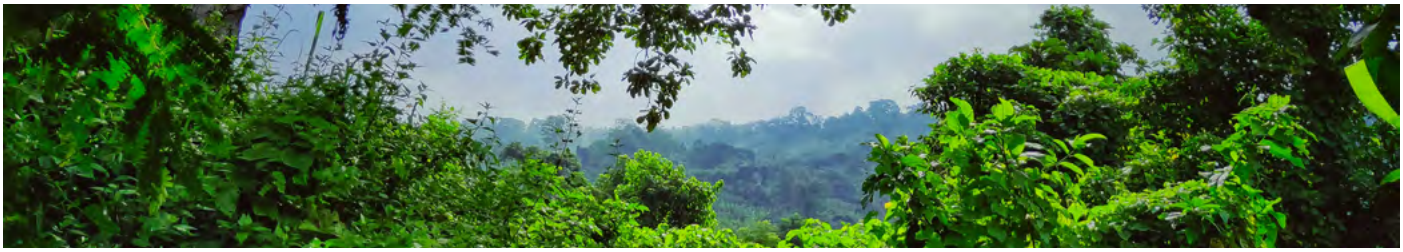
PACM REMOVALS NOTE | **02**

CLIMATE FOCUS

Permanence and durability: the essence

Carbon removal is essential for climate goals. Nature-based approaches can scale now, while engineered methods offer greater durability. This information brief argues that effective policy should combine both, balancing scale, sustainability, storage duration, and reversal risks.



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THE ROLE OF CARBON REMOVALS IN MEETING CLIMATE GOALS

To meet the temperature goals of the Paris Agreement, rapid, deep, immediate reductions of all greenhouse gas emissions (CO_2 and non-CO_2) are needed and should be prioritized across all sectors. But reducing emissions will not be enough. The Paris Agreement also mandates balancing emissions and removals by the second half of the century to counterbalance residual CO_2 and hard to abate non-CO_2 emissions. In the light of different climate goals, carbon dioxide removal (CDR) is essential to

- reduce net emissions today,
- help achieve net zero in the coming decades, and
- create net-negative emissions later this century.

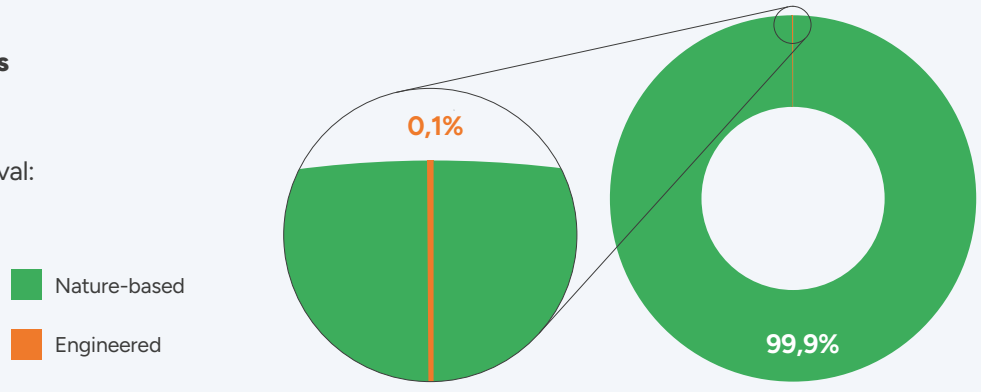
REMOVING CARBON IS ONLY HALF THE JOB

CDR requires not only *removing* CO_2 from the atmosphere but also *storing* it.

Different methods store carbon in different ways. Engineered approaches can inject CO_2 underground or lock it into minerals and geological formations, potentially for centuries or millennia. Nature-based approaches store carbon in forests, soils, wetlands, and other ecosystems. Although these systems continuously exchange carbon with the atmosphere, some carbon can remain stored for

Figure 1:
Nature-based approaches dominate global CDR

Total carbon dioxide removal:
≈ 2.2 $GtCO_2$ per year



Engineered CDR contributes only about 0.002 $GtCO_2$ per year (≈2 $MtCO_2$), or around 0.1% of total removals. Source: The State of Carbon Dioxide Removal 3rd Edition 2026.

decades, centuries or even longer. The ability to remove CO_2 from the atmosphere as well as the durability and security of these storage options vary considerably. Nature-based approaches are ready and tested and can scale CDR today. Engineered approaches can store carbon for potentially very long periods, but most approaches are still in the piloting phase.

In sum: Today, nature dominates actual CDR delivery; engineered CDR is growing but not yet deployable at scale. At the same time, engineered CDR dominates the discussion on durability. While most pathways to net zero require significant scale-up of engineered removals, for the next decades, essentially all CDR available at large scale is nature-based **(Figure 1)**.

Figure 2: Nature-based CDR and engineered CDR are complementary

KEY CRITERIA FOR CDR

Carbon dioxide removal (CDR) methods can be evaluated on **three key criteria**. No single CDR method perfectly excels across all criteria, which is why a diverse portfolio is essential.

READINESS AND SCALABILITY

Can we deploy it right now and at the needed scale?

DURABILITY OF STORAGE

How long is CO_2 stored and what are the reversal risks?

SUSTAINABILITY AND CO-BENEFITS

Does it provide co-benefits for people and the planet?

COMPLEMENTARY CDR APPROACHES

Nature-based CDR (e.g., forests, soils) and engineered CDR (e.g., direct air capture) are two complementary approaches. Nature-based CDR is immediately deployable at scale, helping to meet 2050 and 2100 climate targets while mitigating tipping point risks. Engineered CDR is still in early deployment and can deliver very durable storage in the long run.

	NATURE-BASED CDR	ENGINEERED CDR
READY & SCALABLE TODAY	✓	
HIGHLY DURABLE STORAGE		✓
SIGNIFICANT CO-BENEFITS	✓	

Source: "Considering durability in carbon dioxide removal strategies for climate change mitigation." Climate Policy (2025).

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DURABILITY MATTERS MORE THAN "PERMANENCE"

The term "permanence" is widely used in carbon markets, but there is no universally accepted definition of what constitutes permanent carbon storage. Scientists increasingly prefer the term "durability," which recognizes that carbon storage exists along a spectrum rather than a simple permanent-or-not binary.

Durability depends on two factors:

- how long carbon remains stored; and
- how likely it is to be released back into the atmosphere.

A storage method does not need to store carbon forever to provide climate benefits. Even storage lasting several decades can reduce peak temperatures and lower the risks associated with climate change, provided the carbon remains out of the atmosphere during critical periods.

THE RISK OF REVERSAL

All forms of carbon storage carry some risk that the carbon will be released again.

For mineral or geological storage, this risk tends to decline over time as CO_2 becomes trapped or mineralized underground. Some storage sites may take centuries or longer to reach maximum stability, while others, such as basalt formations, can stabilize CO_2 much more quickly.

Nature-based storage is generally less predictable. Ecosystems can lose stored carbon through fires, droughts, pests, storms, or land-use change. Climate change itself may increase many of these risks.

This does not mean that nature-based storage is ineffective. It means that its risk profile differs from that of geological storage and must be assessed accordingly.

IMPLICATIONS FOR CLIMATE POLICY

For CDR to contribute effectively to the goals of the Paris Agreement, it must meet three conditions: First, it must be deployable at scale and quickly enough to matter. Second, it must keep carbon stored for long enough, with reversal risks kept at acceptable levels. Third, it should support sustainable development and avoid significant environmental or social harm.

Different CDR approaches excel on different criteria. Nature-based CDR solutions are available now, tested, and can deliver large-scale removals in the near term, at lower cost and with additional benefits such as biodiversity conservation, water regulation and ecosystem restoration. Engineered CDR solutions generally offer greater durability and lower reversal risks and are likely to become increasingly important later in the century, particularly for balancing residual emissions over the long term **(Figure 2)**.

Based on their complementary strengths, both nature and engineered CDR are needed. The debate should not be framed as a choice between them. Treating nature-based and engineered CDR solutions as competitors and preferring engineered solutions over nature on grounds of permanence is a mistake. Instead, policy should concentrate on finding ways to incentivize combinations of nature and novel/engineered CDR that have a high enough expectation of starting now and being sustained over a long timeframe to yield atmospheric stabilization.

For effective climate policy, the most sensible and practical strategy is therefore to combine both approaches: scale nature-based CDR without delay, while further working on getting engineered CDR investment ready.

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