benefits as NCS. They are more nascent but could offer higher guarantees of permanence and the benefit of immediate sequestration, as:

- The amount of CO_2 sequestered via storage can be fairly precisely defined, and can be managed on a year by year basis.
- Permanence in geological storage is inherently easier to ensure, provided robust project design, monitoring and verification systems are in place.[28]

In the case of BECCS and Biochar (but not DACCS) issues relating to the sustainable supply of biomass must also be carefully considered.

Exhibit 3 summarises several characteristics of different CDR approaches.

28 IPCC(2005), *Special Report on Carbon Dioxide Capture and Storage*

Exhibit 3

What is the feasible portfolio of CDR Solutions available and what is the right taxonomy for assessing them?

CDR options have different pros and cons

SOURCES: Fuss et al. (2018) N*egative Emissions Part 2 – Cost, Potentials and Side Effects; Royal Society* (2018) *Greenhouse Gas Removal Report*
[1] Refers to ease of monitoring storage to ensure its permanence;
[2] Risks to permanence considered include economic, political and climate risks. Arrows indicated risks that can be mitigated with effective project design;
[3] TRL adjusted from (0-9) scale to (0-11) scale for comparison.

Managing the risks

In the case of Engineered and Hybrid solutions independant regulation will be required to define technical storage, monitoring and verification standards. In addition, future commercial deployment will depend on cost reduction, supported by large-scale deployment of clean power supply.

For NCS projects, the challenge is to overcome the inherently greater variability and uncertainty of future removals, while grasping the significant low-cost potential. This should entail:

- Putting aside an independently-managed, risk-adjusted percentage of "buffer credits" for all land-based projects in use today by carbon standards such as Verra, if any sold credits are lost (e.g. through wildfire) then the equivalent number can be withdrawn from the 'buffer pool' to take their place.[29] This means making conservative estimates of the scale of sequestration which is expected to be achieved, or which actually has been achieved, to cover future adverse developments. Given low sequestration cost estimates (although costs will increase as demand for high-integrity credits increases), many NCS projects will still look attractive despite conservative estimates of CO_2 removal.

- Ensuring that NCS projects – and in particular those which are at risk of the return of deforestation drivers – are embedded within wider national strategies for land use over time. Such "jurisdictional approaches" will also often be essential to ensure the permanence of avoided deforestation projects.[30]

- Improving and expanding high-quality monitoring and verification systems to ensure high-integrity credits, including standards vetting processes to avoid leakage of deforestation activities.

- Scaling up blended-finance mechanisms which create stable financial flows for projects, alongside expanding business models which create value from protecting forests and support long term project stability for local communities.[31]

Actions can be taken to reduce the risk of CDR projects of any particular type. A further measure to reduce overall risk is for purchasers of removal credits to invest in a portfolio of several different CDR types. This means that a global strategy for removals should deliver early investment in both NCS (to ensure maximum sequestration before mid-century) and Engineered solutions (to scale deployment and cost reduction).

29 Vertree (2021), https://vertree.earth/compensationandneutralisation/; Verra (2021), https://verra.org/not-the-full-story/
30 World Resources Institute (2020), *4 Reasons Why a Jurisdictional Approach for REDD+ Crediting Is Superior to a Project-Based Approach*
31 FOLU (2019), *Prosperous Forests*

4. Who should pay: Countries and/or companies?

- **Removals will only occur at the required scale with much greater funding than currently delivered by compliance or voluntary carbon markets.**
- **Corporate purchases of removal credits in compliance or voluntary carbon markets could play a significant role, but must be as well as - and not instead of - strong targets to reduce companies' own emissions as rapidly as possible to net-zero.**
- **Governments will have to play a significant role in delivering sufficient removals, both as direct providers of funding, and by creating the policy frameworks which can ensure that NCS removals are permanent.**

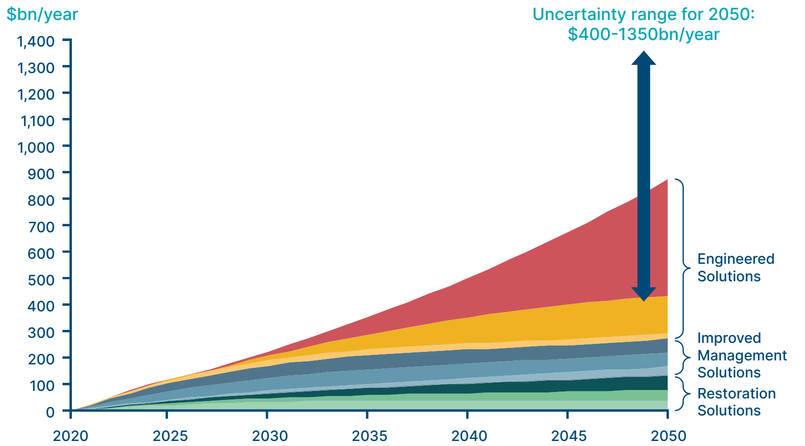
Funding requirements and current flows

Exhibit 2 indicated that there exists technically feasible solutions to remove ~6Gt per annum of CO_2 by 2030. Exhibit 5 shows that at an average cost of around USD$40 a ton, that would require USD$230 billion of financial flows per annum.

Today, financial flows from compliance and voluntary markets are a small fraction of this, and most of these are focused on various forms of reduction offset credits, as opposed to actual removals. Government finance of removals (whether within own country or in others) are currently also very small. In total we estimate that no more than USD$10 billion per annum is currently supporting removals.[32]

A massive increase in financing flows to support removals is therefore required (Exhibit 4).

Expected annual cost of CDR solutions, USD bn/year, global



	Cost estimate (2030)	Cost estimate (2050)	Cumulative potential (2020-2050)[1]
Engineered and Hybrid Solutions	\$125-450 /tCO_2	\$50-150 /tCO_2	50 GtCO_2
NCS: Improved Management Solutions	\$0-100/tCO_2		115 GtCO_2
NCS: Restoration Solutions	\$5-50/tCO_2		60 GtCO_2
TOTAL			220 GtCO_2

Exhibit 4

SOURCE: [1] Totals may not sum due to rounding. ETC analysis based on Fuss et al. (2018) *Negative Emissions Part 2 – Cost, Potentials and Side Effects;* Royal Society (2018) *Greenhouse Gas Removal Report; Direct Air Capture of CO_2 with Chemicals* (APS, 2011); Roe et al. (2021) *Land-based measures to mitigate climate change.*

NOTE: Cost estimates for different solutions vary strongly, the above chart shows the averages between the low and high estimates. Current funding for removals estimated to be less than $10bn/year. Additional funding would be required for non-CDR emissions reductions (e.g., avoided deforestation). NCS are estimated to have the same average cost throughout, however it is possible costs will rise over time.

32 SYSTEMIQ analysis for the ETC, and Coalition for Negative Emissions (2021), *The case for Negative Emissions.*

Who should pay; The role of carbon markets

Carbon removals will only occur if someone pays to make them happen; the question is who and by what mechanism. One option is for governments simply to pay for them, whether in their own country or in others. Another could be for companies to pay for removals by buying removals in carbon markets (either "compliance" or "voluntary"), for example, to achieve "net-zero" emissions even if their own gross emissions are still above zero. However, credits sold in carbon markets might also be used to drive a reduction in existing emissions (sometimes called a "reduction offset"[33]) rather than true removals. To decide the appropriate role of carbon market "removal credits" we therefore need to consider the wider issue of what role credits of any sort should play in emissions reductions.

In principle, trade in carbon credits could reduce the global cost of achieving emissions reductions, with countries or companies which face high marginal costs to abate emissions, paying to achieve emission reductions (or removals) elsewhere. Moreover, large financial flows are required to support decarbonisation in many developing countries: purchases of reduction credits could be one source of such finance.

But there are also strong arguments for limiting company or country reliance on credits to achieve emissions reductions, and for ensuring a focus on specific categories of offset credit:

1. The latest climate science shows that we need to reduce global emissions to net-zero by mid-century. Net-zero is only achievable if residual gross emissions are fully offset by carbon dioxide removals. The potential role for any reduction credits must therefore decline towards zero over time, with mid-century markets focused almost entirely on removals.

2. When countries, companies, or sectors set ambitious targets to reduce their own emissions, this drives technological progress and cost reductions, reducing future abatement costs. Purchases of credits (whether reductions or removals) should therefore be on top of, not instead of, strong targets for reductions of countries' and companies' gross emissions.

3. Technological progress and cost reductions (for instance in renewable energy) in turn mean that many projects which purchased credits might support, would be likely to occur in any case, either immediately or in a few years time. Therefore, it is essential to ensure that any reduction actions financed by credit purchase are truly additional to what would be likely to occur in any case.

These factors argue strongly for countries, companies, and sectors setting as strong as possible targets for emission reductions *within themselves*, reaching close to zero gross emissions by 2050, rather than overly depending on the purchase of any form of offset credit.

For private sector actors, the Science-Based Target initiative (SBTi), has sought to enforce this maximum internal action principle for companies seeking to claim accreditation.[34] Complementing this, the Mission Possible Partnership is now developing sector by sector pathways for all the harder to abate sectors to the economy.[35] Together these demonstrate that deep decarbonisation is possible in all sectors of the economy, and countries and companies should seek to decarbonise their emissions in line with these pathways.

However, provided that company purchase of credits is in addition to strong internal action, it can play a useful role, particularly if focused on actions which are most likely to be additional to a business as usual scenario. This will most likely be the case for:

- Many categories of removals, most of which will only occur if someone pays for them. For instance, no one is likely to perform a DACCS operation except if paid to do so.

- Some specific categories of reductions where it is clear that there is not yet a low/zero cost route to emission reduction and where crucially important emissions reductions will only occur if supported by a financial flow from developed to developing countries. In particular, the ETC's recent report on *Keeping 1.5°C Alive*,[36] shows that in the next decade the world must both reduce deforestation and accelerate the closure of existing coal plants before the end of their useful life to make a 1.5°C pathway attainable by 2030. It is likely neither will occur without a flow of compensation towards low-income countries. Given the additional cost, accelerating actions in these two categories (e.g., by bringing forward the closure of an existing coal plant to 2030 or earlier), if time-limited,[37] are more likely to be additional than many other forms of emission reduction.

33 Credits which avoid or reduce emissions are interchangeably called reduction or compensation credits. This report uses the term 'reduction' credits.
34 SBTi (2021), *The SBTi Net-Zero Manual & Criteria Version 1.0;* SBTi recommends most companies to make emission reductions of at least 90% to reach net-zero, leaving only a maximum of 10% of a company's base year emissions to be addressed through [removals].
35 *"Mission Possible Partnership unveils how three of the most carbon intensive industries can reach net zero by 2050 and cut emissions in the next decade"* (Oct 13 2021), missionpossiblepartnership.org
36 ETC (2021), *Keeping 1.5°C Alive: Closing the gap in the 2020s*.
37 ie., only within the next decade.

The challenge is therefore to design a set of rules, norms and guidelines which does not remove pressure on companies (or countries) to achieve maximum possible internal emissions reductions, but which also encourages credit purchase where this is clearly in addition to within company actions and provides a focus on the forms of credit purchase which are most likely to be additional.

Implications for private sector credit purchase

These principles and objectives could suggest the following approach:

In compliance markets, such as the EU ETS or other future equivalents, total emission credits available should be designed to fall along a path compatible with limiting global warming to 1.5°C, but a limited quantity of removal credits should be allowed to achieve net-zero in 2050 (Exhibit 5).[38] Expanding compliance markets – in both sectoral and geographical coverage – can be an important driver in scaling up removals.

Illustrative introduction of CDR into compliance carbon markets over time, resulting in the cap of the system reaching net-zero

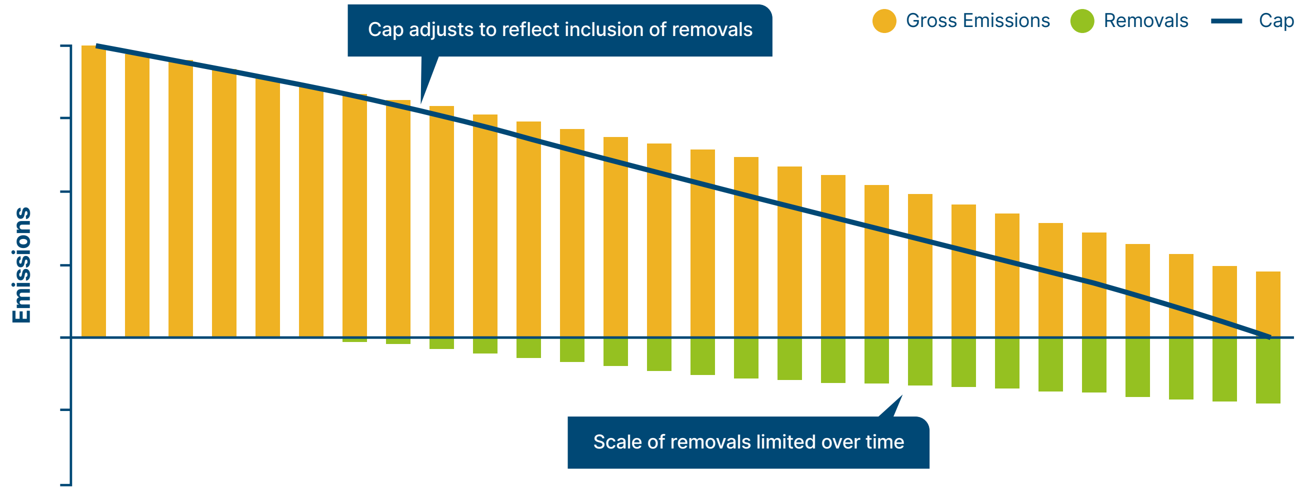


Exhibit 5

SOURCE: SYSTEMIQ analysis for the ETC, based on UK CCC (2019) *The Future of Carbon Pricing (Annex).*

In voluntary markets, where companies go beyond compliance markets and choose to make commitments beyond their legal obligations, contributions can only be encouraged, not enforced (although regulation can play a role in ensuring corporate claims are robust and integrity standards met). Both likely and appropriate practices in these markets will vary by type of company.

- For companies in harder-to-abate sectors such as steel or cement, which need to make major investments to reduce emissions, the overwhelming focus should be on reducing their own emissions as rapidly as possible, rather than diverting funds to purchase credits.
- For many companies the next priority beyond their own Scope 1 and 2 emissions should be to make commitments that enable decarbonisation of supply chains (Scope 3 emissons), for instance via the purchase of green products or services.[39]
- But many companies, particularly in easier-to-abate sectors of the economy, may choose to make commitments to be “climate neutral” or “net-zero” not only in 2050 but at a much earlier date, or to use carbon credits to cover Scope 3 (Exhibit 6) or legacy emissions.[40]

38 With the possible exception of REDD+ credits (e.g. in CORSIA) which support projects capable of delivering both emissions reductions and removals.
39 For example, the recent commitment by Unilever, IKEA, Amazon and others to zero carbon shipping in their supply chain by 2040. Aspen Institute, 2021, *Companies Aim to Use only zero-carbon ocean shipping by 2040*
40 Various concepts around emissions neutrality exist, including carbon neutral, climate neutral, net zero, carbon negative, and climate positive. This report uses ‘climate neutral’ to refer to all gross greenhouse gas emissions being offset.

Exhibit 6

A possible optimal approach? A strategy which prioritises credits from NBS Reduction offsets and Removals

First, consider the priority hierarchy of addressing atmospheric carbon…

Priority 1

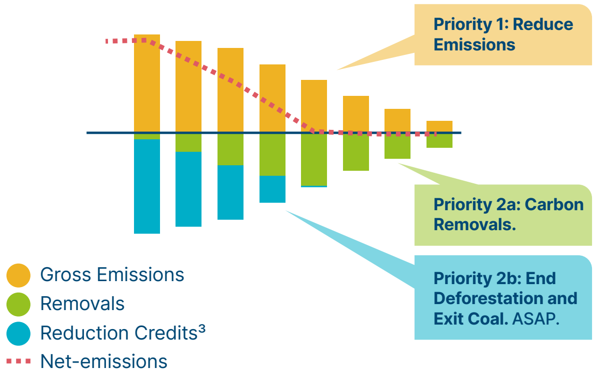
Reduce own country / company / sector emissions as rapidly as possible

Priority 2

Offset remaining emissions via:

- **a** **Removal credits** to close the carbon gap[1]
- **b** **Reduction credits** for a transitional period : mainly **avoided deforestation and possible 'exit credits' (e.g. for early coal phaseout)** but with very tight focus on additionality[2]

…To develop a High Ambition Strategy for Nature and Removals?



NOTES: [1] Overshoot of the carbon budget as defined by the IPCC (2021).[2] Assuming time needed to scale up removals market in the 2020s, especially for BECCS and DACCS. Offsetting strategies should transition towards removals over time.[3] Likely to be restricted to time-limited credits for avoided deforestation and possible 'exit credits'. For the purposes of this illustration reduction credits don't contribute to net emissions.

Exhibit 7 shows a range of possible approaches, in which we describe a continuum of these strategies.

To ensure any such voluntary commitments have integrity, trusted standard setters (e.g. the Taskforce for Scaling Voluntary Carbon Markets, the Science Based Target Initiative, the Voluntary Carbon Market Integrity initiative and others) have a valuable role to play in advising on appropriate use of credits and appropriate use of terms such as "climate neutral" or "net-zero".

Given the principles set out above, we recommend that these standard setters should:

- Make it clear that by 2050 the world will need all residual gross emissions to be matched by removals.
- Encourage a significant focus on removals at much earlier dates.
- Limit the use of reduction offsets to situations where additionality can be clearly proven.[41]

As for the use of language, there is value in developing common approaches which distinguish between objectives achieved via the use of reduction credits and via actual CDR, including a proposed distinction between:[42]

- "Climate neutrality" to cover situations where a company is voluntarily offsetting all its remaining gross emissions with either high quality reduction or removal credits.
- "Net-zero" to cover situations where all remaining gross emissions are offset by removals only

The ETC will consult further with our members on this use of terms before publication of our final report.

The vital role for governments in funding removals

The approach described above could encourage a significant flow of finance from companies to achieve removals and high-priority forms of reduction, but they will not be sufficient.

Governments will therefore also have to play a major role, with financial support flowing from richer to poorer countries. Very large financial flows – whether in debt or equity form – will be required to support the development of a wide range of decarbonisation investments across the developing world. Additionally, developed country governments, working in particular via multinational development banks, should play a major role in reducing the cost of capital faced by developing countries.

41 In the case of avoided deforestation, proving additionality may be extremely difficult except where governments are also involved to ensure the jurisdictional approach described above. And in the case of exit from existing coal, credits should be time-limited (e.g. to before 2030) since beyond some date existing coal plants would in any case close as the cost of removals falls below the marginal cost of running the existing coal plants.
42 Aligned, for example, with the recommendations of the Taskforce for Scaling Voluntary Carbon Markets. See TSVCM (2021) *Phase II Report*.

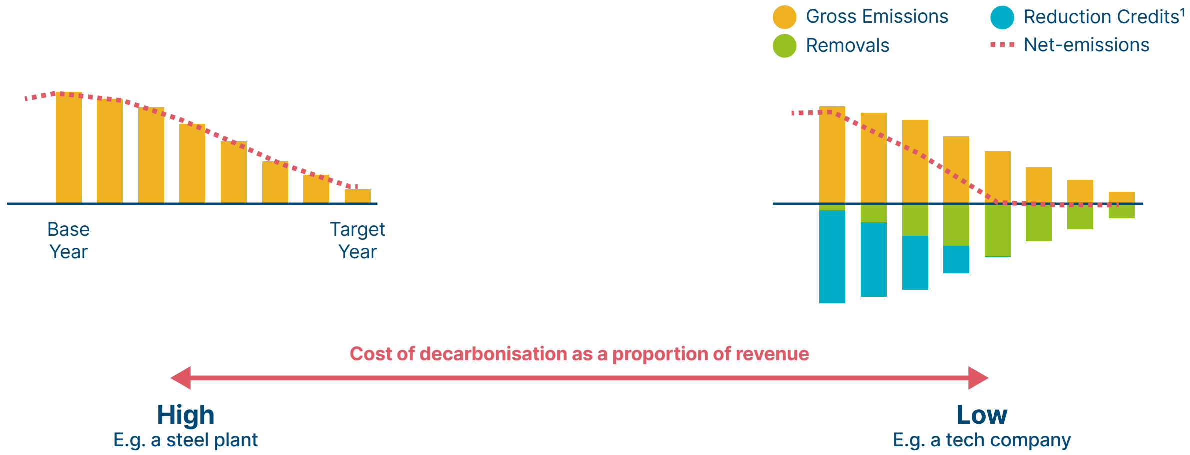
However, some specific elements of emissions reductions will only occur if there is explicit grant finance, and the ETC's *Keeping 1.5°C Alive* report has argued that ending deforestation and closing existing coal should be two priority uses of the grant elements within international climate finance.[43] In addition to this, further funding is likely to be required to incentivise emissions removals.

The reductions and removals achieved through this finance should, however, be in addition to the rapid reduction of developed world production emissions to zero. Finalising the agreement of "Article 6" of the Paris Agreement[44] is critically important, but this implies that the use of any "Article 6" credits to meet national production emission targets should be limited to a subset of removals required to offset residual gross emissions to zero by mid-century.

Financing flows to support avoided deforestation or early coal closure should not therefore be counted as a mechanism to meet developed world NDC commitments, but as a necessary additional contribution to the global fight against climate change. In addition, some countries may choose to describe them as compensating for the excess of consumption over production emissions, contributions in excess of NDC commitments, or for historical emissions.

Exhibit 7

The right pathway for any organisation will vary. Collectively there could be a continuum of action, based on the cost of decarbonisation as a proportion of revenues



NOTES: [1] Likely to be restricted to time-limited credits for avoided deforestation and possible 'exit credits'. For the purposes of this illustration reduction credits don't contribute to net emissions.

43 ETC (2021) *Keeping 1.5°C Alive: Closing the Gap in the 2020s.*
44 'Article 6' of the Paris agreement seeks to establish an international emissions trading market, within which emissions reductions within one country, could be counted in another countries' Paris Agreement contributions.

5. To deliver CDR at necessary scale, key policy and corporate actions must support them in the 2020s

Robust policy, supplemented by corporate action, must underpin the necessary scale of up of a functioning, credible, low-risk carbon dioxide removal industry, starting from today. In particular:

- **Governments will need to increase support for CDR** through investment in research, strengthening and scaling compliance carbon markets, and further policy action such as subsidy support, standards and regulation (see below). They must also ensure that carbon dioxide removal is in addition to but not instead of rapid reductions in gross emissions. In addition, Governments will have a role in targeting climate finance to priority areas for emissions reduction, and through targeted funding for removals. Government's should also purchase removals beyond NDCs.

- **Governments will need to help ensure permanence of emissions removals, and high integrity reductions by:**

    - Developing carbon capture and storage infrastructure to support engineered emissions removals and accepting some long-term liability for the carbon sequestered.

    - Defining standards for emissions removals, and develop robust monitoring frameworks.

    - Ensuring that actions taken to scale forest-based natural climate solutions (including avoided deforestation) are truly additional, even if voluntary company credit purchases help to finance them. One possible model indeed is for governments to play a key role in agreeing and enforcing avoided deforestation arrangements and developing jurisdictional approaches, but to invite companies that wish to contribute to help finance them through the purchase of reduction credits.

- **Standard setters looking to reform voluntary carbon markets should encourage corporate purchases** of carbon offsets to focus on categories of reduction which are likely to meet tight additionality criteria and to begin to shift purchases towards carbon removal.

- **Corporates should target their voluntary action to ambitious pathways which align with their unique challenges.** Private sector actors should consider expanding upon their Science-based Net-Zero pathways to become "High Responsibility" or "High Ambition" actors in meeting claims of "climate neutrality" or "net-zero" (see Exhibit 7 above).

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