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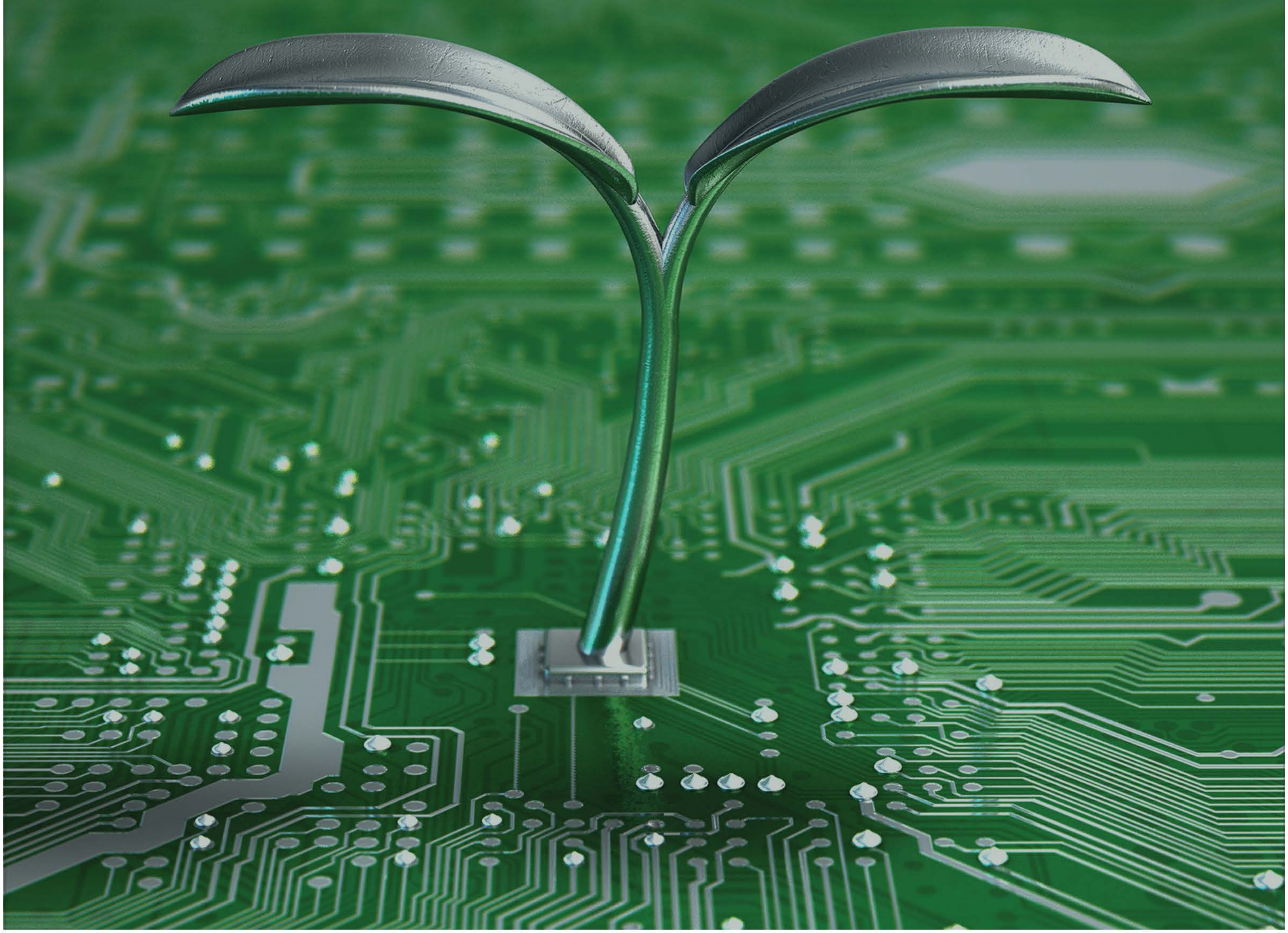
INCREASING ACCESSIBILITY TO TRUSTED CLIMATE PERFORMANCE DATA



A Policy Report by: Professor David J. Hayes and Graduate Student Research Team

Increasing Accessibility to Trusted Climate Performance Data

A Stanford Law & Policy Lab Report

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The "Why"

The climate crisis requires urgent action, and companies, investors, and policymakers need reliable and accessible climate performance data to prioritize investments in the most effective mitigation activities. Trusted climate performance data is needed for companies to make accurate carbon disclosures, measure progress against climate goals, and participate in market-based opportunities. Policy-makers and government officials at all levels also need climate performance information to evaluate mitigation investment returns and to track and confirm that promising carbon reduction strategies are actually generating measurable, positive atmospheric impacts. The goal must be producing investor-grade climate performance data that are based on the type of assurances and standards that are broadly required by accountants, financial markets, institutional investors, and regulators in other contexts.

Skeptics may question the need for better climate performance information and data (hereinafter climate performance "information" and "data" will be used interchangeably), given that tens of thousands of companies all around the world already are gathering carbon emissions data for carbon disclosure reports. Plus a growing number of carbon registries and third-party verification entities have emerged to collect and review carbon data, largely to support voluntary carbon market transactions. And technological advances in the earth observation and artificial intelligence fields are opening new and better ways to collect relevant data, as illustrated by Planet Labs, Climate Trace, and other pioneering companies and organizations.

Even with these advances, however, the lack of standards and transparency in how climate performance information is collected and analyzed is eroding trust in performance claims. For example, while carbon disclosure reporting serves an important function helping companies understand their emissions and climate risks, it often relies on generalized models, emissions factors, and "spend-based" carbon estimates that can vary significantly in their accuracy and applicability across different GHG contexts and scales. Disclosure-oriented data gathering practices typically do not reliably generate the type of granular performance information needed to track and confirm the carbon benefits flowing from specific investments in emissions reduction or removal activities.

A body of open-source climate performance information available in user-friendly formats is especially needed in areas where there is limited or no agreement regarding the best protocols for measuring and verifying emissions reductions and removals, and where there are limited or no mechanisms for publicly aggregating and sharing baseline and on-going measurement, monitoring, reporting, and verification (hereinafter, referred to simply as MRV) information. These data management deficiencies are particularly acute in three important use cases—methane emissions; hybrid (or engineered) carbon dioxide removal (CDR); and forest carbon interventions.

Establishing a robust foundation of accessible, transparent, and trusted climate performance data standards and insisting on generating investor-grade climate data that meets accounting standards will open up a new world of investments in nature-based

climate solutions, methane (and other powerful greenhouse gases) reductions, and in scalable carbon removal activities.

Likewise, showcasing performance data in easy-to-use decision-making formats—as is already being demonstrated in the urban CO_2 context by Crosswalk Labs and the Climate Data Collaborative—will make this vital information truly accessible to a broad array of public and private stakeholders that have common interests in tracking greenhouse gas emissions and removals[1] to: (1) confirm atmospheric impacts from investments in carbon emissions reductions and removals; (2) trigger innovations and increase investments in scalable, top-performing mitigation opportunities; (3) bolster the credibility and effectiveness of voluntary and compliance carbon markets and carbon accounting constructs[2] and (4) reliably identify lower carbon-intensity product information that can generate market premiums and trade preferences.

This report[3] reviews the current climate data landscape and explores opportunities to improve public access to trusted climate performance, with a special focus on the key use cases of methane emissions, CDR, and forest carbon interventions. The report also covers a fourth instructive use case—urban carbon dioxide emissions—where, unlike the other three use cases, urban industrial and transportation CO_2 emissions sources have been subject to federal reporting requirements and resulting data are available for inspection and use.[4] However, urban CO_2 data are not collected or organized in a way that optimizes their usefulness to key decision-makers.[5] The lack of useful access to urban CO_2 data presents a different type of—but no less important—challenge than those faced by use cases that are grappling with data deficiencies.

The "How"

Across many sectors the deployment of modern data management tools has transformed how key performance information can be developed and shared in ways that make it accessible to a broad array of investors, practitioners, researchers, public officials, and interested citizens. More specifically, data are trusted when they are: (1) collected using scientifically sound, consensus-based methods (i.e., protocols); (2) coded using common definitions and other machine-readable tools so that data from multiple sources becomes "interoperable" —that is, easily accessed, aggregated and analyzed; and (3) made broadly available in open source portals. Data interoperability can drastically improve data-driven decision-making, foster cross-sector

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[1] See Appendix B for a fuller description of the range of stakeholders with an interest in improved climate performance data.

[2] For example, there is growing interest in creating carbon ledgers through the application of accounting principles. To be credible, ledger entries need to be based on broadly-accepted and publicly available (i.e., trusted) carbon data measurement, monitoring and reporting conventions. Claimed reductions on the liability side of the ledger must be backed by measured and confirmed carbon reductions.

[3] This report has been prepared by a Stanford Law and Policy Lab class led by Stanford Professor of the Practice, David J. Hayes, in coordination with the Data Foundation. Stanford University and the Data Foundation sponsored a conference and workshop on March 13, 2025, entitled "Improving Accessibility to Trusted Climate Performance Data," Speakers and participants of the conference and workshop informed key points and recommendations in the report. A copy of the conference pre-read and agenda is attached at Appendix B.

[4] Major industrial sources of greenhouse gas emissions that are regulated under the Clean Air Act are subject to mandatory reporting requirements. Environmental Protection Agency. (2009, October 30). Mandatory reporting of greenhouse gases; Final rule. *Federal Register, 74*, 56260–56519. https://www.federalregister.gov/documents/2009/10/30/E9-23315/mandatory-reporting-of-greenhouse-gases.

[5] See the discussion of Crosswalk Labs in Part II.C.3 and Appendix F.

collaboration, and enhance AI-driven insights. Open-access datasets also increase transparency and democratize access to high-quality data, building public trust.

Unfortunately, however, modern data management tools are not widely implemented in the climate space. A major new wave of emissions-relevant data will be generated in the coming months and years due to technological advancements in detecting and measuring greenhouse gas emissions and removals; the ever-higher economic stakes in making smart, effective investments in emissions reduction and removal activity; and continued frustration with poor quality, non-replicable performance data in key climate areas such as methane emissions, hybrid CDR removals, and forest carbon interventions.

Rather than pushing for a grandiose, across-the-board climate performance data solution, this report recommends targeted data initiatives that focus on methane emissions, hybrid CDR removals, and forest carbon interventions—each of which has developed strong communities of interest in deploying modern data management tools. Companion work also needs to progress on a fourth use case which focuses on how trusted data sets in the urban CO_2 context are democratized and made available to multiple users.

Although the U.S. federal government traditionally has been a major proponent for this type of work, that is not the case today. This unfortunate reality cannot be allowed to stop forward progress in the four high-priority target areas outlined above. In that spirit, this report lays out a roadmap for how the corporate, non-profit, academic, and philanthropic sectors can work with sub-national governments and the international community to develop the type of strong, trusted, foundational climate performance data in that the U.S. and the world needs now and for decades to come.

Acknowledgements

This report has been prepared by a Stanford Law and Policy Lab class—"Bridging the Climate Data & Decision-making Divide"—led by Stanford Professor of the Practice, David J. Hayes. The Policy Lab class culminated in a conference that Stanford University and the Data Foundation held on campus on March 13, 2025, entitled "Improving Accessibility to Trusted Climate Performance Data."[6] Insights and perspectives from the conference's speakers and workshop participants have greatly enriched this report—including framing remarks by David J. Hayes (see Appendix A) and Doerr School of Sustainability Dean Arun Majumdar; investor perspectives by Nancy Pfund and Jane Woodward; corporate perspectives by Catherine Atkin and Liv Watson; urban carbon emissions data perspectives by Jason Burness and Ryan Alexander; modern data management perspectives from non-climate contexts, including broad-based lessons learned by Dr. Julia Lane and Nick Hart and medical researchers and practitioners' perspectives by Dr. Sam Volchenboum and Dr. Mark Musen; and use case panels' GHG data perspectives on methane emissions reductions by Rob Jackson, Steve Hamberg, Chris Konek, Sonia Wang; forest carbon interventions by Jad Daley, Chris Wood, Ashley Conrad Saydah, Lauren Cooper; and hybrid carbon dioxide removals by Kate Maher, Ryan Orbuch, Anu Khan, David J. Hayes.

[6] The conference was sponsored by Stanford Law School's Environmental and Natural Resources Law and Policy and CODE-X programs, the Stanford Doerr School of Sustainability's Accelerator and Woods Institute for the Environment, and the Data Foundation. A copy of key conference materials are attached at Appendix A.

I. Overview of the Current Greenhouse Gas Data Landscape

The following sections examine two core features of the current greenhouse gas data landscape. Subpart A explains how existing carbon reporting and voluntary crediting frameworks allow companies to make carbon claims without providing accessible, credible, or activity-specific performance data. Subpart B then explores how recent advances in monitoring technologies and data infrastructure offer a path toward generating more accurate and trusted climate performance information.

A. Corporate Carbon Reporting and Voluntary Carbon Market Schemes Need to Base Their Carbon Claims on Accessible and Trusted Climate Performance Information.

1. Corporate Carbon Disclosure Reporting

Companies preparing carbon disclosure reports typically follow guidance laid out by the Greenhouse Gas Protocol and utilize the CDP's (formerly known as the Carbon Disclosure Project) questionnaire and disclosure platform when reporting their climate emissions. Most corporate carbon reporting is being done voluntarily. However, the European Union's Corporate Sustainability Reporting Directive (CSRD) mandates that large companies and listed companies, both EU and non-EU based, disclose their greenhouse gas emissions and other sustainability-related information, following the European Sustainability Reporting Standards (ESRS).[7]

These frameworks categorize emissions in three buckets: Scope 1 (direct emissions from the reporting company's operations), Scope 2 (emissions from the reporting company's energy use), and Scope 3 (emissions from the reporting company's supply chain).[8] The reporting framework develops an entity-level inventory of emissions, compiled through a backwards-looking assessment of emissions sources.

The Greenhouse Gas Protocol gives companies significant flexibility in selecting data sources and methodologies they can use to estimate their Scope 1, Scope 2, and Scope 3 emissions.[9] Scores of consultancies provide data and analytical services to assist companies' compilation of

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[7] Meynier, T., Mishkin, S. H., & Triggs, M. (2023, January 30). *EU finalizes ESG reporting rules with international impacts*. Harvard Law School Forum on Corporate Governance. https://corpgov.law.harvard.edu/2023/01/30/eu-finalizes-esg-reporting-rules-with-international-impacts/. In addition, companies that do business in California and meet certain revenue thresholds must comply with similarly-structured climate disclosure laws that impose reporting deadlines starting in 2026. Hein, J., Jack, W. A., Poloncarz, K., & Gilmour, J. (2024, October 7). *California climate disclosure laws' compliance timeline remains stable while new amendments give state regulator more time and flexibility*. Inside Energy & Environment. https://www.insideenergyandenvironment.com/2024/10/california-climate-disclosure-laws-compliance-timeline-remains-stable-while-new-amendments-give-state-regulator-more-time-and-flexibility/. For more information on E.U. and California corporate reporting requirements, see Appendix C.

[8] World Resources Institute, & World Business Council for Sustainable Development. (2004). *The greenhouse gas protocol: A corporate accounting and reporting standard* (Revised ed.). https://ghgprotocol.org/corporate-standard.

[9] Bowler, L., & Redburn, M. (2024). *The future of the GHG Protocol: How the standards are evolving*. Ramboll. https://www.ramboll.com/en-us/insights/decarbonise-for-net-zero/ghg-protocol-how-the-standards-are-evolving.

their carbon profile, using many different types of emissions factors, models, and spend-based tools to generate entity-level estimates across Scopes 1, 2, and 3.[10]

Importantly, this inventory-based corporate reporting scheme is not designed to—and does not, in fact—identify or measure "actual interventions [that companies are taking] to reduce, avoid, and remove emissions."[11] As such, corporate reporting typically fails to track the performance of investments in specific emissions reductions activities. And even for those (rare) situations in which companies may be collecting and reporting activity-level performance data against baseline conditions, such data typically will be obscured in entity-level totals that are not available for individual review and confirmation.

Thus, although corporate reporting may provide generalized GHG emissions estimates that are useful for high-level, comparative purposes, the data and analytics underpinning current carbon reporting schemes do not satisfy investor and other stakeholders' needs for accounting-quality information on project-based carbon reductions (or increases) and year-over-year totals.

2. Voluntary Carbon Markets

The voluntary carbon market (VCM) is a fragmented market where private actors voluntarily buy and sell carbon credits which represent reductions in emissions from the atmosphere.[12] The decentralized system is composed of independent project developers, standards organizations, carbon registries, third-party validators, and rating agencies that provide voluntary carbon credit issuance and verification services.[13] This has led to a number of challenges, including the VCM's inability to develop trusted climate performance information.[14]

Carbon registries, which issue and track carbon credits, have historically put a primary focus on analyzing and overcoming three high-profile roadblocks that can stand in the way of credit issuance—additionality, permanence, and leakage—while giving relatively short shrift to the accuracy of how carbon reductions are measured and verified. As with corporate carbon reporting, registries typically lean heavily on broad-based models and emission factors rather

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[10] CDP. (n.d.). *Find an accredited solutions provider*. https://www.cdp.net/en/find-accredited-solutions-providers.

[11] Ballentine, R. (2025). *The unfinished business of corporate greenhouse gas accounting and target-setting frameworks: Incentivizing, enabling, and counting impact through a dual ledger*. Carbon Management. https://doi.org/10.1080/17583004.2025.2451866.

[12] Integrity Council for the Voluntary Carbon Market. (n.d.). *The voluntary carbon market explained*. https://icvcm.org/voluntary-carbon-market-explained/.

[13] Hargreaves, J. (2024, January 24). *Understanding fragmentation in voluntary carbon markets*. Thallo. https://www.thallo.io/understanding-market-fragmentation-in-voluntary-carbon-markets/. Notably, Article 6.4 of the United Nations Framework Convention on Climate Change authorizes the use of carbon markets for meeting country commitments made under the Paris Agreement. The mechanism potentially could improve the consistency and integrity of the VCM regime, but early implementation efforts have not been encouraging. *See* Mulder, I (2025, April 10). *First wave of Article 6 carbon credits misfire spectacularly* https://carbonmarketwatch.org/2025/04/10/first-wave-of-article-6-carbon-credits-misfire-spectacularly/

[14] Haya, B. K., Alford-Jones, K., Anderegg, W. R. L., Beymer-Farris, B., Blanchard, L., Bomfim, B., Chin, D., Evans, S., Hogan, M., Holm, J. A., McAfee, K., So, I. S., West, T. A. P., & Withey, L. (2023, September 15). *Quality assessment of REDD+ carbon credit projects*. Berkeley Carbon Trading Project. https://gspp.berkeley.edu/assets/uploads/page/Quality-Assessment-of-REDD%2B-Carbon-Crediting.pdf; National Academies of Sciences, Engineering, and Medicine. (2022). *Greenhouse gas emissions information for decision making: A framework going forward*. The National Academies Press. https://doi.org/10.17226/26641.

than GHG measurements, to check the MRV box. Project developers and registries also can (and do) select methodologies that maximize credit generation, creating tension between market incentives and integrity. And third-party validators, often chosen and paid by project developers themselves, have not been willing or able to fill the performance data gaps.[15]

Recognizing these issues, the Integrity Council for the Voluntary Carbon Market (ICVCM) has undertaken a serious effort to establish a category of "high integrity" carbon credits that adhere to a set of Core Carbon Principles that address the full range of VCM critiques, including the need for improved MRV.[16]

As part of this work, the ICVCM has begun to evaluate and promote the adoption of higher-quality MRV protocols for specific emissions sources—a key prerequisite for developing trusted climate performance data. As described more fully in Appendix D, the ICVCM has initiated a category assessment process in which multi-stakeholder working groups ("MSWGs") made up of a consultant pool of carbon crediting methodology experts from within and outside the ICVCM, together with the ICVCM's Standard Oversight Committee (a sub-committee of the Governing Board), identify and validate specific MRV methodologies for key GHG source categories.

This category assessment standardization effort—effectuated through its consultant pool and multi-sector working groups—represents a major step toward the development of consensus-based protocols and MRV standards. Sensibly, it does not push toward a single acceptable methodology; it allows for the identification of alternative methodologies so long as each satisfies a rigorous measurement and monitoring approach.

Notably, the ICVCM has deployed this approach for the landfill gas category—the second-largest industrial source of methane emissions and one that is well-positioned for MRV standardization and the public sharing of methane emissions performance information. The ICVCM explained its philosophy behind this effort in "Observations in Relation to Category Assessment" that it published in May 2024:

> "The Governing Board of the Integrity Council for the Voluntary Carbon Market (ICVCM), when considering the assessment of methodologies related to landfill gas capture (and utilisation) identified that it would be beneficial to make public the Integrity Council's observations in relation to this Category, for the purpose of supporting the future development of methodologies in this Category….

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[15] Other VCM deficiencies that can erode trust in carbon claims include (1) the lack of generally-accepted approaches for verifying carbon credit projects, leading to inconsistent validation practices; (2) the fact that validators typically are hired by project developers, creating a financial incentive to approve projects rather than conduct rigorous assessments; (3) even when standards exist, enforcement is often lacking, allowing low-quality projects to receive approval and enter the market; and (4) the lack of a centralized system for aggregating and analyzing performance data across carbon credit projects is a major gap in the VCM. Without comprehensive and publicly accessible data, it is difficult to validate GHG performance claims or compare projects effectively.

[16] Integrity Council for the Voluntary Carbon Market. (n.d.). *The voluntary carbon market explained*. https://icvcm.org/voluntary-carbon-market-explained/.

> "The ICVCM will consider whether the next version of the Assessment Framework may include a requirement for Landfill Gas methodologies to require information about landfill cover types, and associated oxidation rates (by geography or region). The ICVCM may also consider a requirement to apply remote sensing technologies to enable accurate measurement of greenhouse gas emissions. The ICVCM notes that it may include the latter issue as part of the Digital Measurement, Reporting and Verification (MRV) Continuous Improvement Work Program that will commence later in 2024."[17]

The ICVCM initiative represents a timely illustration of how a committed, independent organization can facilitate the development of consensus-based technical protocols and standards—an indispensable first step in establishing an accessible, trusted system of climate performance information for GHG sources and use cases.

B. New Measurement and Monitoring Technologies Can Increase Accuracy, Accessibility, and Trust for Climate Performance Data.

Recent technological advances have significantly enhanced the ability to measure and monitor emissions reductions and removals associated with on-the-ground, activity-level interventions. Due in part to the relative lack of MRV rigor that has been traditionally undertaken for unregulated emissions sources, however, there has not been widespread adoption of new MRV-enhancing technologies and analytics across a number of key sectors. This is beginning to change, but not quickly enough. As illustrated below, a suite of new remote sensing, soil testing, sensor-based, and AI tools that can generate more accurate and reliable climate performance data have become available, and should be utilized.

1. Enhanced Monitoring Tools

New remote-sensing technologies are providing exciting new capabilities to identify and estimate above-ground biomass and to identify point-source methane emissions in the U.S. and around the world.

CTrees, for example, relies heavily on publicly-available U.S. and E.U. satellite-generated data—in combination with other data inputs and AI—to calculate forest carbon stocks in near real-time across different global geographies.[18]

The Environmental Defense Fund's MethaneSat satellite, launched in March 2024, is training its methane detection capabilities on oil and gas sites around the world. By using remote sensing to identify emissions sites, MethaneSat promotes transparency and assists governments and companies in identifying areas and facilities that need methane abatement attention.[19] CarbonMapper's Tanager-1 satellite deploys even more powerful methane detection technology that can detect CO_2 and methane emissions at a facility level using hyperspectral imaging across

[17] Integrity Council for the Voluntary Carbon Market. (2024, May). *Observations in relation to category assessment: Landfill gas*. https://icvcm.org/wp-content/uploads/2024/06/ICVCM_Board-Observations-for-LFG.pdf.
[18] CTrees. (n.d.). *Land carbon*. https://ctrees.org/products/land-carbon.
[19] Environmental Defense Fund. (n.d.). *MethaneSAT*. https://www.methanesat.org/; Environmental Defense Fund. (n.d.). *Fighting climate change with MethaneAIR*. https://www.edf.org/methanesat/fight-climate-change-methaneair.

sites such as landfills, agriculture, oil and gas, and power plants—with a special focus on super-emitter sites.[20]

Other private satellite vendors such as GHGSat and Planet Labs offer proprietary remote sensing data to interested buyers. Finding ways to work with these and other private vendors to increase public accessibility to foundational climate performance data needs to be a top priority.

In addition, low-cost sensor networks, like those created by Stanford University and other research institutions, are demonstrating significant promise in delivering real-time, high-resolution emissions data.[21] For example, Stanford's Terrestrial Carbon Cycle Group[22] is building low-cost electronics and hardware sensor platforms to tackle the challenges around remote sensing for natural ecosystems.

New ground-based sensor networks also are playing an increasingly important role in measuring carbon stocks and tracking methane emissions. Some landfills and industrial sites, for example, are deploying Unmanned Aerial Vehicles (UAVs) equipped with TDLAS (Tunable Diode Laser Absorption Spectroscopy) and infrared sensors to detect and quantify methane leaks.[23] These drones can provide continuous, real-time monitoring, reducing reliance on modeled estimates that have historically been used in MRV systems.[24] In the oil and gas sector, sensor-based continuous monitoring systems are now operational at some sites.[25]

Likewise, innovative portable technology solutions—such as YardStick's in-situ soil carbon measurement tool and related software platform—are generating valuable carbon quantification data for land management and carbon sequestration projects.[26]

2. The Adoption of Modern Data Management Tools Can Facilitate the Aggregation of Trusted Climate Performance Data

With the advent of exciting new technologies and methodologies to collect and analyze climate performance information, the challenge now is how to synthesize and integrate relevant and trusted data sources into a cohesive, actionable data to drive action. This requires

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[20] Carbon Mapper. (2024, November 15). *Carbon Mapper data from the Tanager-1 satellite reveals methane and carbon dioxide super-emitter activity around the world.* https://carbonmapper.org/articles/carbon-mapper-data-from-tanager1-satellite-reveals-methane-and-co2-super-emitters. The CarbonMapper coalition is a public-private partnership backed by philanthropies, major corporate supporters, and environmental NGOs. Operational and technical partners include NASA's Jet Propulsion Lab, PlanetLabs, and the University of Arizona. Carbon Mapper. (n.d.). *Methane, CO_2 detection satellite | Greenhouse gas*. Carbon Mapper. (n.d.). *Methane, CO_2 detection satellite | Greenhouse gas*. https://carbonmapper.org/.

[21] Jordan, R. (2023, September 18). *'Getting a handle' on a potent climate threat*. Stanford University School of Engineering. https://engineering.stanford.edu/news/getting-handle-potent-climate-threat.

[22] Terrestrial Carbon Cycle Group. (n.d.). *Low-cost GHG measurements*. Stanford University. https://carboncycle.stanford.edu/low-cost-ghg-measurements.

[23] SPH Engineering. (n.d.). *Methane detection*. https://www.sphengineering.com/integrated-systems/technologies/methane-detection.

[24] Fosco, D., Molfetta, M.D., Renzulli, P., & Notarnicola, B. (2024). Progress in monitoring methane emissions from landfills using drones: An overview of the last ten years. *Science of The Total Environment*, *905*, 167472. https://doi.org/10.1016/j.scitotenv.2024.173981.

[25] Qube Technologies. (n.d.). *Emissions monitoring solutions*. https://www.qubeiot.com/.

[26] YardStick PBC. (n.d.). *Soil carbon revealed*. https://www.useyardstick.com/.

the development of standardized approaches for data collection and harmonization.

Across multiple sectors, the deployment of modern data management tools has transformed how foundational information is structured, accessed, and shared. While innovative climate data solutions are emerging in specific sectors within the climate space, these powerful tools have yet to achieve widespread adoption across the entire ecosystem. It is time to change that.

At the core of modern data infrastructure is the principle of interoperability—the ability for different systems and organizations to seamlessly exchange information. This is achieved by establishing common definitions, open standards, and machine-readable formats. For example, adopting structured data-numerical formats such as JSON or XML can enable data to be easily analyzed by algorithms and integrated into modeling platforms. These formats also ensure that climate data is "AI-ready"—an increasingly important feature as machine learning tools become essential for forecasting and emissions verification. [27]

Another foundational tool is the API (Application Programming Interface), which allows systems to "talk to" one another automatically. APIs are widely used across industries, from banking to healthcare, to connect datasets and reduce manual data entry.[28] In the climate context, APIs can enable project-level GHG data to flow directly into dashboards or MRV platforms in real time, greatly increasing transparency and usability.

Cloud-based storage and distributed computing systems further support accessibility and scalability.[29] Rather than storing data in a single central repository, modern systems allow distributed access while maintaining version control and data integrity. This is crucial for supporting cross-institutional collaboration—which is especially important in climate work that involves researchers, governments, NGOs, and private sector actors.

3. The Role of AI in the Modern Data Management Toolbox

Artificial intelligence is playing an increasingly critical role in the modern data management toolbox. A number of entities already are demonstrating the potential power of AI in GHG emissions and removals contexts. As noted above, CTrees uses cloud-based computing and artificial intelligence to integrate advanced satellite technology (lidar, radar, optical imagery), science-based algorithms, and inventory plot data to accurately map variations of carbon stored in forest and non-forest landscapes.[30] Companies like Vibrant Plant also are using AI to improve forest land mapping and address climate resilience issues.[31]

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[27] Stanford Institute for Human-Centered Artificial Intelligence. (2022, January 25). *Data-Centric AI: AI Models Are Only as Good as Their Data Pipeline*. Stanford University. https://hai.stanford.edu/news/data-centric-ai-ai-models-are-only-good-their-data-pipeline .

[28] IBM. (n.d.). *What is an API (application programming interface)?* https://www.ibm.com/think/topics/api.

[29] Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konwinski, A., Lee, G., Patterson, D., Rabkin, A., Stoica, I., & Zaharia, M. (2010). A view of cloud computing. *Communications of the ACM, 53*(4), 50–58. https://doi.org/10.1145/1721654.1721672.

[30] CTrees. (2022, November 11). *CTrees contributes data to Climate TRACE emissions inventory*. https://ctrees.org/news/ctrees-contributes-forestry-and-land-use-data-to-climate-15.

[31] Vibrant Planet. (2024, March 26). *Vibrant Planet uses AI for land mapping and improving climate resiliency*. https://www.vibrantplanet.net/press-room/vibrant-planet-uses-ai-for-land-mapping-and-improving-climate-resiliency

Climate TRACE, an independent global emissions tracking coalition backed by former U.S. Vice President Al Gore, also uses a combination of satellite data, AI, and modeling to generate facility-level emissions estimates in key sectors such as energy, industry, transportation, and land use.[32] In 2024, the Climate TRACE coalition published a groundbreaking report identifying the 500 most polluting sources globally including power plants, fossil fuel production sites, and industrial facilities.[33]

AI is not a panacea, however, that can overcome inscrutable or inadequate underlying data sets. To be effective, data needs to be "AI-ready"—that is, available in structured formats (ideally, through the adoption of interoperability tools discussed below), with enough origin information to assure its reliability. As summarized by the Bipartisan Policy Center:

> "On a basic level, preparing [AI-Ready] data means cleaning and parsing the information into a structured format (e.g., non-proprietary CSV/TSV formats) with unique column labels. On a more complex level, making data AI-ready means providing documentation, in the form of sample code and visualizations, as an on-ramp for researchers to start working with unfamiliar data. It is most efficient to do this work during front-end data collection, because the data provider has context that program offices and later researchers lack.[34]

Unless these steps are taken to make GHG datasets AI-Ready, AI may not generate "trusted" estimates of GHG emissions at the project- or activity-level—where climate performance information current is the weakest and arguably most needed.

4. The Importance of Adhering to "FAIR" Data Principles

To ensure that data are not only shared but usable, modern data management practices emphasize adherence to so-called "FAIR" principles: Findability, Accessibility, Interoperability, and Reusability.[35]

The National Academies of Sciences has underscored the importance of following FAIR principles in the climate context, calling them essential for building the data infrastructure necessary to support robust emissions tracking and climate accountability. The European Open Science Cloud and initiatives like GO FAIR in the EU also actively promote these standards to

[32] Climate TRACE. (n.d.). *Climate TRACE*. https://climatetrace.org/.
[33] Nicholas Institute for Energy, Environment & Sustainability. (2025, February 7). *Duke experts provide clearest picture yet of global building emissions*. Duke University. https://nicholasinstitute.duke.edu/articles/duke-experts-provide-clearest-picture-yet-global-building-emissions. Designed to provide independent verification for national emissions stocktaking, the report revealed significant underreporting, particularly in the oil and gas sector due to methane leaks. Climate TRACE. (2024, November 14). *Climate TRACE data reveal high-impact opportunities for cutting greenhouse gas emissions*. https://climatetrace.org/news/climate-trace-data-reveal-high-impact-opportunities-for.
[34] Long, S., & Romanoff, T. (2023, February 17). *AI-ready open data*. Bipartisan Policy Center. https://bipartisanpolicy.org/explainer/ai-ready-open-data/.
[35] Note that FAIR principles can accommodate privacy concerns by aggregating data and using other techniques to anonymize data.

maximize the societal value of scientific and environmental data.[36]

5. Learnings from Applying Modern Data Management Tools in the Medical Field

Outside the climate field, the University of Chicago's "Data for the Common Good" initiative is a meaningful example of how these tools can be implemented effectively. Led by Dr. Sam Volchenboum, Data for the Common Good is a public-private partnership, combining academic, philanthropic, and commercial stakeholders to create new open data systems that serve both innovation and public benefit.

Data for the Common Good initially focused on capturing and consolidating widely-disparate and previously-unavailable data on rare cancer disease cases from around the world. Toward that end, Dr. Volchenboum's team collaborated intensively with the global medical community to create common interoperable data frameworks that link hospitals, researchers, and patients through shared protocols for rare diseases. By using APIs and standardized data formats, the program ensures that medical records can be integrated in real time while preserving privacy and security.[37]

Through these collaborations, the Data for the Common Good initiative has developed a Pediatric Cancer Data Commons (PCDC). It began with a "big tent" consortium that included industry, registries, cooperative groups, and academic medical centers, followed by an intensive process with stakeholders to reach consensus on data dictionaries and standards that have been widely adopted in the field. The effort has expanded into a global effort to centralize and integrate data from around the world in compliance with international regulations, and to make anonymized data easily and readily available through a PCDC data portal.[38]

The Data for the Common Good initiative has contributed to significantly improved health outcomes. The integration of pediatric cancer data across institutions enables more timely diagnoses and personalized treatment planning. It also facilitates faster identification of clinical trial candidates, accelerating research discoveries, and improving treatment coordination across care teams.

A parallel successful initiative is applying modern data management tools—including, in particular, the application of open source FAIR principles—is underway at Stanford University. Under the leadership of Dr. Mark Musen, Stanford's Center for Expanded Data Annotation and Retrieval (CEDAR) has developed a platform that enables researchers to generate structured, machine-readable metadata that adhere to Findable, Accessible, Interoperable, and Reusable (FAIR) principles by both humans and machines.[39] The CEDAR workbench allows users to

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[36] National Academies of Sciences, Engineering, and Medicine. (2022). *Greenhouse gas emissions information for decision making: A framework going forward*. The National Academies Press. https://doi.org/10.17226/26641.
[37] Center for Research Informatics. (n.d.). *Data for the Common Good*. University of Chicago. https://commons.cri.uchicago.edu.
[38] Pediatric Cancer Data Commons. (n.d.). *Pediatric Cancer Data Commons Portal*. University of Chicago. https://portal.pedscommons.org/login.
[39] Musen, M. A., Bean, C. A., Cheung, K.-H., Dumontier, M., Durante, K. A., Gevaert, O., Gonzalez-Beltran, A., Khatri, P., Kleinstein, S. H., O'Connor, M. J., Pouliot, Y., Rocca-Serra, P., Sansone, S.-A., & Wiser, J. A. (2015). The

construct metadata using intelligent, ontology-linked templates—smart digital forms that use standardized terms and definitions to ensure consistency and compatibility across datasets. These templates guide users in selecting precise, regulated descriptors, thereby reducing variability and improving the interoperability and reusability of the data. The platform also includes automated validation features and supports integration with public data repositories, streamlining submission processes and enhancing compliance with open data mandates.

By eliminating reliance on ad hoc spreadsheets and unstructured documentation, CEDAR promotes the creation of consistent, rich data that are primed for computational use and reuse. Although designed initially for biomedical research, the CEDAR framework offers valuable lessons for climate and environmental data systems—particularly with regard to the standardization of emissions performance data across sectors. CEDAR's emphasis on machine-actionable metadata, alignment with shared ontologies, and commitment to open source infrastructure exemplifies the type of foundational tooling required to scale trusted climate performance data systems.

Together, the Data for the Common Good and CEDAR initiatives demonstrate that data interoperability can significantly improve data-driven decision-making, foster cross-sector collaboration, and enhance AI-driven insights through machine-readable data. Open-access datasets also increase transparency and democratize access to high-quality data, building public trust. They provide successful playbooks for how modern data management tools can facilitate broad public access to open source information that materially advances both the private and public good.[40]

The lesson for the climate sector is clear: trusted, foundational data infrastructure is not an aspirational goal. It is a proven practice that climate stakeholders need to deploy to generate trusted climate performance information. This includes developing open APIs for climate data, requiring machine-readable data reporting standards, and investing in cross-sector data-sharing platforms that prioritize accessibility and transparency.

Center for Expanded Data Annotation and Retrieval. *Journal of the American Medical Informatics Association, 22*(6), 1148–1152. https://doi.org/10.1093/jamia/ocv048.

[40] Many "data commons" efforts are underway in other sectors. Of special note is datacommons.org—a Google-supported non-profit organization that "offers data exploration tools and cloud-based APIs to access and integrate cleaned datasets." Stanford's Doerr School for Sustainability has created a "Stanford Data Commons for Sustainability" to "enable researchers, citizens, journalists, policymakers, nonprofits, and private sector decision makers to find public data and explore connections between data sets." Data Commons. (n.d.). *Data Commons*. https://datacommons.org/.

II. Applying Modern Data Management Tools in the Climate Context: Recommendations for Four Key Use Cases

While there is no question that applying modern data management tools to track and share information on three key use cases—methane emissions reductions, carbon dioxide removals, and forest carbon interventions—will deliver enormous benefits to multiple data users, there is no uniform pathway to achieve this desired end. The reality is that methane emissions reductions, carbon dioxide removals, and forest carbon interventions involve different and unique starting-points in terms of data needs and opportunities, key players, and potential change agents.

Rather than try to force development of a single data-improvement approach, we recommend standing up pilot projects for three use cases highlighted below. In that way, more focused attention can be given to the relevant communities of interest that need to come together to develop common definitions, protocols, and data standards for the key emissions sources and removal activities in each area. The opportunity lies in creating an integrated network of networks approach where a flexible framework can be tailored to different use cases while being underpinned by shared core principles, ultimately building toward a cohesive system that provides granular, timely climate performance data.

By establishing common foundational elements—such as interoperability standards, data validation protocols, and shared taxonomies—these pilots can demonstrate how diverse climate initiatives can maintain their unique methodologies while participating in a unified data framework. Consistent with this approach, the sections that follow describe the current state of performance data development in the three areas of methane emissions reductions, carbon dioxide removals, and forest carbon interventions, and recommend a way forward for each.

The section below also addresses how climate performance data can be improved in a fourth use case—the urban CO_2 context—where the interplay of carbon dioxide emissions from buildings, transportation, and industrial activities in cities creates uniquely complex challenges for local decision makers.

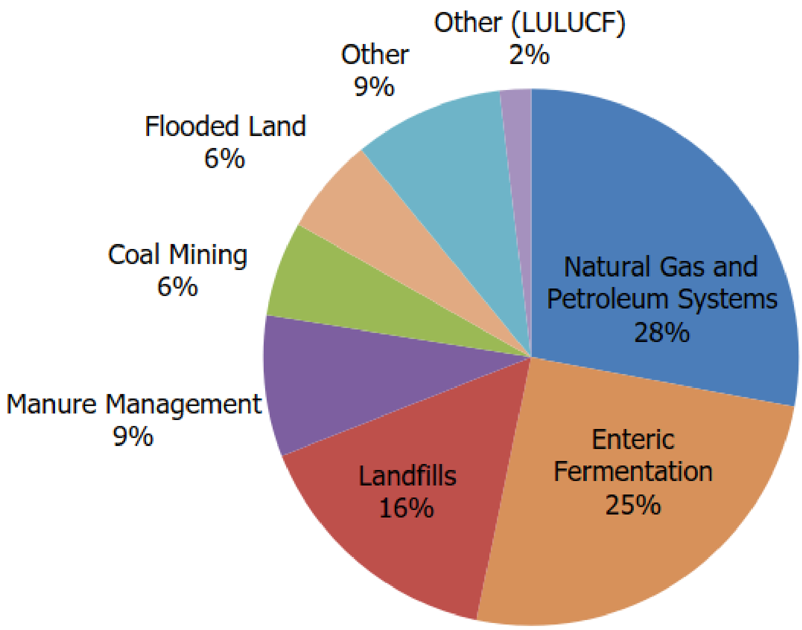
A. Use Case #1: Methane Emissions Reductions.

1. Why Reducing Methane Emissions Is a Priority

Methane is a powerful "super-pollutant" that has a warming effect about 80 times more potent than CO_2 over 20 years. Methane has been responsible for 30% of total warming since the Industrial Revolution and is the second largest contributor to global warming after CO_2.[41] Given methane's significant contribution to near-term atmospheric warming, the U.S. and more than 150 nations worldwide have vowed to cut emissions by at least 30% by 2030 via the Global Methane Pledge.[42]

[41] Global Methane Pledge. (n.d.). *Global Methane Pledge*. https://www.globalmethanepledge.org/.
[42] Global Methane Pledge. (n.d.). *Global Methane Pledge*. https://www.globalmethanepledge.org/.

In the U.S., methane emissions come from three major anthropogenic sources—oil and gas operations (28% of U.S. emissions), landfills (16%), and livestock/agriculture (34%).



U.S. Methane Emissions, By Source. Note: All emission estimates are sourced from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*.[43]

Methane emissions in the U.S. historically have been difficult to reliably measure and monitor. Traditional approaches for estimating emissions have tended to understate actual emissions—sometimes significantly.[44] As discussed in the preceding section of this report, this has triggered the development of satellite-based and other new technologies and tools that can more accurately detect, quantify, and track methane emissions from key sources.

Each of the three major U.S. anthropogenic methane sources—oil and gas; landfills (and waste activities, more generally); and livestock/agriculture—are in different stages of development regarding data collection and emissions reduction solutions and, as a result, a pilot methane emissions data initiative would be logically divided into three parts—one for each of the three major methane source areas.

2. Oil & Gas Sector Methane Emissions

[43] U.S. Environmental Protection Agency. (2025, March 31). *Methane emissions*. https://www.epa.gov/ghgemissions/methane-emissions.

[44] *See, e.g.,* EDF (2018, June 21). *New Study Finds U.S. Oil and Gas Methane Emissions Are 60 Percent Higher Than EPA Reports.* https://www.edf.org/media/new-study-finds-us-oil-and-gas-methane-emissions-are-60-percent-higher-epa-reports-0

Methane emissions in the oil and gas sector have received the most public attention and investment in recent years. Multiple reports have indicated higher-than-expected leakage rates throughout the oil and gas value chain,[45] with so-called "super-emitter" sources accounting for a significant proportion of methane losses.[46]

Disclosures of these leakage losses have motivated large oil and gas operators to increase their investments in methane leak detection and repair activities to reduce the loss of valuable natural gas products and to protect their social license to operate. Leakage disclosures also have drawn attention from regulators and advocates at the federal and state level. In late 2023, the Environmental Protection Agency published final regulations that require regular inspections and data gathering to detect and repair sources of methane leakage in oil and gas operations.[47] In addition, oil and gas producing states are imposing methane leak detection and repair obligations under state law.[48] And third parties are using privately-funded leak detection technology, including increasingly sophisticated remote-sensing satellites, to monitor oil and gas-producing regions and even individual oil and gas facilities that are sources of significant methane leakage.[49] On the global stage, the European Union's 2024 Methane Regulation requires importers to verify compliance with EU MRV standards which, in turn, is pushing U.S. producers to lower methane intensity in liquefied natural gas (LNG) exports.[50]

Together, these developments have triggered the deployment of a robust ecosystem of cutting-edge technology services and sensing devices that are generating significant amounts of performance data on the oil and gas industry's efforts to reduce methane emissions. While the Trump Administration has called for "reconsideration" of methane leak detection and repair regulations that it alleges are "throttling the oil and gas industry,"[51] it appears likely that major oil

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[45] Environmental Defense Fund. (2024, July 31). *New data show U.S. oil & gas methane emissions over four times higher than EPA estimates*. https://www.edf.org/media/new-data-show-us-oil-gas-methane-emissions-over-four-times-higher-epa-estimates-eight-times.

[46] Carbon Mapper. (2022, September 13). *Study finds super-emitters responsible for nearly 40% of methane emissions in five U.S. basins*. https://carbonmapper.org/articles/mutli-basin-paper.

[47] U.S. Environmental Protection Agency. (2025, February 12). *EPA's final rule to reduce methane and other harmful pollution from oil and natural gas operations and related actions*. https://www.epa.gov/controlling-air-pollution-oil-and-natural-gas-operations/epas-final-rule-reduce-methane-and-other. Note that the EPA promulgated a later methane waste tax rule that Congress rescinded under the Congressional Review Act. Vinson & Elkins LLP. (2025, March 19). *Congress has disapproved the EPA's methane tax rule—What happens next?* https://www.velaw.com/insights/congress-has-disapproved-the-epas-methane-tax-rule-what-happens-next/.

[48] Colorado Department of Public Health & Environment. (2025, February 21). *Colorado takes action to further reduce methane emissions from oil and gas operations*. https://cdphe.colorado.gov/press-release/colorado-takes-action-to-further-reduce-methane-emissions-from-oil-and-gas-operations.

[49] *See supra* notes 19 & 20. The final EPA oil and gas methane rule includes a provision which authorizes third parties to alert EPA when it detects a potential super-emitter leak at a covered oil and gas facility. U.S. Environmental Protection Agency. (2025, January 17). *Methane Super Emitter Program*. https://www.epa.gov/compliance/methane-super-emitter-program.

[50] K. Talis, G. Steck & J. Atkins. (2024, October 15). *EU Methane Regulation and its impact on LNG imports.* https://academic.oup.com/jwelb/article/18/1/jwae022/7823205.

[51] U.S. Environmental Protection Agency. (2025, March 12). *EPA launches biggest deregulatory action in U.S. history*. https://www.epa.gov/newsreleases/epa-launches-biggest-deregulatory-action-us-history.

and gas companies, states, NGOs, academic institutions,[52] investors, and insurers[53] will continue to prioritize leak detection activities and generate valuable methane performance data.

Significant methane MRV activity also is underway on the international front. The philanthropy-supported Global Methane Hub is working collaboratively with major NGOs and companies around the world to "build a global network of scientists, experts, activists, policymakers, and philanthropists, all pushing in the same direction toward the single goal of mitigating methane."[54] The United Nations also is active in the area. The United Nations' International Methane Emissions Observancy (IMEO) has, as its mission, to "provide open, reliable, and actionable data to the individuals with the agency to reduce methane emissions." It explicitly acknowledges the "need to shift from inaccurate estimates to real-world, empirical data" by "provid[ing] accurate, unbiased, and up-to-date information on methane emissions – starting with the fossil fuel sector."[55] Among other initiatives, IMEO has developed the voluntary Oil and Gas Methane Partnership reporting standard (OGMP 2.0) that is used by approximately 40% of global oil and gas producers.[56] OGMP 2.0 promotes better methane reporting by encouraging companies to shift from default emissions factors to site-specific measurements and advanced monitoring.

Recommendations for Oil & Gas Methane Emissions.

Forge Cross-Sector Oil & Gas Methane Collaborations Among Industry, NGOs & Academic Leaders. Given the extraordinary level of national and international attention on methane leakage in the oil and gas industry and the related technological advances in leak detection, a number of key actors have an interest in agreeing on protocols for collecting and pooling oil and gas methane emissions data. This group includes major oil and gas companies that have invested heavily in leak detection technology and in repairing leaks; philanthropy-supported research and advocacy non-profits like CarbonMapper and the Environmental Defense Fund; international organizations like the Global Methane Hub and the International Methane Emissions Observatory (IMEO); and other leading NGOs such as the World Resources Institute and the Natural Resources Defense Council.

Explore How U.S.-Based Methane Oil & Gas MRV Advances Could Help Accelerate IMEO Standard-Setting. Given the global importance of reducing oil and gas-related methane emissions and the international commitments that have been made in

[52] For example, the University of Texas at Austin hosts the Energy Emissions Modeling and Data Lab (EEMDL)--a multidisciplinary research and education initiative backed by industry support that has a major focus on addressing methane leakage. Hildebrand Department of Petroleum and Geosystems Engineering. (2023, January 10). *New data lab to tackle oil & gas greenhouse gas emissions accounting*. The University of Texas at Austin. https://www.pge.utexas.edu/pge-news/new-data-lab-to-tackle-oil-gas-greenhouse-gas-emissions-accounting/.

[53] During the Climate Data Conference, participants noted that methane leakage is increasingly being used as a proxy for operational risk, with insurers and investors prioritizing companies that adopt robust emissions management practices. This growing market pressure is driving voluntary adoption of advanced methane tracking technologies beyond regulatory requirements.

[54] Global Methane Hub. (n.d.). *Global Methane Hub*. https://www.globalmethanehub.org/.

[55] United Nations Environment Programme. (n.d.). *About IMEO*. https://www.unep.org/topics/energy/methane/international-methane-emissions-observatory/about-imeo.

[56] Oil and Gas Methane Partnership. (n.d.). *Partnership*. https://www.ogmpartnership.org/partnership.

the sector, IMEO could be a promising forum for advancing common methane measurement and monitoring protocols and data sharing mechanisms. As IMEO itself has explained, a core IMEO mission is to generate more "real-world, empirical data" on methane emissions from the oil and gas sector.[57]

A US-based oil and gas methane data collaborative potentially could help jump-start an effective IMEO process by engaging domestic oil and gas methane emissions stakeholders in preliminary standard-setting and data-sharing discussions. Participants in the initiative could involve experts from industry, government (including subnationals), NGOs, academics, and data management companies, along the lines originally envisioned by the National Institute of Standards and Technology.[58]

A key to success would be recruiting respected, neutral convenors that have experience in deploying modern data management tools to construct open source, shared databases by developing consensus-based data collection protocols and negotiating common definitions, APIs, and other interoperability standards to facilitate formation of a trusted data commons. Technical assistance could be provided by methane experts at universities and organizations with deep methane detection expertise like the Global Methane Hub, EDF, CarbonMapper, the University of Texas-Austin, Stanford University, and others.

3. Landfill Methane Emissions

Landfill methane is produced by the anaerobic decomposition of organic waste. It varies significantly over space and time making MRV particularly challenging.[59] Outdated and infrequent measurement techniques practiced throughout the industry often fail to capture these dynamics, complicating regulatory compliance and corporate climate reporting. However, new technology is significantly improving methane detection at landfills. From high-resolution satellite imaging[60] to AI-powered ground-based sensors, innovations are enabling more accurate, continuous, and independent methane measurement.

As discussed above, the Integrity Council for the Voluntary Carbon Market (ICVCM) is undertaking a category assessment and developing new criteria to evaluate the validity of landfill methane carbon credit claims. The criteria include requirements like information on scientifically backed oxidation rates used in calculation methodology and better data on landfill cover types associated with the landfill. The ICVCM also plans to consider the inclusion of a requirement to

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[57] United Nations Environment Programme. (n.d.). *International Methane Emissions Observatory*. https://www.unep.org/topics/energy/methane/international-methane-emissions-observatory.
[58] National Institute of Standards and Technology. (2024, December 30). *Establishment of the Methane Plume Remote Sensing Measurements Consortium*. Federal Register. https://www.federalregister.gov/documents/2024/12/30/2024-30952/establishment-of-the-methane-plume-remote-sensing-measurements-consortium.
[59] U.S. Environmental Protection Agency. (2025, March 20). *Quantifying methane emissions from landfilled food waste*. https://www.epa.gov/land-research/quantifying-methane-emissions-landfilled-food-waste.
[60] *See, e.g.*, https://wastemap.earth/map

apply remote sensing technologies to enable accurate measurement of greenhouse gas emissions.[61]

Recent subnational regulatory developments show promise of enhancing landfill methane MRV. While the new Administration will not be moving forward with methane standard-setting for landfills,[62] the state of Colorado has initiated a rulemaking to develop landfill methane emissions reduction standards.[63] Colorado also has promulgated a Recovered Methane rule which includes "protocols for recovered methane from…municipal solid waste or landfills…and gas utility system leaks."[64]

Outside of the regulatory landscape, landfill management practices have significant impacts on methane emissions. Implementing best practices such as early gas collection, minimizing the size of active landfill cells, and extending gas recovery periods, can substantially reduce methane emissions compared to other management approaches.[65] Effective landfill management is critical in mitigating methane emissions and reducing financial risks for landfill operators, investors, and insurers.

Recommendations for Landfill Methane Emissions.

The landfill sector appears to be an excellent candidate for an initiative that would seek consensus around specific measurement and monitoring and data sharing protocols and tools that should be adopted by landfill operators. The effort could build upon the significant progress that the ICVCM already has made in this area.

Leadership by U.S. State and Local Leaders. Because many landfills in the U.S. are owned by municipalities with input and some regulatory oversight by local, state, and federal authorities, there is an existing community of interest around landfills that could be encouraged to participate in a pilot project to establish a data commons for landfill methane data. State and local authorities, working through organizations like Climate Mayors and the U.S. Climate Alliance (composed of state governors) that have a direct stake in quantifying and reducing methane emissions from publicly-owned and/or

[61] Integrity Council for the Voluntary Carbon Market. (2024, August). *Observations in Relation to Category Assessment Landfill Gas Capture and Utilisation, V2 July 2024*. https://icvcm.org/wp-content/uploads/2024/08/ICVCM_Board-Observations-for-LFG-v2.pdf.

[62] At the federal level, the U.S. Environmental Protection Agency issued an RFI under the Greenhouse Gas Reporting Program aimed at developing a rulemaking for both municipal solid waste (MSW) landfills and petroleum and natural gas systems, with the goal of refining methods for converting raw sensor data into quantifiable methane emission rates, estimating annual emissions from intermittent observations, and establishing standardized protocols for detection, attribution, verification, and uncertainty assessments. *Use of advanced and emerging technologies for quantification of annual facility methane emissions under the Greenhouse Gas Reporting Program* (EPA-HQ-OAR-2024-0350). https://www.epa.gov/system/files/documents/2024-08/ghgrp_rfi_2024.pdf.

[63] Colorado Department of Public Health & Environment. (n.d.). *Landfill methane reductions in Colorado*. https://cdphe.colorado.gov/landfill-methane-reductions-in-colorado.

[64] Details on each protocol can be found in Colorado's recovered methane rule fact sheet. Colorado Department of Public Health & Environment. (n.d.). *Recovered methane*. https://cdphe.colorado.gov/air-pollution/recovered-methane.

[65] Scharff, H. et al. (2023). *The impact of landfill management approaches on methane emissions*. Waste Management & Research: The Journal for a Sustainable Circular Economy. https://doi.org/10.1177/0734242X231200742.

regulated landfills could work with data management conveners and methane detection experts to develop consensus-based protocols and information-sharing tools to develop landfill best-in-class methane standards and quantification information. As with other major methane sources, technological advances in methane detection and broad-based stakeholder interest in reducing methane emissions can help advance a trusted landfill methane data collection and sharing effort.

4. Livestock/Agricultural Methane Emissions[66]

Livestock and agricultural emissions are the largest source of methane in the U.S..[67] The primary livestock-related emissions sources—enteric fermentation (the ruminant livestock digestive process that generates methane) and manure management—pose a variety of difficult methane abatement challenges.[68] While significant research activity regarding livestock methane abatement alternatives is underway, the generation and sharing of performance data for feed additives, genetics, and other potential emissions reduction strategies lags behind protocol and data development activity in other major methane source areas.

To illustrate, while anaerobic digesters have long been recognized for their ability to abate methane emissions by converting manure into usable biogas for on-site energy sources, programs promoting the use of anaerobic digesters have generated limited useful or reliable methane performance data.[69] For example, USDA-sponsored programs to incentivize farmers and ranchers to utilize anaerobic digesters—including the joint EPA/USDA AgSTAR program—focus more on deployment issues than on measuring and monitoring emissions reductions. Likewise, while the State of California helpfully promotes non-digester manure management practices that can reduce emissions, its measurement and monitoring approaches remain generalized, and crude.[70]

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[66] It should be noted that agriculture is also a major source for another greenhouse gas "super-pollutant"—nitrous oxide (N_2O) emissions emanating from synthetic fertilizer overuse. A. Eagle (2024, Dec, 18) *We can feed a growing population while shrinking fertilizer pollution. Here's how.* https://blogs.edf.org/growingreturns/2024/12/18/reducing-nitrous-oxide/ The Environmental Defense Fund, the Natural Resources Defense Council and other NGOs are ringing the alarm bell about the need to develop mitigation strategies to reduce N2O emissions. Developing common protocols and MRV data sharing will be essential to the success of these efforts. Id.; Rath, D. & Sharma, A. (2024, Sept. 20). *Nitrogen Pollution: Too Much of a Good Thing,* https://www.nrdc.org/bio/daniel-rath/nitrogen-pollution-too-much-good-thing

[67] Searchinger, T., Herrero, M., Yan, X., Wang, J., Dumas, P., Beauchemin, K., & Kebreab, E. (2021). *Opportunities to reduce methane emissions from global agriculture*. Princeton University. https://searchinger.princeton.edu/sites/g/files/toruqf4701/files/methane_discussion_paper_nov_2021.pdf.

[68] Spark Climate Solutions. (n.d.). *Livestock enteric methane mitigation*. https://www.sparkclimate.org/enteric/home. Rice production is the other major agricultural source of methane. There are much better known and promising ways to reduce methane emissions from rice production than there are for livestock-related emissions. Spark Climate Solutions. (n.d.). *Livestock enteric methane mitigation*. https://www.sparkclimate.org/enteric/home.

[69] U.S. Environmental Protection Agency. (n.d.). *Practices to reduce methane emissions from livestock manure management*. https://www.epa.gov/agstar/practices-reduce-methane-emissions-livestock-manure-management; U.S. Environmental Protection Agency. (n.d.). *AgSTAR: Biogas recovery in the agriculture sector*. https://www.epa.gov/agstar; U.S. Department of Agriculture, Economic Research Service. (2011, February). *Climate change policy and the adoption of methane digesters on livestock operations* (ERR-111). https://ers.usda.gov/sites/default/files/_laserfiche/publications/44808/7839_err111.pdf.

[70] California Department of Food and Agriculture. (n.d.). *Alternative Manure Management Program*. https://www.cdfa.ca.gov/oefi/AMMP/; California Department of Food and Agriculture. (2024, July 18). *Alternative*

While promising research on using feed additives[71] and genetics[72] to reduce methane emissions from enteric fermentation is underway, measuring and monitoring emissions from widely-variable numbers and types of livestock activities pose unique challenges. Nonetheless, major dairy and other companies are supporting and closely following research advances, and NGOs such as the Meridian Institute, the Platform for Agriculture and Climate Transformation, EDF, NRDC, and Spark Climate Solutions, among others, are engaged in and/or supporting technical and policy work in this area.

Historically, the U.S. Department of Agriculture (USDA) has supported this type of research and data development. Given the major funding cuts and changes in priorities at the USDA, however, this important work now will likely need to be led by non-federal actors.[73]

Recommendations for Livestock/Agricultural Methane Emissions.

Sponsor Research Symposiums and Technical Workshops on Livestock/Agricultural Methane Emissions.

With many research institutions in the U.S. and around the world focused on techniques to reduce livestock and other agricultural methane emissions, it is important that the research and policy communities stay up to date on developments in the area, and share information on protocols and research results.

Organize Collaborations Among Leading Companies, NGOs, Researchers, and Data Management Experts.

Because limited attention to date has been given to protocol development and data sharing for livestock-related methane emissions, now is arguably the best time for methane detection and data management experts–including experts that have had data management experience in multiple sectors—to work with researchers and technical experts in academia; dairy and meat processing companies; and NGOs to develop data gathering and sharing conventions that facilitate common approaches for measuring,

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Manure Management Program: Final User Guide. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/cdfa_ammp_finaluserguide_7-18-24.pdf.

[71] The University of California at Davis has emerged as a leader in research in this area. UC Davis CLEAR Center. (n.d.). *How can cattle feed additives reduce greenhouse gas emissions?* Among the most promising feed additives is 3-nitrooxypropanol (3-NOP), which is designed specifically to inhibit, or block, methane formation. UC Davis CLEAR Center. (n.d.). *How can cattle feed additives reduce greenhouse gas emissions?* https://clear.ucdavis.edu/explainers/how-can-cattle-feed-additives-reduce-greenhouse-gas-emissions. *See also* Expert Panel on Livestock Methane. (2024, May). *Potential of animal feed additives for methane mitigation*. https://livestockmethane.com/wp-content/uploads/2024/05/2024-03-Animal-feed-supplements-.pdf (identifying potential 30% reduction in methane emissions). Another notable example is red seaweed, whose active ingredient, bromoform, is a chemical long known to inhibit the metabolic activity of methanogens, with studies showing up to a 28% reduction in methane emissions. Id.

[72] Bezos Earth Fund. (2025, April 8). *Bezos Earth Fund and Global Methane Hub launch $27.4M initiative to breed low-methane livestock across four continents*. https://www.bezosearthfund.org/news-and-insights/low-methane-livestock-selection-global-initiative.

[73] As required by the Inflation Reduction Act, the Biden-Harris Administration was set to invest $300 million to improve measurement, monitoring, reporting and verification of greenhouse gas emissions and carbon sequestration in climate-smart agriculture and forestry. It is not clear whether the USDA will continue to disburse this funding.

monitoring, and authoritatively confirming methane reductions from feed additive, genetic advances, and other livestock methane mitigation efforts.

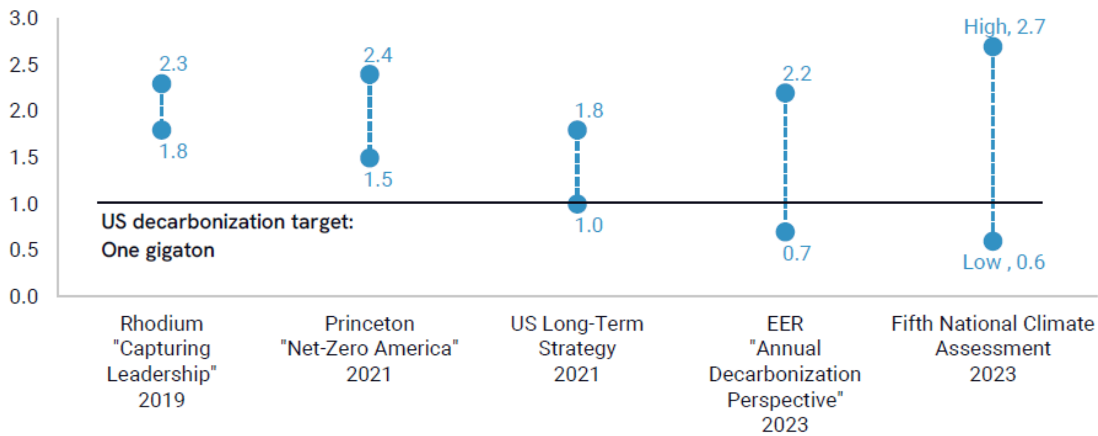
B. Use Case #2: Hybrid Carbon Dioxide Removals.

There is now broad agreement in the science and policy community that in order for the U.S. to decarbonize by mid-century—and assuming aggressive greenhouse gas emissions reductions over that same time period—at least one gigaton of annual carbon dioxide removal (CDR) capacity will need to be available by then.[74]

FIGURE ES 1

Estimates of CDR required by mid-century from US decarbonization studies

Gigatons of CO_2



Source: Rhodium Group; Princeton University Net-Zero America: Potential Pathways, Infrastructure, and Impacts; The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050; Evolved Energy Annual Decarbonization Perspective 2023: Carbon-Neutral Pathways for the United States; The Fifth National Climate Assessment

As the need to produce CDR at scale has become more evident, research and investment in potential CDR options has increased dramatically. Ground-breaking studies have surveyed and analyzed potential CDR options;[75] researchers and entrepreneurs have pushed headlong into exploring and developing promising CDR technologies and approaches;[76] and philanthropies and companies committed to achieving aggressive net-zero goals have invested millions of dollars in promising CDR projects.[77]

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[74] Jones, W., Bower, G., Pastorek, N., King, B., Larsen, J., Houser, T., Dasari, N., & McCusker, K. (2024, April 10). *The landscape of carbon dioxide removal and US policies to scale solutions*. Rhodium Group. https://rhg.com/research/carbon-dioxide-removal-us-policy/.

[75] Pett-Ridge, J., Kuebbing, S., Mayer, A. C., Hovorka, S., Pilorgé, H., Baker, S. E., Pang, S. H., Scown, C. D., Mayfield, K. K., Wong, A. A., Aines, R. D., Ammar, H. Z., Aui, A., Ashton, M., Basso, B., Bradford, M., Bump, A. P., Busch, I., ... Zhang, Y. (2023, December). *Roads to removal: Options for carbon dioxide removal in the United States*. Lawrence Berkeley National Laboratory. https://roads2removal.org/wp-content/uploads/00_RtR_FM-and-Executive-Summary_v-20.pdf.

[76] Stanford Doerr School of Sustainability. (n.d.). *Greenhouse gas removal flagship destination*. https://sustainability-accelerator.stanford.edu/focus-areas/greenhouse-gas-removal.

[77] De Luna, P. (2024, April 9). Why are companies buying so many carbon removal credits? *Forbes*. https://www.forbes.com/sites/phildeluna/2024/04/09/why-are-companies-buying-so-many-carbon-removal-credits/.

This report focuses on hybrid (also sometimes called engineered) CDR approaches like biochar, enhanced rock weathering (ERW), and biomass removal and storage that bridge engineered and nature-based approaches for removing carbon dioxide from the atmosphere. These methods potentially offer scalable, durable CO_2 removals. Like the methane and forestry contexts, however, trusted climate performance data is in short supply for important CDR applications—primarily due to a lack of agreed-upon MRV protocols and data sharing arrangements. There is an increasing recognition that coordinated standards development and open source data sharing are essential keys to building investor confidence and enabling CDR solutions to scale.

A number of promising CDR project types are uniquely positioned to fill gaps in trusted performance information while, at the same time, they face some challenging barriers.

1. Early CDR Initiatives

On the opportunity side, early CDR projects have received significant financial backing by investors who are deeply committed to achieving—and transparently demonstrating—the positive atmospheric results that carbon removal technologies can achieve. Investors recognize that taking the type of evidentiary short-cuts that have damaged the credibility of voluntary carbon markets could harm their CDR investments.[78]

Early CDR investors such as Frontier and Microsoft are demonstrating this commitment by engaging in extensive project-specific due diligence before entering into advance market commitments with CDR companies. Investors also are hiring a new breed of carbon registry companies to undertake thorough, independent validation of asserted carbon benefits.[79] This approach avoids the inherent conflict in the current VCM ecosystem in which carbon sellers typically hire the registries that then validate the sellers' carbon credit claims. In a further show of transparency, Frontier is publicly disclosing contracting arrangements and identifying important CDR "knowledge gaps" to encourage the sharing of experiential data.[80]

A number of other notable efforts to develop publicly available CDR performance-related information are underway. For example, Cascade Climate, a nonprofit focused on enhanced rock weathering solutions, has produced a "shared framework for quantifying carbon removal in ERW deployments"[81] and has launched the *Enhanced Rock Weathering Data Quarry*, a collaborative data-sharing platform to facilitate the pooling of MRV data to refine/redefine baseline conditions,

[78] For example, Frontier—a coalition led by Stripe, Alphabet, Meta, Shopify, and McKinsey—has made more than $1 billion in advance market commitments (AMCs) of durable carbon removal credits. Frontier Climate. (n.d.). *An advance market commitment to accelerate carbon removal*. https://frontierclimate.com/. These commitments help establish pricing benchmarks and ensure that carbon removal companies have access to the longer-term funding needed to generate confirmatory MRV data and other key success metrics at scale.
[79] Orbach, R. (2024, April 26). *In registry we trust (it's about time!)*. Lowercarbon Capital. https://lowercarbon.com/2024/04/26/in-registry-we-trust/.
[80] Ranevska, S. (2024, August 19). New offtake agreements template by Frontier to stimulate more CDR. *Carbon Herald*. https://carbonherald.com/new-offtake-agreements-template-by-frontier-to-stimulate-more-cdr/; Frontier Climate. (n.d.). Carbon removal knowledge gaps. https://gaps.frontierclimate.com/.
[81] Mills, J. V., Sanchez, J., Olagaray, N. Y., Wang, H., & Tune, A. K. (2024). Foundations for carbon dioxide removal quantification in enhanced rock weathering deployments. Cascade Climate. https://cascadeclimate.org/blog/foundations-for-carbon-removal-quantification-in-erw-deployments.

ensure comparability across ERW sites,[82] and standardize inputs and protocols across projects.[83] To promote transparency, Cascade Climate is aligning this initiative with buyer coalitions like Frontier and MilkyWire, who now require ERW project data contributions as part of purchase agreements.[84]

Complementing this deployment-focused work, CarbonPlan has emerged as a technical leader in data transparency and comparative MRV analysis. A nonprofit research organization, CarbonPlan develops open source tools and models that allow stakeholders to assess the scientific validity of various carbon removal claims. Its *Verification Confidence Framework* maps the level of uncertainty associated with key MRV criteria, such as additionality, durability, leakage, and system boundaries, for a wide range of CDR approaches, helping to identify where improvements are most needed.[85] CarbonPlan emphasizes open, peer-reviewed data as essential to MRV credibility, and is actively collaborating with policy and buyer groups to ensure that new standards reflect this principle.

The Carbon Removal Standards Initiative (CRSI), a new independent organization launched in 2024, also is seeking to bridge the gap between CDR technical work and policymaking. CRSI is looking to develop and curate quantification standards for different types of carbon removal, offering them as public resources for use in procurement programs, compliance markets, and verification regimes.[86] The organization recently released its *Quantification Resources Database*, a living repository of MRV methodologies drawn from academic research, voluntary markets, and government programs. It also published a *Jurisdictional Monitoring Framework* for ERW, outlining how governments can track large-scale rock application over farmland and estimate net carbon effects with scientific confidence. CRSI has also begun advising U.S. federal and state agencies on integrating CDR eligibility criteria into climate finance and infrastructure legislation.[87]

These types of efforts reflect a growing consensus that transparent, standardized, and independently verifiable MRV systems are foundational to the credibility and scale-up of hybrid CDR approaches. They also respond directly to institutional concerns regarding the need for clear pathways to connect data to carbon asset formation. Stakeholders emphasized the importance of defining shared performance metrics that can benchmark project efficacy across contexts.

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[82] Cascade Climate. (2024). *Introducing the ERW Data Quarry: A Data Sharing System for Enhanced Rock Weathering*. https://cascadeclimate.org/blog/erw-data-quarry.
[83] Cascade Climate. (2024). *Introducing the ERW Data Quarry: A Data Sharing System for Enhanced Rock Weathering*. https://cascadeclimate.org/blog/erw-data-quarry.
[84] Cascade's 2024 white paper, *Foundations for Quantification in ERW*, provided early guidance for how to quantify net CO_2 uptake, avoid double-counting, and address environmental safety, all priorities identified by investors and scientists during stakeholder workshops. *See* https://cascadeclimate.org/CC_Foundations%20for%20CDR%20Quantification%20in%20ERW%20Deployments.pdf. The next phase of this work will involve vetting and synthesizing the pooled data to refine ERW MRV models and calibrate methods across diverse deployment environments.
[85] CarbonPlan. (n.d.). *CDR verification framework*. https://carbonplan.org/research/cdr-verification-framework.
[86] *See* Carbon Removal Standards Initiative. (2024). Quantification Resources Database. https://carbonremovalstandards.org.
[87] CRSI maintains independence by refusing funding from credit-selling entities, ensuring its standards development remains neutral, science-driven, and shielded from commercial influence. *See* Carbon Removal Standards Initiative, Why Independent Standards Matter for Carbon Removal (2024), https://carbonremovalstandards.org.

2. Impediments to CDR Standard Setting & Data Sharing

While these early efforts at promoting publicly accessible information on CDR performance are encouraging, the CDR industry still faces significant impediments that are holding back the development of common standards and data sharing mechanisms.

First, a number of promising hybrid CDR projects involve interventions in "open systems" that could impact environmental conditions in the project area.[88] For example, the application of carbon-capturing biochar or rock materials on farm, forest, or pasture lands may generate run-off that potentially could impact downstream lands or waters in ways that need to be understood and taken into account. To do so requires the development of sophisticated models, backed by representative on-site sampling activities that typically go beyond the capabilities of start-up companies with limited resources.

Second, and relatedly, the limited and highly competitive CDR market is prompting some CDR start-ups to treat performance data as proprietary and confidential. This approach reflects the reality of the market. Companies want to protect their intellectual property in a nascent industry where technological advances can determine market success. Without independent standardized measurement protocols, some companies have been unwilling to allow public review of their data sources and analysis. The resulting proliferation of proprietary MRV platforms and closed methodologies can make it impossible to evaluate and compare climate performance claims, leading to the collapse of users', investors' and markets' trust.

It is important that influencers of the CDR market such as buyers, investors, researchers, and other data users lobby strongly for—and, where they can, insist upon—consensus-based adoption of common protocols and open source CDR data sharing. Opportunities for shared licensing models and de-risking open data contributions through frameworks that respect community data rights, also need to be considered.

Recommendations for Hybrid CDR Solutions.

The relatively small (but growing) U.S. CDR community has a unique opportunity to demonstrate how modern data management tools can be used to create open source datasets that will provide reliable, trusted confirmatory information for the most promising types of hybrid CDR solutions.

Leadership by CDR Buyers and Adjacent Industry Players. CDR buyers and their agents (including registries in their employ) are making substantial expenditures in scientific reviews and other due diligence to ensure that CDR projects will generate quantifiable, durable removals. Currently, the primary focus is on one-off projects in which CDR buyers are investing, with much less attention being given to mapping and pooling MRV information for similar types of CDR projects.

As noted above, however, Frontier and other industry leaders are clearly aware of the need to broaden data sharing and collaboration, and new organizations like

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[88] D. Ellis, Great Unwind. (2023, March 15). *Leveling the playing field for open-system carbon removal*. Great Unwind. https://greatunwind.substack.com/p/leveling-the-playing-field-for-open.

Beyond-Alliance.org[89] are providing potential new vehicles for lifting up and broadening out open source performance data for key types of CDR projects. Also, the National Institute for Standards and Technology (NIST) has initiated a Carbon Dioxide Removal Consortium, with an initial focus on forestry and direct air capture projects.[90] If the new administration withdraws support for the science-based CRD Consortium, an independent non-profit or university should be encouraged to continue and expand NIST's efforts to build consensus around protocol and data sharing standards for hybrid CRD projects.

Because significant investment dollars are already being spent in generating quantifiable, durable removals, CDR buyers, early-stage CDR company investors, rock companies, agricultural producers, waste management companies, and other adjacent industry players that stand to profit from future CDR investments are well-positioned to establish data management expectations for this young industry.

Workshop Data Management Learning from Other Sectors. An important first step would be to share data management learnings from other sectors so that key players can see what is possible, and appreciate the tremendous benefits from collaborating on common open-source data management approaches. For example, key buyers and other CDR supporters could request that expert data management organizations like the Data Foundation sponsor workshops that introduce MRV interoperability data learnings from the accounting, medical, and other sectors to the growing CDR industry. Such workshops could open the door to a work plan or research roadmap that could focus on the development of definitions, standards, and data commons for discrete lines of CDR activity.

Forge Company & University Collaborations. A special initiative also could be developed to address the special challenges of measuring and monitoring the potential off-site environmental ramifications of "open system" CDR solutions like biochar or ERW applications. The science community agrees that for these types of applications, it will be necessary to study off-site impacts and construct sophisticated predictive ecosystem models that account for such potential impacts.

Individual CDR companies are not well-positioned to undertake this type of landscape-scale modeling, nor may they be good candidates to undertake the representative on-site sampling required to support such a modeling exercise. Indeed, to the extent that periodic confirmatory sampling must be undertaken for model integrity, those locations should be chosen by the modelers, rather than being subject to the randomness of CDR company-owned (or otherwise readily-available) lands.

This situation suggests that for open system CDR, pooled investments may be needed to develop, calibrate, and refine models that analyze transport and potential environmental impacts of biochar, ERW, and other open system solutions. This could present an opening for universities and other researchers to partner with CDR companies and potential suppliers of CDR materials to create MRV tools that will benefit multiple companies and

[89] Beyond Alliance. (n.d.). Members & partners. https://beyond-alliance.org/members-partners/.
[90] National Institute of Standards and Technology, *Carbon Dioxide Removal Consortium*, n.d., https://www.nist.gov/programs-projects/carbon-dioxide-removal-consortium.

locations. In addition, industries that will potentially benefit from CDR expansion—such as rock companies and biomass suppliers—potentially could be enlisted to provide financial support and (rock or biomass) materials for such an exercise. The ERW Data Quarry concept that Climate Cascade has begun to construct from commercial data sets may provide another key piece to the open system puzzle.

C. Use Case #3: Forest Carbon Interventions.

The third use case for which trusted climate performance data are needed are forest carbon interventions that have great promise as nature-based climate solutions,[91] but which have been held back by the lack of transparent and reliable climate performance data.

Forest management activities that can increase carbon stocks include reforestation, agroforestry, improved wildfire management, extended harvests, and other carbon-enhancing timber production techniques. For example, experts have estimated that U.S. forests have the potential to remove more than 90 million tons of carbon per year through reforestation activities alone.[92]

Unfortunately, most currently-available forest carbon data focus on overall carbon stocks in forests. They do not seek to isolate and measure carbon gains due to investments in reforestation and other carbon-positive interventions. There is no agreement on how to best measure and monitor the carbon benefits associated with changed practices, nor are there publicly shared databases tracking carbon benefits from such activities.[93]

Additionally, many existing forest MRV methodologies rely on outdated or inconsistent models that have not been calibrated with field-based measurement data and/or that ignore the increasing negative impacts that climate change is having on some forests' health, including their ability to maintain (much less increase) carbon stocks. There also are disagreements over the appropriate resolution of forest carbon data, making it difficult to ensure accuracy and comparability across projects.[94]

[91] Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., ... Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences of the United States of America, 114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114.

[92] Naturebase. (n.d.). Naturebase interactive map. https://app.naturebase.org/map/.

[93] The U.S. Forest Service's Forest Inventory and Analysis (FIA) database is the primary source for generalized estimates of U.S. forests' carbon stocks. U.S. Department of Agriculture, Forest Service. (n.d.). Forest Inventory and Analysis (FIA) program. https://research.fs.usda.gov/programs/fia. Unfortunately, however, the FIA database does not provide real-time information (as it typically is updated infrequently—on a five or ten-year cycle), it has been slow to take advantage of powerful satellite-based remote sensing and AI tools to improve carbon stock estimates, and it does not correlate forest carbon accumulations with practice-based interventions like reforestation or extended harvest activities.

[94] Recent studies suggest that too low resolution could create 100-fold variations in estimated carbon accumulation rates across the globe, while too high resolution could decrease accuracy and interpretability. Duncanson, L., Hunka, N., Jucker, T., Armston, J., Harris, N., Fatoyinbo, L., Williams, C. A., Atkins, J. W., Raczka, B., Serbin, S., Keller, M., Dubayah, R., Babcock, C., Cochrane, M. A., Hudak, A., Hurtt, G. C., Montesano, P. M., Moskal, L. M., Park, T., Saatchi, S., Silva, C. A., Tang, H., Vargas, R., Weiskittel, A., Wessels, K., & Goetz, S. J. (2025). Spatial resolution for forest carbon maps. *Science, 387*(6732), 370–371. https://doi.org/10.1126/science.adt6811.

Finally, even when high-quality, transparent data on forest carbon performance exists, it often is inaccessible due to fragmented datasets, proprietary restrictions, landowner privacy concerns, and limited incentives for data sharing.[95] Without reliable and widely available data on relevant scales for action, policymakers struggle to incorporate forests into regulatory frameworks, investors face increased risks when financing forest carbon projects, and landowners lack the confidence to adopt sustainable management practices at scale. These challenges create barriers to scaling forest carbon projects, ultimately slowing progress in leveraging forests as a key carbon removal and climate mitigation tool. Addressing these data gaps is essential to unlocking the full potential of forests in achieving climate goals.

The checkered history of selling questionable forest-based carbon credits on voluntary and compliance markets also has led to a loss of confidence in forestry as a nature-based climate solution. Over-reliance on unprovable avoided deforestation claims, combined with the lack of science-based standards that link and measure additional carbon buildup (sequestration) with specific forestry practices has triggered embarrassing exposés and prompted potential investors to walk away from the field.[96]

1. New Commitments to Improve Forest Carbon Data Collection and Sharing

Although the current status of U.S. forest carbon data is sub-optimal, it is encouraging that four of the most prominent U.S. forestry NGOs have acknowledged forest carbon data deficiencies and have launched separate initiatives to address the most critical forest carbon performance data gaps.

In particular, the American Forest Foundation—which represents tens of thousands of smaller private foresters throughout the U.S.—has pioneered application of a "dynamic matched baseline" approach that compares enrolled forests to similar unenrolled forests in real-time, enabling the measurement of carbon increases resulting from investments in improved management practice interventions.[97] It also hosts a "data room" that enables prospective carbon credit buyers to review available data.[98]

The National Alliance of Forest Owners (NAFO)—which represents large commercial-scale foresters in the U.S.—has been working with the non-profit U.S. Endowment for Forestry and Communities and the U.S. Forest Service to create decision-support software that would provide access to "high quality carbon data on forests and wood products" by, among other things,

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[95] Cook-Patton, S. C., Leavitt, S. M., Gibbs, D., Harris, N. L., Lister, K., Anderson-Teixeira, K. J., Briggs, R. D., Chazdon, R. L., Crowther, T. W., Ellis, P. W., Griscom, H. P., Herrmann, V., Holl, K. D., Houghton, R. A., Larrosa, C., Lomax, G., Lucas, R., Madsen, P., Malhi, Y., Paquette, A., Parker, J. D., Paul, K., Routh, D., Roxburgh, S., Saatchi, S., van den Hoogen, J., Walker, W. S., Wheeler, C. E., Wood, S. A., Xu, L., & Griscom, B. W. (2020). Mapping carbon accumulation potential from global natural forest regrowth. *Nature, 585*(7826), 545–550. https://doi.org/10.1038/s41586-020-2686-x.

[96] White, N. (2023, March 21). Bogus carbon credits are a 'pervasive' problem, scientists warn. *Time Magazine*. https://time.com/6264772/study-most-carbon-credits-are-bogus/.

[97] American Forest Foundation. (n.d.). Dynamic baselines are the necessary future of forest carbon. https://www.forestfoundation.org/why-we-do-it/family-forest-blog/feature-dynamic-baselines-are-the-necessary-future-of-forest-carbon/.

[98] American Forest Foundation. (2025, January 14). A carbon buyer's guide to the AFF data room. https://www.forestfoundation.org/why-we-do-it/family-forest-blog/a-carbon-buyers-guide-to-the-aff-data-room/.

"combin[ing] forest sector inventory data with tools, technologies and approaches to enable forest owners to determine the forest carbon stock impacts of forest management regimes for various forest types or species composition."[99]

American Forests has been working with a number of states to "develop detailed models to project how different forest management actions and natural disturbances will affect carbon capture and storage at state and regional levels." The models "consider the broad range of management practices used in each state and account for the ways climate change may impact forest growth in the future…[and] account for the carbon in the forest itself as well as the carbon still stored in wood products after trees are harvested."[100]

The Sustainable Forestry Initiative also has developed an on-line "Tableau" tool to quantify "the carbon value of SFI-certified forests and can help diverse partners and organizations understand the value of sustainably managed forests."[101]

These initiatives demonstrate the commitment by all of the leading U.S. forestry NGOs to collect, share, and make available upgraded carbon performance data that will support carbon claims. In so doing, they are explicitly acknowledging the imperative to increase the reliability and trustworthiness of forest carbon measurement and monitoring information.

As illustrated by NAFO's and the U.S. Endowment's proposed data initiative, the NGOs' interest in carbon benefits extends beyond in-forest carbon benefits associated with reforestation and other management interventions to post-harvest carbon storage in long-lived wood products, calculated through holistic life-cycle analyses. It is essential that a disciplined full life-cycle quantification exercise be part of any comprehensive forest carbon data exercise given the carbon opportunities that working forests can provide in the U.S. and globally.

2. The Importance of Addressing Community Interests and Accounting for Non-Carbon Co-Benefits of Sound Forest Management

Although the focus of this report is on measuring and monitoring carbon benefits, it is important to recognize that forest interventions may produce unintended negative outcomes if implemented without careful consideration. For example, forest carbon interventions that prioritize carbon sequestration exclusively—such as creating fast growing plantation monocultures—can remove or degrade native forests, harming ecosystem functions while also damaging cultural uses and wildlife habitats.[102]

On the other hand, forest carbon interventions also can generate valuable non-carbon co-benefits, including climate resilience benefits (including community protection); biodiversity benefits[103];

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[99] U.S. Endowment for Forestry & Communities. (n.d.). Forest & Wood Carbon Data Platform. https://www.usendowment.org/what-we-do/ecosystem-markets/forest-wood-carbon-data-platform/.
[100] American Forests. (n.d.). Forest carbon modeling. https://www.americanforests.org/project/forest-carbon-modeling/.
[101] Sustainable Forestry Initiative. (n.d.). Carbon tool. https://forests.org/carbon-tool/.
[102] Zhu, H., Zhang, J., Cheuk, M. L., Hau, B. C. H., Fischer, G. A., & Gale, S. W. (2023). Monoculture plantations impede forest recovery: Evidence from the regeneration of lowland subtropical forest in Hong Kong. *Frontiers in Forests and Global Change, 6*, Article 1098666. https://doi.org/10.3389/ffgc.2023.1098666.
[103] Hayes, D. J., Barbara, M., Chen, M. M., Chichilnisky du Lac, A., Galli, Z., Gonzales, C. M., Hedayat, A., Rubin, J. J. M., von der Leyen, J. G., & Wyss, L. (2024, July). *Investing in nature to fight climate change and help*

cultural and social value benefits for local communities and indigenous peoples[104]; recreational benefits; and water quantity and quality benefits. It is vitally important that forest carbon benefits not be measured and valued in isolation.

Recommendations for Forest Carbon Interventions.

The forest data work that major U.S. forestry NGOs have begun provides a strong basis for a collaborative effort that a expert intermediary like the the Data Foundation's Climate Data Collaborative could launch with NGOs, states, private forest owners and commercial entities to develop an open source forest carbon data sharing platform that would integrate diverse data sources across multiple scales—from project-level to regional and datasets — with the overarching goal of providing a comprehensive, scientifically-grounded basis of forest carbon data that enhances the credibility of nature-based solutions and accelerates their adoption at scale.

This project could focus on key themes that recur throughout this report, including development of:

Establishing A Data Integration Framework: Developing agreed-upon protocols for data quality, transparency, governance, and interoperability, to authenticate data providers and facilitate machine-actionable knowledge sharing across key forest carbon datasets from multiple inputs including MRV inputs from reforestation and improved forestry practices; applied research; private and government-sponsored monitoring systems, etc. Significant efforts should be made in parallel to develop data inputs and a data integration framework for non-carbon ecosystem services benefits that accrue from forestry investments.[105]

Public-Private Partnerships: Creating a collaborative model that balances privacy concerns, proprietary information, and varying data ownership models while systematically highlighting where private sector innovation is most needed.

Decision Support & Implementation: Developing visualization capabilities and analytical tools that transform integrated data into actionable insights for landowners, project developers, researchers, and policymakers to accelerate adoption of nature-based solutions.

Comprehensive Analysis of Working Forests Issues and Opportunities. Collaborate with working forest owners and operators and develop a verified database that combines

communities thrive. Stanford Law School Policy Lab. https://law.stanford.edu/wp-content/uploads/2024/07/Final-NBS-Report-7.22.24-DJH.pdf.

[104] Ding, H., Veit, P. G., Blackman, A., Gray, E., Reytar, K., Altamirano, J. C., & Hodgdon, B. (2016). *Climate benefits, tenure costs: The economic case for securing indigenous land rights in the Amazon*. World Resources Institute. https://www.wri.org/research/climate-benefits-tenure-costs.

[105] Paxton, N. (2025, March 3). *Nature Needs Its Own ID.* https://www.project-syndicate.org/commentary/transformative-potential-of-digital-nature-id-by-midori-paxton-2025-03; Bagsted, K. et al., *Interoperability for ecosystem service assessments: Why, how, who, and for whom?*, April 2025, https://doi.org/10.1016/j.ecoser.2025.101705.

interoperable carbon stock data from working forests with post-harvest carbon storage and losses, based on verified life-cycle analyses.

This type of initiative would create opportunities for innovation, drive forest carbon estimates to convergence (i.e., leveraging both top down and bottom up methods to provide the best possible forest carbon insights), improve data quality, and potentially streamline verification processes for forest carbon projects.

The initiative also would highlight data and methodology gaps where private sector innovation is most needed, creating targeted opportunities for advancements in measurement, reporting, and verification technologies and capabilities.

Drawing inspiration from successful models like the Internet of Water[106] and the Data for the Common Good[107] framework, such a collaborative would seek to bridge critical data gaps, reduce redundancy, and enhance data accessibility. Successful piloting of forest carbon data integration could provide insights and frameworks to expand this model to other key nature-based climate solutions.

Identify and Evaluate Promising Performance Metrics for Non-Carbon Forestry Co-Benefits.

As referenced above and described more fully in a 2024 Stanford Law & Policy Lab report, efforts should be taken to identify and calibrate the potential benefits and consequences of forest carbon and other nature-based interventions.[108] Significant academic and project-based research and experimentation is underway in this area. It would be useful to engage a respected, independent technical and policy organization to sponsor public reviews of promising measurement and valuation approaches for typical forestry co-benefits and, ideally, to recommend additional investments and test piloting of the most promising calibration and valuation approaches.

D. Use Case #4: Learning from the Urban GHG Context: Sharing Key Climate Performance Data through User Friendly Data Dissemination

Getting accurate, hyper-local carbon dioxide emissions data into the hands of local decision-makers is essential for effective climate action. Yet the urban context presents a critical challenge for climate performance data, as the interplay of carbon dioxide emissions from buildings, transportation, and industrial activities in cities creates uniquely complex measurement difficulties.

Multiple efforts are underway to enable mayors, city planners, and community leaders to track carbon dioxide pollution sources and guide climate policy decisions and interventions in their communities.

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[106] *See* Internet of Water Coalition, *Internet of Water*, n.d., https://internetofwater.org/.
[107] *See supra* note 35.
[108] Hayes, D, et al., (2024, July). *Investing in Nature to Fight Climate Change and Make Communities Thrive, Stanford Law School Policy Lab Report Stanford Law School Policy Lab Report* https://law.stanford.edu/wp-content/uploads/2024/07/Final-NBS-Report-7.22.24-DJH.pdf

The Data Foundation's Climate Data Collaborative has hosted or participated in a series of workshops to bridge the science-policy divide by bringing together scientists and local policymakers to better understand urban decision-makers' greenhouse gas information needs.

Over the past year, the Climate Data Collaborative has partnered with Crosswalk Labs to launch an open data tool, open.crosswalk.io, that brings census level CO_2 data to communities across the United States.[109] The tool allows any user to zoom in or out to facility, community, or regional level emissions and transforms complex emissions modeling into accessible, decision-ready information for non-technical users. It exemplifies the type of open-source tool that can take available emissions datasets and make them more readily available and actionable for public officials and other interested user groups and has been presented at conferences and workshops in Washington DC, Stanford, CA, and most recently at the World Meteorological Organization in Geneva.

Crosswalk's approach utilizes a unique measurement, reporting, and verification methodology that is designed to present a digital twin of emissions in every neighborhood of the United States.[110] Crosswalk builds its digital twin using publicly available data and a uniform methodology, modernizing emissions modeling by incorporating web-scraping and data-fusion methods. Crosswalk data have been developed through various methods, including utilizing scientific research developed in academia with funding from the National Oceanic and Atmospheric Administration, the National Institute of Standards and Technology, and the National Aeronautics and Space Administration.[111]

Recommendations for Urban Performance Information.

Looking ahead over the next five years, the priority in the urban context should be bridging the science-policy gap to empower a community of local decision makers to use the best available scientific evidence to inform climate action. As a starting point, efforts could include establishing an ecosystem with three distinct sets of players to improve climate performance data in the urban context. With federal capabilities at risk due to uncertain support, a new public-private institutional approach like this is needed to ensure scientific integrity while promoting innovation. This model could include:

A Consortium that serves as an independent body that convenes agencies, commercial service providers, NGOs, and researchers to co-develop standards and best practices in urban emissions measurement and modeling. This consortium should accelerate the translation of state-of-the-art science into decision-ready information while providing baseline R&D that enables private sector innovation, potentially creating a "race to the top" where organizations compete to exceed established standards through continuous improvement and innovation. The consortium would serve as a trusted platform/group to help evaluate emissions data using transparent methods and observational validation approaches.

[109] Crosswalk Labs. (n.d.). *Open data portal*. https://open.crosswalk.io/.
[110] Current data runs through 2023; Crosswalk is developing quarterly data updates and now-cast capabilities.
[111] See Appendix F for more technical information on the Crosswalk open source urban CO_2 Information tool.

Organizations focused on understanding stakeholder needs, like the Data Foundation/Climate Data Collaborative, should prioritize ensuring the best urban greenhouse gas (GHG) information makes its way to cities and local decision-makers. These organizations serve as crucial intermediaries between technical data providers and end users, translating complex emissions data into actionable insights. By conducting regular needs assessments and maintaining open communication channels with diverse urban stakeholders, they can identify information gaps and usage barriers. Stakeholder needs for climate action should then inform future R&D priorities for the consortium, creating a feedback loop that ensures scientific advances remain relevant to real-world implementation challenges.

Service Providers that create data visualization tools, aggregation platforms, and value-added services could leverage the consortium's scientific foundations while receiving credibility through third-party validation. By implementing the consensus standards in innovative commercial applications, these companies can deliver solutions that directly address stakeholder needs identified by organizations like the Data Foundation/Climate Data Collaborative.

This three-player model would facilitate building trust in burgeoning data tools, connecting decision-makers with training and support, building partnerships, and connecting trusted datasets to improve climate mitigation decisions at local levels.

CONCLUSION

Confronting the climate crisis requires a coordinated, data-driven strategy. Across all three use cases analyzed in this report—methane emissions, hybrid carbon dioxide removals, and forest carbon interventions—a common set of core principles emerges as essential for establishing trusted climate performance data. Building investor-grade data systems requires rigorous standards for measurement, reporting, and verification, support for machine-readable formats, and open-source platforms that encourage cross-sector collaboration. Without clear, consistent protocols, fragmented data systems will continue to undermine confidence in climate action and delay urgently needed investments.

Beyond developing the right tools and systems, equally important is the creation of communities willing to disseminate data; generating buy-in for prompt data sharing is essential. Linking data contributors into trusted networks can foster shared experimentation and rapid diffusion of best practices. These networks can reinforce the uptake of new data standards and tools. Furthermore, participant feedback mechanisms are necessary to ensure that the tools evolve in response to technological advances in areas such as remote sensing.

Building trusted data systems and data dissemination networks will involve at least three phases. First, framework development will include crafting interoperable standards, defining transparent governance protocols, and enabling privacy-preserving data sharing. Second, coalition-building will require establishing structures for participation and exploring data integration models—perhaps by assimilating learnings from other fields, such as the medical field. Finally, the implementation of data-sharing approaches may begin with targeted pilots and documenting lessons learned to inform future scaling efforts.

Ultimately, building investor-grade climate data systems rooted in transparency and open standards will equip decision-makers with the necessary tools to pursue the most effective climate mitigation activities. Though improvements in data sharing are already being made across all three use cases, there remains significant potential to turn fragmented data landscapes into a foundation for shared progress—helping drive investment, improve accountability, and accelerate global mitigation efforts.

Appendix A: Conference Materials

Opening Remarks by David J. Hayes (Conference Organizer)— March 13, 2025

Good morning, and welcome to Stanford and today's conference and workshop.[112]

If we were to ask passers-by outside Paul Brest Hall about the topic of today's event -- "Increasing the Accessibility to Trusted Climate Performance Data" – we doubtlessly would get some quizzical reactions.

A conference on Trusted Climate Performance Data? What the heck? Sounds esoteric, opaque, and . . . does anyone really care about this topic?

The answer is yes, yes, and yes.

Friends, we have a serious problem to solve.

The problem, in a nutshell, is that in order to unleash the capital needed to reduce harmful methane emissions, to remove carbon dioxide from our atmosphere, and to increase the health of our forests, we need to forthrightly confront the reality that in each of these important areas, we have no common metrics for measuring success.

At a time when modern data management advances and technological breakthroughs in data collection, analysis, and sharing have given us amazing new tools to measure success, we are stuck in a bad place:

- A place where guesswork on climate performance has been and continues to be the norm, and
- And a place where there is no plan – for the common good or for the benefit of the capital markets – to collect, analyze, and share performance data in three of climate's top opportunity areas – methane abatement, carbon dioxide removal, and forestry. These are three important areas in which an avalanche of new data is in the process of being generated – but with no plan for how it might be collected, shared, validated and made publicly available for the investors, companies, policy-makers and others who want to deploy climate-smart solutions in these sectors.

But this is a problem that can be solved. Today, we will be learning how other sectors have created accessible and trusted data commons that provide open-source, foundational data for

[112] I want to thank our sponsors: First, the Environmental & Natural Resources Law & Policy and CODE-X programs from Stanford Law School – and in particular Molly Melius, Catherine Atkin, Michael Schmitz and Dean George Triantis – plus Monique, Jodie and the SLS team that has been doing such a fabulous job on the logistics end of the conference. Second, the Stanford Sustainability Accelerator and the Woods Institute for the Environment, both part of Stanford's Doerr School of Sustainability – and in particular Charlotte Pera, Chris Field and Dean Arun Majumdar – who will be making remarks later today. Third, the Data Foundation and its CEO, Dr. Nick Hart and the leaders of the Data Foundation's Climate Data Collaborative – Ryan Alexander and Sonia Wang. I also want to do a quick shout-out to my Policy Lab class here at Stanford– a class aggressively entitled "Bridging the Climate Data and Decision-making Divide." All to be done in one academic quarter! Several of my students are here today and we will be producing a post-conference report that we hope all of you will find useful.

everyone in the field. It's a data collection and sharing approach that implements so-called FAIR principles – Findable, Accessible, Interoperable and Reusable.

I am particularly excited about hearing from our luncheon speakers – Dr. Sam Volchenboum and Dr. Mark Musen – about progress in how key research and performance data is being generated and shared in the medical field – and then from a fire-side chat between Data Foundation CEO Dr. Nick Hart and democratizing data expert Dr. Julia Lane as they review how leaders in other fields have come together to identify and incentivize the use of modern data management tools to pool together shared, trusted data.

Our primary attention, of course, is on how to apply this learning and experience into the climate field and, in particular, to pilot new ways of collecting, sharing, and validating performance data in the methane, forestry, and CDR contexts.

Through our panel discussions – and in the workshop sessions that you will be participating in this afternoon – w**e will dive into these use cases, looking for the promising work streams that key players in each sector are engaging in around data collection and standardization -- and exploring how we can leverage and expand these efforts to advance toward the goal of accessible, trusted performance data in these bell-weather areas.**

But before we start the music, I need to address two overarching issues that are on many of our minds and relevant to the challenge and opportunity before us.

The first issue is how an effort to improve access to trusted climate performance data connects – if at all – with the proliferation of climate data services that have grown up around the Greenhouse Gas Protocol's framework for calculating corporations' carbon footprints.

So what about all that climate data that companies are collecting for **carbon disclosure and reporting purposes?** Isn't this data enough? And why are these data sources not producing the type of **trusted climate performance data** that investors, companies, and advocates must have to demonstrate that their activities are producing results i**n the atmosphere** in terms of reduced emissions or removals.

The simple answer is that when compiling the Scope 1, Scope 2, and Scope 3 greenhouse gas emissions information under the Greenhouse Gas Protocol, companies are putting together estimates of the direct, energy-related, and supply chain-related greenhouse gas emissions based on whatever estimation tools they and their consultants deem appropriate and available.

Typically, reporting estimate tools rely heavily on use of emission factors, "spend-based" models and other generalized model-based assumptions. Corporate carbon reporting is not based on actual measurements for projects that are designed to reduce methane emissions or remove carbon.

These sources of climate data provide a snap-shot estimation of a company's carbon footprint but they do not speak to the climate performance of specific investments that companies or their partners are making to remove carbon from the atmosphere or to reduce emissions. To test for performance, baseline conditions for each emitting or removal activity must be identified, and then the beneficial impacts of the activity – namely, the quantified emissions reductions or removals – need to be measured and confirmed over time.

As some have put it, carbon disclosures typically involve "counting" but not "accounting." The same is true for the greenhouse gas inventories that are being collected in the U.S., and internationally, at the nation-state level.

> [It is important to note parenthetically that for fossil fuel-related climate mitigation activities, it can be relatively easy to quantify climate performance. Because scientists know how much carbon dioxide burning a gallon of gasoline or a tank of natural gas will put in the atmosphere, it is possible to state with confidence how much atmospheric benefit will flow from reductions in fossil fuel combustion.
>
> [Applying simple emission factors, however, do not generate trusted performance results in the important use cases that we are focusing on today – methane, CDR, and forestry. For these areas, we are in a climate **performance** data desert. Some data are being generated in these areas – with much more on the way – but the data typically are not tied to activity-based performance. And there are few or no agreed-upon protocols for how performance data should be collected, shared, and validated.

The second issue is what is going on now in Washington and the current Administration's antipathy toward all things climate.

As you know, the Administration historically has been a key partner in helping to collect and analyze climate data. The EPA's annual inventory of greenhouse gas emissions and sinks – while relying in some areas too heavily on gross estimates – nonetheless has provided an ever-improving store of key climate data. And NASA, NOAA, the USGS, and the USDA have been providing key science capabilities that played essential roles in understanding emissions, removals, and climate impacts in specific sectors.

It looks like that much great work at the federal level may grind to a halt. Indeed, given recent events in Washington, there is significant fear that important climate data sets will be removed from public view, monitoring activities that have generated important long-term climate records will be terminated, and some important climate data sets may be trashed.

It is very regrettable – tragic, really – that the federal government will no longer join with corporate, non-profit, philanthropic, and academic entities and with international, state, and local leaders on the journey to increase accessibility to trusted climate performance data. This is a big loss but it means that communities like this one – which has spear-headed the technological advances like remote-sensing, AI, and new field-based testing capabilities that are revolutionizing climate data collection, analytics, and sharing needs to step up.

Indeed, as our panelists today will be confirming, it is noteworthy that most of the creativity and push for better climate performance data in the methane, CDR, and forestry fields has been coming from non-federal entities and communities-of-interest – in line with a long history of information development and leadership by companies, NGOs, philanthropy, and sub-national authorities.

So, in review, we hope that through the presentations today and our workshop this afternoon, we will

- take lessons from other sectors in how to apply modern data management principles,

- leverage and expand the promising data collection and standardization work streams that key players in the methane, forestry, and CDR sectors already are engaging in
- And advance toward the goal of accessible, trusted performance data in these bell-weather areas.

It makes sense to start with important areas like methane, forestry and CDR where there already is a strong commitment by a large swath of non-federal actors including, in particular, investors, companies, NGOs, universities, philanthropies, and international entities and where non-political entities like the Data Foundation's Climate Data Collaborative, the Carbon Removal Standards Initiative, and the academic research community are ready to dig in.

I want to close with a couple of parting thoughts.

First, I want to emphasize the broad number of data users and stakeholders who share an interest in shoring up the integrity of foundational climate performance data.

For example, having accessible, trusted climate performance data will materially improve inputs into corporate disclosures and reporting. Personally, I hope that it also will help redirect reporting to those corporate investments that are generating measurable, verifiable atmospheric benefits.

Having accessible, trusted climate performance data also will help focus investors, existing companies, and entrepreneurs on opportunity areas for investments and profit-making activities.

In that regard, having accessible, trusted climate performance data will provide the evidence-based foundation for that is essential for healthy market transactions of all types, and for improved accounting, and accountability, for climate progress.

My second parting point is that getting better, open-source performance data is not the end – but in some sense it is the beginning – of learning how to use data wisely.

When there is a solid foundation of climate performance data for specific practices, the door opens for companies to combine climate with other pertinent data sets and analytics to create valuable decision-making tools for a variety of users. With a strong, open-source data foundation in place, a world of new opportunities opens up. As we have learned the hard way, however, if trusted foundational data is not in place, decision support tools built on top of it will be far less useful and valuable.

Also, even when solid data on carbon dioxide emissions is available – as it is for fossil fuel-based emission sources like cars, trucks and power plants – many users will not have practical access to its teachings unless it is organized and presented in user-friendly, GIS-based format. This is an important part of the story, and you will hear about this from Ryan Alexander and Jason Burnett as Jason's Crosswalk Labs has teamed up with the Data Foundation to create just such an open-source portal for carbon dioxide emissions sources. It will wow you.

So buckle up – interesting discussions on these topics lie ahead – to be followed by workshop sessions in which we will split up into separate groups addressing methane, CDR, and forestry. That is where we want to hear your ideas on how we can use these pilot areas as testbeds for developing foundational, trusted, climate performance data that will spur more attention and capital investment in these major opportunity areas.

Thank you again for being here and helping to advance this important work.

Pre-Read for the March 13, 2025, Conference on
"Increasing Accessibility to Trusted Climate Performance Data"

OVERVIEW

Because the climate crisis requires urgent action, companies, investors, and policymakers need reliable, accessible, and discoverable climate performance information so they can prioritize investments in those mitigation activities that will produce the most effective results. Trusted climate performance data is needed for companies to make accurate carbon disclosures, measure progress against climate goals, and participate in voluntary carbon market opportunities. And policy-makers and governmental officials at all levels need climate performance data to evaluate mitigation investment returns and to track and confirm progress for promising carbon reduction strategies.

Better climate performance data is particularly needed in areas where there is limited or no agreement regarding the best protocols for measuring and verifying emissions reductions and removals, and limited or no mechanisms for publicly aggregating and sharing "measurement, reporting, and verification" (MRV) information. This conference and workshop focuses on three such areas: **methane**, hybrid (or engineered) c**arbon dioxide removal (CDR)**, and **forestry**. A fourth instructive use case discussed in the conference involves areas in which solid climate performance data have been produced—as is the situation for **urban carbon dioxide** emissions—but where the information is inaccessible as a practical matter.

Skeptics may question the need for better climate performance data, given that tens of thousands of companies all around the world are regularly issuing detailed carbon disclosure reports, following guidance and inputs from the Greenhouse Gas Protocol and CDP (formerly, the Carbon Disclosure Project). In addition, dozens of carbon registries and third-party verification entities are active in the area, largely to support voluntary carbon market transactions. And technological advances in the earth observation and artificial intelligence fields are opening new and better ways to collect relevant data, as illustrated by Planet, Climate Trace, and other pioneering companies and organizations.

Even with these advances, however, the lack of standards and transparency in how climate performance information is collected and analyzed erodes trust in performance claims. For example, while carbon disclosure reporting serves an important function, carbon disclosures typically rely on the use of generalized models, emissions factors, and so-called "spend-based" carbon estimates that can vary significantly in their accuracy and applicability across different GHG contexts and scales.

In short, disclosure-oriented data gathering practices typically do not generate the type of performance data needed to track and confirm how much benefit a specific investment or activity is producing in terms of GHG emissions reductions or removals. A strong body of accessible and trusted climate baseline and performance data is needed—especially in critical areas where today there are limited protocols and data sharing conventions.

The conference is focused on how to address this need. Speakers will address current climate performance shortcomings and challenge conference participants to take advantage of opportunities that are emerging in key areas. In the workshop portion of the conference, participants will discuss and recommend concrete steps to advance the development of trusted and accessible climate performance information in three important use cases that are poised for progress: methane, hybrid carbon dioxide removal, and forestry.

The conference will also highlight two areas in which modern technology and data management tools are being used to improve decision-making in the climate and medical fields. The first involves recent breakthroughs in the accessibility of climate performance data in the **urban carbon dioxide use case**–as demonstrated by Crosswalk Lab's development of an open-source portal, in partnership with the Data Foundation, which provides aggregated, location-based information on urban sources of carbon dioxide emissions from multiple sources for the benefit of many user groups. (See the urban carbon dioxide use case #4, below.) The second involves the medical world's use of modern data management practices to enhance research, enable new discoveries, and measurably **improve health outcomes** through the open sharing of data—as will be illustrated by luncheon speakers Dr. Sam Volchenboum from the University of Chicago and Dr. Mark Musen from Stanford**.**

ADDITIONAL BACKGROUND ON FEATURED CLIMATE USE CASES

Use Case #1: Methane. Methane is a powerful "super-pollutant" whose U.S. emissions come from three major anthropogenic sources—oil and gas operations (28% of U.S. emissions), landfills (16%), and livestock/agriculture (34%). Given methane's significant contribution to near-term atmospheric warming, the U.S. and nations worldwide have pledged to cut methane emissions by at least 30% by 2030.

Methane emissions in the U.S. historically have not been reliably measured or monitored. The growing concern about methane emissions, however, has prompted companies, public entities, and interested third parties to devote significant attention to methane in recent years, including through the development of new technologies and tools that can more accurately detect, quantify, and track methane emissions. Satellite-based methane detection systems, for example, have advanced significantly over the past five years.

Each of the three major methane sources are in different stages of MRV development, with the oil and gas sector receiving the most significant national and international attention; the landfill sector beginning to trigger more concerted action; and the livestock/agricultural sector being in the early stages of research and protocol development.

In the oil and gas sector, for example, major oil and gas companies have supported efforts to identify and stop methane leakage through a variety of efforts. Final regulations issued by the U.S. Environmental Protection Agency, developed cooperatively with the oil and gas industry, provide flexibility in how methane leaks will be identified and remediated.

Significant MRV activity also is underway on the international front. For example, approximately 40% of global oil and gas production is adhering to the Oil and Gas Methane Partnership (OGMP 2.0)—a voluntary reporting standard backed by the United Nations Environment Programme (UNEP). OGMP 2.0 promotes better methane reporting by encouraging companies to shift from default emissions factors to site-specific measurements and advanced monitoring.

In the landfill sector, the State of Colorado incorporated strong MRV components into its 2021 Greenhouse Gas Reduction Roadmap and is taking action to measure and verify emissions from oil and gas operations and landfills. The state is implementing landfill methane emissions reduction measurement standards that exceed federal standards and launched a third-party verified methane monitoring program in July of 2024.

In the summer of 2024, the Integrity Council for the Voluntary Carbon Market (ICVCM) made assessments and began developing new criteria to evaluate the validity of landfill methane carbon credits, a move that underscores the sector's need for standardized MRV protocols. The criteria include requirements like information on scientifically backed oxidation rates used in calculation methodology and better data on landfill cover types associated with the landfill.

Livestock-related methane emissions are beginning to attract significant measurement, monitoring, and mitigation attention. Governmental agencies and corporate and university researchers are developing protocols to quantify methane emissions from ruminants, and to test promising new feed additives that may reduce emissions from enteric fermentation digestive processes. Methane emissions from manure management processes also are receiving significant attention.

Workshop discussants will explore options to utilize organizations that potentially could facilitate the development of standards and protocols that enable data sharing and comparisons across different sources of methane. Examples include the Data Foundation's Climate Data Collaborative, the Energy Emissions Modeling and Data Lab at the University of Texas-Austin, the Solid Waste Association of America, the Integrity Council for the Voluntary Carbon Markets, the Platform for Agriculture and Climate Transformation (PACT), the Meridian Institute, and others.

Use Case #2: Hybrid Carbon Dioxide Removals. Hybrid carbon dioxide removal (CDR) includes approaches like biochar, enhanced rock weathering (ERW), and biomass storage that bridge engineered and nature-based solutions. These methods offer potentially scalable, durable CO_2 removals that—alongside emissions reductions—are needed to blunt climate change's damaging impacts. However, a coordinated approach to MRV and standards development in the CDR space is needed to attract the level of investment that will enable these methods to scale.

Standards and transparency are particularly important for hybrid carbon dioxide removal efforts as many CDR approaches are being advanced by companies that are reluctant to publicly share their performance data. A number of CDR approaches involve complex landscape, "open system" interactions for which shared data collection and modeling may be particularly important, but are not yet in place.

Because investors and buyers are driving demand for stronger CDR-MRV frameworks, a number of early efforts are underway to promote standard setting and data sharing in the CDR space. The Stanford Doerr School of Sustainability's Accelerator is supporting multiple CDR projects that are engaged in MRV issues from multiple perspectives. The Carbon Removal Standards Initiative is "provid[ing] technical assistance and capacity building for carbon removal policy, focused on quantification standards. Cascade Climate is organizing an ERW "Data Quarry" to, among other things, tap into key commercial data sets that include real-world deployment information that potentially can inform enhanced rock weathering MRV. Carbonplan is enhancing transparency by tracking and standardizing CDR data, while Frontier is identifying key knowledge gaps and facilitating open-access sharing of CDR proposals and legal templates. The Integrity Council for the Voluntary Carbon Market and the Greenhouse Gas Protocol also are evaluating potential CDR-related MRV initiatives.

Workshop discussants will explore options to take advantage of these and other emerging activities to advance standard-setting and the development of trusted and accessible CDR climate performance information.

Use Case #3: Forestry. The third use case for which trusted climate performance data is needed is forestry—a nature-based climate solution that has great promise, but which has been held back by the lack of transparent and reliable climate performance data. The U.S. forestry sector is poised to make significant advancements in generating trusted forestry climate performance data due to new forestry measurement and monitoring capabilities and significant new NGO and state initiatives focused on improving forest modeling capabilities, practice-based data analysis, data sharing, and the development of user-friendly data platforms.

Particularly noteworthy are advances in remote sensing and AI-enhanced monitoring and modeling for high-resolution forest carbon tracking. Satellite-based remote sensing and AI models now enable high-resolution, near real-time tracking of forest carbon dynamics, and improved accuracy in carbon stock estimation and emissions accounting. As one example, CTrees.org is integrating LiDAR data from NASA's ICESat and GEDI satellites with machine learning to provide high resolution mapping of global forest carbon, while WRI's Land & Carbon Lab is developing an AI-powered global forest growth model that integrates ground and satellite data to improve forest carbon stock assessments. However, resistance from carbon registries and verifiers to utilize new measurement technologies, privacy concerns, the lack of common protocols and standards, and the failure to successfully integrate government and privately-generated databases are standing in the way of data progress in the field.

These barriers can be overcome. Encouragingly, the U.S.'s major forestry NGOs have initiated complementary efforts to improve forest carbon MRV capabilities. The American Forest Foundation, for example, is pioneering the use of Dynamic Matched Baselines to benchmark forest carbon investments against unmanaged reference forests—helping to address both additionality and measurement concerns. American Forests is partnering with seven states to augment the Canadian carbon budget's practice-based model with projections of future climate impacts on forest health on a landscape scale. And the National Alliance of Forest Owners is working with the U.S. Endowment for Forestry and Communities to develop a platform that will incorporate a number of MRV tools that will help standardize forest carbon data and reporting at entity-level and national scales. A collaborative data sharing platform modeled on what the Internet of Water has developed for water also might be developed. As with the other use cases, workshop discussants will explore options to take advantage of these and other emerging activities in the U.S. forestry sector to advance standard-setting and the development of trusted and accessible climate performance information.

[As noted above, the following use case will be discussed in the opening session of the conference.]

Use Case #4: Urban Carbon Dioxide Emissions. Urban carbon emissions represent a critical challenge for climate performance data, as the complex interplay of buildings, transportation, and industrial activities in cities creates unique measurement difficulties. Getting accurate, hyper-local emissions data into the hands of local decision-makers is essential for effective climate action.

There are multiple efforts to ensure that mayors, city planners, and community leaders have the evidence needed to guide their climate policy decisions and investments toward the most effective interventions. The Data Foundation's Climate Data Collaborative has both hosted or participated in a series of workshops to bridge the science-policy divide by transforming complex emissions modeling into accessible, decision-ready information for non-technical users. The Climate Data Collaborative's open.crosswalk.io tool, developed by Crosswalk Labs, allows any user to zoom in or out to see facility, community, or regional level emissions. It exemplifies the type of open-source tool that can take available emissions datasets and make them more readily available and actionable for public officials and other interested user groups.

INCREASING ACCESSIBILITY TO TRUSTED CLIMATE PERFORMANCE DATA

CONFERENCE & WORKSHOP AGENDA

9:00 am Welcome David J. Hayes, *Professor of the Practice, Stanford Doerr School of Sustainability, Stanford Law School*

9:10 am The Imperative to Improve Accessibility to Trusted Climate Performance Data

The Investor Perspective
Nancy Pfund, *DBL Partners*
Jane Woodward, *WovenEarth Ventures; MAP Energy; Stanford University*
The Corporate Perspective
Catherine Atkin, *Global Digital Single Market Data Alliance*
Liv Watson, *Expert in Digital Statutory Reporting*
The Public Decision-Maker Perspective
Jason Burnett, *Crosswalk Labs, Packard Foundation, former Mayor & EPA official* (with Ryan Alexander, *Data Foundation*)

10:30 am Break

10:40 am Addressing U.S. Methane Mitigation Data Needs & Opportunities

Speakers: Rob Jackson, *Woods Institute for the Environment; Precourt Institute for Energy*
Chris Konek, *Global Methane Hub*
Steve Hamburg, *Environmental Defense Fund*
Moderator: Sonia Wang, *Data Foundation - Climate Data Collaborative*

11:25 pm Addressing U.S. Forest Carbon Data Needs & Opportunities

Speakers: Chris Field, *Stanford Woods Institute for the Environment and Interdisciplinary Environmental Studies, Stanford University*
Jad Daley, *American Forests*
Allison Wolff, *Vibrant Planet*
Moderator: Lauren Cooper, *Sustainable Forestry Initiative*

12:10 pm Lunch break

Luncheon Speakers: Dr. Sam Volchenboum, *Director, University of Chicago, Data for the Common Good*; Dr. Mark Musen, *Stanford Center for Biomedical Informatics Research*

1:30 pm Addressing U.S. Carbon Dioxide Removal Project Data Needs & Opportunities

Speakers: Anu Khan, *Carbon Removal Standards Initiative*
Kate Maher, *Woods Institute for the Environment*
Ryan Orbuch, *Lowercarbon Capital*
Moderator: David J. Hayes, *Doerr School of Sustainability and Stanford Law School*

2:15 pm Comments from Dean Arun Majumdar, *Dean of the Stanford Doerr School of Sustainability*

2:25 pm Lessons Learned from Other Trusted Data Contexts – a fireside chat featuring Nick Hart, *Data Foundation*, and Julia Lane, *NYU Wagner Graduate School of Public Service*

2:50 pm Break

3:00 pm Simultaneous participatory workshop sessions for methane, forestry, and carbon dioxide removal use cases

Reporters: Michael Schmitz, *ReCarbon; Climate Data Policy Initiative, CodeX – The Stanford Center for Legal Informatics*
Kelley Kizzier, *Bezos Earth Fund*
Ryan Alexander, *Data Foundation*

4:45 pm Wrap-up

5:00 pm Reception in the Courtyard

Appendix B: MRV Standards Stakeholders

Companies, investors and policymakers alike need reliable performance data on GHG reduction activities for effective climate action. In the absence of a clear signal from national governments, a fragmented and inconsistent approach to emissions data collection and synthesis has emerged. As discussed below, there are no consistently-applied Measurement, Reporting, and Verification (MRV) standards for unregulated greenhouse gas emissions and removals.

- **Tracking Progress in Reducing Carbon Emissions and Increasing Removals**

Public officials and regulators need robust, transparent climate performance data to justify incentive programs and compliance obligations. From offering subsidies for carbon sequestration to enforcing cap-and-trade requirements, these authorities must rely on trusted information to implement policies, verify reductions, and maintain the integrity of emissions regulations. Many regulators cannot conduct data collection and synthesis first-hand for a broad range of environmental activities given steep costs and labor requirements. Hence, they must work with vendors and service providers. Given the lack of standardization, governments and regulators are often making decisions on both incentives and punitive measures from incomplete public inventories on emissions. As regulations and disclosure laws expand around the world, more regulators will demand robust, verifiable data on carbon emissions—intensifying the need for accessible and trusted climate performance information.

- **Market Participants Seeking Credible Carbon Advantages**

Investors, project sponsors, and companies (in both compliance and voluntary carbon markets) rely on credible data to substantiate claims of GHG reductions or lower-carbon products to determine cost, pricing, and return-on-investment. Whether it is securing better market prices for carbon credits, attracting additional investment, or meeting buyer expectations for environmental product disclosures, these market players risk devaluation and potential fraud if their climate performance information is unverified or not reproducible for similar projects. Companies eyeing trade with regions imposing carbon border adjustments (like the EU's CBAM) also fall into this category, recognizing the competitive edge—or costly disadvantage—tied to proven carbon intensities. Lastly, new entrants in emerging green sectors—such as sustainable cement or steel—often struggle to find customers willing to pay a green premium because it can be difficult to translate emissions reduction measures into transparent, clearly definable costs.

- **Corporations Making Carbon Disclosures**

Many businesses now make carbon disclosures either voluntarily or to meet regulatory requirements or as part of investor diligence. As discussed further below, corporations often rely on multiple methodologies and informed guesswork – particularly for emissions from their supply chains. These firms see first-hand how unverifiable or inconsistent data erodes trust and effectiveness. Faulty data may be used to drive key business decisions such as vendor selection or corporate venture investments. These entities would prefer to base their carbon reporting on reliable, standardized emissions data in order to bolster their environmental credentials and ensure accurate reporting to stakeholders.

Appendix C: EU Regulations

EU REGULATION ON CARBON EMISSION DISCLOSURES UNDER THE CORPORATE SUSTAINABILITY REPORTING DIRECTIVE (CSRD)

This Appendix addresses the provisions of the European Sustainability Reporting Standards (“ESRS”). These are a set of guidelines that require companies to report on their environmental, social, and governance (“ESG”) performance. The ESRS were developed by the European Financial Reporting Advisory Group (“EFRAG”) and they are mandatory for companies subject to the Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 as regards corporate sustainability reporting (“CSRD”).

More specifically, this annex addresses the disclosure obligations related to carbon emission in the private sector, as foreseen by the ESRS.

Companies Subject to the CSRD

Starting in 2025, EU companies and EU subsidiaries of non-EU companies meeting two of the three following criteria will have to comply with the reporting obligations under the CSRD:

- more than €40 million in revenue;
- more that 260 million employees;
- total assets of over €20 million.

In total, nearly 50,000 companies across Europe will be obligated to report their emissions, along with over 10,000 non-EU companies and their EU subsidiaries. Starting in 2028, the CSRD will also apply to non-EU parent companies that have €150 million in annual revenues in the EU and possess at least one subsidiary or branch in the EU that engages in substantial business activities.[113] These companies must submit their first report in 2029, using emissions data from 2028 at a consolidated group level, which will include non-EU operations. Additionally, listed small and medium-sized enterprises will be impacted by the CSRD in 2026, with their reports due in 2027, although they have an option to opt-out until 2028.[114]

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[113] Importantly, the EU is reconsidering the timing and content of required reports. McGowan, J. (2025, March 30). EU wants new European sustainability reporting standards by October 31. *Forbes*. https://www.forbes.com/sites/jonmcgowan/2025/03/30/eu-wants-new-european-sustainability-reporting-standards-by-october-31/.

[114] Wilkinson, B. (2023, August). What You Need To Know About Carbon Accounting In Europe: Understanding the CSRD and ESRS sustainability regulations. *Oliver Wyman*. https://www.oliverwyman.com/our-expertise/insights/2023/aug/carbon-accounting-europe.html.

Appendix D: California Corporate Climate Reporting Obligations

Overview of SB 253: The Climate Corporate Data Accountability Act

SB 253 requires U.S. companies with annual revenues exceeding $1 billion that conduct business in California to disclose their GHG emissions across all scopes[115]:

- **Scope 1:** Direct emissions from sources owned or controlled by the company.
- **Scope 2:** Indirect emissions from the consumption of purchased electricity, steam, heating, and cooling.
- **Scope 3**: All other indirect emissions occurring in the company's value chain, including both upstream and downstream activities.

The reporting timeline is structured as follows[116]:

- **2026**: Disclosure of Scope 1 and Scope 2 emissions for the 2025 fiscal year, with limited assurance required to be reported in 2026.
- **2027**: Disclosure of Scope 3 emissions for the 2026 fiscal year, with limited assurance required to be reported in 2027.
- **2030**: Scope 1 and Scope 2 emissions disclosures must obtain reasonable assurance, while Scope 3 emissions continue under limited assurance.

These disclosures are to be made publicly available on a digital platform managed by the California Air Resources Board (CARB).[117]

SB 253 stipulates that companies must calculate their GHG emissions in accordance with Greenhouse Gas Protocol standards and guidance, at least for reports covering the years 2026 through 2033.[118] As noted above, the Greenhouse Gas Protocol is a widely adopted international framework that provides guidelines for estimating GHG emissions from an inventory perspective, but not from an activity-level performance perspective. The legislation also mandates third-party assurance for reported emissions data. Stated in SB 253, beginning in 2033, and every five years thereafter, CARB is tasked with assessing the reporting methodologies to ensure they remain effective and relevant.

Overview of SB 261: The Climate-Related Financial Risk Act

SB 261 mandates that companies with annual revenues exceeding $500 million and operating in California biennially disclose climate-related financial risks and the measures they are implementing to mitigate these risks. The disclosures should align with the recommendations of

[115] Salesforce. (n.d.). California's climate disclosure laws: A guide for companies. https://www.salesforce.com/net-zero/california-climate-disclosure-laws/.
[116] California Legislature. (2023). Senate Bill No. 253: Climate Corporate Data Accountability Act. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240SB253.
[117] Salesforce. (n.d.). California's climate disclosure laws: A guide for companies. https://www.salesforce.com/net-zero/california-climate-disclosure-laws/.
[118] California Legislature. (2023). Senate Bill No. 253: Climate Corporate Data Accountability Act. https://legiscan.com/CA/text/SB253/id/2844397.

the Task Force on Climate-Related Financial Disclosures (TCFD), encompassing vulnerabilities related to employees, supply chains, consumer demand, and shareholder value.[119]

[119] Persefoni. (2024, October 4). California climate disclosure: Getting ready for SB 253 and SB 261. https://www.persefoni.com/blog/california-climate-disclosure-readiness.

Appendix E: ICVCM Category Assessment Process

This section presents an overview of the Integrity Council for the Voluntary Carbon Market's ("ICVCM") assessment process for the issuance of high-quality carbon credit **programs**[120] and **categories**[121] based on the "Core Carbon Principles" ("CCPs") set by the ICVCM. The ICVCM's development of preferred MRV approaches for specific categories of sources is an important step in the right direction. To date, the ICVCM has assessed and approved several categories including "Landfill gas capture and utilization" (with methodologies related to "Landfill methane recovery"); "Leak detection/repair in gas systems"; and "Reducing emissions from deforestation and forest degradation" ("REDD+").[122]

I. **CCPs**.

The CCPs are ten fundamental principles for high-quality credits that create real and verifiable climate impact based on the latest science and best practices. The ICVCM sets the detailed criteria for assessing if the carbon credits meet the CPP in a rulebook named "Assessment Framework" ("AF").[123] The AF requires participants to publish comprehensive information in an accessible manner so all stakeholders can understand how projects issuing CCP-labelled carbon credits impact emissions, society, and the environment.[124]

To ensure the quality of carbon credits, **programs** must meet CPPs related to effective governance, tracking, transparency, robust independent third-party validation and verification, robust quantification of GHG emission reductions and removals, no double-counting, and sustainable development benefits and safeguards. **Categories** must meet CPPs that reflect additionality, permanence, robust quantification, no double-counting, sustainable development benefits and safeguards, and support the transition to net zero.

In the AF, the ICVCM describes its call for "robust quantification" with reference a set of general principles, including the following:

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[120] It is likely to be considered a program if the organization can meet and prove that (i) develops and maintains a standard that is used to register/approve mitigation activities; and (ii) organization issues carbon credits from mitigation activities following this named standard. Integrity Council for the Voluntary Carbon Market. (n.d.). How we assess carbon-crediting programs. https://icvcm.org/how-we-assess-carbon-crediting-programs/.

[121] Categories can be understood as "types of carbon crediting methods sorted into groups of similar types." Integrity Council for the Voluntary Carbon Market. (n.d.). How we assess carbon-crediting programs. https://icvcm.org/how-we-assess-carbon-crediting-programs/.

[122] Integrity Council for the Voluntary Carbon Market. (n.d.). How we assess carbon-crediting programs. https://icvcm.org/how-we-assess-carbon-crediting-programs/.

[123] Integrity Council for the Voluntary Carbon Market. (n.d.). The assessment framework. https://icvcm.org/assessment-framework/.

[124] ICVCM has taken particular care to ensure that Indigenous Peoples and Local Communities have a powerful voice in shaping the CCPs. This included organizing workshops specifically for input from IPs & LCs and reserving three of 22 seats on its Board for IPs & LC members. Integrity Council for the Voluntary Carbon Market. (2023, March 29). Integrity Council launches global benchmark for high-integrity carbon credits. https://icvcm.org/integrity-council-launches-global-benchmark-for-high-integrity-carbon-credits/.

1. Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Compliance: Quantification approaches must meet CORSIA requirements.[125]
2. Conservativeness in quantification:

   - Approaches should ensure that emission reductions or removals are not overestimated, considering overall uncertainty.
   - Should be highly unlikely that the reductions or removals can be significantly overestimated.

3. Uncertainty considerations:

   - Uncertainty must account for all sources, including assumptions (e.g., baseline scenario), estimation models, parameters, and measurement accuracy.
   - Overall uncertainty should be assessed as a combined total from these individual causes.

4. Program accountability:

   - The carbon-crediting program must ensure conservativeness per criterion indicated in No. 2 above, and robust quantification according to specific provisions in criteria related to "boundary for the mitigation activity" and "monitoring approaches".

5. Alternative approaches:

   - If a program's alternative quantification approaches meet the same thresholds as the requirements achieved in criteria related to "boundary for the mitigation activity" and "monitoring approaches", it can submit an explanation and make it publicly available.

II. TWO-LEVEL ASSESSMENT

The ICVCM is conducting parallel assessments to determine if the carbon credit programs and categories align with the CPPs.[126] Once approved, the credits are labeled "CCP-eligible" and "CCP-approved," respectively. Only when both levels of assessments are complete are the carbon credits marked as "CCP-labelled" as high-quality carbon credits.

III. CATEGORIES ASSESSMENT PROCESS

Programs are assessed internally by the ICVCM, but the process of assessing **categories** of carbon credits started with the work of the "Categories Working Group" ("CWG")[127] —an expert

[125] International Civil Aviation Organization. (n.d.). Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx.
[126] Integrity Council for the Voluntary Carbon Market. (n.d.). How we assess carbon-crediting programs. https://icvcm.org/how-we-assess-carbon-crediting-programs/.
[127] Membership of the CWG included: a buyer, carbon-crediting Programs, a data provider, IPs & LCs, a rating agency, project developer, UNFCCC Article 6 expert, three members of the Integrity Council's Expert Panel and three members of the Integrity Council's Standards Oversight Committee. Integrity Council for the Voluntary

group comprised of members of the ICVCM's Governing Board, its Expert Panel, and external stakeholders that has grouped similar carbon credit methodologies into 36 different categories, which will undergo one of three types of assessment:[128]

1. **Internal assessment** (8% of the market[129]): fast-tracked categories assessed internally by the ICVCM Secretariat staff and Expert Panel members as considered to be highly likely to meet the CCP. This includes capturing methane from mines and landfill sites, detecting and repairing leaks in gas systems, destroying chemicals that damage the ozone layer, and reducing emissions of the powerful greenhouse gas sulfur hexafluoride.

2. **Multi-stakeholder assessment** (47% of the market): complex issues in specific areas will be assessed by multi-stakeholder working groups ("MSWGs")[130], i.e., carbon crediting methodology experts from within and outside the ICVCM and from the ICVCM's Standard Oversight Committee (a sub-committee of the Governing Board). This includes renewable energy, efficient cookstoves, improved forest management, and REDD+.

   ICVCM will prioritize those categories with the largest current or expected market share.[131]

3. **Unlikely to meet criteria** (1% of the market): categories considered unlikely to meet CPP will be assessed once other assessments are complete. This includes new natural gas power, waste heat recovery, and industrial energy efficiency.

ICVCM has set up a consultant pool to support their technical work during the initial category assessment phase. The outcome of this work will define whether categories meet the criteria and requirements for CCP-approval or if remedial action needs to be undertaken. Once approved, the ICVCM will have the power to review a program or category if there are concerns about its adherence to the CCPs. Annual reporting to the ICVCM ensures ongoing compliance, while a

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Carbon Market. (n.d.). How we assess carbon-crediting programs. https://icvcm.org/how-we-assess-carbon-crediting-programs/.

[128] Integrity Council for the Voluntary Carbon Market. (2024, January 31). Integrity Council reaches new milestone, assessing 100 carbon credit methodologies against high-integrity benchmark. https://icvcm.org/integrity-council-reaches-new-milestone-assessing-100-carbon-credit-methodologies-against-high-integrity-benchmark/.

[129] ICVCM market share calculations relating to total issuance of these categories, based on data from most VCM registries. Integrity Council for the Voluntary Carbon Market. (2024, January 31). Integrity Council reaches new milestone, assessing 100 carbon credit methodologies against high-integrity benchmark. https://icvcm.org/integrity-council-reaches-new-milestone-assessing-100-carbon-credit-methodologies-against-high-integrity-benchmark/.

[130] MSWGs include external expertise, comprising up to 12 carbon crediting methodology experts, including methodology development and project development. They also include ICVCM expertise, with up to 2 ICVCM Standards Oversight Committee Co-Chair & members, and up to 3 ICVCM Experts. Integrity Council for the Voluntary Carbon Market. (n.d.). How we assess categories of carbon credits. https://icvcm.org/how-we-assess-categories-of-carbon-credits/.

[131] Integrity Council for the Voluntary Carbon Market. (2023, March 29). Integrity Council launches global benchmark for high-integrity carbon credits. https://icvcm.org/integrity-council-launches-global-benchmark-for-high-integrity-carbon-credits/.

risk-based oversight process – including spot checks, performance monitoring, and stakeholder input – helps identify and address issues. If ICVCM finds material failings, it will be able to suspend or terminate the eligibility of the program or category.[132]

The ICVCM has taken a flexible but structured approach, approving different methodologies that align with its Core Carbon Principles (CCPs) while allowing for project-specific variations.[133] **The ICVCM's category assessment standardization effort—effectuated through its consultant pool and multi-sector working groups—represents a major step toward the development of consensus-based protocols and MRV standards.** The process does not push toward a single acceptable methodology; it allows for the identification of alternative methodologies as satisfying a rigorous measurement and monitoring approach.

For example, in June 2024, the ICVCM approved four methodologies for landfill gas projects (LFG), covering an estimated 15 million carbon credits generated by landfill methane capture. These methodologies include:[134]

- **ACM0001** (versions 15-19) – Flaring or use of landfill gas, used by Verra and Gold Standard.
- **AMS III G** (version 10) – Landfill methane recovery, also used by Verra and Gold Standard.
- **ACR's Landfill Gas Destruction and Beneficial Use Projects** (versions 1-2).
- **CAR's US Landfill Protocol** (version 6).

ICVCM Observations in Relation to Category Assessment (May 2024)

> "The Governing Board of the Integrity Council for the Voluntary Carbon Market (ICVCM), when considering the assessment of methodologies related to landfill gas capture (and utilisation) identified that it would be beneficial to make public the Integrity Council's observations in relation to this Category, for the purpose of supporting the future development of methodologies in this Category.

https://icvcm.org/wp-content/uploads/2024/06/ICVCM_Board-Observations-for-LFG.pdf

> "The ICVCM will consider whether the next version of the Assessment Framework may include a requirement for Landfill Gas methodologies to require information about landfill cover types, and associated oxidation rates (by geography or region). The ICVCM may also consider a requirement to apply remote sensing technologies to enable accurate measurement of greenhouse gas emissions. The ICVCM notes that it may include the latter issue as part of the Digital Measurement, Reporting and Verification (MRV) Continuous Improvement Work Program that will commence later in 2024.

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[132] Integrity Council for the Voluntary Carbon Market. (n.d.). How we assess categories of carbon credits. https://icvcm.org/how-we-assess-categories-of-carbon-credits/.
[133] Perspectives Climate Group. (2024, July 9). Analysis of the ICVCM's Core Carbon Principles and Assessment Framework. https://perspectives.cc/wp-content/uploads/2024/07/PCG_CCPs-AF-analysis_07_2024.pdf.
[134] Integrity Council for the Voluntary Carbon Market. (2024, June 6). Integrity Council announces first high-integrity CCP-labelled carbon credits as assessments continue. https://icvcm.org/integrity-council-announces-first-high-integrity-ccp-labelled-carbon-credits-as-assessments-continue/.

Having flexibility in recognition here is important because LFG capture projects can operate under different conditions, technologies, and regulatory frameworks. Some projects prioritize flaring methane to prevent it from being released into the atmosphere, while others focus on beneficial use – converting methane into energy.[135] By approving multiple methodologies, the ICVCM is positing that both approaches should be recognized as long as they meet the same integrity thresholds mentioned earlier. Additionally, many existing projects have been operating under methodologies developed by major carbon standards like Verra, Gold Standard, ACR, and CAR.[136] Rather than forcing a complete shift, the ICVCM is reviewing and approving methodologies that already align with its high-integrity framework, providing continuity for market participants while elevating standards.[137]

IV. STEPS OF THE CATEGORY ASSESSMENT PROCESS

The steps in the category assessment process are summarized as follows:[138]

1. Internal or MSWG assessment has been scheduled or is in progress;
2. Internal or MSWG assessment is complete;
3. A draft evaluation report based on the assessment will be prepared by the Secretariat for each category based on the order that which assessments are completed;
4. The reports are submitted to the Standard Oversight Committee which makes a recommendation to the Governing Board of the ICVCM; and
5. The Governing Board of the ICVCM will meet to consider the recommendation of the Standard Oversight Committee and make a final decision.

V. CCP AND AF UPDATES

The ICVCM plans to update the CCPs every two to three years, based on experience, the latest science and technology, and new developments in the market. AF next will include multi-stakeholder work programs, public consultations, and workshops with key stakeholders including programs, project developers, and Indigenous Peoples and Local Communities. ICVCM expects to launch the first process to revise the CCPs and AF in 2025, in time for implementation in 2026.[139]

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[135] 3Degrees. (2024, November 12). Landfill methane projects: A leader in carbon market standards with CCP approval. https://3degreesinc.com/insights/landfill-methane-projects-a-leader-in-carbon-market-standards-with-ccp-approval/.

[136] Integrity Council for the Voluntary Carbon Market. (2024, June 6). Integrity Council reveals first carbon crediting programs. https://icvcm.org/integrity-council-reveals-first-carbon-crediting-programs/.

[137] Integrity Council for the Voluntary Carbon Market. (2024, June 6). Integrity Council announces first high-integrity CCP-labelled carbon credits as assessments continue. https://icvcm.org/integrity-council-announces-first-high-integrity-ccp-labelled-carbon-credits-as-assessments-continue/.

[138] Integrity Council for the Voluntary Carbon Market. (n.d.). Assessment status. https://icvcm.org/assessment-status/.

[139] Integrity Council for the Voluntary Carbon Market. (2023, January 19). Integrity Council unveils timetable to introduce high-integrity label to voluntary carbon market in Q3.

https://icvcm.org/integrity-council-unveils-timetable-to-introduce-high-integrity-label-to-voluntary-carbon-market-in-q3/.

Appendix F: The Crosswalk Model

Technical overview. The Crosswalk model generates emissions estimates at a gridded resolution of 1 km² spatial resolution, as well as down to the scale of emissions sources at coordinates (i.e., industrial facilities, power plants, airports), lines (road segments), and polygons (census block aggregation of buildings). Direct CO_2 emissions from fuel combustion for the entire US show that emissions were 5,284 $MMTCO_2$ in 2023. The largest activity sector contributing to the national emissions was electricity generation (1,665 $MMTCO_2$, 31.5% of national total).

Comparison against multiple federal (EPA GHGI, SIT) and independently developed datasets (Vulcan, ODIAC, CarbonTracker) demonstrate robust agreement, though the Crosswalk dataset generates relatively higher CO_2 emissions estimates overall. The Crosswalk data product agrees best with the EPA GHGI, with differences in emissions of 10% on average year-over-year. Crosswalk data also is highly correlated in year-over-year trends compared to EPA, Vulcan, and Carbon tracker ($r > 0.99$). Further, by integrating energy forecasts, the Crosswalk model can be used to estimate emissions in the future based on macroeconomic trends and could be used to estimate the impacts of decarbonization policies.

Additional background. The Crosswalk model presents a CO_2 emissions inventory for the year 2010 – 2023, gridded to a 1 km spatial resolution. It integrates the sectoral definitions set by the National Emissions Inventory, with activities based on the EPA's Source Classification Codes (SCC) and other independent datasets (e.g., GPS-based traffic data from StreetLight). As such, this inventory follows a similar sectoral aggregation to Vulcan and the Anthropogenic Carbon Emissions System (ACES).[140] Crosswalk's domain covers the entire United States excluding US territories.

The Crosswalk emissions model is built in Python with a separate module for each activity sector, using the Python Pandas, Geopandas, Dask, and Dask Geopandas libraries. Input data from public sources is accessed via APIs, webscraping, or downloading directly from a FTP, then copied to Amazon S3 for traceable usage within the model. Files are stored as Parquet files to take advantage of this newer technology's efficient handling of larger datasets. The data are transformed to have a standardized schema so that disparate datasets can be merged together. The model routine takes one or more data sources, applies emission factors, and applies a logic hierarchy to select the final emission calculation. The spatialization routine takes the calculated emissions and geolocates the emissions output. The spatial surrogates for the model output are customized for the sector. The raw model output is then available in point, line, and polygon shape formats which then can be gridded. The output is also written as GeoParquet files using the newer GeoParquet 1.1 specification, which allows for more efficient filtering of data during downstream geo-processing routines.

Using the development framework presented herein, the Crosswalk emissions model can easily digest multiple data sources while still maintaining a consistent output format. Further, this

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[140] Gurney, K. R., Liang, J., Patarasuk, R., O'Keeffe, D., Huang, J., Hutchins, M., Lauvaux, T., & Rao, P. (2020). The Vulcan Version 3.0 high‑resolution fossil fuel CO_2 emissions for the United States. *Journal of Geophysical Research: Atmospheres, 125*(18), e2020JD032974. https://doi.org/10.1029/2020JD032974.

framework allows for quarterly updating, utilizing the latest available datasets and interpolating data where older datasets have more time lag. To generate the model output, the model is run distributed on a cluster of Amazon EC2 instances using AWS Batch which takes ~72 days real-world runtime for end-to-end national output for 14 years of data. The software is version controlled using Github, and we maintain a consistent execution environment across runs via Docker containers.

Crosswalk data product output compared well to published national inventories. The datasets used for comparison are the EPA Greenhouse Gas Inventory (GHGI), the EPA state implementation tool (SIT), CarbonTracker v2022 product, Vulcan, and ClimateTrace. To maintain consistency, testing datasets were cropped to include only fossil fuel emissions over the continental US, limiting the analysis to this specific emission category and spatial extent.

At the national level, the Crosswalk CO_2 product agrees best with the EPA GHGI, with the lowest differences (10% on average). Crosswalk shows similar year-over-year trends as the EPA, Vulcan, and Carbon tracker datasets ($r > 0.99$), with the lowest agreement with ClimateTrace, though the total amount of CO_2 converges in the most recent years. This high level of agreement with established inventories demonstrates the commonality in methodology and/or shared data sources between the inventories and the Crosswalk CO_2 product, while the discrepancies with ClimateTrace highlight the differences in methodology and data sources, particularly in earlier years. These variations underscore the importance of continued cross-comparison and validation to improve consistency across emissions datasets and provide a more comprehensive understanding of national CO_2 trends.

Conclusion. Crosswalk's work builds off existing research into anthropogenic-based CO_2 emissions and integrates updates to better address the limitations of current CO_2 emissions models. These advancements allow for a more comprehensive and flexible modeling framework capable of addressing both historical trends and future projections of CO_2 emissions. By combining high-resolution activity data with cutting-edge computational infrastructure, this study aims to improve spatial granularity and consistent releases, enabling decision-makers to better understand localized emissions patterns and their drivers. First, we integrate public and private activity datasets to best capture historical emissions (e.g., airplane types and counts from FAA, GPS-based traffic data from StreetLight, and self-reported quarterly emissions for large point sources from the Clean Air Markets Database (CAMD)). Second, we integrate this modeling framework into a cloud-native environment to produce reliable and consistent outputs. Finally, we integrate energy fuel forecasts to allow for emissions to be modeled to near-real time, and out to 2050. The integrated approach presented herein not only addresses existing gaps in emissions modeling, but also establishes a robust foundation for dynamic and data-driven climate action strategies.