DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Global impacts of enhancing domestic ecosystem carbon sinks (WBS#1.1.1.7/1.1.1.8)

April 3, 2023

Feedstock Technologies

Patrick Lamers, Marshall Wise, Maridee Weber, Yong Wang, Greg Avery, Kendalynn Morris, Jae Edmonds (NREL/PNNL)

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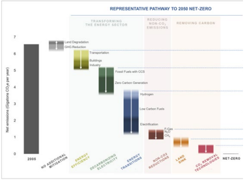
Project Overview

Context

THE WHITE HOUSE
WASHINGTON

THE LONG-TERM STRATEGY OF THE UNITED STATES
Pathways to Net-Zero Greenhouse Gas Emissions by 2050

30-50% of the CO_2 removals needed for a net zero U.S. economy could come via domestic terrestrial carbon sink enhancements.



Goal: Specify *U.S. cropland* carbon sink strategies and quantify potential impacts on *global* agriculture production, land use, and related greenhouse gas (GHG) emissions.

Approach

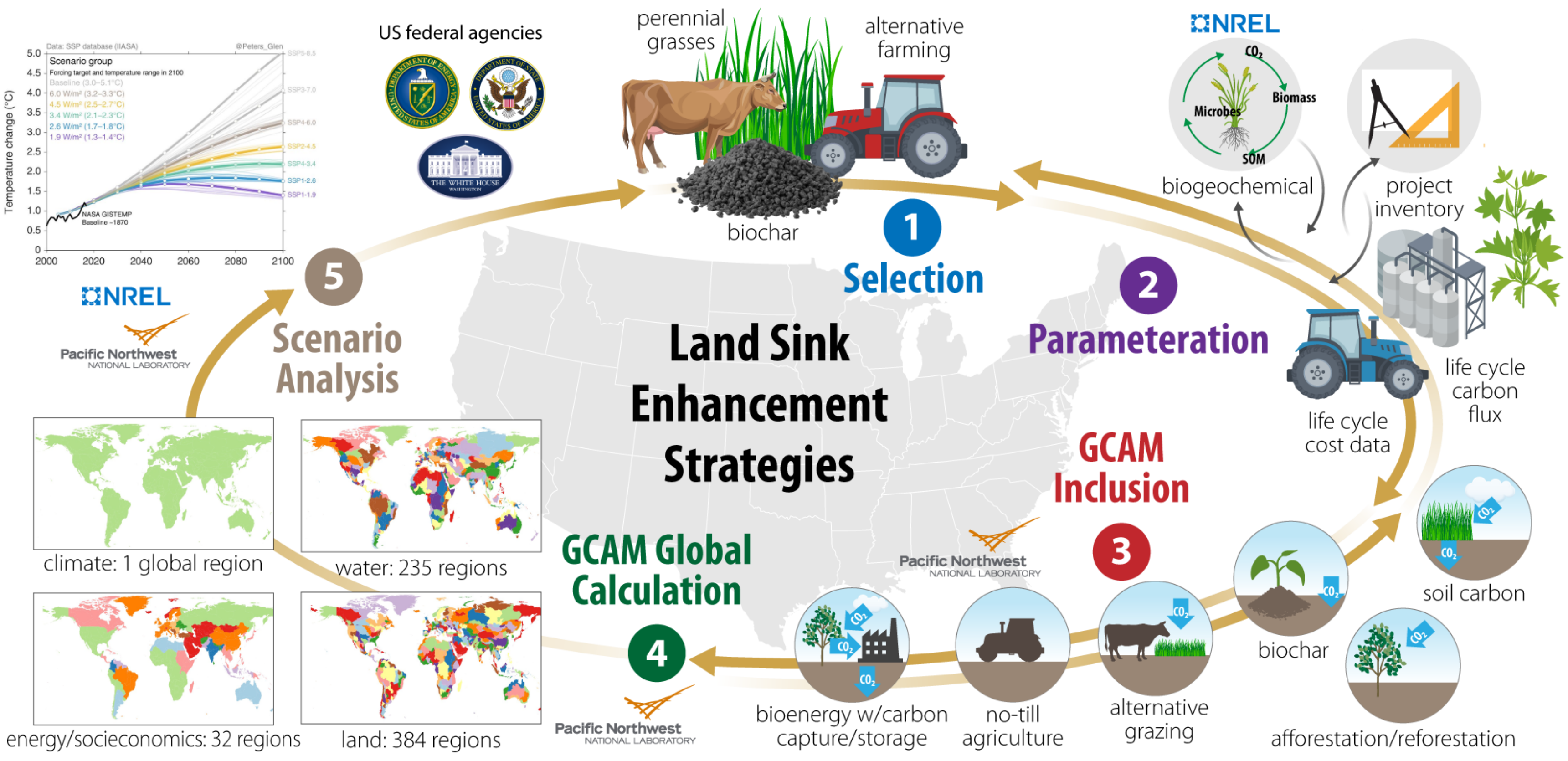
Quantify regional permutations with a biogeochemical model and use outputs to parameterize a global, integrated assessment model (IAM) for net effects analysis.

Outcome: Assess and compare carbon removal and mitigation strategies in a global, multi-sector model accounting for potential leakage effects across commodity markets.

Impact

- Federal-level decision making (The White House, U.S. Department of Energy, USDA, EPA)
- IAMC (Integrated Assessment Modeling Consortium, Founded 2007) — Advancing the state-of-the-science — AGU
- Inter-/non-governmental processes and efforts (ipcc — Intergovernmental Panel on Climate Change, WMO, UNEP)

Approach: Overview



Project focus: ***Improve*** (crop-) ***land management***; not protect or restore land (as defined by UNEP 2021).

GCAM: Global Change Analysis Model

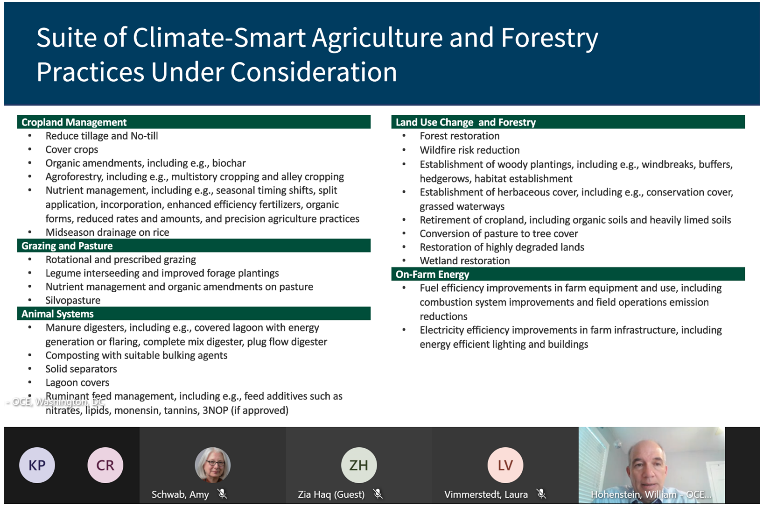
Approach: Strategy selection (Step 1)

In coordination with DOE BETO, using guidance from other federal agencies and peer-reviewed literature.

USDA cropland management priorities

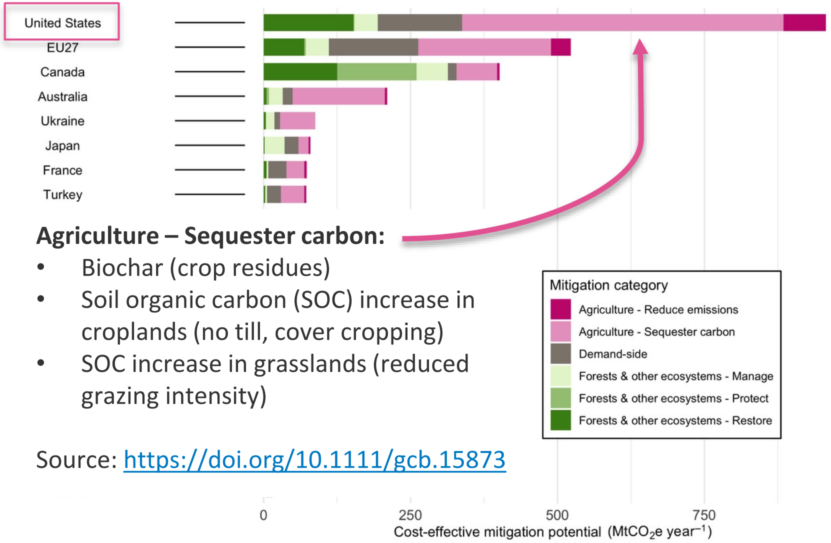
1. Reduced and no-till
2. Cover crops
3. Soil amendments - including biochar

Source: USDA Chief Economist William Hohenstein; (virtual) DOE BETO Modeling Workshop 2021



Peer-reviewed literature

Most comprehensive bottom-up assessment of potential carbon removals sees largest carbon sequestration potential in the agriculture sector.



Agriculture – Sequester carbon:

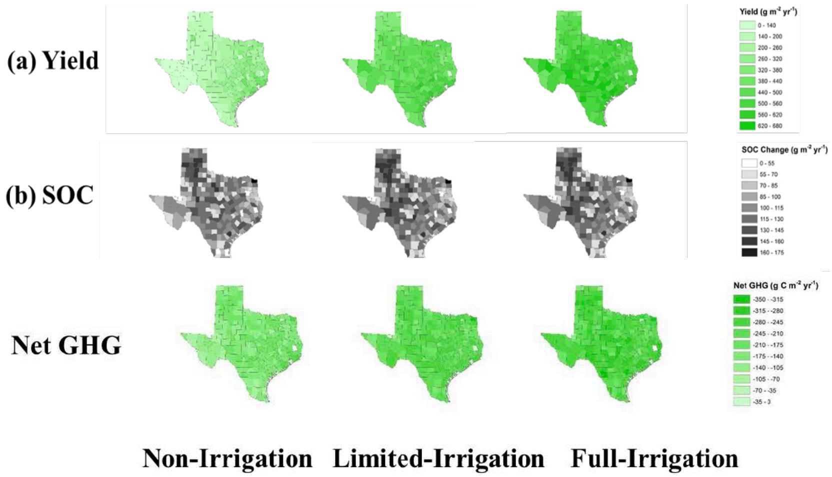
- Biochar (crop residues)
- Soil organic carbon (SOC) increase in croplands (no till, cover cropping)
- SOC increase in grasslands (reduced grazing intensity)

Source: https://doi.org/10.1111/gcb.15873

Approach: Biogeochemical model (Step 2)

- **Challenge**: Multitude of cropland management options *vs*. available, empirical data.
- **Approach**: Biogeochemical simulation of fluxes of carbon (C) and nitrogen (N) among the atmosphere, vegetation, and soil using a vetted model (**DAYCENT**).
  - 2a: Model calibration & validation (using empirical data),
  - 2b: Computation of *hundreds of regional permutations* to derive generalizable inputs, e.g., **net GHG balance, crop yield effects,** for parameterization in a global, higher aggregate model (GCAM).

Example: GHG mitigation potential on TX arable land (Wang, 2017)



DAYCENT has been ***extensively tested and vetted*** *across various native and managed agricultural systems. Developed by Colorado State University (CSU), the NREL team has years of experience working with it and collaborates directly with CSU.*

Pacific Northwest
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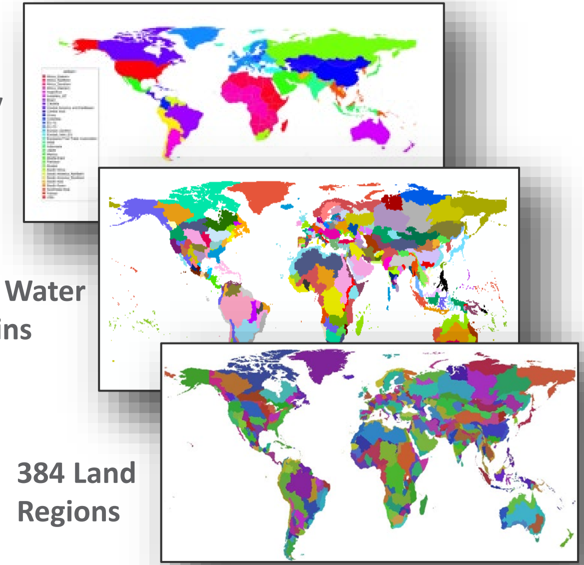
Approach: Global model (Step 3)

Global Coverage

32 Energy & Economy Regions

235 Water Basins

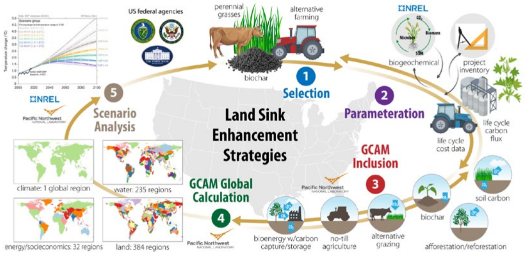
384 Land Regions



- **Integrated**: Assesses interactions between human and natural systems across the Energy-Economy-Land-Climate system.
- **Solution space**: scenario analysis to evaluate options for managing global greenhouse gas emissions.
- **Dynamic recursive**: Decisions are made per period; not considering what happens in future periods.
- **Periods**: Market equilibrium solutions for energy, agriculture, water, and emissions in 5-year increments to 2100.
- **Community-model**: https://jgcri.github.io/gcam-doc/overview.html

Approach: Timeline & Decision Points

Land sink enhancement strategy (%-complete)	*Project steps*					*Peer-review*
	1	*2*	*3*	*4*	*5*	
Biochar	FY21				**FY22**	Manuscript (a)
No-till (80%)	**FY22**				**FY23***	Conference presentations (b, c)
Cover crops (40%)	**FY23**					

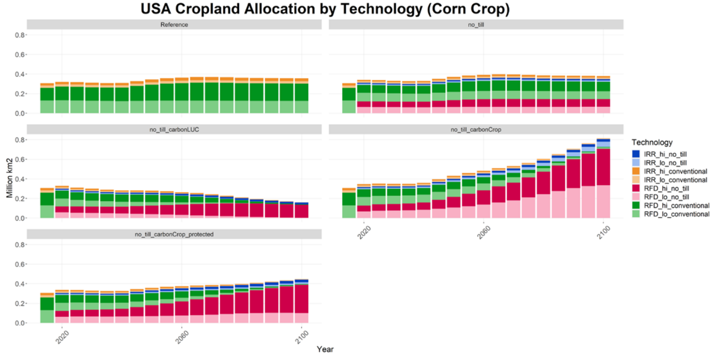


Peer-review references

a. Bergero *et al.* (in review)
b. Lamers *et al.* (2022)
c. Weber *et al.* (2022)

***Go/No-Go Decision Point (12/31/22):**
Demonstrate Capability of Modeling Terrestrial Carbon Banking in GCAM to address policy-relevant questions.

Criteria: Generate at least two draft scenarios that demonstrate physical and economic feedback between carbon banking, land use, and emissions. **(Go Decision)**



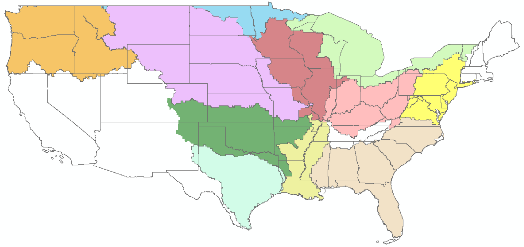
Diversity, Equity, Inclusion: NREL is offering a Minority Serving Interns Program through the NREL Foundation. The project hired a high school student as a summer intern and participated in her senior project studying impacts of alternative rice cultivation practices on land use emissions and trade using GCAM.

Progress & Outcomes: No-till agriculture (Step 2a)

Step 2a: Model calibration & validation

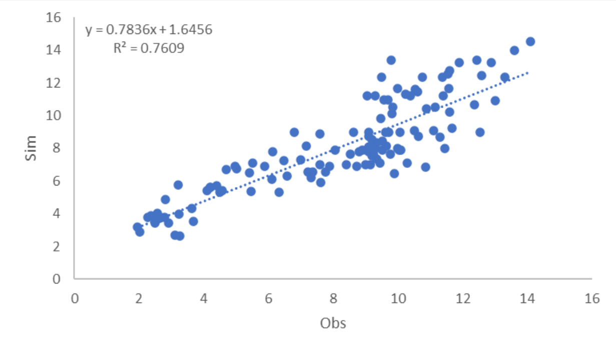
Mapping GCAM watersheds and historic commodity crop production, we identified **31 crop-region combinations** representing 74% of the total U.S. cropland and 93% of the no-till relevant cropland.

No-till relevant GCAM watersheds

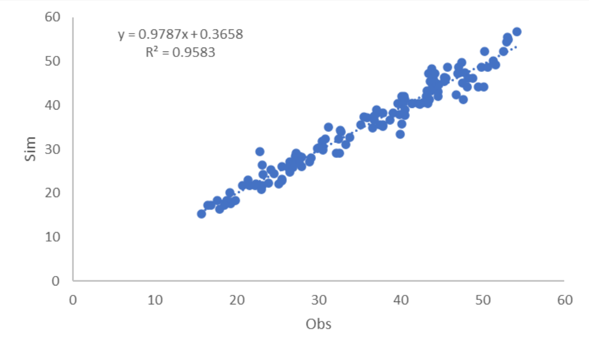


Empirical data from corn, wheat, soy, sorghum, and cotton rotations was collected to calibrate and validate DAYCENT. Example fittings (corn):

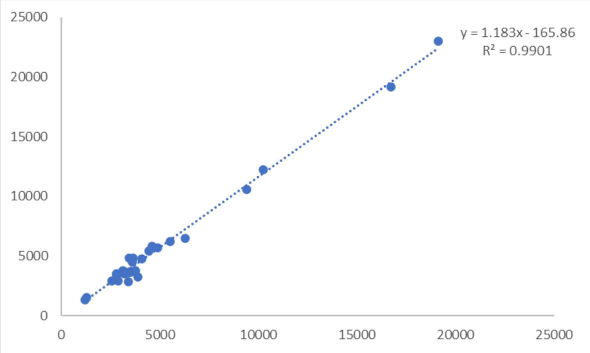
Yield **(R^2 = 0.7609)**



SOC **(R^2 = 0.9583)**



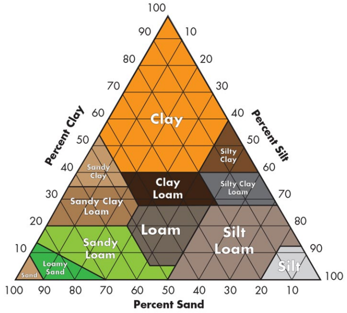
CO_2 **(R^2 = 0.9901)**



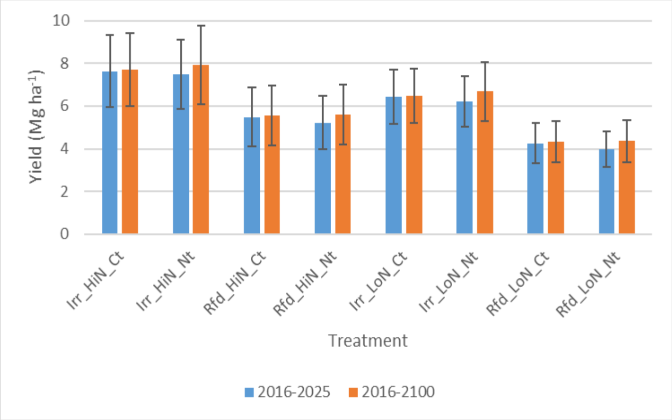
Progress & Outcomes: No-till agriculture (Step 2b)

Step 2b: Run combinations

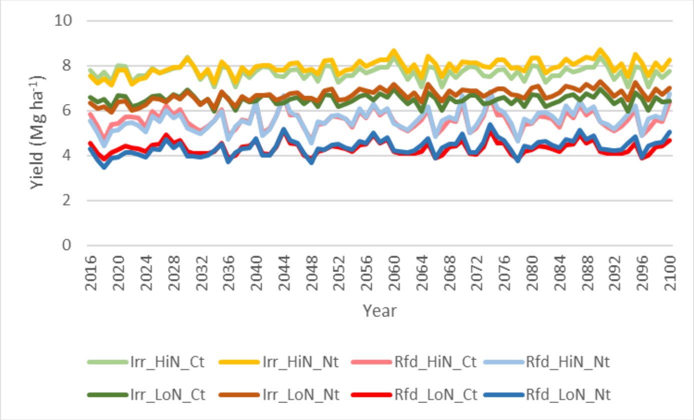
- **248 model run combinations** based on 31 crop-region combinations fitted to 2^3 GCAM treatment options (2 irrigation, 2 fertilization, and 2 tillage options)
- Weather data historical (DAYMET)
- Representative soil mixture of 40% sand, 40% silt, 20% clay



Results example: Yield effects (average across crops & regions)



Short-term decreases *vs*. long-term increases

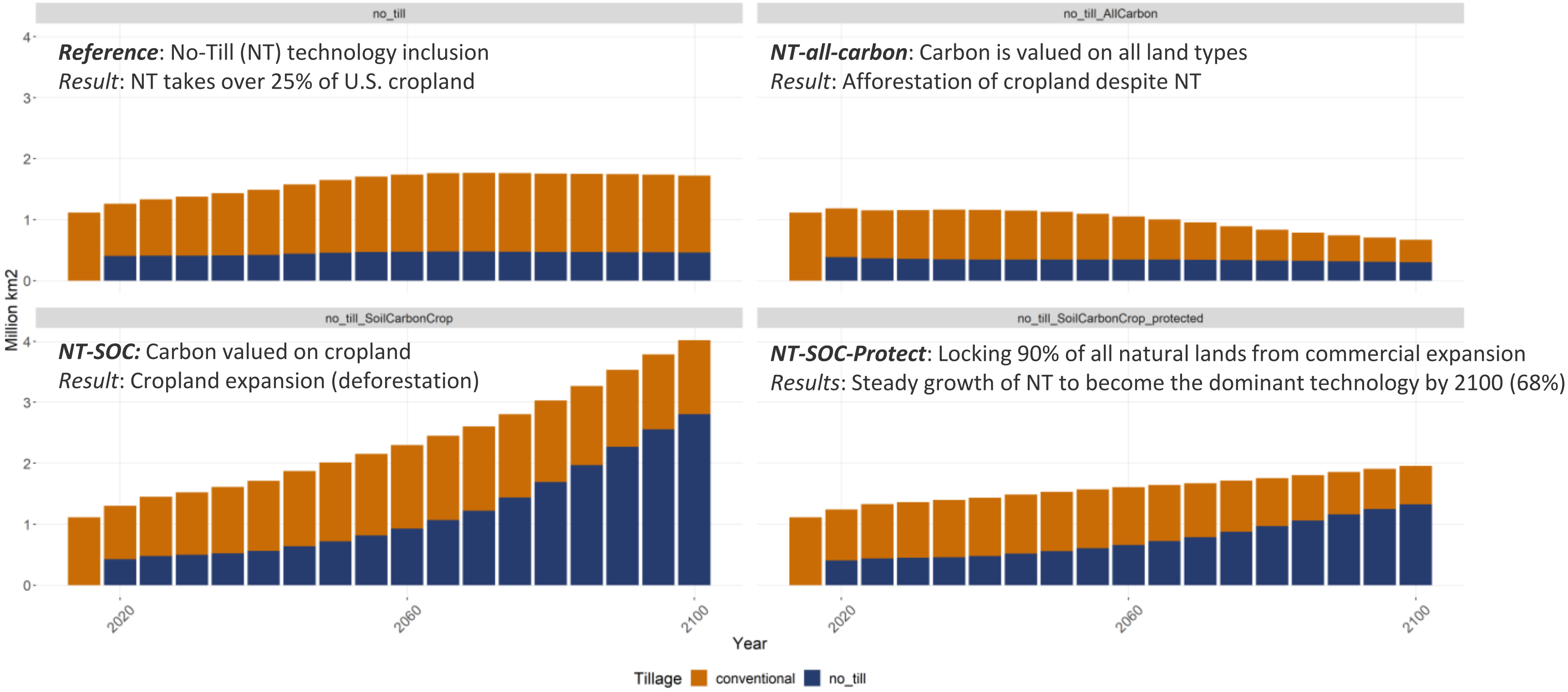


After 20-25 years, higher yields tend to occur in plots with no-till treatments.

Treatment combination legend:
Irr: Irrigated
Rfd: Rainfed
HiN: High fertilizer/tech
LoN: Low fertilizer/tech
Ct: Conventional tillage
Nt: No-till agriculture

Progress & Outcomes: No-till agriculture (Step 3-4)

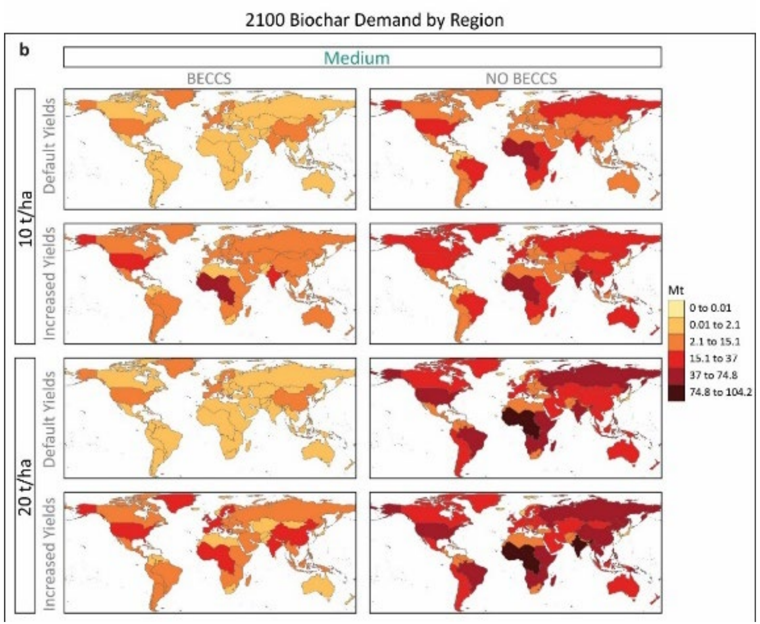
Preliminary results of no-till scenario analysis with GCAM



Progress & Outcomes: Biochar (Step 5)

Calibration:
- Slow pyrolysis inclusion to produce biochar and syngas;
- Two basic biochar application rates;
- Evaluated across three carbon price scenarios.

Key conclusions:
- Global annual sink capacity: 2.8 GtCO2
- Could help reduce global mean temperature increases by an additional 0.5-1.8% across scenarios by 2100 for a given carbon price path.
- Deployment depends on potential crop yield gains and application rates, and competition for resources with other measures.
- Biochar is a competitive removal strategy, especially at lower carbon prices when bioenergy with carbon capture and storage (BECCS) is not economical.

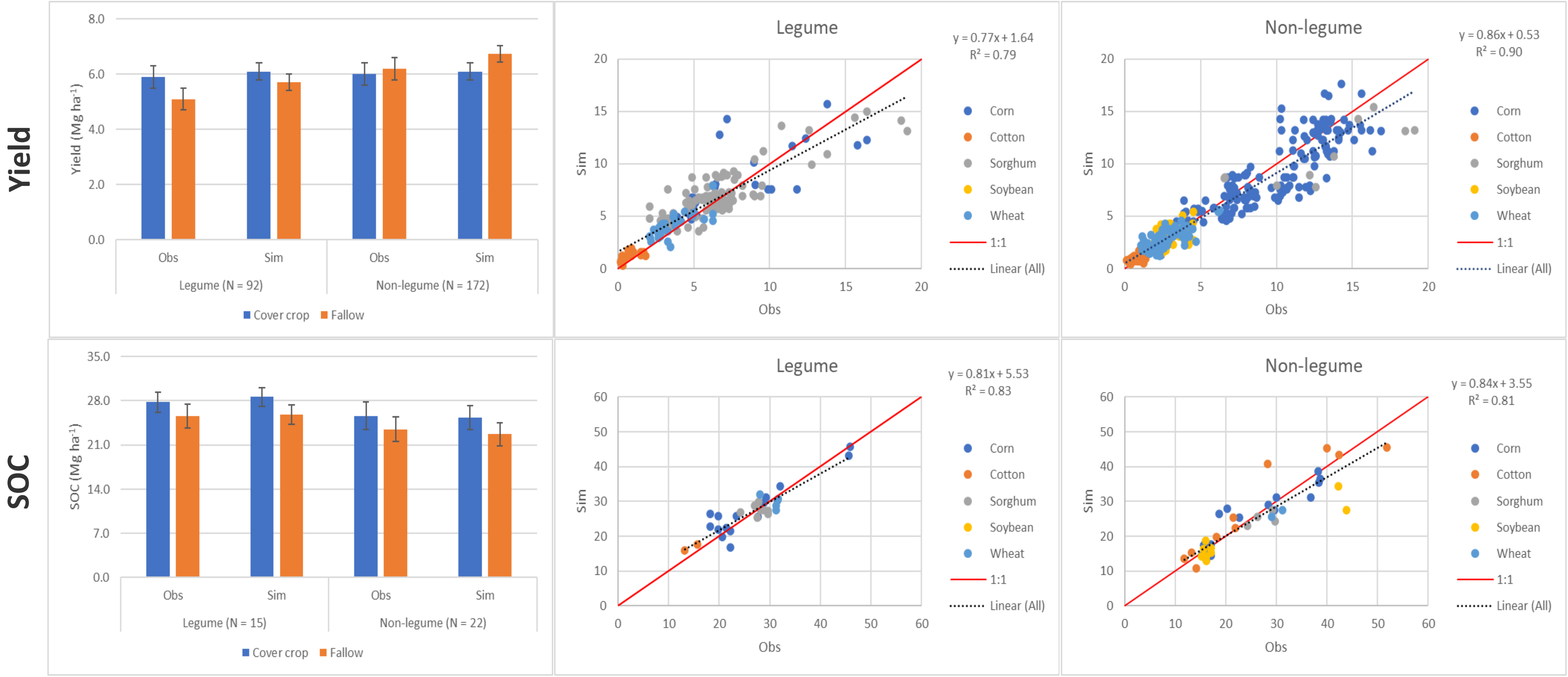


Bergero, C., Wise, M., Lamers, P., Wang, Y., Weber, M. (in review). Biochar as a carbon dioxide removal strategy in integrated long-run climate scenarios. *Environmental Research Letters.*

The biochar analysis is presented in more detail by Marshall Wise (PNNL) in the Data, Modeling and Analysis (DMA) Session.

Progress & Outcomes: Cover crops (Step 2a)

Cover crops: Model calibration & validation *(preliminary results)*



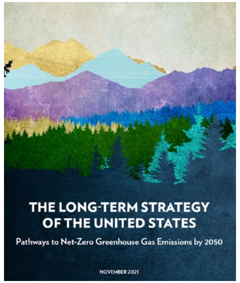
3. Impact

Federal-level decision making

Advancing the state-of-the-science

Inter-/non-governmental processes and efforts

GHG Emissions



Viability of targets, GHG mitigation options

Local Development

Feedstock availability & competition

Global Leadership

Informing international strategies/efforts

3. Impact

Federal-level decision making

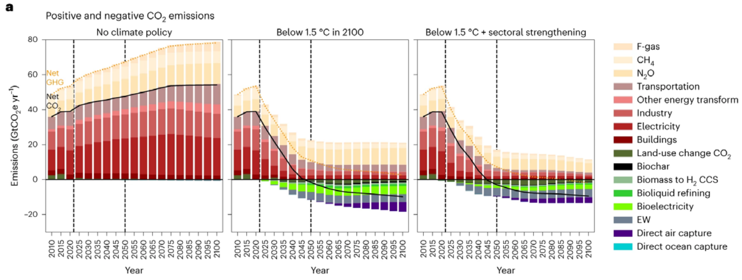
Advancing the state-of-the-science

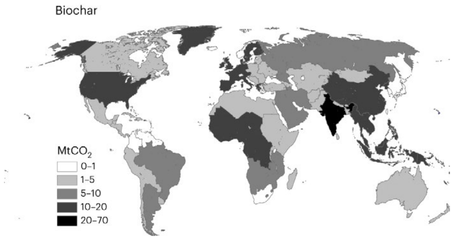
Inter-/non-governmental processes and efforts

Presentation and discussion of the approach and draft findings at three peer-reviewed scientific conferences.

Input to other research efforts, enhancing the representation of carbon dioxide removal in GCAM, e.g., Fuhrman et al. 2023, https://www.nature.com/articles/s41558-023-01604-9:

nature climate change





3. Impact

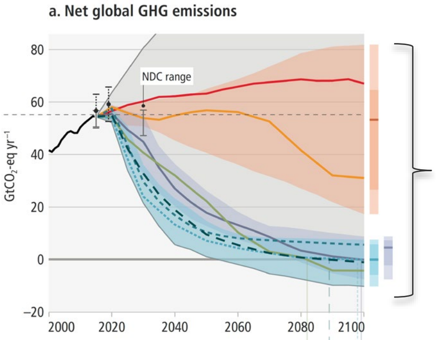
Federal-level decision making

Advancing the state-of-the-science

Inter-/non-governmental processes and efforts

IAMC
Integrated Assessment Modeling Consortium
Founded 2007

Integrated Assessment Modeling (IAM) is a discipline, not a specific methodology. We actively engage with its international community (IAMC) whose model suites inform global climate change mitigation strategy making, e.g., the IPCC, and other entities.



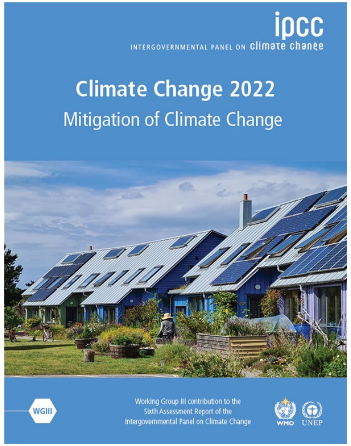
Funnels = 'same' scenarios across different IAMs

(diversity of approaches helps inform solution space)

BEZOS EARTH FUND

EPRI

climateworks FOUNDATION



URL: IPCC 6th Assessment Report

Summary

Filling a critical research gap: Parameterizing terrestrial carbon sink strategies to assess the domestic net-zero strategy and CO_2 removal potential in a global context.

Step-wise, structured implementation using vetted models and data **with several decision points and external peer-review of results**.

Comprehensive and integrated: Quantification of impacts on *global* agriculture production, land use, and related emissions.

Informing federal-level decision making, scientific communities, inter- and non-governmental processes and organizations.

Federal-level

USDA EPA

Scientific communities

IAMC Integrated Assessment Modeling Consortium Founded 2007

AGU

Inter-/Non-governmental

BEZOS EARTH FUND

ipcc INTERGOVERNMENTAL PANEL ON climate change WMO UNEP

Quad Chart Overview

Timeline

- 10/1/2021 (FY22)
- 9/30/2024 (FY24)

	FY22 Costed	Total Award
DOE Funding	PNNL $375K NREL $350K	PNNL $1.25MM NREL $1.05MM
Project Cost Share	*n/a*	n/a

TRL at Project Start: n/a
TRL at Project End: n/a

Project Goal

Quantify the potential impacts of domestic terrestrial ecosystem carbon sink expansions on global agriculture production, land use, and emissions.

End of Project Milestone

Quantitative and qualitative description of the potential global impacts of 2-5 domestic carbon banking strategies including applied methodology, models, scenarios, and results delivered in draft manuscript format.

Funding Mechanism

BETO Lab Call | Feedstock | FY21

Project Partners

Pacific Northwest National Laboratory (PNNL), Joint Global Change Research Institute (JGCRI)

Thank you

www.nrel.gov

NREL/PR-6A20-85285

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Additional Slides

Global Impacts of Enhancing Domestic Ecosystem Carbon Sinks

Marshall Wise/PNNL, Patrick Lamers/NREL

WBS# 1.1.1.7 (PNNL), WBS# 1.1.1.8 (NREL)

Project Objective

- Quantify the potential impacts of domestic terrestrial ecosystem carbon sink expansions on global agriculture production, land use, and emissions.

Technical Approach

- Biogeochemical, life cycle and techno-economic analysis of selected terrestrial carbon banking strategies.
- Representation of the strategies in GCAM.
- Develop GCAM modeling to analyze the US and global economic and emissions impacts of terrestrial carbon management strategies in US.
- **Project Type: Continuation**

Project Attributes

Project Start, End Dates	10/01/2021 – 9/30/2024	
FY22 Budget	PNNL $375K, NREL $350K	
Collaborations	PNNL/NREL	Marshall.Wise@pnnl.gov Patrick.Lamers@nrel.gov
DOE TM Lead	Michael Shell	Michael.shell@ee.doe.gov

Project Milestones and Outcomes

Q4FY23: Quantitative, integrated analysis of the impacts of 1-2 domestic terrestrial carbon banking strategies on global agriculture production and land use delivered in draft manuscript format.
Q4FY24: Quantitative and qualitative description of the potential global impacts of 2-5 domestic carbon banking strategies including applied methodology, models, scenarios, and results delivered in draft manuscript format.
Go/No-Go (12/31/22): Demonstrate the capability of modeling terrestrial carbon banking in GCAM to address policy-relevant questions via draft scenarios that demonstrate the physical and economic feedback between carbon banking, land use and emissions.

Decarbonization Pillars and EERE Emphasis Areas

The project directly supports EERE's Decarbonizing Agriculture Pillar by addressing several BETO Focus areas including

- Soil carbon sequestration,
- Improved agricultural practices,
- Biochar production and application.
- Use of biomass and improving efficiency of agriculture energy consumption.

Additional workforce development and equity impacts are expected through actively recruiting form Minority Serving Institutions during the lifetime of this project.

Responses to Previous Reviewers’ Comments

Highlights from Go/No-Go Reviews:

Focus of the first phase of the project was to study the potential scale and integrated impact of terrestrial carbon banking through the example of no-till agricultural practices. We summarized the combined research efforts to determine parameters for representing no-till agriculture in GCAM and demonstrated the viability of modeling these practices in GCAM by showing and discussing model results, including market shares, carbon emissions, and international implications, under different scenarios for incentivizing terrestrial carbon banking and no-till agriculture. We presented these results in three prominent forums:

1. USDA Terrestrial Carbon Workshop in September 2022 in Atlanta, Georgia
2. Integrated Assessment Modeling Consortium (IAMC) 2022 International Conference, November 2022, College Park, Maryland
3. American Geophysical Union (AGU) 2022 International Conference, December 2022, Chicago, Illinois

The presentations attracted a lot of listeners suggesting that there is community interest in the technical integration of carbon banking strategies using biogeochemical modeling into GCAM. While the audience had very specific questions regarding the draft findings and approach taken, they were not challenging the results or approach. Rather, we have since gotten several requests for future engagements and collaboration.

Publications, Patents, Presentations, Awards, and Commercialization

- Bergero et al. (in review). "Biochar as a carbon dioxide removal strategy in integrated long-run climate scenarios." *Environmental Research Letters.*
- Weber et al. (2022). Implications of converting conventional tillage to no-till agriculture on emissions, land, and water usage. *American Geophysical Union Fall Meeting*. Chicago, IL, USA.
- Lamers et al. (2022). The potential scale and impacts of enhancing the terrestrial carbon sink via changing agricultural practices in long-run climate scenarios. *15th Integrated Assessment Modeling Consortium Annual Meeting*. College Park, MD, USA.
- Weber & Lamers (2022). Assessing the potential global effects of domestic terrestrial carbon drawdown. *USDA Terrestrial Carbon Workshop.* Atlanta, GA, USA.
- Vera et al. (2022). "Land use for bioenergy: synergies and trade-offs between Sustainable Development Goals (SDGs)." *Renewable & Sustainable Energy Reviews* **161**(6): 112409.

Management: Risks & Mitigation Strategies

Key challenge: Ensuring the robustness of bridging disciplines (using empirical data to calibrate and validate a biogeochemical model to parameterize strategies in an IAM).

- Both models are tested, vetted, and peer-reviewed, i.e., seen as robust within their discipline.
- Linkage allows comprehensive assessment within global carbon and commodity markets.

<u>**Risk Identification**</u>

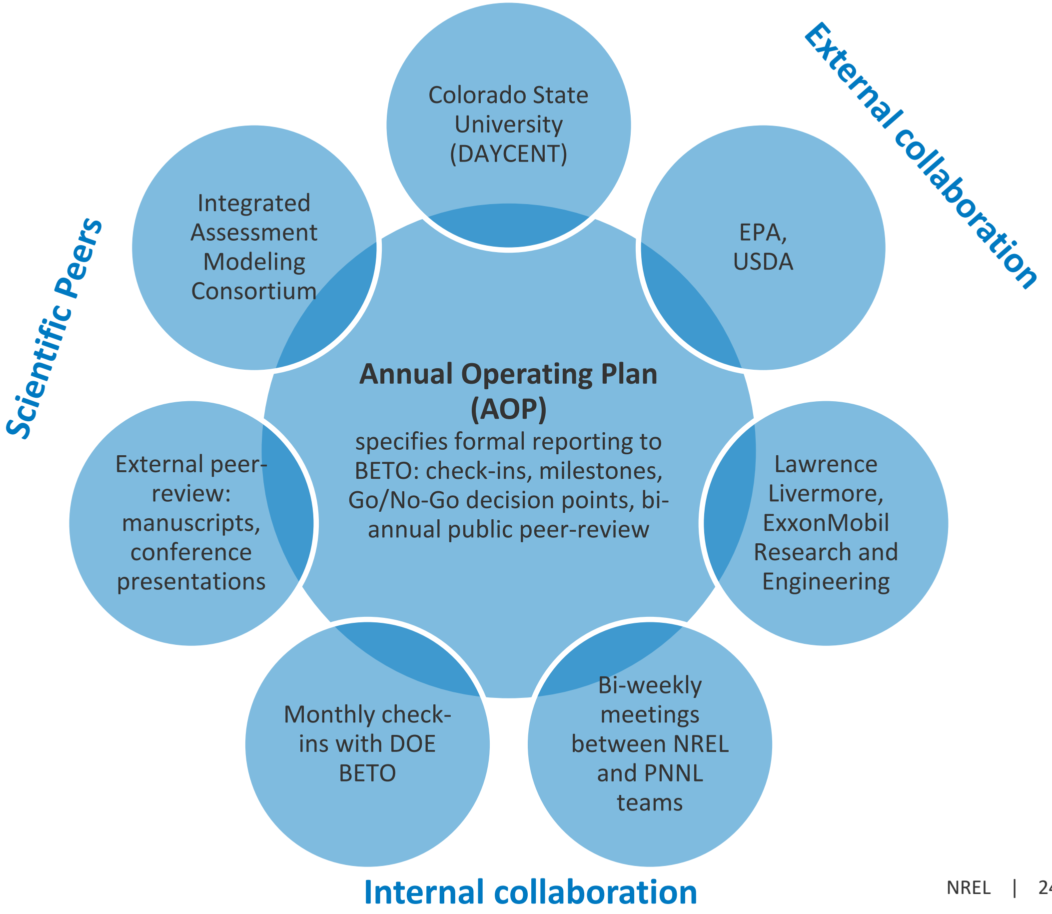
– **Complexity**: permutations of options and regional variations *vs*. stylized representation,
– **Additionality**: carbon removals require measurement against a continuously evolving common practice baseline,
– **Permanence**: risk of reversibility requires accounting of lands in specific treatments/ strategies.

<u>**Mitigation Strategies**</u>

✓ **Stepwise** build-out (by pathway),
✓ Structured **reviews** from peers to validate the results,
✓ **Model intercomparison** (e.g., via the IAMC),
✓ Implementation of a **dynamic baseline**,
✓ **Tracking** of total amount of land in specific strategies across time-steps.

Management: Plan and Implementation Strategy

- **Annual Operating Plan** (AOP): each lab has a separate agreement with BETO. Objectives, tasks, milestones, monitoring and reporting requirements are aligned across the two agreements.
- **Regular meetings:** labs meet bi-weekly; lab-DOE meetings monthly.
- **Step-wise model build-out** and review by scientific peers via conference presentations and manuscript submissions.
- **Linking to other efforts across professional fora**, e.g., the Integrated Assessment Modeling Consortium (IAMC), the American Geophysical Union (AGU), Road to Removals (DOE, LLNL), Natural Sinks (CRADA).



Management: Project Teams – roles and expertise

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Patrick Lamers
NREL Project Lead

- **Yong Wang** – DAYCENT Modeler
- **Greg Avery** – Data Analyst

Pacific Northwest NATIONAL LABORATORY

Marshall Wise
PNNL Project Lead

- **Maridee Weber** – GCAM Modeler
- **Kendal Morris** – Soil Scientist
- **Jae Edmonds** – Senior GCAM Fellow

Lab Project Leads have decade long-experience leading modeling and analysis projects for DOE.
The teams combine subject matter expertise in integrated assessment and biogeochemical modeling, soil science, life cycle assessment, economics and mathematics.