



Digital Infrastructure for Carbon Removal



Introduction

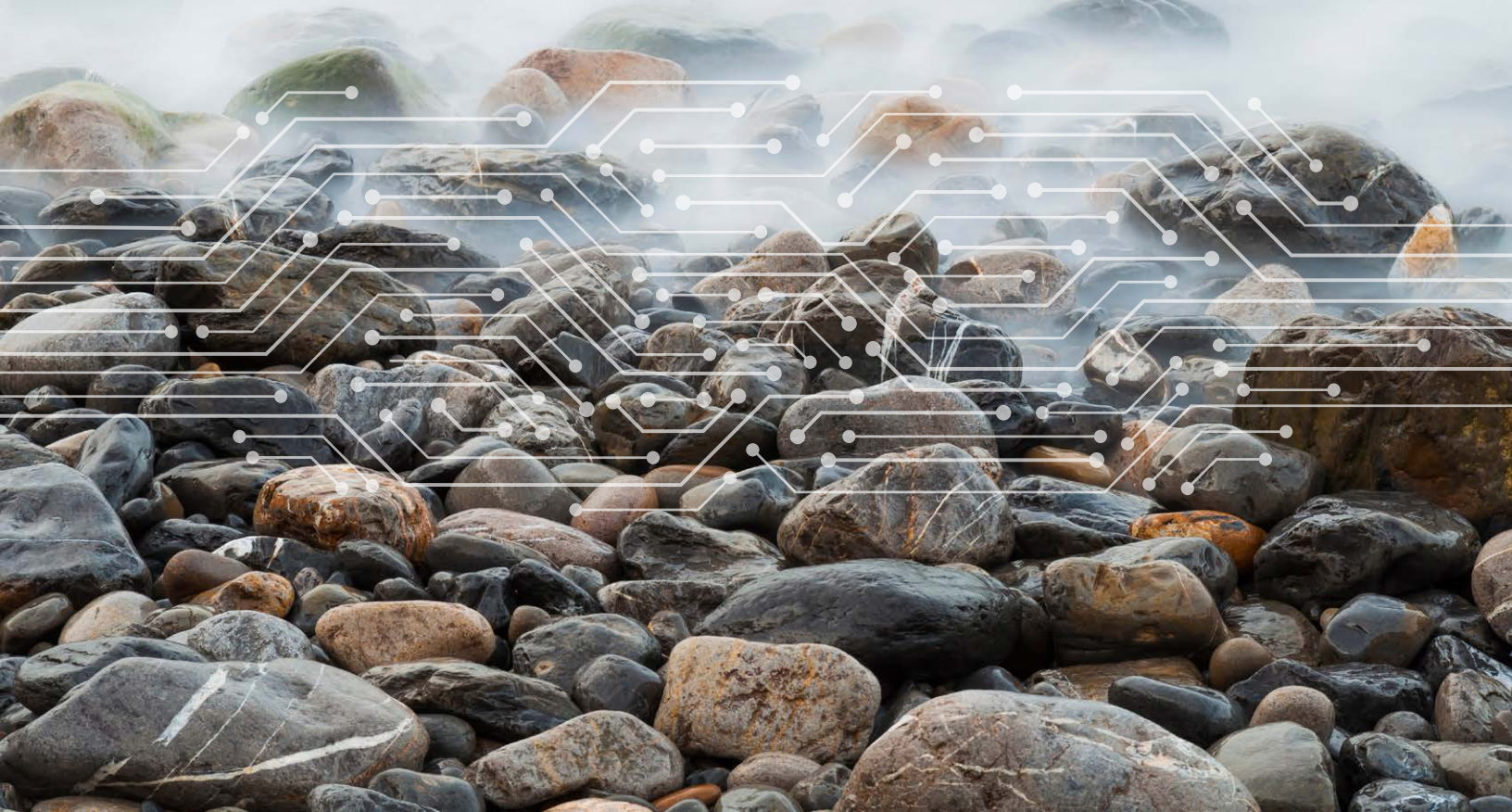
Software and other digital infrastructure have dramatically transformed every industrial sector of the global economy over the past few decades, from reducing costs to increasing efficiency and unlocking scale.¹ Digital technologies are already critical components of ongoing global efforts to scale climate finance, decarbonize societies, and build market mechanisms to address challenges such as biodiversity loss, climate adaptation, and the energy transition.² The rapidly growing carbon dioxide removal (CDR) field will be no exception.

The IPCC AR6 Synthesis Report confirms that CDR – alongside a strong prioritization on global emissions reduction of carbon dioxide and other greenhouse gases — will be required at massive, multi-gigatonne scale by mid-century for us to have a chance to limit warming to 1.5 or even 2°C.³ While CDR is ultimately an immense and intensely physical process, purposeful development and effective deployment of digital infrastructure across the CDR sector will be integral to achieving the velocity and scale that is necessary over the coming decades to prevent the worst outcomes of climate change.

Digital infrastructure for CDR will encompass a broad array of mature and emerging technologies. These include, but are not limited to, remote sensing, cloud computing, mobile applications, artificial intelligence (like machine learning and large language models), and Internet of Things (IoT), as well as blockchain and public distributed ledgers. Just as we will need a diversified portfolio of CDR methods to reach gigatonne scale, a robust portfolio of enabling digital tools will be required to create new efficiencies, reduce costs, increase trust and transparency, and build new market infrastructure. Many of these digital technologies are at early stages of development, and we must start testing and deploying them now.

This white paper, developed by a working group of [Carbon Business Council](#) members and affiliates, and published with generous support from the [Climate Collective](#), outlines key challenges the CDR sector faces; identifies opportunities where digital infrastructure can offer solutions to help address these challenges; and puts forth a set of focused recommendations for the CDR sector on the adoption of digital technologies.

1 Andreesen, “Why Software is Eating the World,” a16z.com, 2011.
2 World Economic Forum, “Blockchain for Scaling Climate Action”, 2023.
3 IPCC AR6 Synthesis Report p 50, 2023.



Challenges

The CDR sector is extremely dynamic, and growing quickly: as of September 2023, cumulative pre-purchase of high-quality CDR was up 700% over the previous year to 4.7 megatonnes (Mts)⁴. However to reach multi-gigatonne scale by 2050, CDR stakeholders face immense challenges and will need to overcome a wide range of obstacles. Examples of these include:

- **Complexity of monitoring, reporting, and verification.** High-quality monitoring, reporting, and verification (MRV) is essential to build the market trust necessary for CDR to achieve gigatonne scale in the coming decades.⁵ MRV is a complex and multifaceted set of processes. The core of MRV is the measurement and

verification of a project's net removal of carbon dioxide from the atmosphere, which for some CDR approaches may occur over varying time intervals. This requires clear baselines, system performance verification, diligent monitoring of durability and reversal risk, and cradle-to-grave measurement of a CDR project's greenhouse gas (GHG) emissions using established lifecycle assessment (LCA) methodologies. Historically much of this work has been conducted through labor-intensive and error-prone manual processes. While some MRV challenges relate to physical processes and scientific uncertainty, others pertain to the complexity of data collection, analysis, normalization, integrity, and interfaces between a multiplicity of actors across the CDR value chain.

⁴ [CDR.fyi](#)

⁵ [Monitoring, Reporting, and Verification: Issue Brief](#), Carbon Business Council, 2023.

- **High project costs.** Long-duration CDR is currently expensive. There is general consensus that these costs need to decline below \$100 per tonne for gigatonne-scale CDR to be practically affordable.⁶ Physical economies of scale and technology learning curves will lead to significant (and hopefully rapid) cost reductions over the coming decade. However, operational and market inefficiencies present an additional challenge across the CDR sector and increase the cost of removal. Pain points include: buyers and sellers managing credit inventories on spreadsheets; manual and analogue MRV processes; a market dominated by high-friction over-the-counter (OTC) transactions; and inefficient processes and infrastructure for registering and retiring CDR credits.
- **Limited market trust.** CDR is an intangible product, and it is important to validate and verify its delivery. Building and maintaining market trust is thus essential to scaling the sector. While the underlying quality of a CDR credit rests upon physical processes, it is essential that the integrity of the data associated with the climate impact of the credit is maintained across its lifecycle. This ranges from: the point of collection; to analysis, normalization, and verification; to transaction, storage, and credit retirement. While the CDR market is nascent, incumbent carbon markets continue to face challenges relating to credit quality and data integrity, including traceability, transparency, and double-counting. To achieve gigatonne scale, stakeholders across the CDR sector must collaborate to overcome these challenges, integrate valuable learnings from previous carbon market iterations, and build market trust and confidence.
- **Constrained demand.** Initial CDR credit supply constraints are starting to ease, particularly for vintages of 2025 and beyond, as companies and project developers begin to scale their solutions and corresponding delivery of credits. For the rest of the decade, and for the foreseeable future, demand will be the primary constraint on CDR market size: the market needs exponentially more buyers, buying at ever increasing volumes.⁷ Demand is to an important extent a function of price and trust. However, the inefficiency and friction of current market platforms, lack of globalized market access, and limited financialization of CDR credits all represent significant challenges to scale demand. Modernized market infrastructure will be required to attract the financial capital necessary to achieve multi-gigatonne scale.
- **Equitable deployment.** To achieve gigatonne scale, CDR project developers must have social license to operate, and stakeholders across the sector are united in a commitment to responsible and equitable deployment of high-quality CDR. This means engaging with communities “from the ground up,” minimizing negative externalities and other harms, and actively seeking to deliver economic and other community benefits broadly and equitably.⁸ It will also be critical to transparently document and communicate climate impact and socio-economic benefits of CDR deployments to local and global communities. Much of this work will be socio-political in nature, however democratizing market participation and access — for both suppliers and buyers — remains an important challenge for the sector to address in order to scale responsibly and equitably. The Carbon Business Council offers [training, tools, and resources](#) to its members and the CDR community at large to support the equitable deployment of carbon removal.

⁶ Carbon Negative Shot, U.S. Department of Energy Office of Fossil Energy and Carbon Management.

⁷ Hoglund, “You Can’t Wait with Buying Carbon Removal,” Marginal Carbon, 2023.

⁸ [From the Ground Up: Recommendations for Building and Environmentally Just Carbon Removal Industry](#), XPRIZE and Carbon180, 2023.

Opportunities

To address these challenges, there are emerging opportunities for stakeholders across the CDR sector to employ digital infrastructure in targeted ways. These novel solutions can enhance and complement the more than two decades of work building systems and processes for incumbent carbon markets, including lessons from quantifying, verifying, and tracking mitigation outcomes across a wide range of project types. Specific opportunities include:

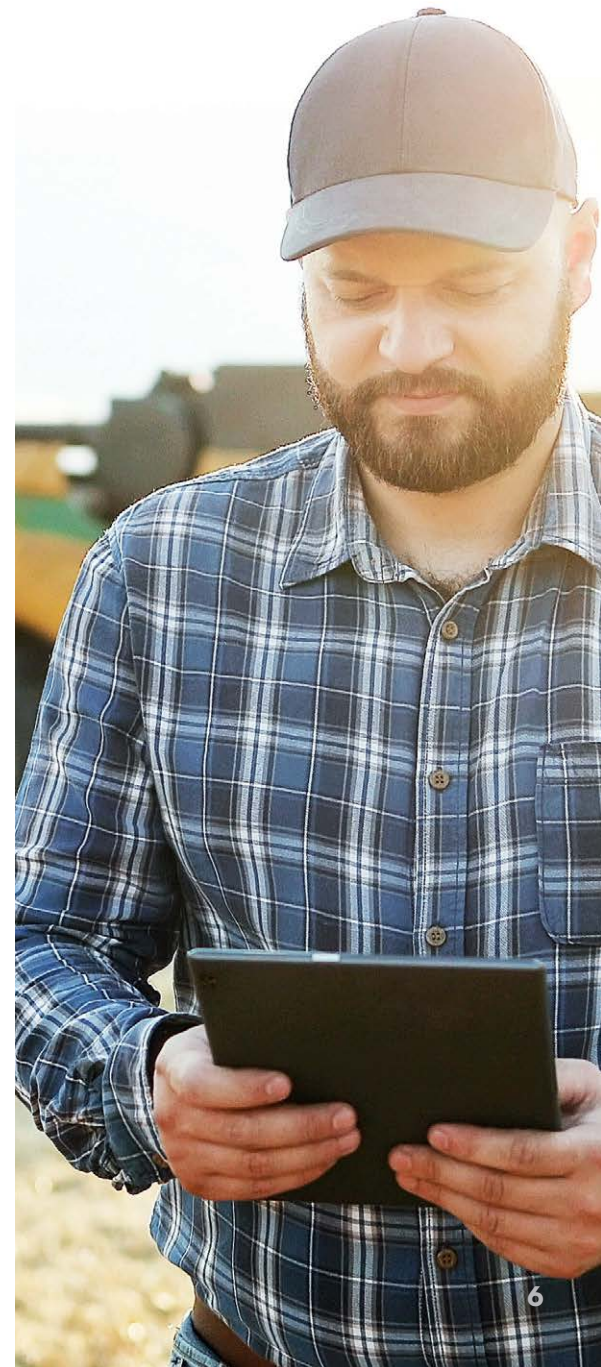
- **High-quality, transparent, and interconnected MRV.** Digital MRV (dMRV) offers significant potential to increase the efficiency and interoperability of the set of interlocking processes that constitute MRV. dMRV can also increase transparency, standardization, auditability, and immutability of data, offering stronger confirmation of climate impact, ensuring greater project integrity, and increasing the value of a CDR credit.⁹ Potential components of dMRV include:
 - Data collection via remote sensors, IoT devices, satellite imagery, and other emerging technologies;
 - Normalization, error detection and correction, and analysis of raw project data using artificial intelligence and machine learning;
 - Streamlined CDR project life-cycle assessments (LCAs) and carbon accounting;
 - Storage of project data on transparent, public distributed ledgers;
 - Automated interfaces to enable interoperability between the project-level carbon accounting and verification by third-party standard bodies;
 - Distributed dMRV applications to enable wider global participation in supplying high-quality CDR credits (e.g. smallholder farmers in the Global South engaged in enhanced weathering or biochar carbon removal micro-projects submitting data and visual evidence, or receiving compensation, via mobile phones); and
 - Tools that connect remote monitoring of carbon storage, reversal risk, and ecosystem impacts over time with credit buyers, regulators, third-party verification bodies, and other stakeholders.
- **Increased efficiency and reduced costs.** Digital infrastructure can unlock a range of operational and market efficiencies to reduce cost across the full CDR credit value chain. In addition to the dMRV use cases outlined above, examples include:
 - Digital tools for CDR credit data storage and management that allow buyers and sellers to efficiently and seamlessly track credit generation, pre-sale or sales, and delivery pipelines, along with the underlying project data. Beyond streamlining these administrative functions, these systems' standardized data architecture and secure, high-integrity data storage can serve as a programmable interface between dMRV, CDR credit supply, marketplaces, buyers, verifiers, and registries — much as Plaid has enabled interoperability for the banking sector; and
 - Replacing current analog and OTC CDR market mechanisms with innovative and nimble digital market infrastructure (including blockchain and potentially other distributed ledger market technologies) has the potential to enhance price discovery while lowering transaction cost, rates of error and fraud, counterparty risk, settlement times, and other market frictions. Digital technologies can increase market liquidity, reducing the need for market intermediaries, delivering better prices to buyers, and directing more value to suppliers.

9 Pour and Toplic. "Why Transparency is Key to Scaling Carbon Removal," WEF Blog, October 2023.

- **Greater trust and transparency.** To achieve climate-relevant scale, the CDR sector must build a strong foundation of trust — with communities, NGOs, buyers, regulators, policymakers, and other key stakeholders. This includes building strong process and data integrity across the emerging CDR market. Effectively deployed dMRV and other digital infrastructure enables greater project and market transparency, ensuring the integrity and public viewability of the data that underlies the value of a CDR credit across the entire value chain of the CDR market.¹⁰ The transparency and immutability of data that public distributed ledgers and other digital infrastructure can enable will further enhance traceability of credits, improve auditability to better ensure project quality, and reduce the risk of double-counting. Other benefits include enhanced price discovery and globalized public and self-service access to credit data to facilitate efficient assessment of project quality and climate impact.
- **New demand sources.** Development and deployment of innovative digital market infrastructure can bring new demand to CDR markets in two ways. First, blockchain-based market tools can open CDR markets to new buyers by reducing friction, globalizing access, and enabling the sale of fractional credits. Second, digital infrastructure for CDR markets (voluntary, compliance, and Article 6) can enable the creation of innovative spot, forward, future, option, and other sophisticated — potentially programmable — contract types that have been beneficially deployed in other financial markets to attract transformative new capital by facilitating investment and trading.
- **Reduced barriers to market participation.** Digital credit inventory management systems and dMRV applications offer the potential to build both scale and equity with a more distributed universe of CDR supply — from community CDR projects to agriculture and forestry co-ops to small landholders worldwide. One promising example of this potential for more distributed supply is the advent of organizations building networks of smallholder farmers in the Global South to responsibly deliver high-quality CDR in a widely distributed fashion with biochar or enhanced weathering. These farmers already report and verify delivery of tonnes of CDR via nascent smartphone-based dMRV applications, and can potentially be compensated for their climate work via blockchain-based payment systems.

¹⁰ Voluntary Carbon Market Landscape Guide, RMI and Climate Collective, 2023.

¹¹ Carbon4Good (biochar in Africa).





Recommendations

The Carbon Business Council offers the following recommendations for digital infrastructure companies and other CDR sector stakeholders:

- **Start deploying now.** Just as we must start scaling high-quality CDR now to meet our mid-century climate targets, we need to accelerate the parallel development, testing, and deployment of accompanying digital infrastructure. Some of these tools exist today, mature and feature complete, only in need of adoption; others are at earlier stages of technological readiness, but advancing quickly. These tools are functionally necessary to deliver megatonne-scale CDR, and now is the time to initiate pilot deployment of the digital technologies discussed in this white paper. These early deployments will enable valuable learning curves, feedback loops, and economies of scale to help operationalize digital infrastructure in the coming years, as the industry is sprinting to scale. As most CDR suppliers are early-stage commercial enterprises that have not yet built significant cash flow — and new digital technologies might be costly when amortized on a per-tonne basis at the sector’s current scale — buyers, marketplaces, project developers, investors, and potentially the public sector are well placed to serve as early adopters and funders of the initial deployment of digital infrastructure.
- **Emphasize function.** The CDR sector comprises a diverse set of stakeholders — from entrepreneurs, investors, and corporate buyers, to scientists, advocates, and policymakers — many of whom misunderstand or are skeptical of the range of digital infrastructure technologies under development. Digital infrastructure companies should place a strong emphasis on communicating the problem their technology solves in clear functional terms, avoiding jargon and highly technical descriptions. Partnering with organizations like the Climate Collective and Carbon Business Council, attending conferences, and distributing educational resources like this white paper are good places to start. Case studies that offer proof points for how digital infrastructure can be integral to the sector’s ability to achieve gigatonne scale will further help build credibility and trust. Finally, it will be important to disassociate digital infrastructure for CDR from the climate impact of bitcoin, which some CDR sector stakeholders attribute to blockchains in general, while many other blockchain technologies operate with orders-of-magnitude smaller carbon footprints.¹²
- **Engage the public sector.** Blockchain and certain other digital infrastructure technologies face an uncertain regulatory environment, for example relating to the possible securitization of credits, tokens, and other digital climate assets. These questions can be complex, subject to qualitative judgements, and differentially assessed at national, subnational, and supranational

12 World Economic Forum: “Guidelines for Improving Blockchain’s Environmental, Social and Economic Impact”. 2023.

jurisdictions. An important point of advocacy for digital infrastructure developers will be to differentiate, and distance, digital climate assets from the highly public scandals that have affected more financially speculative segments of the “crypto” sector in recent years. Digital infrastructure companies should engage policymakers now to develop collaborative and appropriate regulatory structures for digital market infrastructure for CDR. Additionally, companies can advocate for targeted funding from the U.S. Department of Energy (and potentially other federal sources) for dMRV and other digital infrastructure that can help enable the CDR sector to scale.

- **Deliver equitable outcomes.** Digital infrastructure has great potential to contribute to the responsible and equitable deployment and scaling of CDR by enabling broader and more distributed market participation across the board (suppliers and buyers), as well as by reducing market friction and unnecessary transaction costs so that a greater proportion of the credit value accrues to the suppliers who are delivering the climate impact. Developers of digital infrastructure should center these goals of equity and justice in their operations and company mission, and take full advantage of the powerful democratizing effects that blockchain and other digital technologies can potentially deliver.
- **Focus on CDR quality.** Digital infrastructure developers should have a clear, consistent, and strong bias towards high-quality CDR credits generated by a transparent, high-integrity process and independently verified against rigorous third-party standards. dMRV and other

digital infrastructure have a potentially vital role to play in achieving this goal. In order to validly satisfy buyers’ claims, CDR credits must deliver verified and quantified real-world climate impact and mitigation outcomes. The Carbon Business Council’s Defining CDR Issue Brief offers a fuller examination of what high-quality CDR entails.¹³

¹³ *Defining Carbon Removal for Policy: Issue Brief*, Carbon Business Council, 2023.

Credits

This white paper has been developed by a working group of the Carbon Business Council and in partnership with the Climate Collective. Toby Bryce served as lead author. Co-authors include Ben Rubin and Isabella Corpora of the Carbon Business Council.

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About the Carbon Business Council

The Carbon Business Council (CO2BC), a member-driven and tech-neutral trade association of companies unified to restore the climate, is the preeminent industry voice for carbon management innovators. Together, the nonprofit coalition represents more than 100 companies across six continents with more than \$16.5 billion dollars in combined assets.

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About the Climate Collective

Climate Collective is an innovation network dedicated to putting digital technologies to work for climate and nature at scale. They support entrepreneurs and investors who are using data and digital technologies (i.e., AI/ML, blockchain, geospatial tech, etc.) to enable people and the planet to thrive. Climate Collective funds technology innovation, contributes to policy entrepreneurship & thought leadership, and ultimately scales adoption through ecosystem building and strategic partnerships.