INEVITABLE POLICY RESPONSE

Financing Direct Air Carbon Capture and Storage (DACCS): *Quantifying the investment opportunity*

November 2023

THEIA FINANCE LABS

Developed by Theia Finance Labs for the Inevitable Policy Response Programme

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IPR was commissioned by the PRI[1] and is supported by world class research partners and leading philanthropies, financial institutions, & NGOs

1. Principles for Responsible Investment
2. The conclusions of the report are solely those of Energy Transition Advisers and Theia Finance Labs

Commissioned by PRI

In 2018, the Inevitable Policy Response was commissioned by PRI to advance the finance industry's knowledge of climate transition risk & support investor efforts to incorporate climate risk & opportunities in portfolio assessment

PRI Principles for Responsible Investment

A Climate Research Consortium

This report was produced by Energy Transition Advisers and Theia Finance Labs[2]

NGO partners include Carbon Tracker, Climate Bonds & Planet Tracker

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The IPR is funded in part by the Gordon and Betty Moore Foundation through The Finance Hub, which was created to advance sustainable finance, and the ClimateWorks Foundation striving to innovate and accelerate climate solutions at scale

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The Inevitable Policy Response (IPR) forecasts that the 1.5°C no overshoot goal will be missed. It also anticipates that policymakers won’t accept a >1.5°C world as a long-run equilibrium – given the expected risks from social and climate tipping points a +1.5°C world entails.

Scaling Direct Air Carbon Capture (DACC) with subsequent storage or utilization is a crucial instrument to provide a pathway for temperature reductions after they peak in a way that doesn’t involve radical geoengineering (e.g. solar radiation management). While there is debate about the need of DACCs in reaching net zero, there is little debate about the need for the kind of permanent carbon removal that DACCS provides, to reduce temperatures after global overshoot of the1.5°C goal, without resorting to the unknown potential consequences of alternative geoengineering.

Net zero target setters, policymakers and investors interested in investing in the transition more broadly need to understand the opportunity set that arises from this technology. This investor briefing forms part of a three-part series exploring DACCS outlook.

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Why are DACCS so attractive?

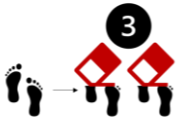
- Unlike most nature-based solutions, CO_2 removal related to DACCS provides a permanent solution
- Unlike traditional CCS related to fossil fuels, DACCS provides negative emissions that provides a roadmap for reducing peak temperatures
- Given the opportunity for DACCS deployment on non-arable land, DACCS does not compete to the same degree with other demands on land use
- There are to date no known potential 'negative feedback loops' from DACCS (e.g. albedo effect from forest canopy offsetting the emissions capture
- There are no identified core engineering or material constraints for mass scaling of DACCS
- At least in theory, DAC systems would allow for subsequent utilization and a related additional potential revenue stream

The ‘Climate Journey’

Realizing temperature goals involves four steps, ordered in hierarchy of desirability from both a climate and cost-efficiency perspectives:

Reduce GHG Emissions is the first priority of climate action, given both its cost-effectiveness across most emissions drivers and the uncertainty around climate feedback loops and temperature forcing effects, once emissions have been released, as well as the growing cost of climate change itself.;

Net / offset GHG Emissions (through nature and technology-based solutions) where emissions reduction may not be considered politically, economically, or culturally (e.g. meat consumption) viable. IPR assumes that nature-based solutions will be the primary mechanism though which this will be achieved although DACCS already begins to scale by 2050.



Erase the historical footprint (through nature and technology-based solutions such as DACCS) in order to contribute towards global temperatures reverting to a 1.5°C (or lower) temperature goal in a case of a temperature overshoot. This step seems increasingly likely in light of the insufficient ambition of #1 and #2 and the forecasted 1.5°C overshoot in the IPR Forecast Policy Scenario.

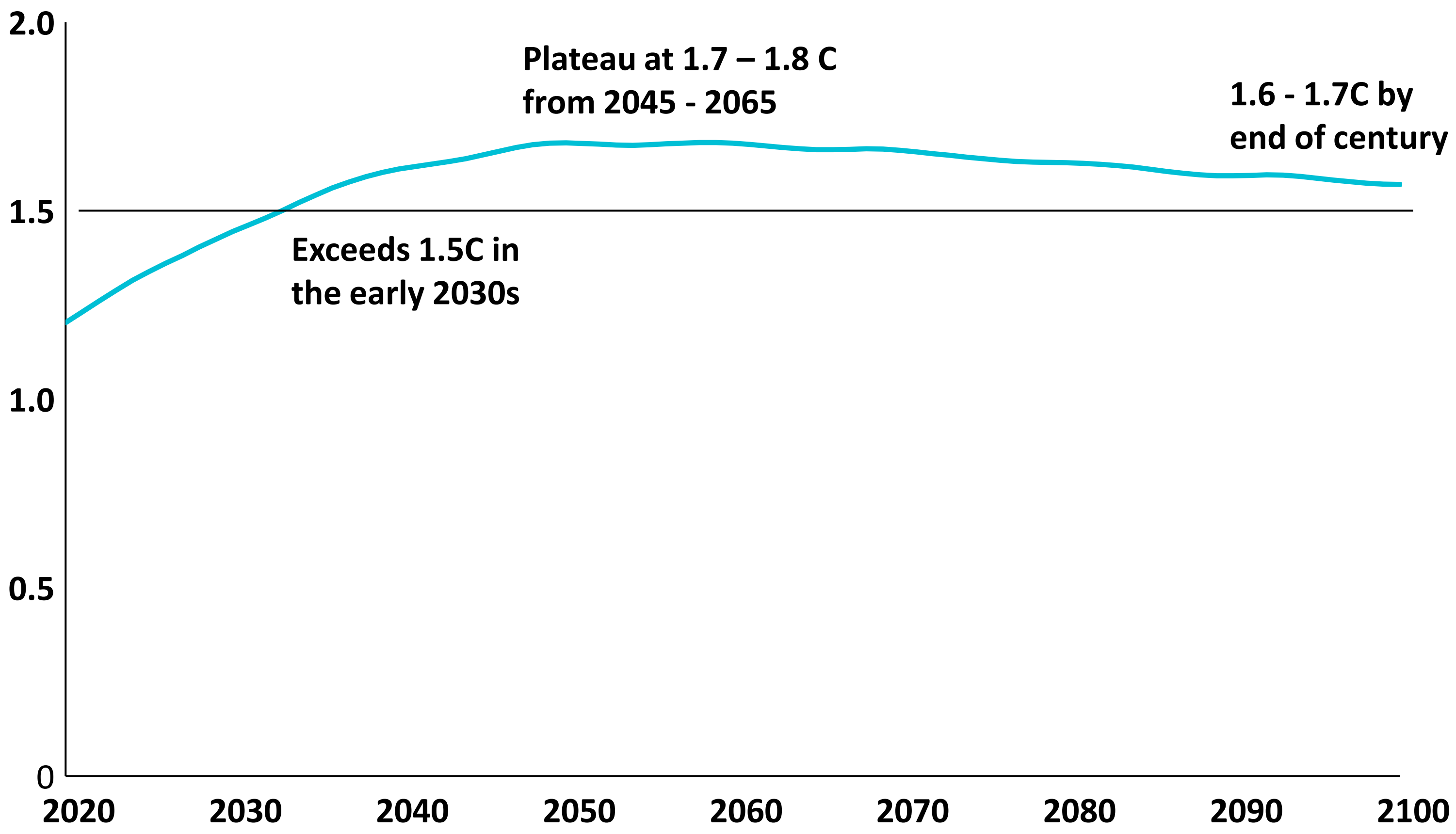
Rebalance the footprint through adaptation and geoengineering is the last resort for society to reduce global temperatures to the stretch target of 1.5°C or lower (or adapt to a higher temperature world). This involves either accepting 1.5°C temperature overshoot and reorganizing society / adapting accordingly or using alternative interventions in the climate system (e.g. solar radiation management) to influence the climate.

IPR considers the 4th option – based on scientific evidence available today – to be the least desirable step on the ‘climate journey’ and that technological progress on DACCS means Nature-Based Solutions (NBS) remain the first port of call for negative emissions until the middle of the century. However, it is clear that DACCS will be needed given the issues around permanent storage and land constraints for NBS

This investor briefing explores the future of DACCS in terms of its financing and investment implications for financial institutions.

FPS 2023 forecasts peak temperatures of 1.7-1.8C around 2045, dropping to 1.6-1.7 C by 2100 if DACCS continues

Surface temperature anomaly, degrees C above pre-industrial reference period[1]



1. The pre-industrial reference period is 1850 to 1900, defined in Kelvin. Temperature anomalies in Kelvin and Celsius are equivalent.
2. Based on MAGICC 7
3. Assuming only impact of continuation of DACCS levels

IPR FPS 2023 forecasts[2]

- An exceedance of 1.5C in the early 2030s
- Peak temperatures of 1.7 - 1.8C around 2045 - 2065
- Net-zero CO_2 emissions around 2060 and net-zero GHG emissions around 2080
- Overall likelihood of staying below 2°C warming is at >90%
- This assumes a build up of DACCS to 0.6GT by 2050 and then to 5GT a year by the 2070s
- At this rate temperatures could return to 1.5C around the 2130s.

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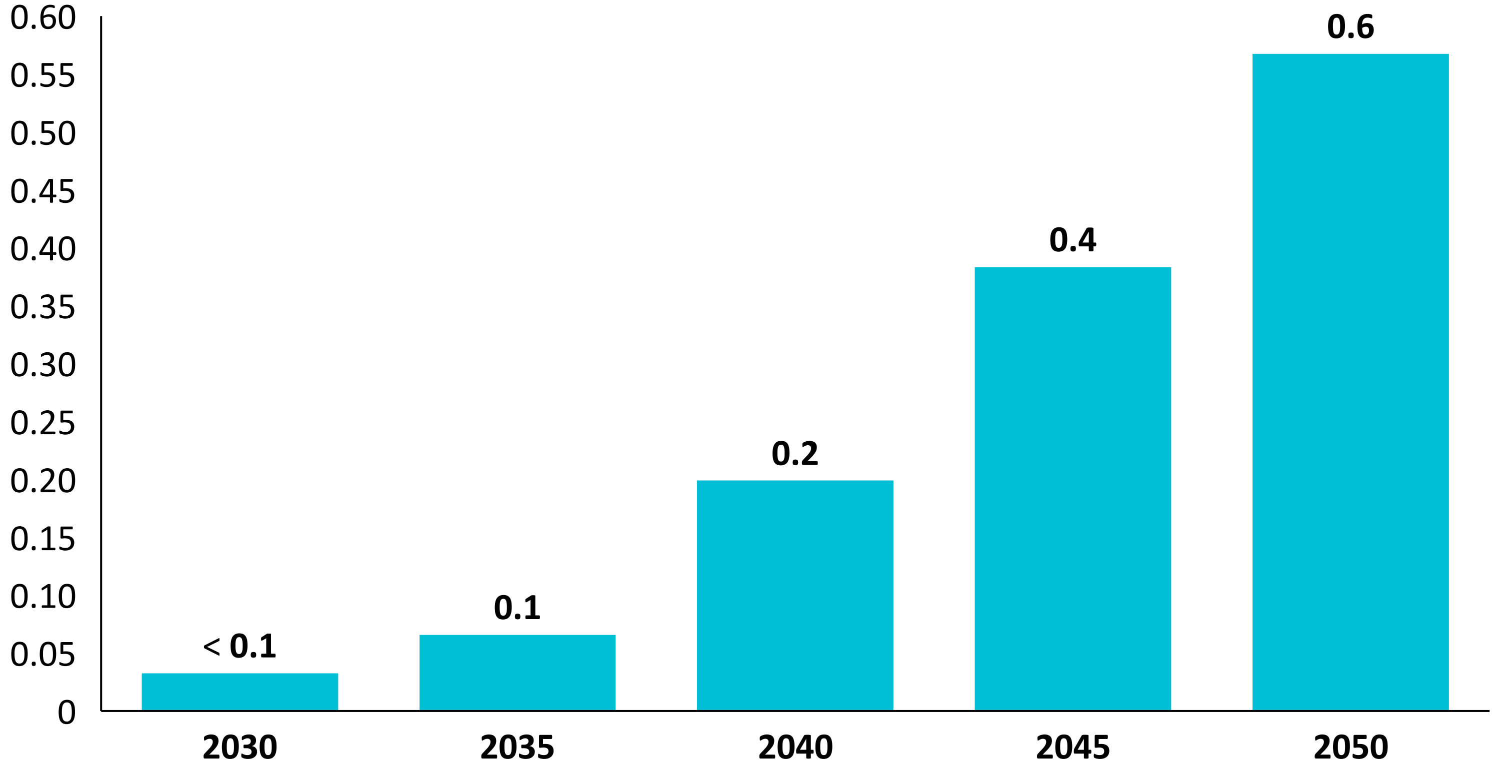
FPS 2023 includes 0.6Gt of DACCS by 2050, predicated on a significant cost reduction as removals ramps up

Global DACCS carbon removals, 2030-2050, $GtCO_2$/year



- **FPS 2023 sees DACCS reach 0.6 $GtCO_2$/year by 2050**, predicated on near-term demonstration DACCS sites, which move the technology along the learning curve in the 2030s and **reduce costs to as low as \$150/tCO_2.**[1] **Eff**
- These cost estimates are consistent with a range of third-party research including BCG, Thunder Said, International Energy Agency, mapping the cost reduction potential until 2050
- DACCS wins over BECCS in the long run once land costs are taken into consideration

1. Cost trajectory from McKinsey Voluntary Carbon Markets modelling
2. Value for energy demand per tCO2 captured taken at the lower bound of values reported by the National Academy for Sciences

Source: IEA, National Academy for Sciences, McKinsey Voluntary Carbon Markets modelling

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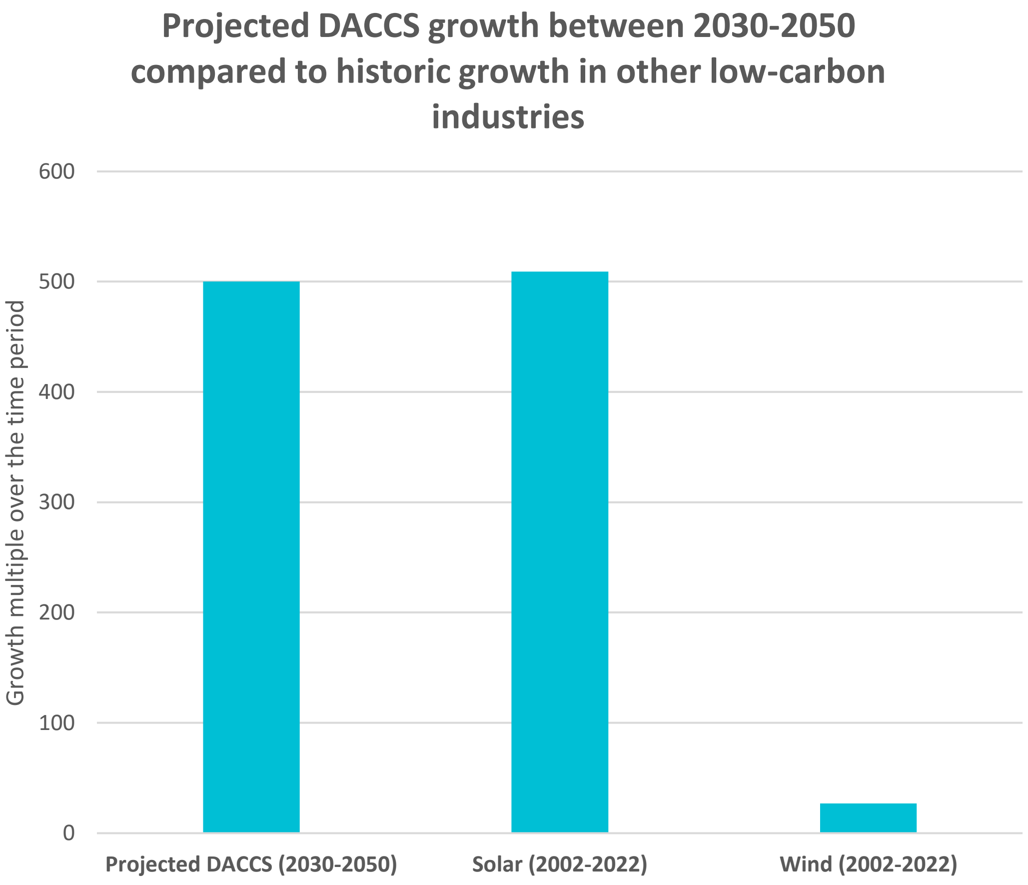
The IPR DACCS 2050 forecast is roughly consistent with the growth trajectory of solar power between 2002 and 2022 from 2030 onwards.

A range of pilot projects are now under way to prove the feasibility of DACCS, supported by government assistance around the world, most notably the Inflation Reduction Act in the United States, but also United Kingdom and Europe (see *IPR Note on DACCS Policy Design).*

The IPR forecast eventually predicts that 0.6 GT of CO_2 will be removed by these projects by 2050, roughly the same level as the IEA Net Zero 2050 scenario. Based on the deployment trajectory and anticipating that this decade will primarily focus on pilot deployments, this would imply a 20 year growth trajectory from 2030 that roughly mirrors the growth trajectory of solar power over the past two decades. However, solar power had decades more experience and significantly lower engineering challenges.

Mirroring that pathway will thus undoubtedly be an ambitious ask. On the other hand, the overall decarbonization pressure in a more rapidly warming planet may facilitate more robust and steady policy support. Moreover, expert analysis suggests there is some reason to believe DACCS can mirror the solar journey, given the scalability opportunity, the technology maturity, and the potential cost reductions.



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Crucial for DACCS success will be the ability to reduce costs to competitive levels to make scaling politically and economically viable.

This likely requires DACCS costs to reduce to ~$120-$150 per ton of CO_2 removed by 2050.

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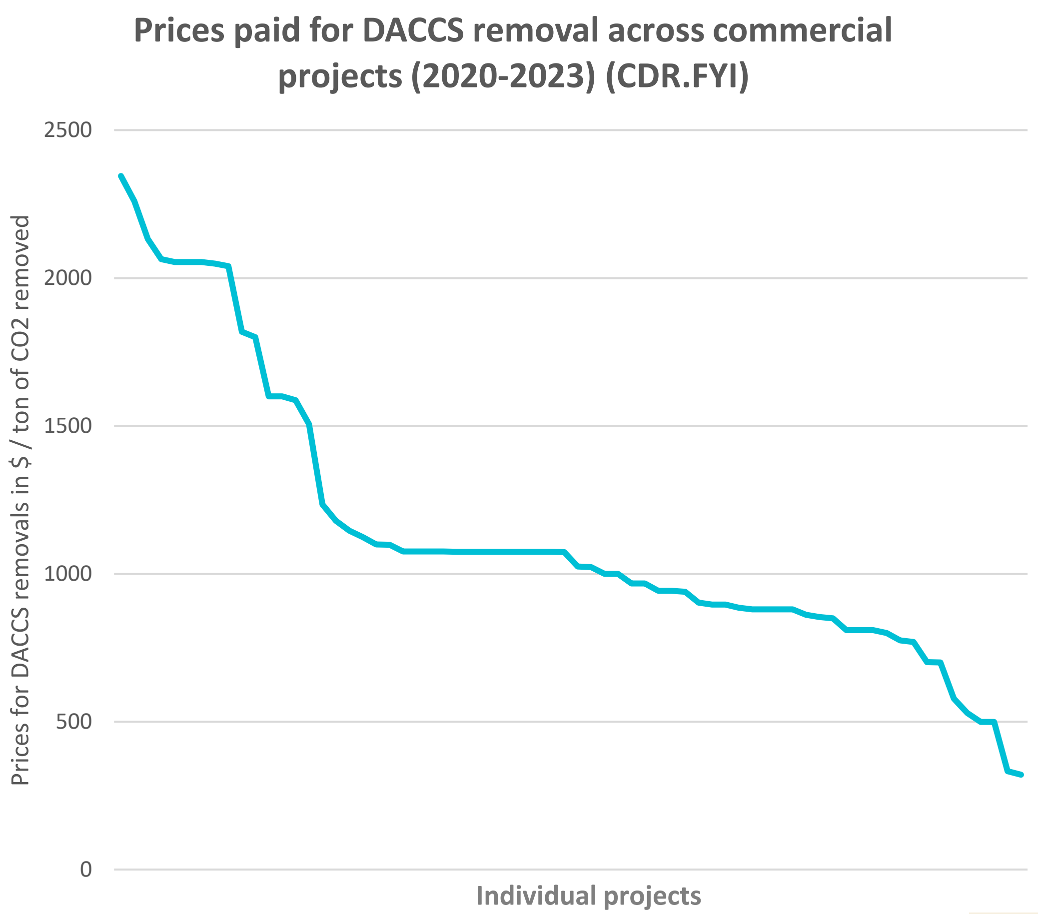
While current DACCS cost ranges are very wide ($700-$1400 per ton of CO2 removed), a full capacity plant would like allow for a $600 breakeven price

There are currently a broad range of costs cited in the market pre subsidy for DACCS ($700-$1400 / ton of CO_2 removed and stored). Individual projects charge over $2000, although prices vary significantly (see Fig. on right). Both IPR cost analysis in-house and analysis of third-party sources suggests that the 'baseline' costs for DACCS over the next few years will settle at $600 given current technologies and learning (using Liquid DACCS as a reference point for the technology analysis) and assuming 100% renewable, non-intermittent energy supply.

One reason why the cost band is so high is that current projects serve the dual function of 'selling credits' in the voluntary carbon markets and 'testing the technology' and thus a plant operating at 'full capacity' would – according to IPR estimates – cost around $600 per ton of CO_2 removed. We use $600 as the reference point in this briefing and across our analysis as the 'market clearing' price for DACCS over the next 2-3 years, recognizing that the diversity of DACCS projects (including technological solutions) will mean price bands will likely remain broad until at least 2030. The IPR baseline costs are estimated based on the sister paper to this briefing focusing on the DACCS Engineering Challenge.



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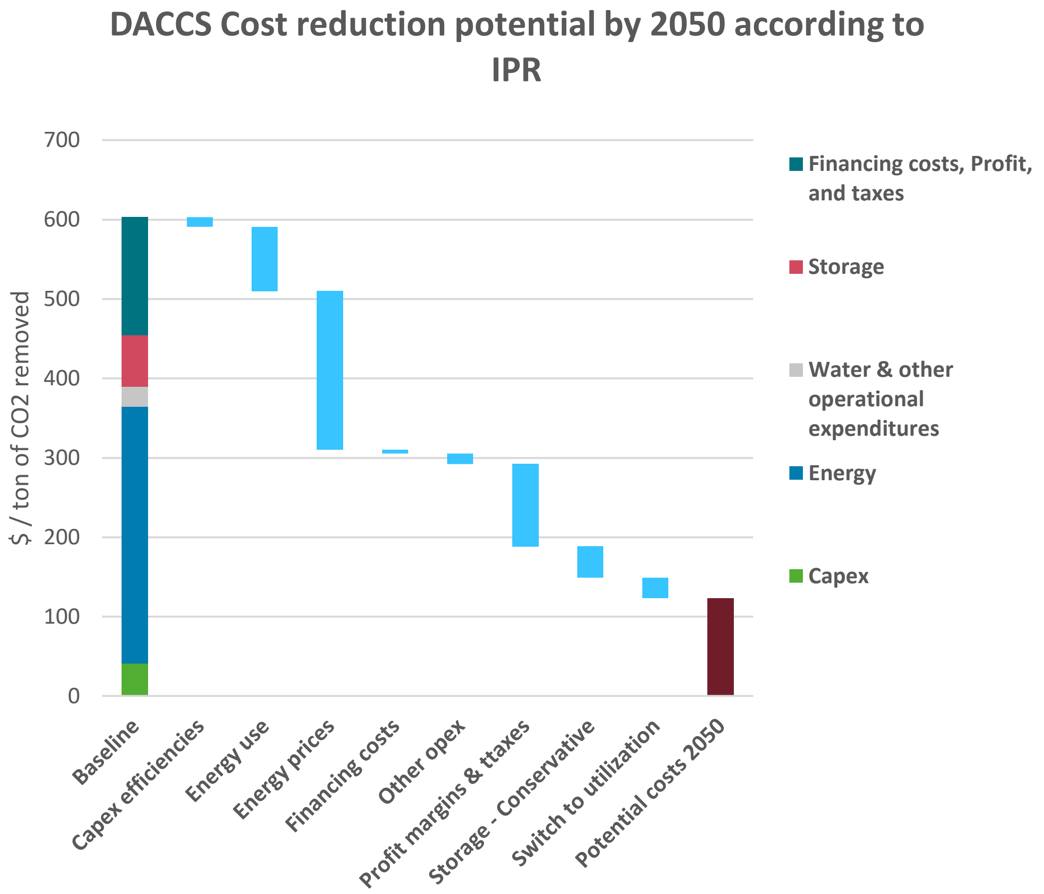
Key drivers of cost reductions are energy efficiency and costs, profits and taxes, and the future of storage vs. utilization

The reason DACCS has the potential for cost reductions at scale can be summarized as follows.

- A combination of energy efficiency, further reduction in electricity generation prices, and the switch from retail to 'at cost' electricity use could shave almost half the costs of DACCS today. Related savings may be possible in the use of heat.
- Storage costs will benefit both from a massive increase in efficiency as projects scale and may eventually reach zero if CO_2 commercial utilization at scale, notably for building materials, becomes reality.
- Crucially, there may even be a point where fees could be earned for the sale of CO_2 as a commodity, further reducing the overall costs.
- Profits are currently a significant share of costs given the need for a meaningful return rate on a very capital-intensive project. Some estimates suggest that roughly one-third of future costs will be associated with a combination of profit margins, taxes, and financing costs. However, a regulated environment may require different profit margins and allow for different tax regimes, not the least if upfront capital is provided by governments.



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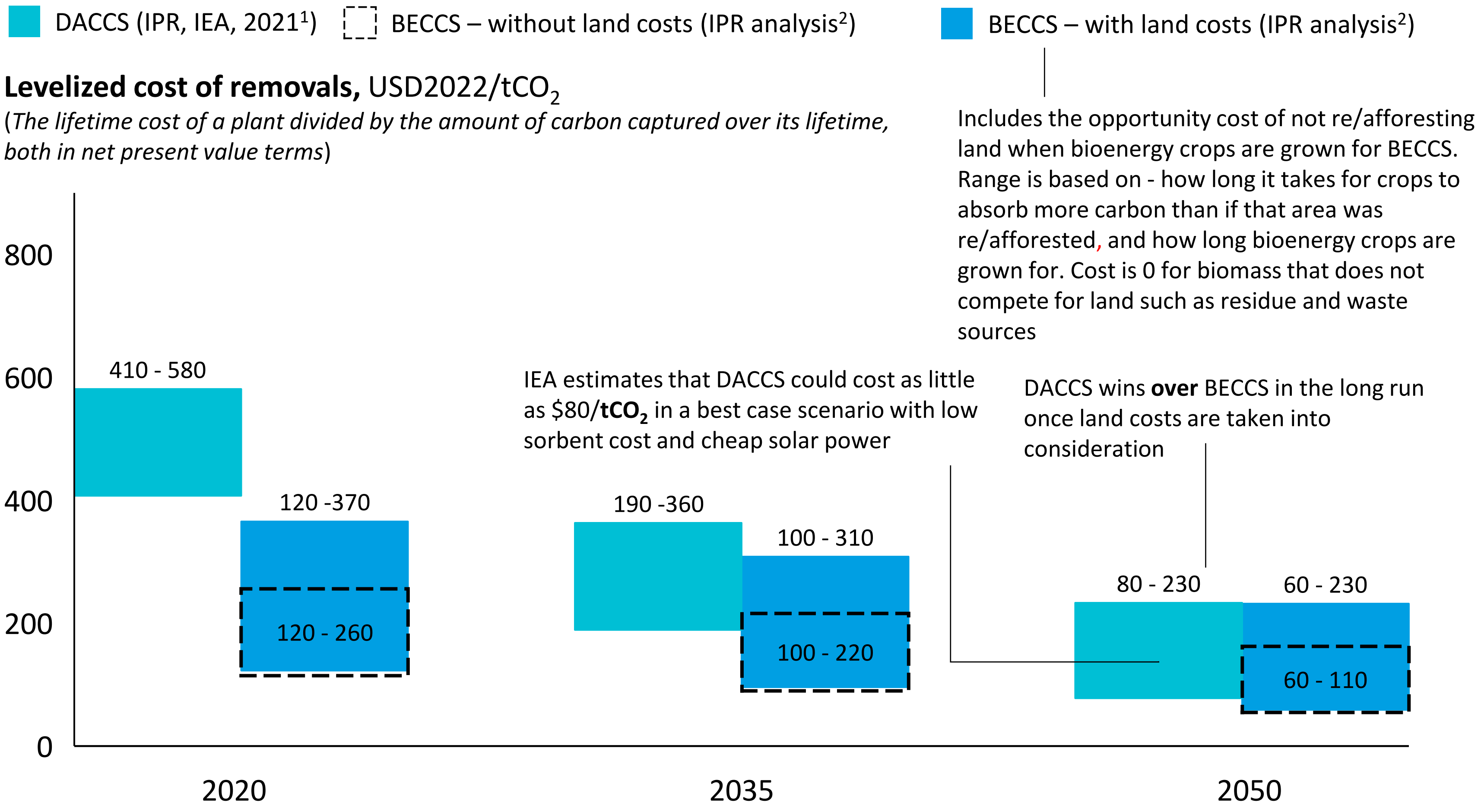
DACCS cost reduction potential means it will be more cost competitive by 2050 relative to BECCS

Levelized cost of removals, USD2022/tCO_2

(*The lifetime cost of a plant divided by the amount of carbon captured over its lifetime, both in net present value terms*)



1. Primarily based on IEAGHG Technical Report, 2021, Global Assessment of Direct Air Capture Costs. Assumes FOAK is 2020 and NOAK is 2050. Range is from base case (lower) to very ambitious (upper)
2. No land cost estimates in line with Fuss et al, 2018, Negative emissions—Part 2: Costs, potentials and side effects. Land costs calculated based on how long it takes for crops to absorb more carbon than if that area was re/afforested: the carbon payback period (CPP), and how long bioenergy crops are grown for: the removal period . Lower bound = 75-year removal period with 5-year CPP, upper bound = 50-year removal period with 15-year CPP
3. BECCS and DACCS represent two of the most often discussed technology-based removals, however other approaches such as biochar or enhanced weathering also offer potential for removals.

There are multiple considerations in estimating the true levelized cost of removals for BECCS relative to DACCS.

In particular, land costs are considered explicitly in the modeling for FPS 2023 (see footnote 2), whilst others' estimates typically may not. BECCS applies a relatively mature technology and so is unlikely to experience significant cost reductions. BECCS costs increase if the land impact of growing biomass is considered.

Direct Air Carbon Capture and Storage (DACCS) removes carbon from ambient air and has the benefit of limited land constraints[3].

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Who pays for DACCS and how much?

We assume that there is some price point (up to $100) where the private sector would be willing to cover the costs of negative emissions although it is unclear whether that 'equilibrium price' would be sufficient to cover all residual global emissions or the requisite need for negative emissions technologies. Moreover, there are also some market actors willing to pay a higher price. DACCS may become a component of regulated emissions trading systems (ETS). As prices in these systems go up, regulation may allow for paying for removal rather than the emissions certificate (hypothetically, governments could use the proceeds of ETS to pay for removals). It is clear that the underlying politics and policies of DACCS *at scale* remain unresolved. Ultimately governments will likely have to explore several different (potentially jointly reinforcing) options:

1) Costs are sufficiently low that voluntary market initiatives can scale. While this appears as an ideal outcome, there is significant uncertainty as to the extent to which companies would – again, at scale – be willing to absorb a 'voluntary cost'. Even if there is some capacity, that won't be enough to reach scale at $150 / t.
2) DACCS is integrated into Emissions Trading Systems in some form, or a similar policy requirement is introduced that functionally serves the same purpose;
3) Governments pay for DACCS directly and finance this through a combination of tax schemes (including potentially ETS) and borrowing.

As this discussion highlights, significant questions remain. Even a simple analysis of required government subsidies suggests scaling to the deployment levels forecasted by IPR or envisioned under the IEA Net Zero scenario may require upwards of $2 trillion in global subsidies over the next three decades. However, this would not be sufficient to reduce warming by 0.1°C by itself, an effort that would require (at $150 breakeven without subsidy) roughly $33 trillion. Policy issues are further explored in a separate IPR report "DACCS – Policy is Essential".

DACCS is expected to reach annual revenues roughly equivalent to the global coffee industry today by 2050, but will likely still be the smallest ‘climate industry’ compared to nature-based solutions and clean energy & battery technologies.

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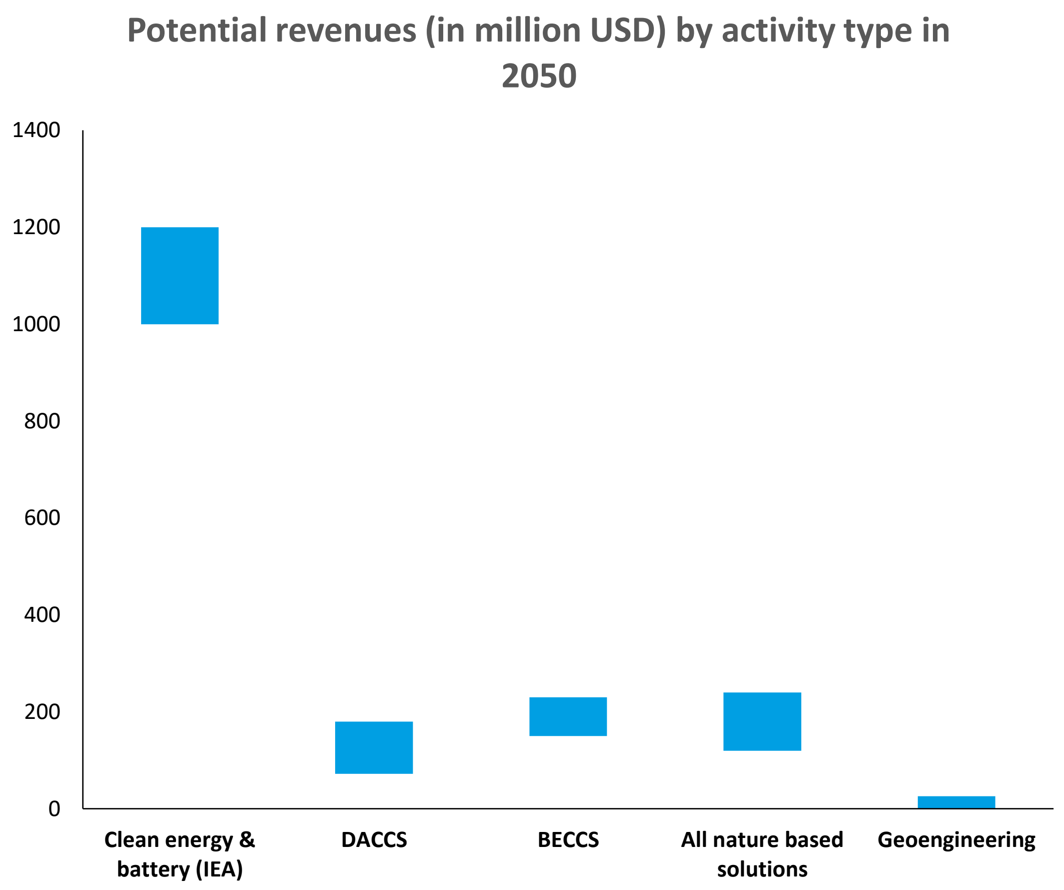
DACCS revenues will remain relatively modest until 2050, reaching roughly the size of the global coffee industry today.

NETs (across DACCS, BECCS and NBS) could account for over $600 billion in revenues by 2050 under the IPR Forecast Policy Scenario (FPS), more than 50% of the clean energy & battery revenues (as estimated by the IEA), demonstrating their growing economic significance.

DACCS has the smallest expected revenue share of $72 to $180 billion (assuming breakeven between $120 and $300), suggesting cash flows from DACCS – while material – would still be only one-tenth of that of the transition revenues. For comparison, in today’s dollars, the global coffee industry has annual revenue of around $200 billion. What is more, most of these revenues are likely only set to materialize post 2040, suggesting that from an investor's perspective the potential cash flows of DACCS will remain marginal in the medium-term.

One key challenge will be the potential low cost of alternative “geoengineering” solutions (should geoengineering be deployed) that will become a tempting alternative for policymakers. Of course, the goal would be to avoid geoengineering revenues given the risks and uncertainties. It is worth flagging that none of these revenues consider the downstream CO_2 utilization, which will be further explored later in this report.



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While revenues until 2050 will still be relatively small compared to the transition opportunity, investment levels may be as high as $500 billion per annum, roughly equivalent to renewable energy investment in 2022.

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While revenues will be limited, DACCS investment levels by 2050 will spike dramatically, significantly outpacing the investment needs for NBS

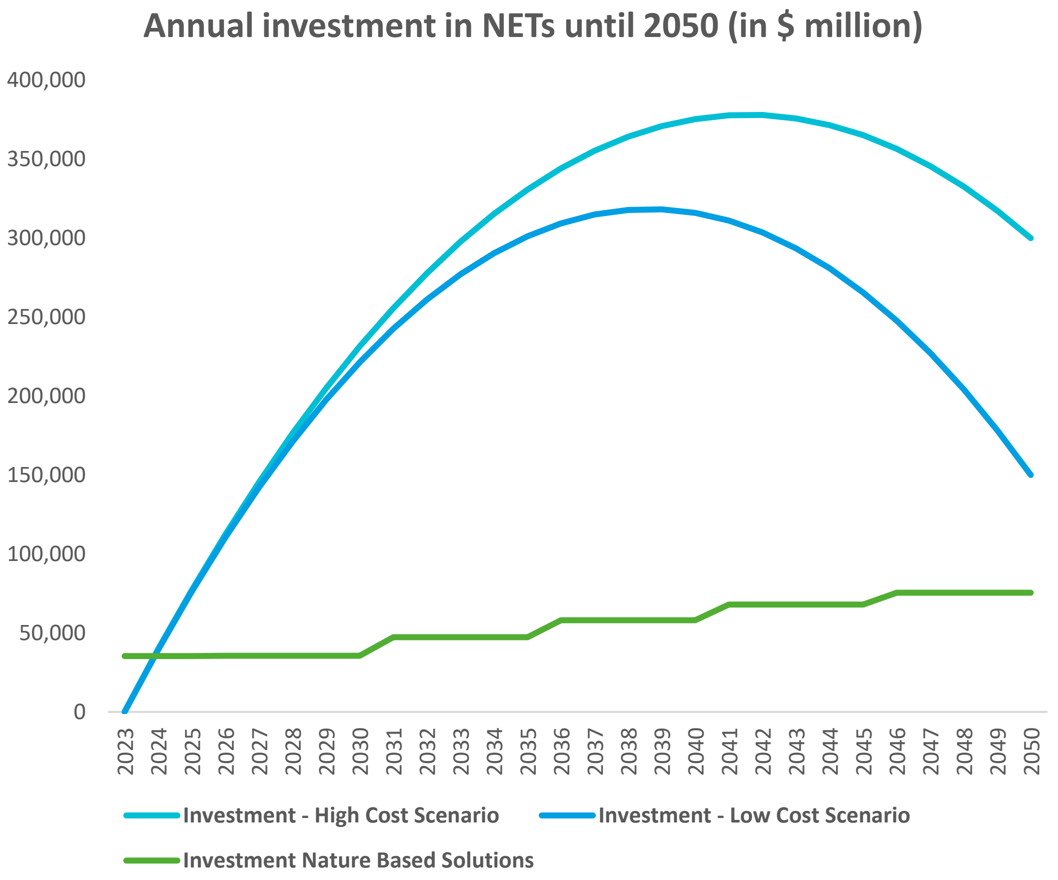
While DACCS is expected to generate ~50% of the revenue of nature-based solutions by 2050, it is a fundamentally different investment opportunity, with potentially upwards of $300 billion in annual investment going into DACCs by 2050.

From a financial sector perspective, the financing need is thus dramatically higher with significant additional opportunities.

To compare, by 2050 DACCs in a high-cost scenario (i.e. assuming $300 breakeven by 2050) would involve annual investment levels roughly equivalent to renewable power investment in 2020 at its peak.

Even in a low-cost scenario (assuming $150 by 2050), investment levels would be almost double that of nature-based solutions in 2050.

However, the key question obviously is the extent to which DACCS would be able to maintain a high growth potential under a high-cost scenario (an issue that will be revisited later in this note).



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The DACCS investment opportunity can be split into four industries: supply chain, DACCS deployment, storage and carbon markets

Supply chain: A significant portion of the future DACCS industry will benefit existing industries, notably construction materials, chemicals, the construction sector, and energy. While some of this “supply chain” may be in-housed by developers (e.g. energy), most of this will likely be delivered by service partners and could represent upwards of 50% of future DACCS investment share. These activities are likely benefiting existing industries with typical financing structures of equity and debt, and given the size, primarily operating on capital markets. The finance sector can also be considered part of the DACCS supply chain.

Direct Air Capture deployment: The deployment or actual operation of DACCS facilities involves a technical and engineering complexity, as well as (potentially) geological knowledge that makes it highly likely it will be delivered at least in part by what is now the oil & gas industry. Given the significant public footprint and public utility of these activities, financing is likely to mirror the financing of other utilities with fixed rates and thus primarily through either government balance sheets or debt financing.

Storage: The ultimate storage or ’end use’ of the captured emissions. This may either be a part of the end deployment, implemented separately (e.g. a different industry manages storage), or involve the selling on of carbon for further utilization (e.g. in building materials). The nature of financing is thus highly uncertain, given the potential for storage costs to eventually be ‘net zero’ as end of life use cases for captured CO_2 is developed.

Carbon trading / carbon markets: DACCS will also impact the ‘client side’ in terms of removal markets, as it seems likely commercial players will play a significant role in the purchasing and trading of carbon credits generated by DACCS.

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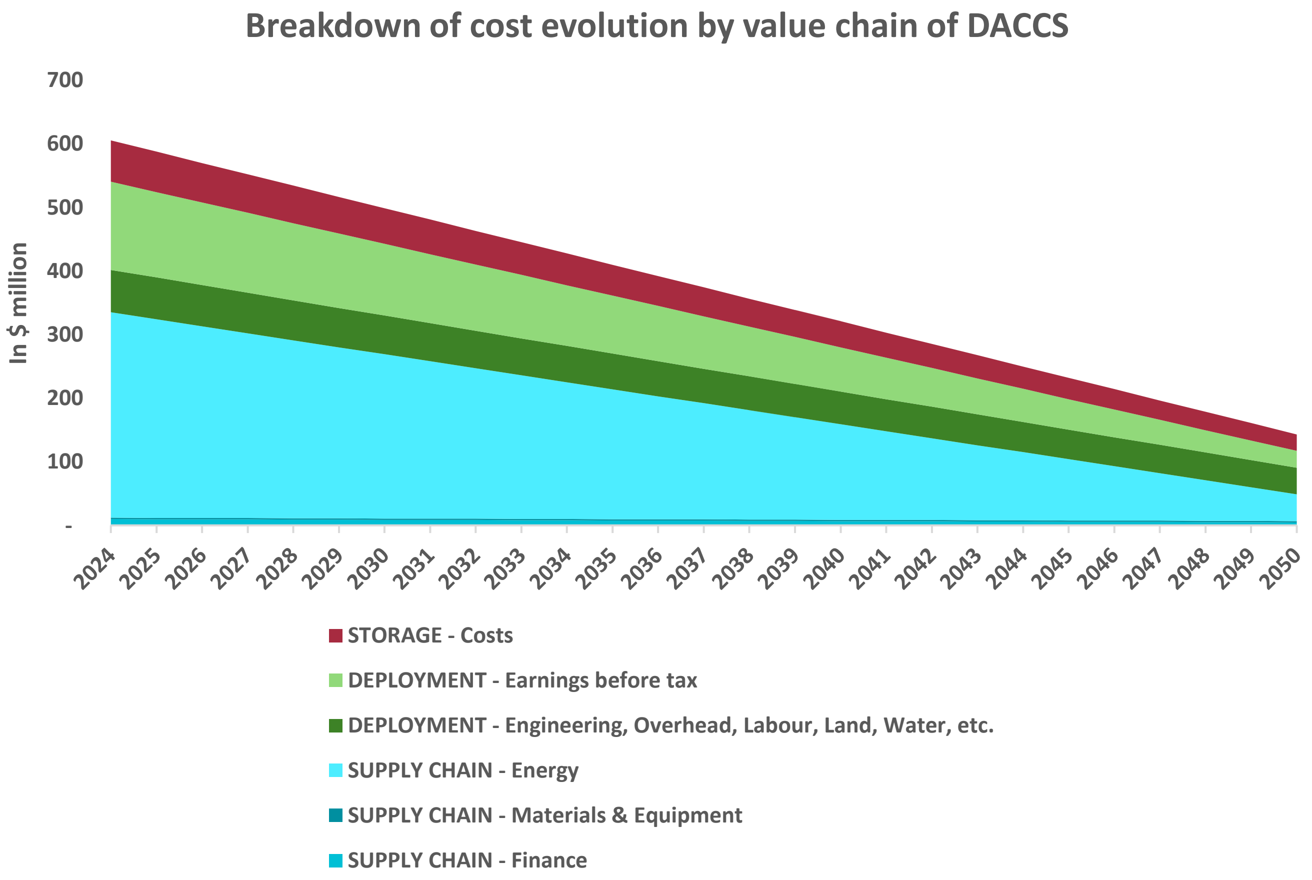
The DACCS opportunity can be split into four industries: supply chain, Direct Air Capture (the direct deployment), storage / utilization, and carbon markets



DACCS annual expenditures by cost categories will throughout most of the next decades be concentrated in the supply chain, notably materials and equipment and energy.

By 2040, the big question mark will be the future of storage. Will a new industry emerge capitalizing on CO_2 as a resource (e.g. building materials) or will disposal via storage without revenues continue to dominate the market. Answering this question will be one crucial factor to determining the viability of DACCS and the investment and financing opportunities it provides.

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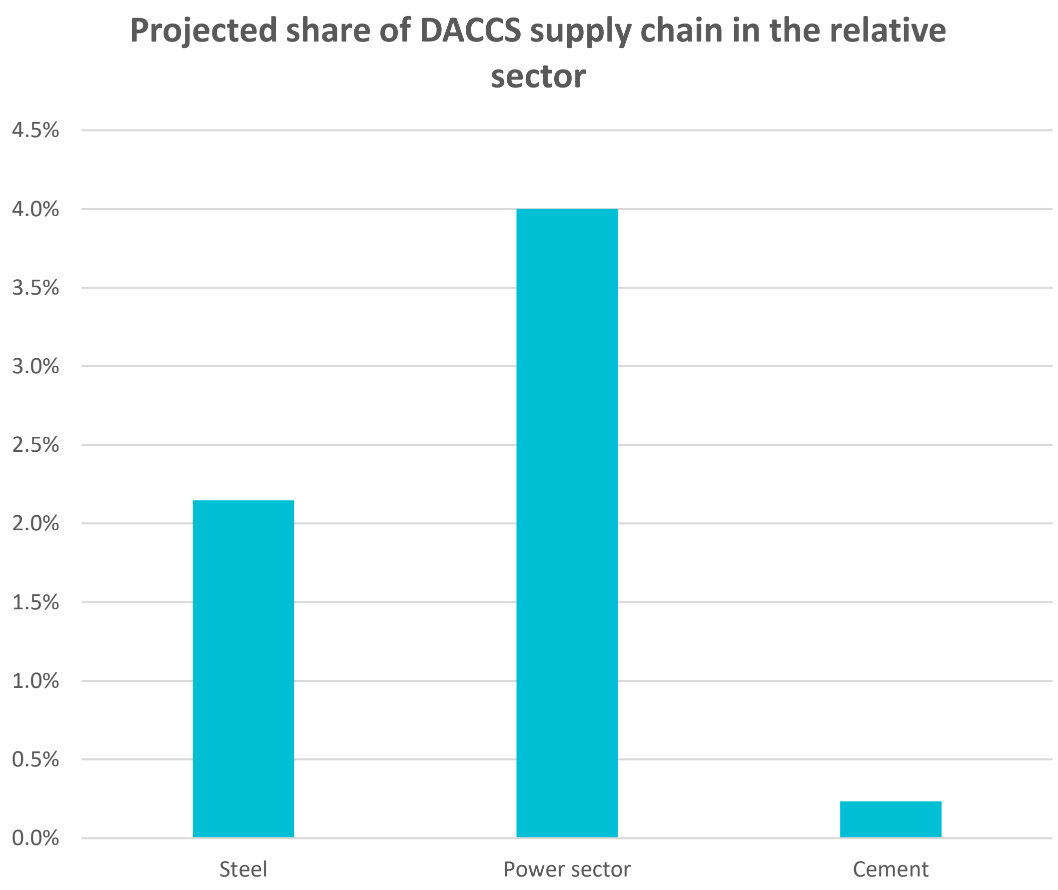
SUPPLY CHAIN – A new source of demand for energy and materials

The DACCS supply chain will be dominated by construction materials and the power sector as well as chemicals. While from a technical perspective, the availability and use of chemicals is the biggest unknown, DACCS will have a significant footprint in the existing power and steel industry.

Upwards of 2% of global steel demand and 4% of global power demand in 2050 (based on current demand) may be linked to DACCS. The role of cement however – in relative terms is more marginal – with 'only' ~0.2% of global cement demand (based on current levels) related to DACCS in 2050.

The role of DACCS in land is harder to define. Most analysis suggests DACCS won't compete with arable land. However, this depends both on the type of DACCS application (with liquid DACCS requiring significant water and thus constraining the geographic availability) as well as the political economy of deployment.



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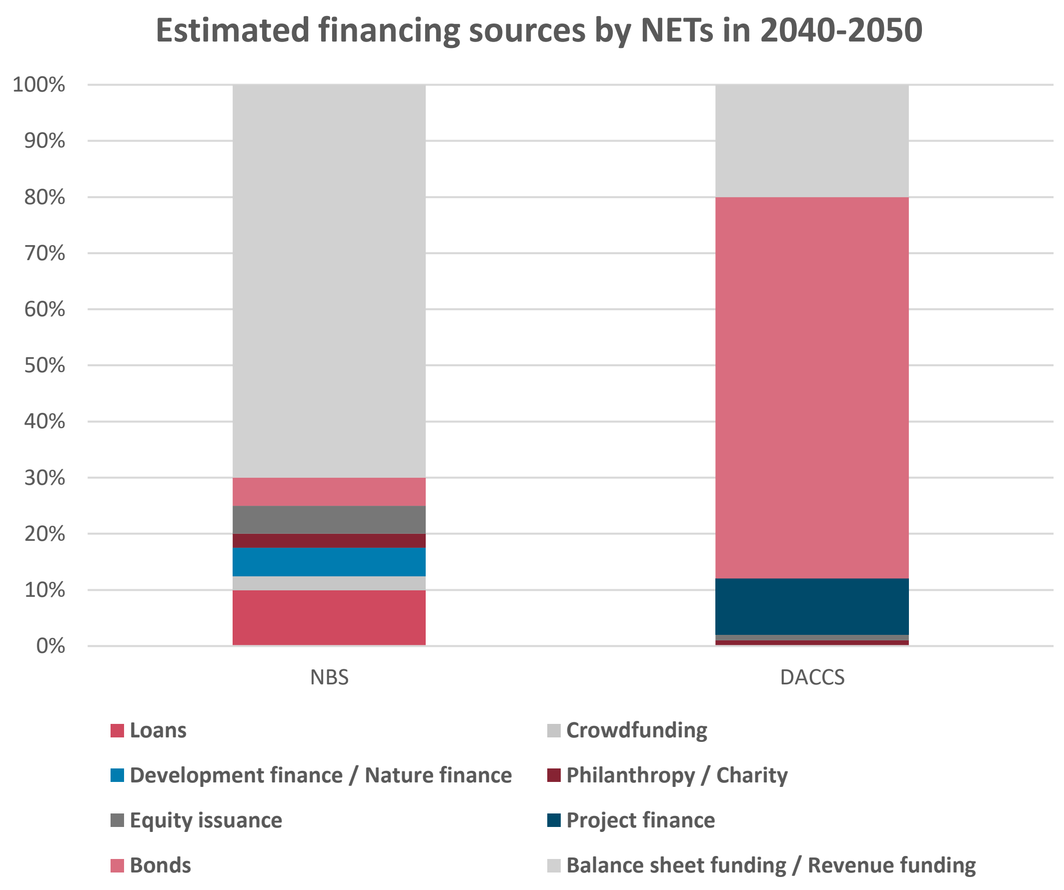
DIRECT AIR CAPTURE/ DEPLOYMENT – A power plant with an extractor fan?

DACCS will likely see dramatically different financing structure to nature-based solutions, which are financed through a range of traditional and non-traditional channels. In principle, the financing structure is likely to be a mix of the “utility” and “oil & gas” funding structure, with limited equity issuance funding development and potentially some philanthropic / charity funding, while the bulk of financing comes from project finance and bond issuance (either by public or private actors).

This is particularly the case as scaling of DACCS will likely require ‘in-house’ energy development (zero carbon and non-intermittent through e.g. battery) and thus over time, what is now the ‘supply chain’ will be submerged into the project design. That does not necessarily mean that DACCS developers will become energy developers, but rather that DACCS projects will involve an integrated planning profile including energy, not the least as grid-connected DACCS systems may also eventually play a role in grid and peak demand management.

While over the next decade there may be a larger role for venture capital and private equity, the utility scale nature of DACCS in order to be cost effective will quickly require a scale of deployment that can only be delivered by large companies with access to capital market funding.



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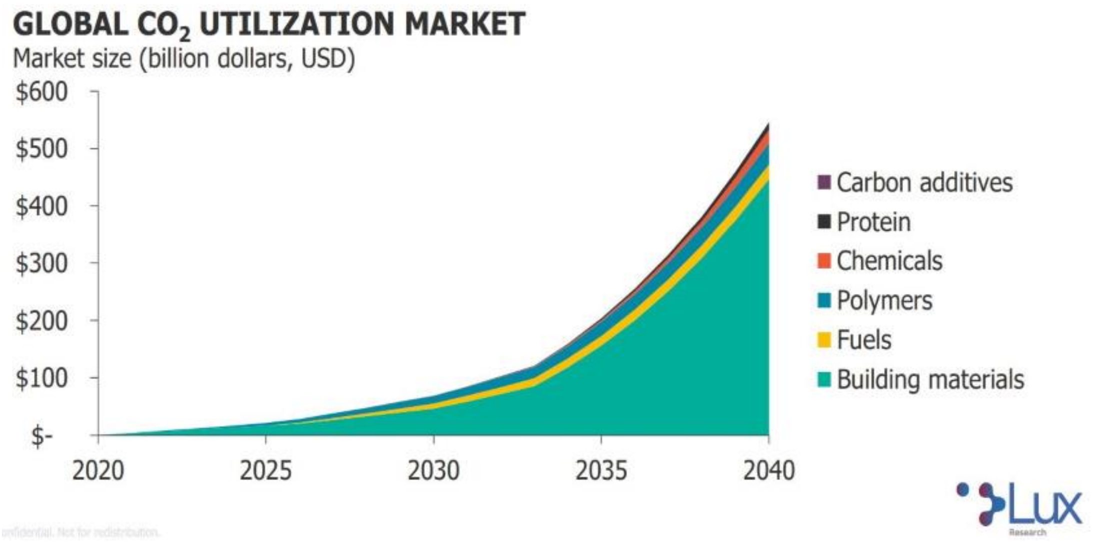
STORAGE – Cost buster or source of revenue?

No part of the DACCS 'value chain' leaves currently more question marks than the question of storage. On the one hand, there are legitimate engineering questions about storage, the appropriate geological profile, the piping and nuts and bolts of long-term and permanent removals. On the other hand, some companies are already looking at developing new industries around what may become one of the most readily available resources in the world.

Projections around the scale of these utilization markets differ widely, with anywhere from half a trillion (Lux Research 2023) to a trillion Dollars by 2050 (Sick et al. 2023) and a market demand that could range anywhere from 0.5 to 10 Gigatons (raising the question of supply). Of course, as long as there is fossil fuel extraction this industry will not exclusively be catered to by fossil fuels. Moreover, this analysis is more on the optimistic side as these technologies and use cases are not yet mature.

Finally, there is significant uncertainty around the 'breakeven price' that CO_2 could generate i.e. the cost that CO_2 could be sold at to make its utilization cost competitive. This is obviously highly industry specific and could range from \$0 (i.e. the industry is only competitive if CO2 is free) to \$230 (Hepburn et al. 2019).



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CARBON MARKETS – The DACCS advantage

Carbon markets (voluntary or mandatory) have been fraught with issues over the past two decades. For nature-based solutions, the accounting of carbon removals in the context of trees and biomass acting as 'non-permanent storage' has been a core challenge. A related challenge for many projects is the extent to which they use the notion of 'avoided emissions' (e.g. through the commitment to not cut down trees), which similarly raise accounting questions. The past few years have also seen a growing focus on the potential negative nature footprint of large scale, monoculture afforestation and the extent to which the 'albedo effect' (i.e. the reflective nature of forest canopy) can unintentionally offset some of the cooling effect associated with CO_2 capture.

DACCS does not suffer from any of these issues. While there may be some challenges around ensuring permanent storage where this forms part of geological solutions (e.g. carbon leakage from storage in former oil & gas fields), but these issues can be much more clearly traced and reliably monitored than for nature-based solutions. Quality increasingly comes at a premium in carbon markets and these features will make DACCS a more attractive proposition for buyers over the next decade, driving demand and investment.

- Permanent storage
- Genuine removal
- No nature footprint
- No albedo effect

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Theia Finance Labs (formerly 2° Investing Initiative Germany) is an independent, non-profit think tank incubating research solutions for the financial sector that help solve the climate crisis. The Theia Finance Labs name is inspired by the Greek goddess of sight, the light of the blue sky, and the value of gold, Theia, and by the Greek word Aletheia, which means “disclosure” or “truth”, literally “the state of not being hidden”. The new brand thus mirrors our goal to develop evidence-based research and tools that shed light on the intersection of finance, climate change, and long-term risks. Theia operates as a 100% non-profit organization.

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Scenario	Policy Forecast Details	Open Access Database
IPR 2023 Forecast Policy Scenario (FPS) • Models impact of forecasted policies on the real economy	IPR FPS 2023 Summary Report IPR 2023 Policy Forecast IPR FPS 2023 Detailed Energy Results IPR FPS 2023 Detailed Land Use and Nature Results IPR 2023 Bioenergy Report	IPR FPS 2023 Value Drivers IPR Scenario Explorer
IPR 1.5°C Required Policy Scenario (RPS) • Required policies to align to a **1.5°C objective** building on the IEA's Net Zero scenario and deepening analysis on policy, land use, emerging economies and value drivers	IPR 1.5°C RPS Energy and Land Use System Results including Policy Details	IPR RPS 2021 Value Drivers
IPR Forecast Policy Scenario + Nature (FPS + Nature) • First integrated climate and nature scenario for use by investors	IPR 2022 FPS + Nature detailed results	IPR FPS + Nature Value Drivers

IPR has published a set of publicly available outputs from the FPS and 1.5°C RPS that offer significant granularity at the sector/country level, allowing investors to assess their own climate risk across 4,000+ variables

Disclaimer: This is not intended to constitute policy advice, financial advice or any specific advice.

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