

Microsoft Carbon Removal Observations from our sixth year

September 2026



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This document is intended to share observations and lessons learned from Microsoft's carbon dioxide removal (CDR) program as of the date of publication. It is provided for informational purposes only and does not constitute legal, financial, accounting, procurement, or investment advice. The views expressed reflect current understanding and experience and may evolve as technologies, markets, regulations, and scientific knowledge continue to develop.

References to projects, suppliers, methodologies, or market developments are included for illustrative purposes and should not be interpreted as endorsements or commitments regarding future procurement, investment, or commercial decisions. Any forward-looking statements are subject to uncertainties and actual outcomes may differ materially from those described. This document does not create contractual obligations or commitments on behalf of Microsoft.

Introduction

When Microsoft launched its carbon dioxide removal (CDR) program in 2020, the market was nascent, few proven pathways existed at scale, and many technical, operational, and infrastructural questions had yet to be answered. Over the past six years, our experience has demonstrated both the promise and complexity of carbon removal. As we know, CDR is not a substitute for reducing emissions, but an essential complement to decarbonization: it can address residual emissions and help reverse the accumulation of carbon already in the atmosphere. As organizations, governments, and investors work toward a net-zero future, we remain convinced that high-quality carbon removal will play an important role, and that continued innovation, transparency, and collaboration will be critical to building the markets and solutions needed to scale it responsibly.

For CDR to achieve the scale the world needs, global capacity must reach billions of tonnes per year by mid-century.¹ It is not yet growing fast enough to do so,² but there is still time to accelerate. To help the industry move faster, we are sharing the most important lessons from our experience as an anchor buyer of CDR. We believe they are most relevant for policymakers in emerging compliance markets, other voluntary buyers with the ambition to underpin new capacity, and financiers and developers working in those markets.



A photograph of overhead land comparison. Photograph by re.green team.

¹ [New report states 7–9 billion tonnes of CO2 must be sustainably removed per year to hit climate targets | Oxford University](#)

² To support this claim: (a) novel approaches are on pace to reach 8.3Mtpa in 2030, far short of the 50Mtpa to 70Mtpa most scientific scenarios estimate will be required to stay on track (*State of Carbon Dioxide Removal 2026*. 3rd ed. Oxford, United Kingdom: Smith School of Enterprise and the Environment, University of Oxford, 2026, 16.), and (b) high-quality nature-based retirements hit 19Mtpa in 2025 (Carbon Direct. *State of the Voluntary Carbon Market 2026*. February 2026, 14). Taken together, these paint a picture of real but insufficient growth.

Since we released our last [lessons learned paper](#) in June 2023, Microsoft's CDR program has been busy. Between then and summer 2026, we signed offtake agreements for 80 million tonnes of additional CDR procurement, annually refined our [quality criteria](#) to reflect our continuous learnings, and sponsored technical whitepapers to make complex qualitative issues practically accessible³. We have also navigated market challenges: CDR demand remains concentrated among a relatively small group of buyers, and first-of-a-kind projects have encountered development setbacks.

Continued action in the 2020s can solidify the foundation for a durable, self-sustaining CDR market. In the first half of the decade, the CDR industry built a growing base of knowledge and practical experience. In the second half, the priority should be to translate those insights into action, continuing to learn through deployment while accelerating responsible scale. Two developments give us confidence in the path ahead

- 1) Learning curves: The entire industry is trying new things, figuratively and literally breaking new ground. While there is much more to learn, initial project deployments have **kickstarted innovation and improvement**. We can now start to recognize factors that separate success from failure.
- 2) Growing demand: We are seeing encouraging signs of **public demand**⁴ that will complement the voluntary carbon market and drive new capacity starting from the early 2030s. While voluntary procurement continues to grow—purchases by buyers other than Microsoft or Frontier increased ~50% from 2024 to 2025⁵—well-designed public demand will be the factor that ultimately pushes CDR to meaningful scale.

Every organization has a role to play in advancing carbon removal. Whether through long-term bilateral offtake agreements, buyer coalitions such as Symbiosis or Frontier, trusted intermediaries, or targeted spot purchases, engagement at any scale can help strengthen demand, support innovation, and accelerate the development of a durable CDR market.

In this paper, we will share four key lessons we have learned since the beginning of our program, suggest insights for how buyers can start engaging, and offer perspective on the most mature CDR pathways.

³ For instance, acceptable forms of biomass (both [forestry](#) and [agriculture](#)) in BiCRS.

⁴ These signs include the draft proposals for inclusion of CDR within both European Union and United Kingdom Emissions Trading Systems.

⁵ [Durable CDR Demand Structure Snapshot: Microsoft, Frontier, and the Rest of the Market | CDR.fyi](#)

What Have We Learned?

Stimulating New Supply Takes Time



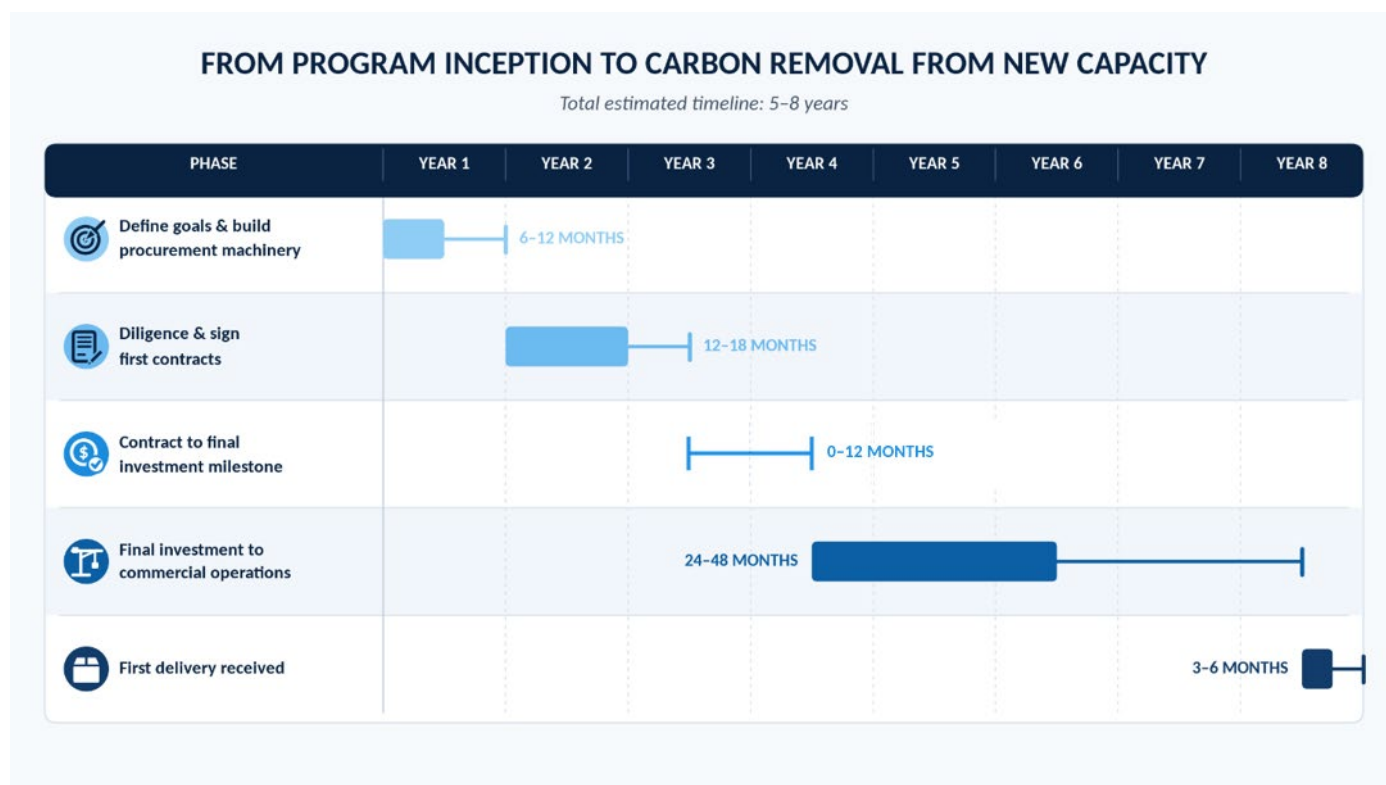
Section Takeaway: It can take five to eight years to go from deciding to anchor net-new CDR capacity to receiving credits.

CDR is infrastructure and infrastructure innovation takes time. If you have CDR targets or ambitions for 2035 or beyond, much of that work may need to start today. Strong offerings won't appear overnight—it takes the market time to respond to new demand and reorient early-stage development efforts. We launched our first rolling procurement in the summer of 2020, and it took 18 months for suppliers to understand our intent, internalize our feedback, and develop project proposals aligned to our needs and expectations. After receiving a strong proposal, it typically takes us about 12 months to diligence a project and sign a deal that will anchor new capacity.⁶ While we want to shrink that diligence and negotiation timeline, new buyers should assume it will take that long to build and execute a bilateral, take-or-pay offtake. Once an offtake is signed, projects generally need at least 2-4 years to complete development and begin delivery at scale; first-of-a-kind projects can take longer.⁷

⁶ Note: We are focused on the timeline to develop and anchor net-new capacity because we believe the CDR market is still in a *capacity-building* phase. Any demand generating activity is important, but we view anchoring new capacity as the highest leverage activity for a corporate buyer to advance the CDR market.

⁷ For more on project development timelines by CDR pathway, please see the Appendix.

Putting that all together: if you are embarking on net-new carbon removal procurement, you should anticipate needing 6-12 months to define your program goals and build procurement machinery (e.g. application process, review criteria, contracting approach, internal approval process), 12-18 months to diligence and sign your first contracts, up to 12 months post-contract for the developer to raise capital⁸, then (depending on pathway) another 24-48 months for the project to achieve commercial operations, and 3-6 months to receive your first delivery. **That equals 5 to 8 years from program inception to receipt of first credit.** Under certain optimal conditions projects may move faster, but in our experience this is a realistic timeline for most CDR projects. The long procurement cycle makes early action especially important; buyers that begin now can help shape the supply, standards, and market infrastructure in the 2030s.



⁸ In engineered CDR projects, this culminates in a milestone typically known as “final investment decision.”

How to Design for Resilient Project Delivery



Section Takeaway: CDR remains an emerging market, and pathways at every stage of maturity are being deployed at unprecedented speed, scale, and rigor. Delivery challenges, delays, and underperformance are therefore an inevitable part of market development. Alongside projects progressing as planned, setbacks provide important insights that can strengthen project design, execution, and future deployment.

Project delivery issues—what happens when operations are delayed, carbon sequestration is lower than expected, or financing challenges impede project development—will test relationships between buyer and seller. As a result, it is important to take the time to think through foreseeable development failures and prescribe solutions, rather than leaving them to be negotiated after experiencing subpar outcomes. Good contracts provide a blueprint for how things are resolved when something goes wrong; for example, effective delivery risk provisions cover acceptable delivery thresholds, cure periods, and any waterfall of remedies. Spelling out what happens when things don't go according to plan will matter to financiers and other stakeholders, who need to see that a potential problem will not fester into default and that a resolution path is already agreed. Buyers should consider typical execution risks both during development and once credit generation begins (see "Project execution risks" box below).

Project execution risks

Here is a non-exhaustive list of crucial risks in project development:

1. **Permissions:** crucial permits came late or not at all; land could not be used due to unforeseen legal complications; local community opposition (further detailed in the "Local community engagement" box on the next page).
2. **Market Risk:** developers could not sell their remaining carbon removal credits or co-products.
3. **Financing:** key subsidies fell through; projects were unable to secure enough capital to make a positive final investment decision (FID).
4. **Execution:** land enrollment took longer than expected; equipment was fabricated incorrectly; developers did not manage their sub-contractors properly.
5. **Generation:** critical technology did not work as expected (or at all) or took longer than promised to reach steady state operations; unfavorable weather or climate suppressed sequestration potential; trees did not grow as expected or experienced high rates of mortality.

To maximize the chances of success, developers must have in-house operational know-how, commercial savvy, and a native understanding of carbon math. Ideally, they have developed analogous projects before. They must also build a robust network of trusted partners.⁹ This network can be a source of strength when knowledge flows freely and each responsibility is matched with the partner best equipped to manage it. However, a project is only as strong as its weakest link; partners who are misaligned, left behind as project design evolves, or hard to replace when issues arise can knock a project off track. Developers must select partners carefully, communicate frequently to keep expectations and incentives aligned, and maintain a high level of accountability throughout the entire value chain.

Local community engagement

*Carbon removal projects can offer tangible community benefits—new jobs paying good wages, opportunities for broader economic development, education and training, and more—and it is **the project developer's responsibility to make that case**. CDR projects require unusual combinations of factors: proper growing conditions, surplus feedstock, access to geologic storage, etc., making suitable sites hard to find. Once a site is selected, a successful project depends on building meaningful community relationships from the outset. Start by learning what the community wants, what prior promises they have received from similar projects and developers, embed yourself, hire locally, and transparently explain the benefits and risks of a project. When the community is involved directly in project activities, ensure free, prior and informed consent (FPIC) and equitably share the project benefits with participants. Trust is the crucial ingredient and allows the host community to become a true stakeholder in the project.*

⁹ Here is an incomplete list of other potential partners: equipment manufacturers, nurseries, logistics companies, farmers cooperatives, biomass suppliers, construction firms, CO₂ storage partners, MRV specialists, auditors, registries, and investors.

How to Navigate Near-Term Deployment and Quality Improvement

 **Section Takeaway:** *Scaling carbon removal requires progress on two fronts: deploying projects responsibly today and continuously strengthening quality standards as experience, science, and the market evolves.*

There are two contrary yet crucial concepts in the market today—1) we need to start building carbon removal projects to learn and reduce costs and 2) methodologies for CDR credits remain imperfect representations of quality. Ultimately, CDR projects only serve their intended purpose if they accurately reflect atmospheric CO₂ impacts (across the complex systems in which they are embedded). Methodologies address this quantification step. The industry’s ability to accurately account for how projects affect net atmospheric CO₂ has improved significantly over the past decade and will continue to improve over the next. This means we will spot more gaps in the methodologies that exist today. To identify and fill these gaps, we must pair responsible deployment with a rapid cycle of methodological improvement. It is impossible to design the perfect CDR industry on paper or in a lab, so to make progress at the pace our planet needs, we must plan well, observe how things go in the real world, and refine our quality requirements based on these observations.

This leads us to two takeaways:

- 1) **Start with the current slate of standards and borrow existing rules that can underpin early development.** For example, on top of our [quality criteria](#), where possible we look to Forest Stewardship Council certification to underpin the sustainability of biomass feedstocks. It is important to borrow approaches that cover major gaps to avoid failures like significant over-crediting that would break trust in the market.
- 2) As an industry (buyers, sellers, NGOs, regulators, standards), **we need to map the principal methodology gaps and assumptions in each pathway and determine the priority issues to solve**—we call out some high-priority items for each pathway in the Appendix. The priorities may differ by project type: open-system pathways¹⁰ tend to focus more on science and data, while closed-system pathways¹¹ could include more accounting and analytic norms.(For more on this theme, see the “Uncertainty” box on the next page.) Standards bodies should publish long-term roadmaps outlining when they intend to tackle each issue, starting with the ones that have the biggest impact on CDR quantification (net of process emissions). Solving those incrementally before deploying significant capacity lets us build a comprehensive rulebook by the time it matters most. However, we must hold ourselves as an industry to a high standard of continuous improvement; accepting iteration cannot mean slowing our pursuit of more perfect standards—hence the importance of public roadmaps.

¹⁰ For example, ARR, IFM, SOC, or ERW.

¹¹ For example, biochar/BECCS/BiCRS, or DAC.

We have taken a similar continuous improvement approach with our own quality criteria; we refine our program view of quality as we learn, and we learn by doing. We started with a set of core principles and, as we learned more about different project types, we tightened key areas with each new iteration. Gradually, our criteria grew more complete, specific, and prescriptive. We are confident they reflect achievable, high-quality removals today, and the collective set of industry stakeholders must decide the most critical problems to tackle next.

Uncertainty

Uncertain quantification of CDR credits is challenging and different than the net risk of miscounting outcomes. The paradox is that open-system pathways are often viewed as riskier because their uncertainties are more obvious and less easily bound. Meanwhile, closed-system pathways (where every captured tonne of CO₂ can be measured directly) are often viewed as lower risk, yet those rely on accounting assumptions that can conceal sources of inaccuracy. For example, feedstock accounting for DAC and BECCS is not yet normalized; making permissive assumptions about each of power matching, biomass sourcing, and embodied emissions risk inaccuracy.

Both open- and closed-system pathways are essential for CDR to achieve climate-relevant scale and to build a resilient portfolio; accurate quantification is possible for each of them. Rather than assuming uncertainty can be eliminated, high-quality carbon accounting should focus on identifying and intelligently quantifying uncertainty and its net effect on accuracy.

Public-Private Alignment Can Accelerate Progress

 **Section Takeaway:** CDR projects are positioned to advance more effectively when private-sector demand is reinforced by public investment, risk-sharing mechanisms, and clear policy frameworks.

Many new technologies initially require robust public sector support to scale (consider railroads,¹² the internet, and solar power¹³ generation¹⁴). Government aid in the form of clear legal structures, permissions, risk-sharing, tax-incentives, and subsidy support clears a way for innovation. CDR is no different: we are in the formative phase of the industry and public-private cooperation is crucial to validating its potential. In the voluntary carbon market, we see that the carbon removal projects that progress fastest are those where the public and private sectors enable each other: the private sector demonstrates demand for carbon removal, and the public sector reduces risk through subsidy, clear legal frameworks, and/or support for enabling infrastructure.¹⁵

One overarching example of public-private enablement centers on claims—Microsoft supports a framework that enables private buyers to make voluntary claims with their CDR purchases while clearly indicating the national climate accounts into which those purchases fit.¹⁶ Here are some other examples of successful public-private enablement, separated into engineered and nature-based CDR.

Engineered CDR typically has a greater degree of technology risk and higher upfront capital costs. Successful public-private enablement examples include a combination of subsidy, risk-sharing, and infrastructure support.

- Orsted, Stockholm Exergi, and BioCirc – Each of these suppliers pursued a publicly-tendered subsidy that covered some of their costs alongside private CDR offtakes. The combination of funding sources demonstrated a model of national support that makes projects highly competitive and can anchor the core of CO₂ transport value chains. Our due diligence revealed that each project benefitted from strong local environmental regulations and norms of political representation and trust. As with Hafslund Celsio (next page), national support for the projects underlined public concern over climate change, reducing the risk of local opposition to the projects.

¹² Engerman, Stanley L. "Some Economic Issues Relating to Railroad Subsidies and the Evaluation of Land Grants," *The Journal of Economic History* 32, no. 2 (1972): 443-463.

¹³ Nemet, Gregory F. *How Solar Energy Became Cheap: A Model for Low-Carbon Innovation*. Routledge, 2019.

¹⁴ Mazzucato, Mariana. *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. Anthem Press, 2013.

¹⁵ Of course, governments can directly drive CDR demand by operational integration of removals into national climate plans and/or regulated carbon markets. This potential is well covered in other literature and we touch on it in the next section.

¹⁶ See this paper for more detail: [CDR Accounting: Transparently structuring corporate claims to reconcile with national goals](#)

- Hafslund Celsio – In addition to exemplifying the offtake + subsidy model, Hafslund Celsio’s case highlights how a government’s assumption of certain limited and novel project risk unlocks value. Through [Project Longship](#), the Norwegian government played a crucial role in advancing CCS and CDR projects in Norway and Europe more broadly—the establishment of Northern Lights,¹⁷ the joint-venture for CO₂ transport and storage, significantly reduced the risk of geologic CO₂ storage in Europe and helped create the infrastructure needed for future deployment. As more project developers (including Orsted and Stockholm Exergi) use Northern Lights, we can better characterize risks, costs are likely to fall, and operational experience will generate valuable lessons for future projects.

Nature-based CDR: Public enablement of nature-based CDR most often comes in the form of clear legal frameworks and policy certainty that increase confidence for CDR buyers and investors.

- In Brazil, we saw that developers like Mombak, BTG Pactual, and re.green move with greater certainty when they engage national and subnational authorities early, align projects with government priorities, and anticipate evolving policy frameworks. Success increasingly depends on navigating national carbon market rules, since government oversight can shape project approval, credit authorization, and market participation.
- Buyers and investors need confidence that credits will not later face competing state claims, expropriation, or regulatory uncertainty. In Sierra Leone, Rainforest Builder’s sustained government engagement de-risked project development by confirming future carbon rights would be recognized.



A photograph of Hafslund Celsio’s Klemetsrud facility. Photograph by Hafslund Celsio team.

¹⁷ A leading geologic storage project that was the first to make FID and sequester CO₂ in geologic reservoirs beneath the North Sea.

Moving from Market Development to Scale

Forward, Firm Demand Can Unlock the Next Wave of Supply

 **Section Takeaway:** CDR supply remains constrained today. Looking beyond 2030, sustained progress will depend on firm, forward demand signals that give developers and investors the confidence to build the next wave of high-quality supply.

If a new buyer entered the market seeking several million tonnes of high-quality CDR to be delivered next year, they would face a stark supply shortage. At the same time, the pipeline of planned high-quality projects for the 2030s is growing beyond what any individual corporate buyer can support, making broader private- and public-sector¹⁸ demand essential to continued market development. Yet it is crucial for buyers to recognize that there is no carbon removal “big box store” and no just-in-time delivery. To stimulate the new capacity that the market will need to scale, demand—both public and private sector—must be firm and signaled years in advance with a clear plan to obligate the funds that unlock investment decisions. Without such a signal in aggregate, only marginal new supply will materialize. Moreover, individual demand that arrives late will pay steep rates for merchant volumes and may not be fully served.

Intermediaries—which fund or advise developers while marketing future CDR tonnage—have a role to play and can help bridge the time mismatch between demand and supply, if they have the following attributes:

- 1) carbon expertise, experience developing projects in the local context, and/or very precise design specifications for quality, quantity, and cost,
- 2) the ability to fund a project directly from balance sheet or via syndicated financing, without a firm offtake that would underpin project finance, and
- 3) the ability and willingness to own the project’s outcomes and absorb its risks.

Without these features, intermediaries may struggle to make markets because they do not help projects differentiate on quality, fill the CDR financing gap, and derisk project delivery. For example, without expertise or specs, they may miss key design nuances and waste years in pre-development. Without access to significant capital, even a perfect design will not get to FID. Finally, a well-designed, well-funded project needs practical knowledge to oversee and confidently deliver project capacity.

¹⁸ In July, the European Commission proposed draft legislation targeting 250 million tonnes of permanent CDR procurement between 2031 and 2040. [EU Emissions Trading System \(EU ETS\) - Climate Action - European Commission](#). Among others, the UK is considering CDR support and integration into its emissions trading system, Canada has ongoing government procurement, and Japan has signaled potential future inclusion of CDR in its carbon market.

Clear Objectives Enable Action

 **Section Takeaway:** *Organizations of every size and level of experience can begin engaging in carbon removal by defining clear procurement objectives and making deliberate choices about risk, cost, timing, and impact.*

Designing or refining a CDR procurement program can be daunting. We had the benefit of several years and a team of buyers to reach our full pace of procurement, and we learned a lot in that time. If you are considering buying CDR, start with the following two questions:

1) What are your design criteria?

To define your procurement goals, consider: How firm is your need? What is your estimated range of tonnes to procure? By when do you need them? And how do you expect your demand to change over time? The answers drive portfolio shape: a buyer needing 1-2 million tonnes in 2033 rising to 4 million tonnes in 2035 would be well served to anchor 3 million tonnes of 2033 capacity but be forgiving for any operational delays. If you have a volumetric or claims-based model, set volume and cost guardrails with key internal stakeholders (e.g. finance) to keep everyone agreed on success criteria.

2) What is your tolerance for risk? What tradeoffs are you willing to make?

There are usually tradeoffs between cost, speed, and portfolio risk. We diversified our portfolio across geographies, counterparties, and pathways, but still ended up with concentration in BECCS and ARR because of our focus on market scaling to enable the foundational decade of CDR and the relative maturity of those pathways. If you have different program considerations (e.g. geographic limitations, durability requirements, pathway preferences, team bandwidth), different compromises may be necessary. That could mean more concentrated bets on higher upside but less mature pathways, greater timeline flexibility, tolerance for higher prices, or comfort with reduced portfolio control. This is new territory, and third-party experts (like diligence agents, ratings agencies, and/or coalitions such as Frontier and Symbiosis) can help fill in gaps in existing knowledge. To mitigate the risk of avoidable errors, you can start with small procurement from operating or in-development projects and build to larger opportunities. Finally, focus on solving the highest risk and most salient design and commercial issues, and be willing to compromise elsewhere.

Conclusion

The CDR industry enters the second half of this decade with stronger quality frameworks, a growing project pipeline, and a deeper base of real-world experience. For Microsoft, the following lessons stand out as we move forward:

- **Act early.** Procurement can take five to eight years from program inception to first credit delivery, making early demand signals and planning essential.
- **Build for resilience.** Strong partnerships and contracts can help projects navigate development challenges and delivery risk.
- **Advance deployment and quality together.** Responsible project development should continue alongside ongoing improvements in standards, methodologies, and market infrastructure.
- **Public-Private alignment is key.** Projects accelerate when the public and private sectors support each other.

There is a clear case for moving now: because the industry is still at such an early stage, even modest support from deliberate organizations will go a long way toward creating a viable CDR industry. Continued leadership from established buyers, participation from new buyers, and well-designed public policy can together expand demand, improve execution, and move CDR toward climate-relevant scale. We are in the foundational decade—let's make the most of it.

Appendix: Briefly Reviewing CDR Pathways

We would like to offer our short and pithy view of the current state of CDR pathways from which we have made multiple purchases in recent years.

Low Durability Pathways

Afforestation, Reforestation, and Revegetation (ARR)	
Our Take	Both large-scale restoration and agroforestry projects are beginning to reach initial scale and issue first credits. Many of these projects are first of their kind in either design or scale and the short-term outcomes are promising, but there remains uncertainty around long-term sequestration timelines and quantification approaches.
Development Timeline	1 - 2 years for initial land enrollment / acquisition and project development, 2 - 3 years for site prep, tree planting, and initial carbon accumulation before trees grow enough for first issuance.
Approximate Scale per project	Wide range but most commonly 50,000 - 500,000 tonnes per year
Delivery Shape	Parabolic delivery curve. Volumes ramp up over the first few years as trees begin to grow before they flatten out for most of the crediting period and then taper off at the end of the crediting period as trees reach maturity and growth slows.
Quality Gaps	Dynamic baseline approaches; activity shifting and market leakage; stakeholder engagement, benefit sharing, and land tenure
Other things to note	ARR includes a broad range of activities, from large-scale native restoration to aggregation of 10,000+ smallholder farmers planting shade trees. Project quality relies on resilient project design, robust quantification (including a dynamic baseline), and alignment between durability and expected long-term project outcomes.

Improved Forest Management (IFM)

Our Take	The implementation of dynamic baselines has meaningfully advanced our confidence in IFM carbon accounting. Some questions remain, particularly around leakage accounting.
Development Timeline	Experienced IFM developer: 2 - 3 years from project inception to first issuance. Forest owner with no IFM experience: 3 - 4 years from project inception to first issuance.
Approximate Scale per project	There is a wide range of IFM project scale, most common is 30,000 – 80,000 removal credits per year. Note: IFM generates both avoidance and removals credits.
Delivery Shape	The removals curve is generally flat and constant from year 1 of deliveries, though developers may have some ability to ramp up or down in response to market conditions.
Quality Gaps	Market and activity-shifting leakage remain challenging topics for IFM. The market should move to project-specific leakage quantification rather than standard universal values that are common in methodologies.
Other things to note	The robustness of carbon accounting in IFM has advanced considerably since 2025 with the introduction of dynamic baselines, which we believe should become standard practice because establishing the correct baseline is the core requirement for high-quality IFM. Developers and buyers must ensure there are clear mechanisms to account for reversals in addition to buffer pool requirements.

Soil Organic Carbon (SOC)

Our Take	Potential to achieve scale across large row crop and grazing operations in the U.S. but the lack of robust data outside the U.S. limits model performance and therefore scalability. Conservatism is key in carbon quantification, and durability must be actively managed.
Development Timeline	1 - 2 years to enroll initial acreage, 2+ additional years to scale
Approximate Scale per project	Wide range given that projects aggregate farms/ranches, but commonly 50,000-1,000,000 tonnes per year. Note: SOC produces both carbon removals and emissions avoidance.
Delivery Shape	Usually a parabolic delivery curve. Early project years include a ramp-up in volumes given rolling enrollment of acres, and the last few years may see a decline due to growers reaching the end of their contracted crediting periods and soil carbon sequestration rates leveling off.
Quality Gaps	Clear guidance on ensuring carbon storage durability through standardized economic and benefit-sharing arrangements.
Other things to note	SOC projects can reach large scales (up to 1 Mtpa) relatively quickly (<5 years). However, high-quality projects must demonstrate robust carbon quantification and contractual durability-enforcement mechanisms.

Medium Durability Pathways

Biochar

Our Take	Biochar represents much of the engineered CDR delivered to date and is well suited to address pockets of available biomass, but is held back by underdeveloped markets for physical biochar.
Development Timeline	1 - 2 years to develop and another 1 - 2 to construct, test, and commission, depending on customizations and innovations introduced
Approximate Scale per project	2,000 - 100,000 tonnes per year
Delivery Shape	Ideally operates with a flat delivery curve, though has more ability to ramp up or down than BECCS and DAC.
Quality Gaps	Clear guidance on 1) acceptable biomass feedstocks, and 2) appropriate end uses for physical biochar that protect carbon storage durability.
Other things to note	Under the right circumstances, biochar projects can be rapidly deployed. Serial development appears to rely on finding a repeatable combination of pyrolizer, feedstock, and end use of the physical biochar. Project quality depends on rigorous monitoring and traceability across the value chain, sustainable biomass sourcing, and durable end-use applications for the biochar produced.

High Durability Pathways

BECCS

Our Take	Poised to be the near-term “workhorse” of high-durability CDR but requires strong biomass sustainability protections. Deployment geographies are limited today by the availability of geologic CO ₂ sequestration.
Development Timeline	2 - 3 years to develop and another 3 - 4 to construct, commission, and deploy
Approximate Scale per project	100,000 - 500,000 tonnes per year, though large BECCS projects can approach 1,000,000 tonnes per year
Delivery Shape	Flat delivery curve. Once the project turns on, it should deliver similar generation year-on-year, within the operational envelope of the underlying bio-energy asset.
Quality Gaps	Clear guidance on acceptable biomass feedstocks; amortization of embodied emissions.
Other things to note	BECCS is the most technically mature opportunity for large projects in high-durability CDR, but its ultimate scale is limited by the availability of sustainable biomass. It frequently will be retrofitted onto existing infrastructure (biomass heat & power plants, pulp & paper mills) and therefore subject to the operations of the underlying asset.

Direct Air Capture (DAC)

Our Take	There is a Cambrian explosion of ideas and now we await execution to show it works at scale.
Development Timeline	Once the tech has reached demonstration scale, it usually takes 2 - 3 years to develop and reach FID, then 3 - 5 years to construct, commission, and deploy.
Approximate Scale per project	250,000 - 1,000,000 tonnes per year
Delivery Shape	Flat delivery curve. Once the project turns on, it should deliver close to 100% of capacity every year it operates. Analogous to baseload power (nuclear, hydro).
Quality Gaps	Progression of energy-use accounting (which could be staged) and the related issue of energy market leakage; amortization of embodied emissions.
Other things to note	DAC requires substantial pre-development work, largely in technology development. Moving from pilot scale to commercial-scale deployment takes more than four years. Some DAC developers plan a modular approach, which could change the delivery shape and shorten learning cycles.

Enhanced Rock Weathering (ERW)

Our Take	Has great promise but requires conservative scientists paired with world-class operators, and needs robust and localized data sets.
Development Timeline	2 - 4 years to deploy and spread rocks for large-scale projects, additional 1 - 2 years to start generating credits
Approximate Scale per project	25,000 - 300,000 tonnes per year
Delivery Shape	Parabolic delivery curve. Cations take time to weather, so CDR generation peaks 2 - 3 years after soil application and then declines. Some developers offer repeated, overlapping deployments that create a longer delivery term and a ramp up-plateau-ramp down shape.
Quality Gaps	Reducing quantification error and increasing certainty generally, in particular: constraining far-field zone effects on net CDR (particularly deep soil dynamics); temporal accounting of lags due to cation sorption; soil organic carbon and microbial responses to ERW.
Other things to note	Like DAC, ERW requires substantial pre-development, in this case pilot spreading and measurement to characterize regional potential and improve MRV and CDR quantification. Integrates with existing value chains (e.g. agriculture) and offers potential co-benefits (e.g. increased yields).

Glossary

ARR: Afforestation, reforestation, and revegetation

BECCS: Bioenergy with carbon capture and sequestration

BiCRS: Biomass carbon removal and storage

CCS: Carbon capture and sequestration

CDR: Carbon dioxide removal

CO₂: Carbon dioxide

DAC: Direct air capture

ERW: Enhanced rock weathering

FID: Final investment decision

IFM: Improved forest management

MRV: Measurement, reporting, and verification

Mtpa: Million tonnes per annum

NGO: Non-governmental organization(s)

SOC: Soil organic carbon



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