Biomass Carbon Removal and Storage: Opportunities and Challenges

New York Marriott Marquis, Ziegfeld Room | NYCW
23rd September 2025

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BiCRS: Opportunities and carbon market standards

September 23, 2025 | NYCW

Steph Herbstritt, CATF Land Systems Program

CLEAN AIR TASK FORCE

Biomass Carbon Removal and Storage (BiCRS)

Systems that utilize biomass resources and bioconversion technologies to achieve net removal of carbon from the atmosphere into durable storage, sometimes producing bio-energy/products.

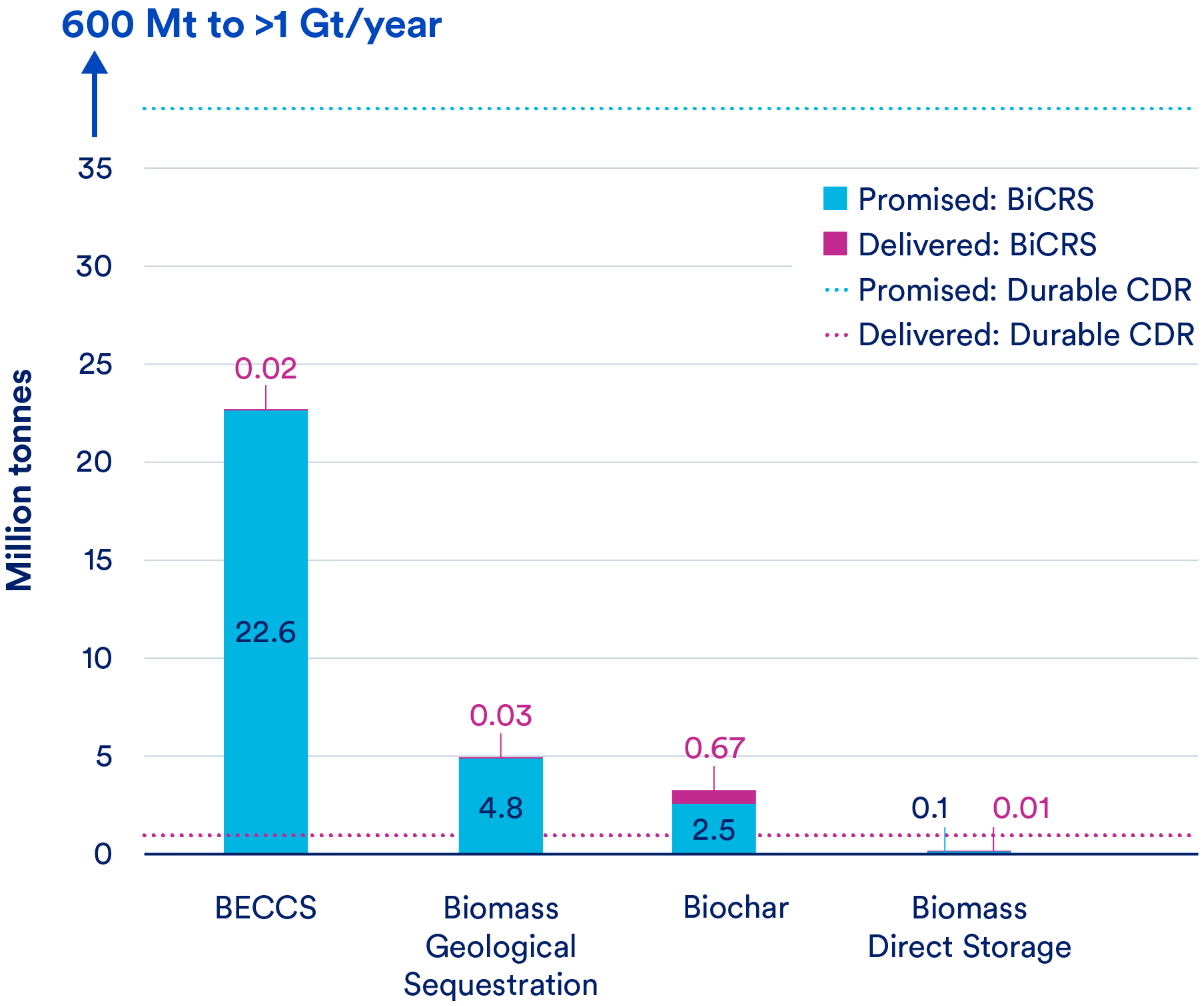
There is a significant opportunity for BiCRS to contribute to climate mitigation.

	U.S. EXAMPLES
Provide Carbon Dioxide Removal (CDR) →	~600 Mt to >1 Gt/year.[1]
Reduce greenhouse gas (GHG) emissions →	~100-1200 Mt CO_2e/year.[1]
Displace fossil-derived resources →	~8-16 billion gallons of aviation fuel/year.[1]
Improve land systems →	~30% reduction in nitrate-nitrogen from winter biomass crops on existing fallow annual cropland in five states.[2]

[1]Pett-Ridge et al. (2023) *Roads to Removal*; [2]Malone et al. (2023) *Harvested winter rye energy cover crop: multiple benefits for North Central US*

But most of this potential does not exist today.

Carbon markets are the main model for financing BiCRS projects.



Creation of a Carbon Capture Regulatory Framework (SB 905)

Source: International Energy Agency

Last updated: 4 November 2022

A Bid to Provide Market Support to Scale Durable Carbon Removal: New York's Carbon Dioxide Removal Leadership Act

Consultation outcome

Integrating greenhouse gas removals in the UK Emissions Trading Scheme

From: Department for Energy Security and Net Zero

Published 23 May 2024

Last updated 21 July 2025 — See all updates

Article 6 and the Voluntary Carbon Markets should promote public-private co-funding of technological carbon removals.

Uncertainties on how to apply the Paris Agreement's Article 6 are slowing down the Voluntary Carbon Market's development.

How Engineered CDR Can Help Bridge the Voluntary and Compliance Carbon Markets

AUGUST 9, 2024

Linking Carbon Removals to the EU ETS – with a net negative emissions target after 2040

Posted on July 12, 2025

EU ETS pilot phase for Beccs, Daccs in 2025: study

ions | 23/04/21

Council of the EU | Press release | 19 November 2024 15:10

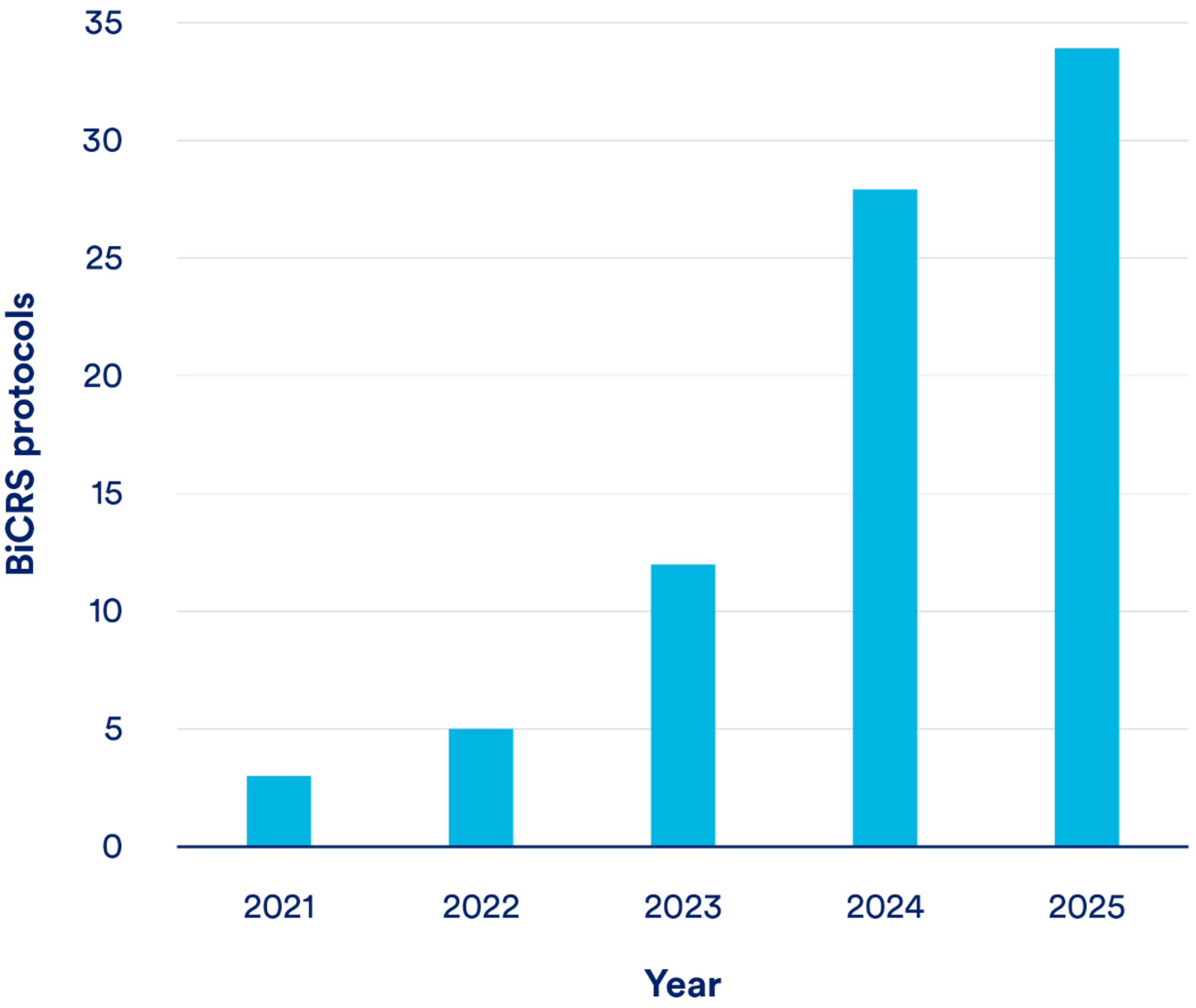
Council greenlights EU certification framework for permanent carbon removals, carbon farming and carbon storage in products

EU Carbon Removal Certification Framework: Key Developments and Implications

By Elahe Bigdeli • June 3, 2025 • Less than 3 min read

For BiCRS to reach its potential, strong standards are needed to build trust and credibility.

But protocols to certify credits are proliferating.



Data from CDR.fyi

Do the methodologies ensure that the generated credits represent a ton of net carbon dioxide removed?

Tom Richard
Penn State; Global Council for Science and the Environment

Lisa Schulte Moore
Iowa State

Jem Woods
Imperial College London

Wei Peng
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CATF

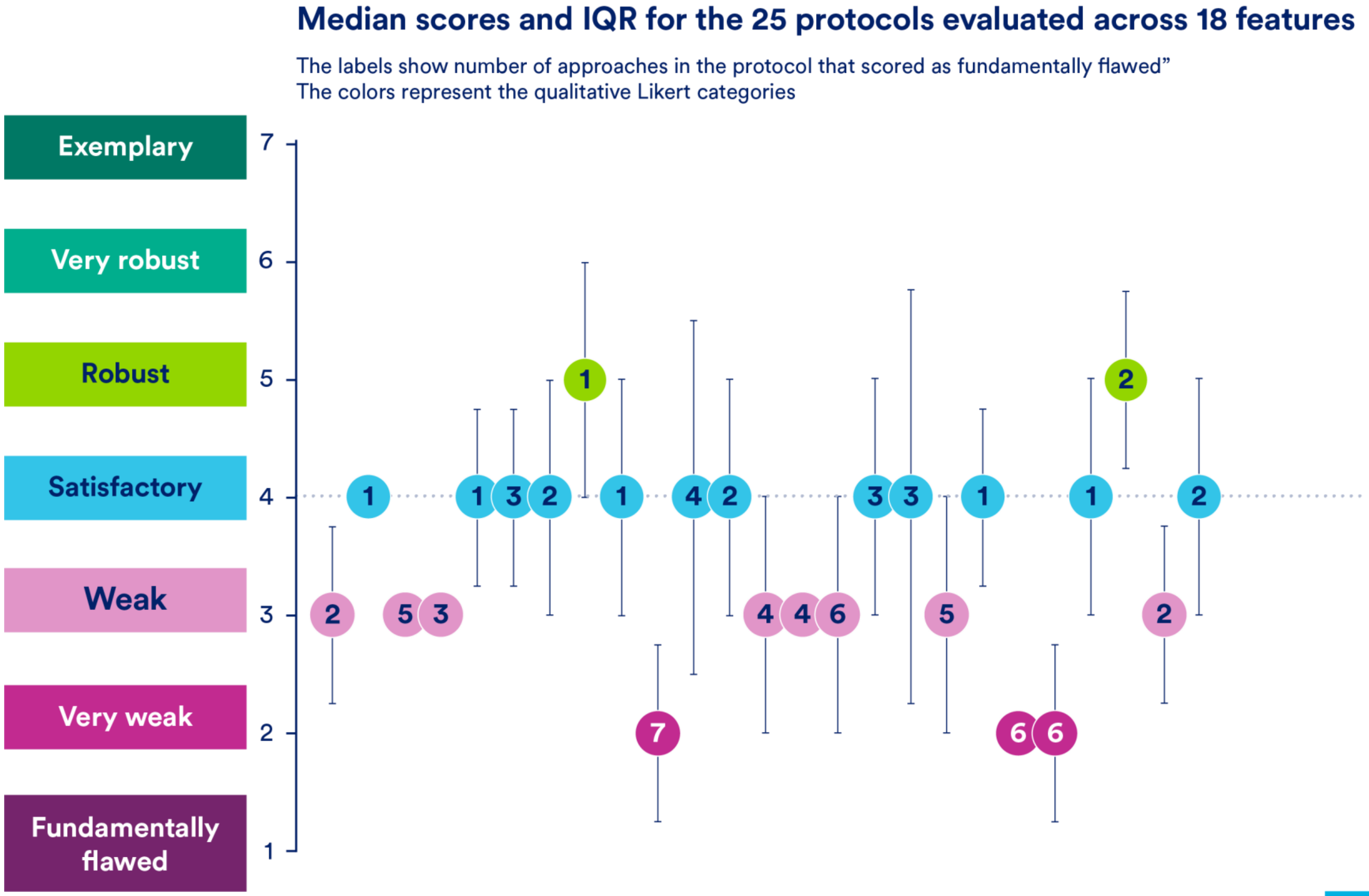
PRELIMINARY RESULTS

There are many features that are critical to effective carbon accounting in protocols.

Overall system	Biomass production/ collection	Bioconversion	Storage
▪ Embodied emissions ▪ Uncertainty	▪ Alternative fate ▪ Production emissions ▪ Leakage	▪ Baseline Determination ▪ Avoided emissions ▪ Coproduct allocation	▪ Storage site MMRV ▪ Leak mitigation/ insurance

PRELIMINARY RESULTS

There is a range in protocol rigor.



PRELIMINARY RESULTS

Emergent takeaways

- There is a lack of harmonization across existing protocols with regard to biomass production and sourcing standards.
- Existing protocols have varied system boundaries that impact GHG accounting and actual climate impact.
- Protocols can provide both ease of implementation and rigor. High-quality default values might reduce multiple burdens to innovation while ensuring GHG benefits.

Register for updates

Thank You

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The Better BiCRS Opportunity

Edie Juno
Climate & Land Use Program Manager
National Wildlife Federation

NATIONAL WILDLIFE FEDERATION

#NewYorkClimateWeek2025

Avoiding "Carbon Tunnel Vision"

Climate Change	*Biodiversity Loss*	*Pollution*

- Too late for solutions that address **one challenge while exacerbating others**
- Parallels with **nature-based solutions** challenges
- **Opportunity costs** of using "wastes and residues"

Planetary Boundaries

- Johann Rockström et al. (2009)
- Identifies **nine processes** that are critical to the stability and resilience of the Earth system as a whole
- 2025 analysis by Braun et al. – assessed BECCS in the context of multiple planetary boundaries

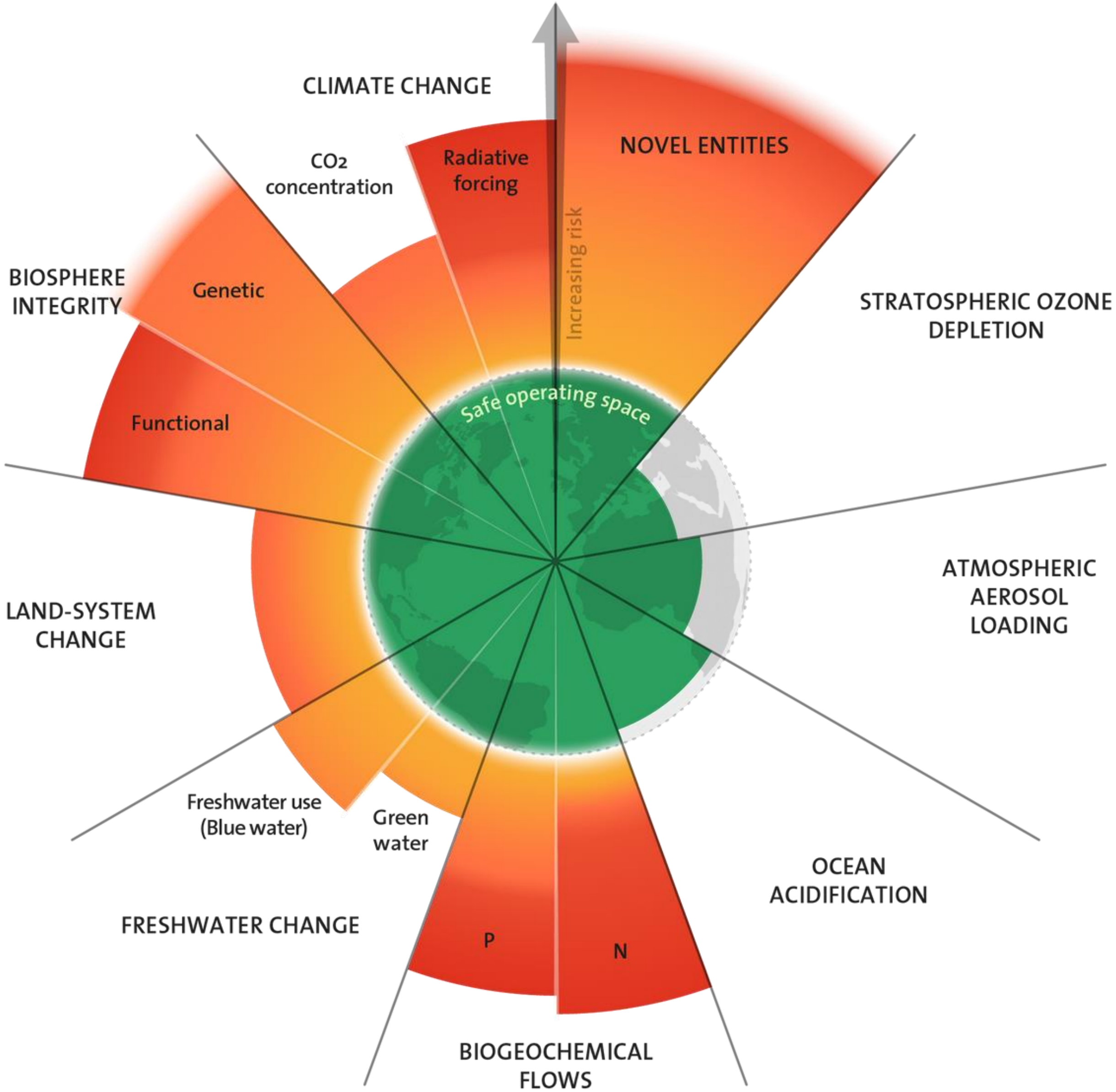


Figure: CC BY-NC-ND 3.0. (Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023)

Potential Criteria for Better BiCRS

- Does it allow for **on-site/distributed utilization** and **flexibility** in feedstock, based on what is available and most suitable to achieve other goals?
    - *Could it support invasive species management, or disaster response and recovery?*
- Does it address **real residue/waste disposal challenges**, or might it create a perverse incentive to create more waste or intensify extraction?

Potential Criteria for Better BiCRS

- Does it make us **less likely to exceed planetary boundaries**?
  - *Does it reduce the need for fertilizer in managed areas, or does it increase it?*
- Does it help to us to **address more than one societal challenge**?
  - *Does it support efforts to enhance ecosystem resilience to climate change?*
  - *Could it help to mitigate the harm of environmental contaminants and toxins?*

Better BiCRS, with Biodiversity & Planetary Boundaries in Mind

- **Sufficient safeguards** for biodiversity, ecosystems, and communities and **guidelines for rigorous accounting** should be in place – for both feedstock sourcing and utilization pathways
- **Multiple planetary boundaries exist –** let's not repeat mistakes
- BiCRS should **effectively and adaptively address other challenge(s)** humanity faces while providing CDR benefits
    - *Ecosystem restoration, agriculture, water treatment*

Thank You

Edie Juno

junoe@nwf.org

References & Credits

- Braun, J., Werner, C., Gerten, D. et al. (2025). Multiple planetary boundaries preclude biomass crops for carbon capture and storage outside of agricultural areas. *Commun Earth Environ* 6, 102. https://doi.org/10.1038/s43247-025-02033-6
- Rockström, J., Steffen, W., Noone, K. et al. (2009). A safe operating space for humanity. *Nature* 461, 472–475. https://doi.org/10.1038/461472a
- Figure credit: 2023 Planetary Boundaries illustration (Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023, Attribution: CC BY-NC-ND 3.0)

NATIONAL WILDLIFE FEDERATION

Biochar's long game: Unraveling the science of carbon permanence

Daniel L. Sanchez, PhD
SEPTEMBER 23, 2025

Biochar's prominence in the voluntary carbon market is rapidly growing.

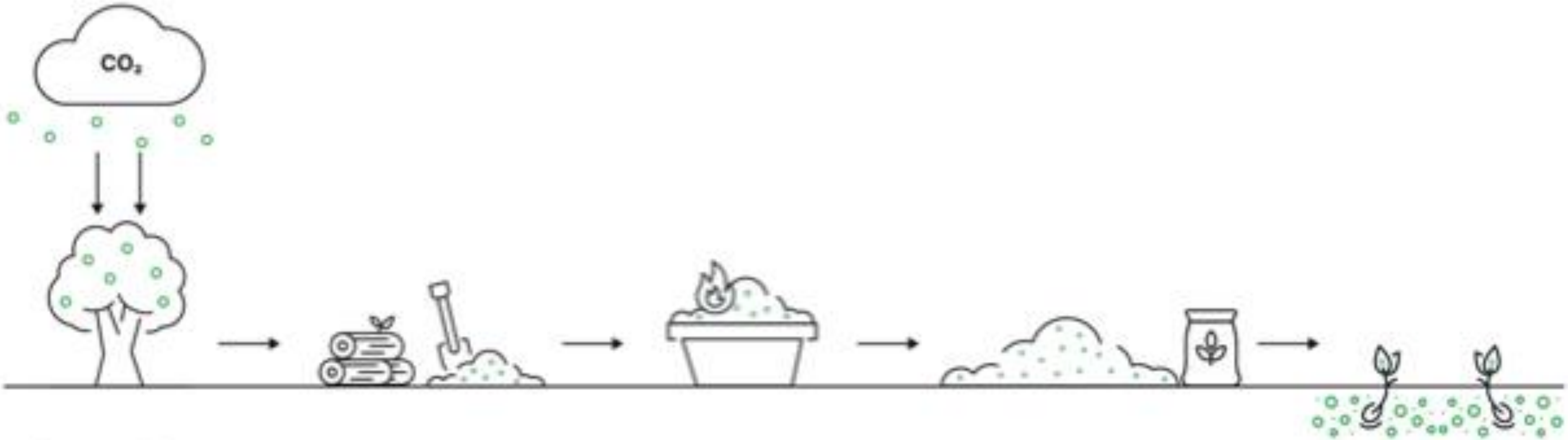
Advantages: near-term readiness, potentially low cost, and environmental co-benefits.

Global biochar production was nascent (<10,000 tCO_2e/yr) until 2019.

Commercial uptake of biochar has expanded dramatically since then due to the voluntary carbon market. As of June 2025, large corporate buyers and nonprofits have purchased over **2.7 million tCO_2e** of voluntary carbon credits from over 80 biochar suppliers.

Established and emerging CDR registries have developed protocols and are certifying biochar carbon credits.

How does biochar work?



1 Trees absorb CO_2 as part of their photosynthesis process.

2 Biomass residues (which still contain the CO_2 absorbed by the trees) are collected from forestry activities.

3 The excess biomass is burnt in a pyrolisis chamber (i.e., it is burnt at extreme temperatures in the absence of oxygen).

4 The result is biochar, a charcoal-like material containing carbon which, had it not undergone this process, would have been released by the excess biomass, into the atmosphere.

5 The biochar is then added to agricultural soil, where it also increases the soil's carbon sequestration capabilities and crop yields.

o = CO_2

Carbon Direct

Biochar durability

Understanding of biochar durability is based primarily on incubation experiments

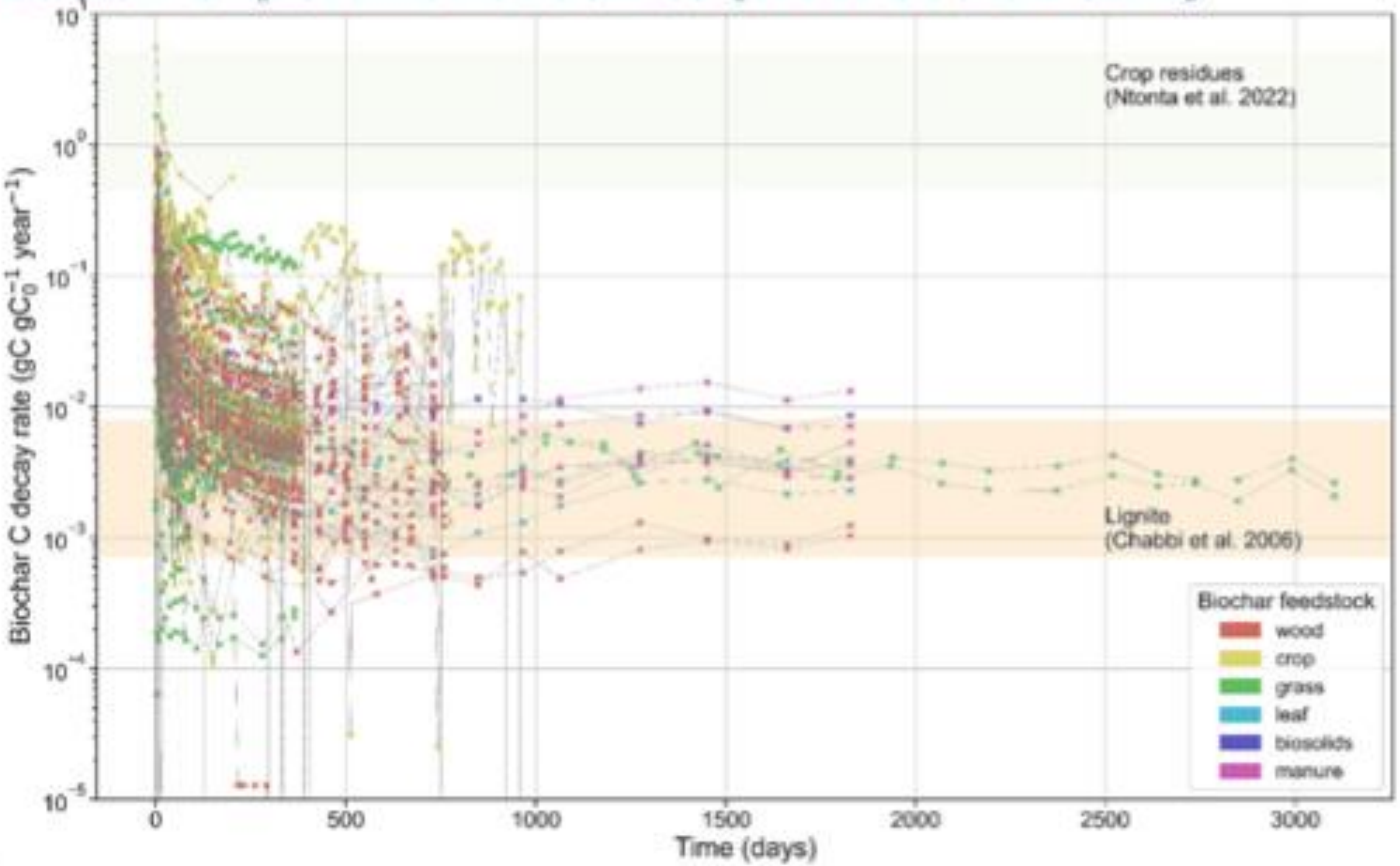
Incubation experiments: scientists seal biochar in a container with other organic matter and measure it over a period of weeks to months.

Balance of evidence indicates that **biochar has multiple "pools" of carbon that differ by their resistance to decomposition**. For example, a two-pool model includes one fraction of carbon that breaks down quickly in months or years, and another that decomposes more slowly, over centuries or longer.

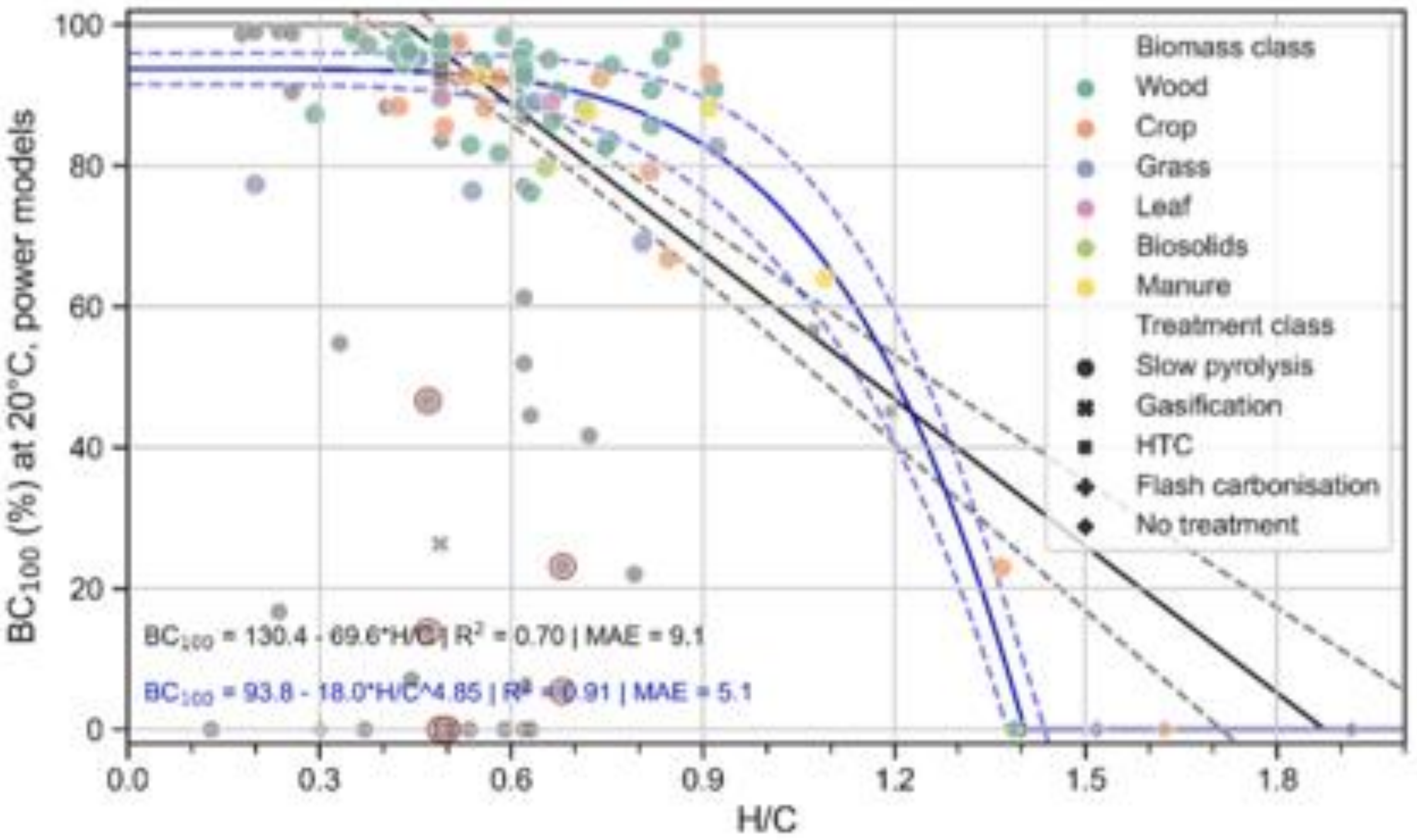
While these experiments offer insights into decomposition dynamics, they have **significant limitations**:

- These approaches *do not measure biochar decomposition and durability in the real-world* (e.g., after biochar is applied to agricultural soils)—meaning these approaches do not capture the effects of actual soil and other environmental factors.
- The short duration of these experiments means there is *significant potential for error in extrapolation* to centuries and beyond.

Incubation experiment results (Azzi et al. 2024)



Biochar durability is (typically) related to elemental H:C ratios



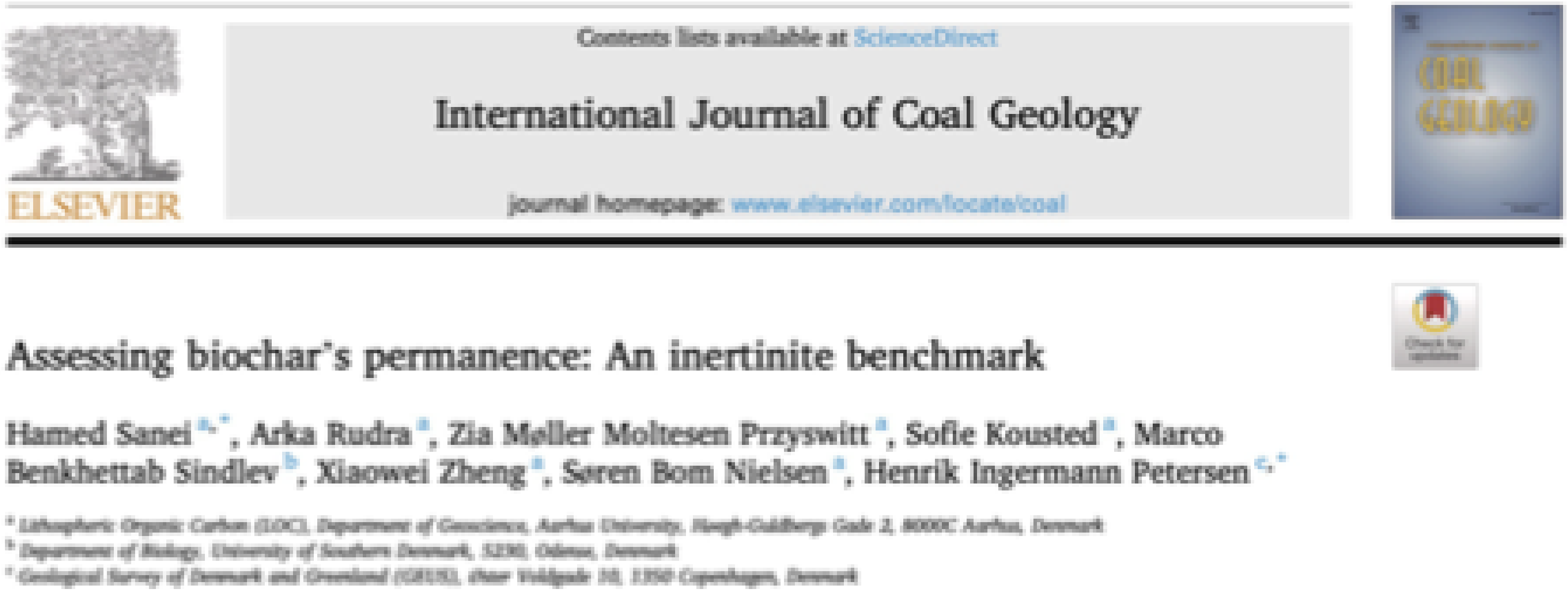
Fraction of biochar carbon remaining stored after 100 years (BC_{100}) for biochar applied to soil, as a function of biochar molar hydrogen-to-carbon ratio (H/C).

MAE = mean absolute error.

Source: Azzi et al. (2024)

Emerging approaches to estimating durability

"Inertinite is the most stable maceral in the Earth's crust and is hence considered an ultimate benchmark of organic carbon permanence in the environment. Therefore, this study aims to measure the degree of biochar's carbonization with respect to the well-established compositional and microscopic characteristics of the inertinite."


Contents lists available at ScienceDirect
International Journal of Coal Geology
journal homepage: www.elsevier.com/locate/coal

Assessing biochar's permanence: An inertinite benchmark

Hamed Sanei [a,*], Arka Rudra [a], Zia Møller Moltesen Przyswitt [a], Sofie Kousted [a], Marco Benkhettab Sindlev [b], Xiaowei Zheng [a], Søren Bom Nielsen [a], Henrik Ingermann Petersen [c,*]

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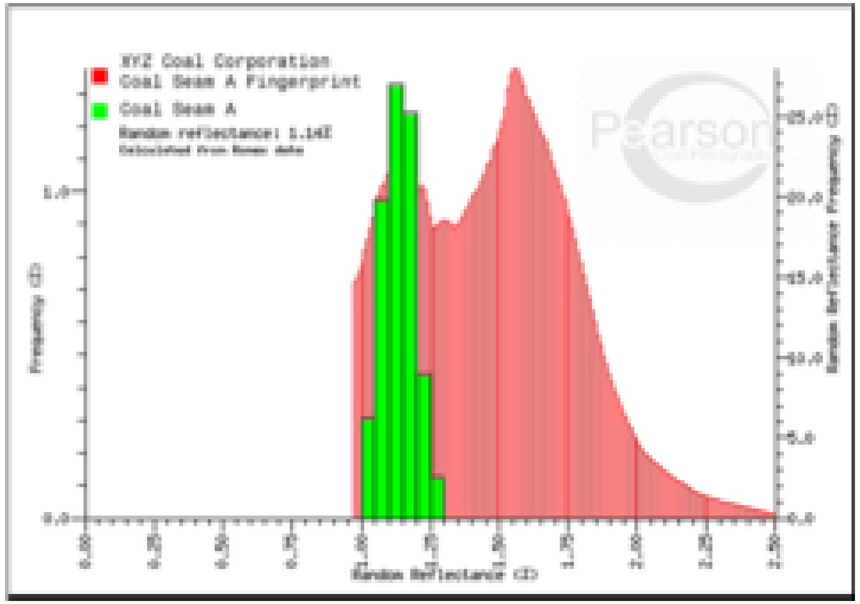
"The **random reflectance (Ro) of 2% is proposed as the "inertinite benchmark" (IBRo2%) and applied to quantify the permanent pool of carbon in a biochar** using the Ro frequency distribution histogram. The result shows that **76% of the studied commercial biochar samples have their entire Ro distribution range well above IBRo2% and are considered pure inertinite biochar**. The oxidation kinetic reaction model for a typical inertinite biochar indicates a time frame of **approximately 100 million years for the degradation and loss of half of the carbon** in the biochar."

Drawbacks to intertinite / random reflectance methods

Sanei et al. propose a benchmark random reflectance (Ro) of 2% as an "inertinite benchmark" for biochar. They argue that the entire fraction of biochar that meets that benchmark will degrade over approximately 100 million years. **This is a large departure from other estimates of biochar durability, and at odds with more conservative models.**

This coal-biochar analogy is inadequate because coal buried underground is not exposed to the same degradation conditions as biochar in soil. Underground coal has **lower exposure to oxygen, water, and ultraviolet (UV) light**, all of which are plentiful in surface soils. Each of these are associated with well-understood decay mechanisms.

The permanence factor that the reflectance method allows (readily up to 1.0, or 100% carbon retention over extremely long time scales) contradicts experimental evidence that some carbon loss will occur over years or decades.



Biochar Durability

Random reflectance methods in carbon markets

Isometric Biochar Storage in Agricultural Soils v1.0

- Allows for 1000-yr storage using inertinite methods
- Allows for 100% of biochar carbon to qualify for 1000-yr storage

European Union draft delegated regulation on Carbon Removal and Carbon Farming (CRCF)

- Allows for permanent storage using inertinite methods
- Allows for 100% of biochar carbon to qualify for permanent storage
- Biochar only requires one year of MRV to be considered permanent

Biochar at Isometric

Scientific rigor simplified

Biochar Durability

Potential solutions

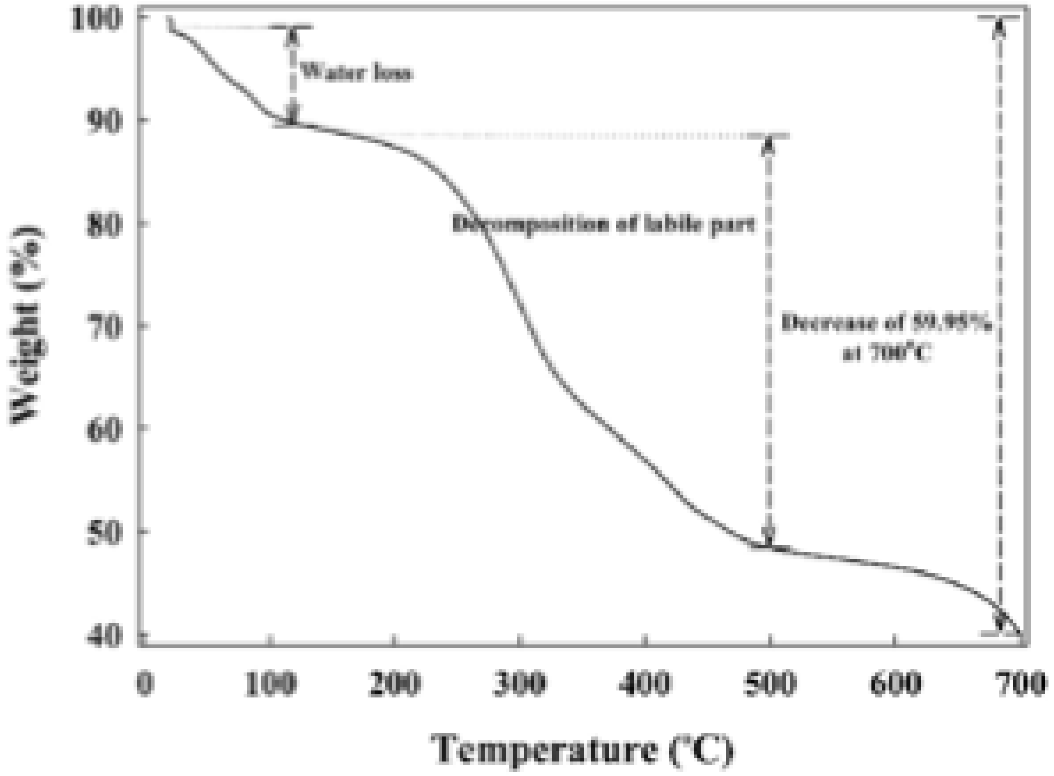
1) Account for labile / non-permanent fraction of carbon within biochar

- Use thermogravimetric analysis (or similar) to quantify reactive organic carbon of biochar
- Do not allow for permanent/long-term storage from reactive organic carbon

2) Use alternate, existing durability methods

- H/C ratios in two-pool models

Based on available literature and evidence, Carbon Direct does not believe random reflectance methods are currently a conservative and rigorous approach to assessing biochar permanence.



Source: Lim et al. (2015) Efficiency of Poultry Manure Biochar for Stabilization of Metals in Contaminated Soil

Want to learn more?

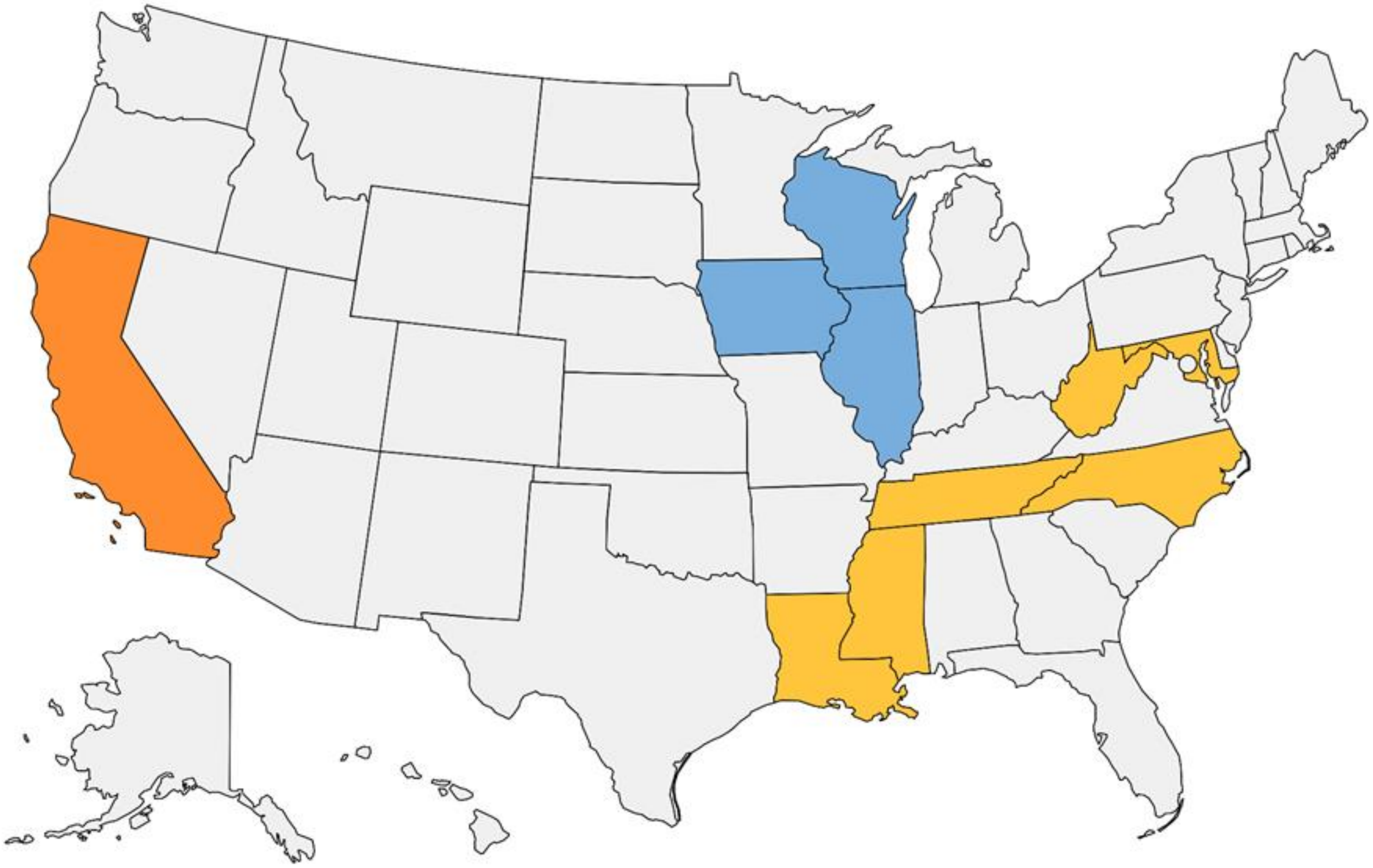
Carbon Direct's Hybrid Decarbonization team

As large offtakes are signed for biomass carbon removal and storage, key areas of focus include:

- Biomass sustainability
- Biochar durability
- Project diligence
- Project assurance

Re-Envisioning the Future of Biomass

Dr. Charlotte Levy - Science & Innovation Team




Carbon180

Biomass and Land Use in a Decarbonizing US Economy

WORLD RESOURCES INSTITUTE

May 2025

Haley Leslie-Bole, Audrey Denvir, Dan Lashof, Angela Scafidi and Caroline Melo Ribeiro

Topline Findings for BiCRS

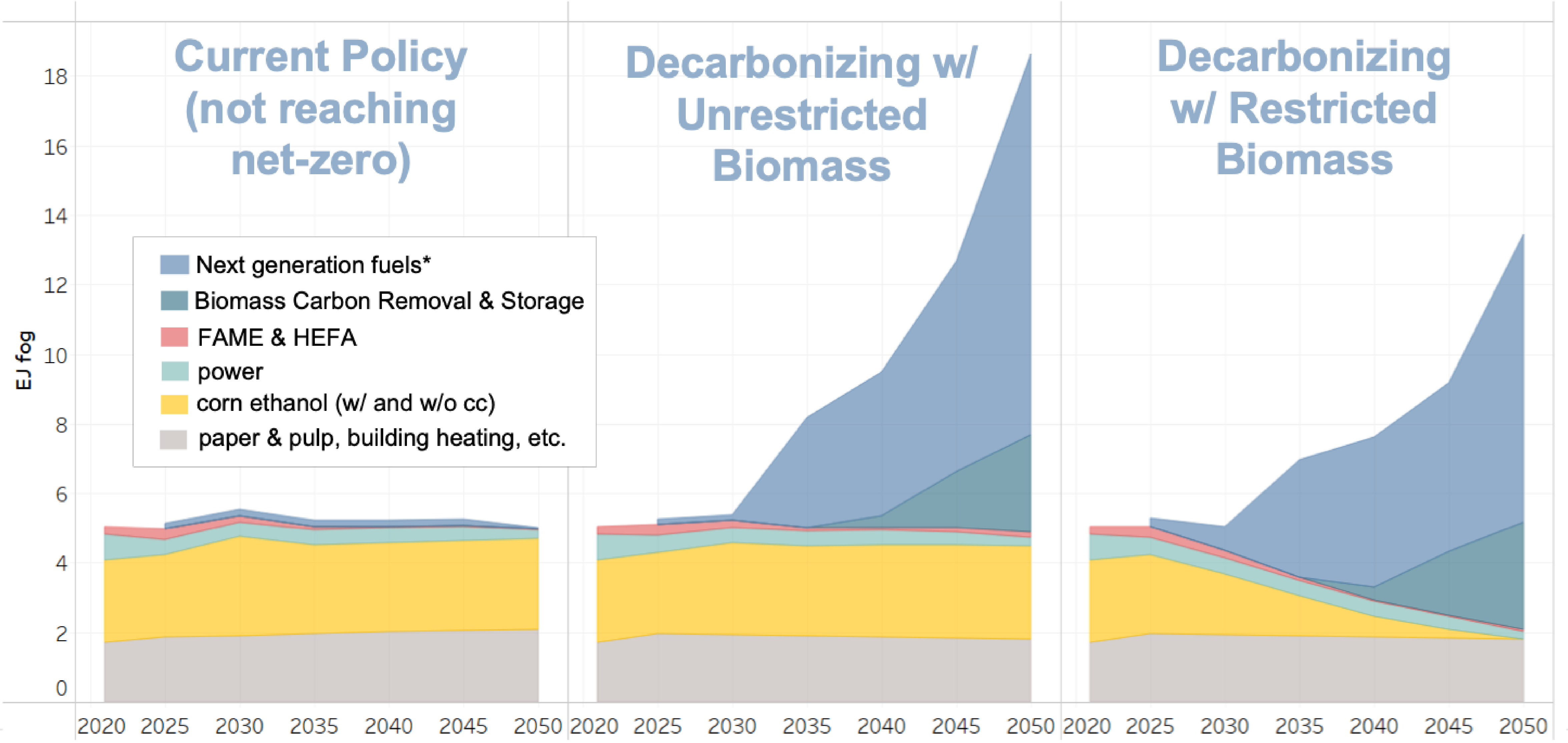
1. The carbon in biomass is more valuable as a **BiCRS feedstock** than as an energy source

2. BiCRS could provide relatively **low-cost CDR, but supply is limited**

3. Without guardrails, **demand for biomass will likely exceed supply** that can be sourced in a climate-friendly manner

4. **Rate of electrification** impacts demand for BiCRS/biomass

Biomass Use is Projected to Skyrocket



*Fast pyrolysis, hydrogen, Fischer-Tropsch, etc. w/ and w/o cc

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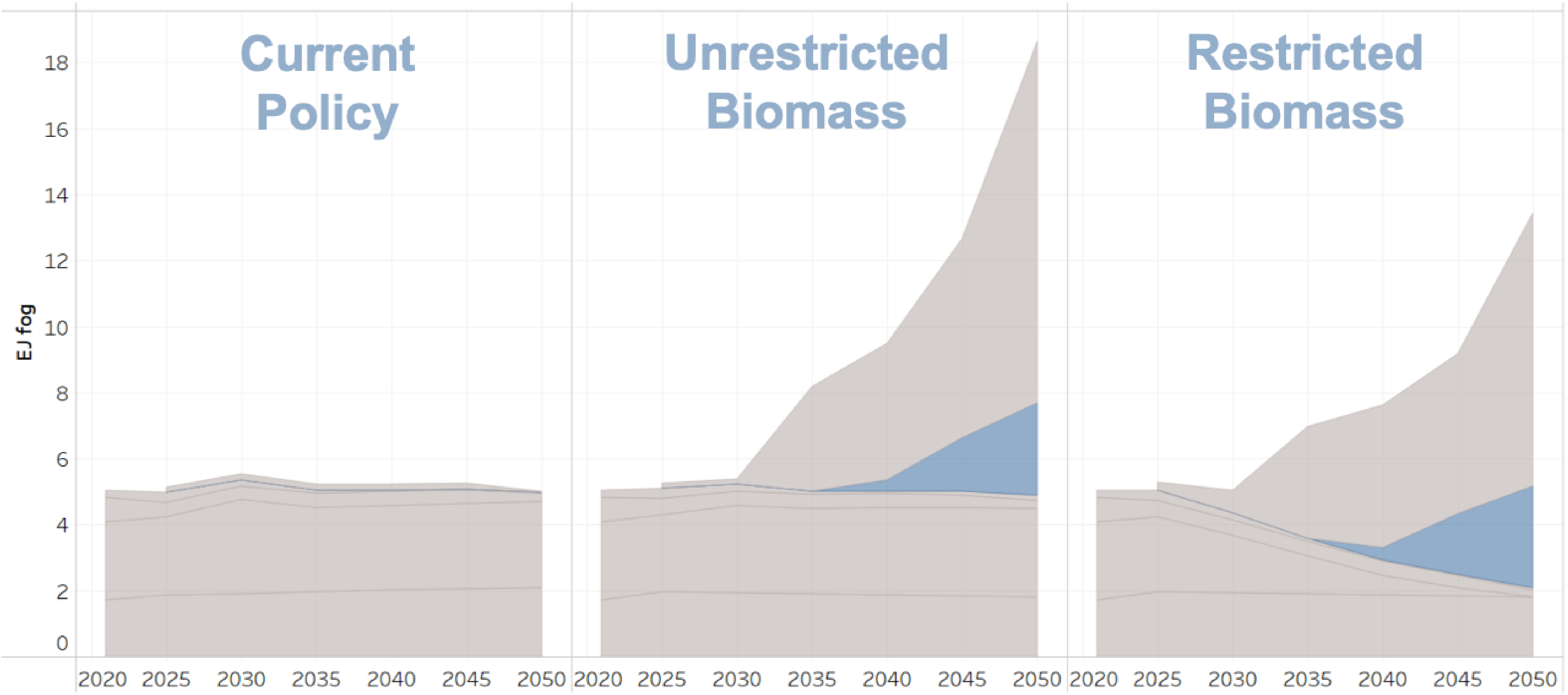
Biomass Use is Especially Valuable for Carbon Removal



Biomass sourcing: Guardrails are vital

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