# Recent GCAM efforts for decarbonization-related agriculture and land use modeling

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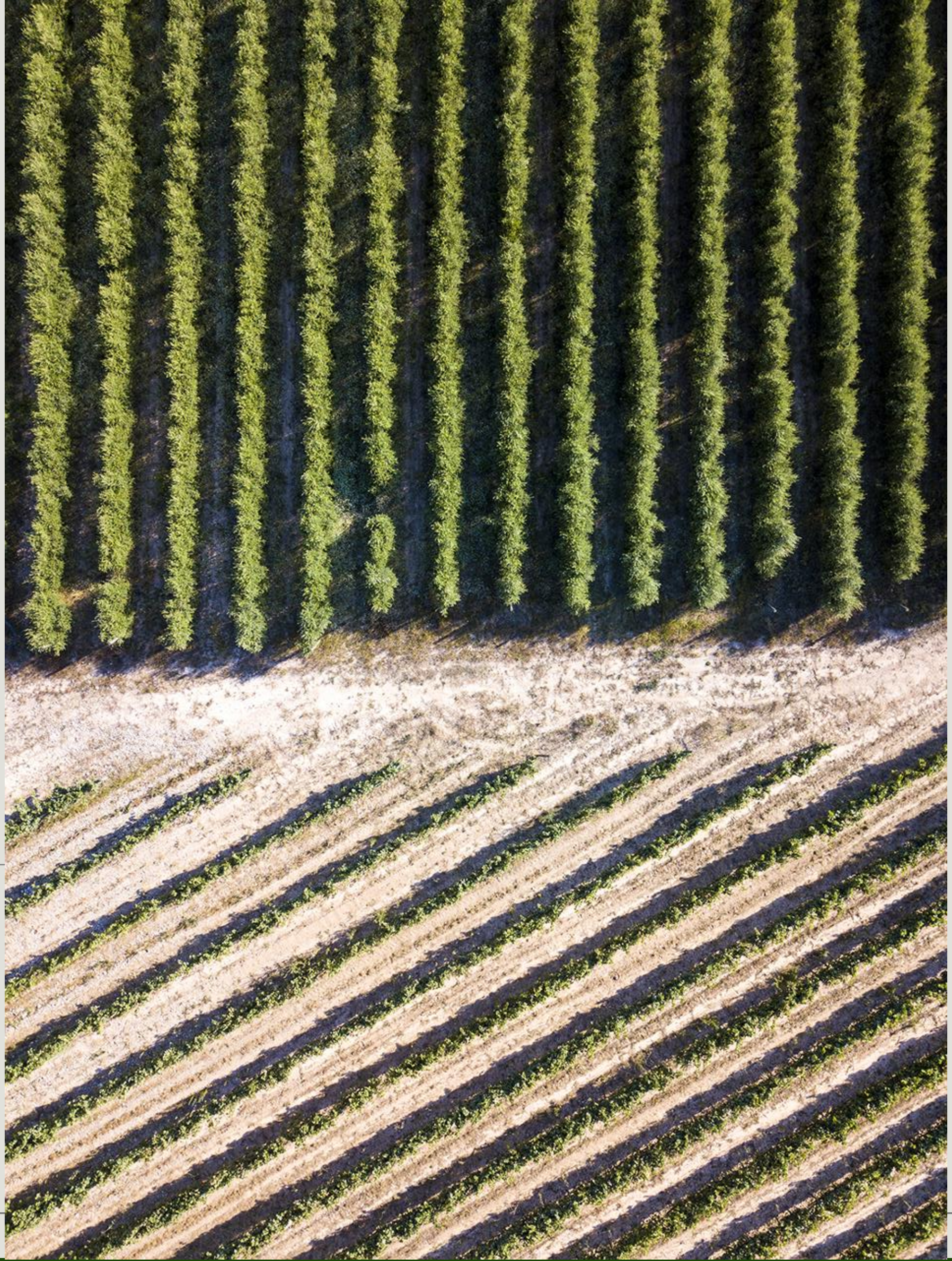


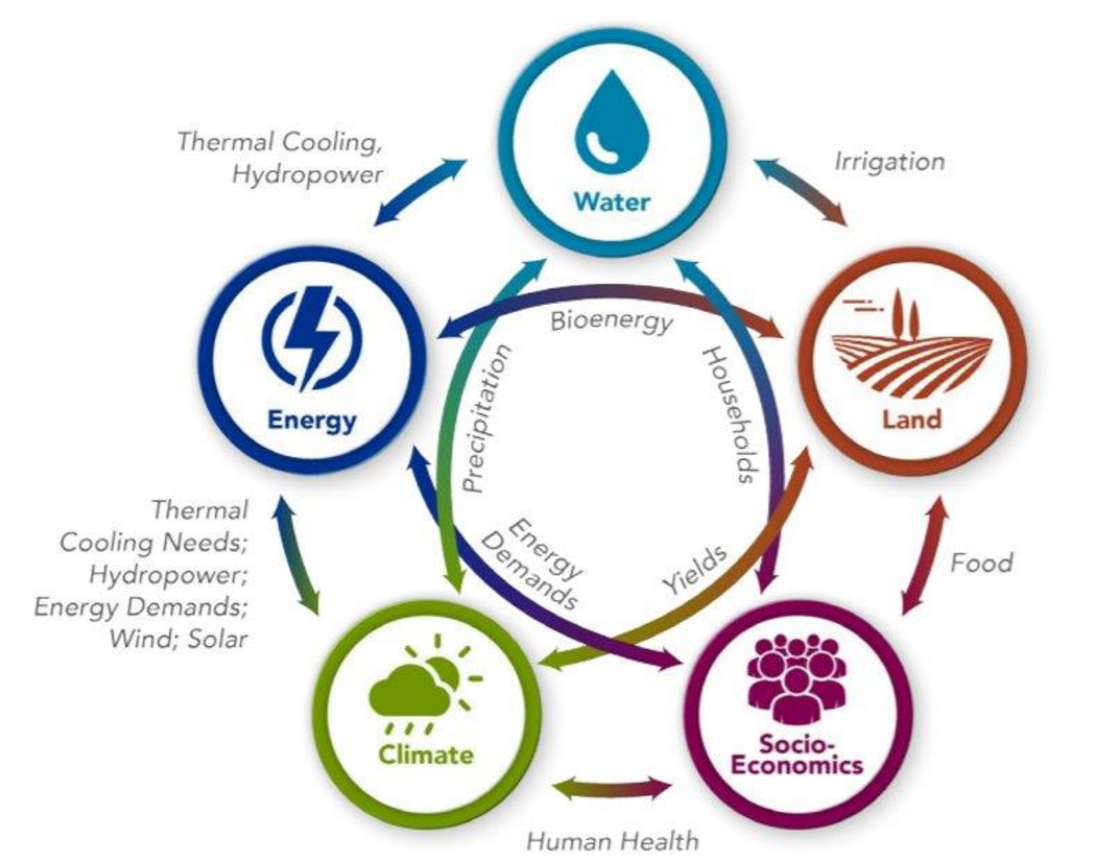
# Overview

- Current GCAM developments and applications
  - GCAM overview
  - Detailed energy for agriculture
  - Irrigation energy consumption
  - Land-based carbon removal
- Deep dive on new GCAM agricultural technologies in the context of decarbonization

# GCAM Overview

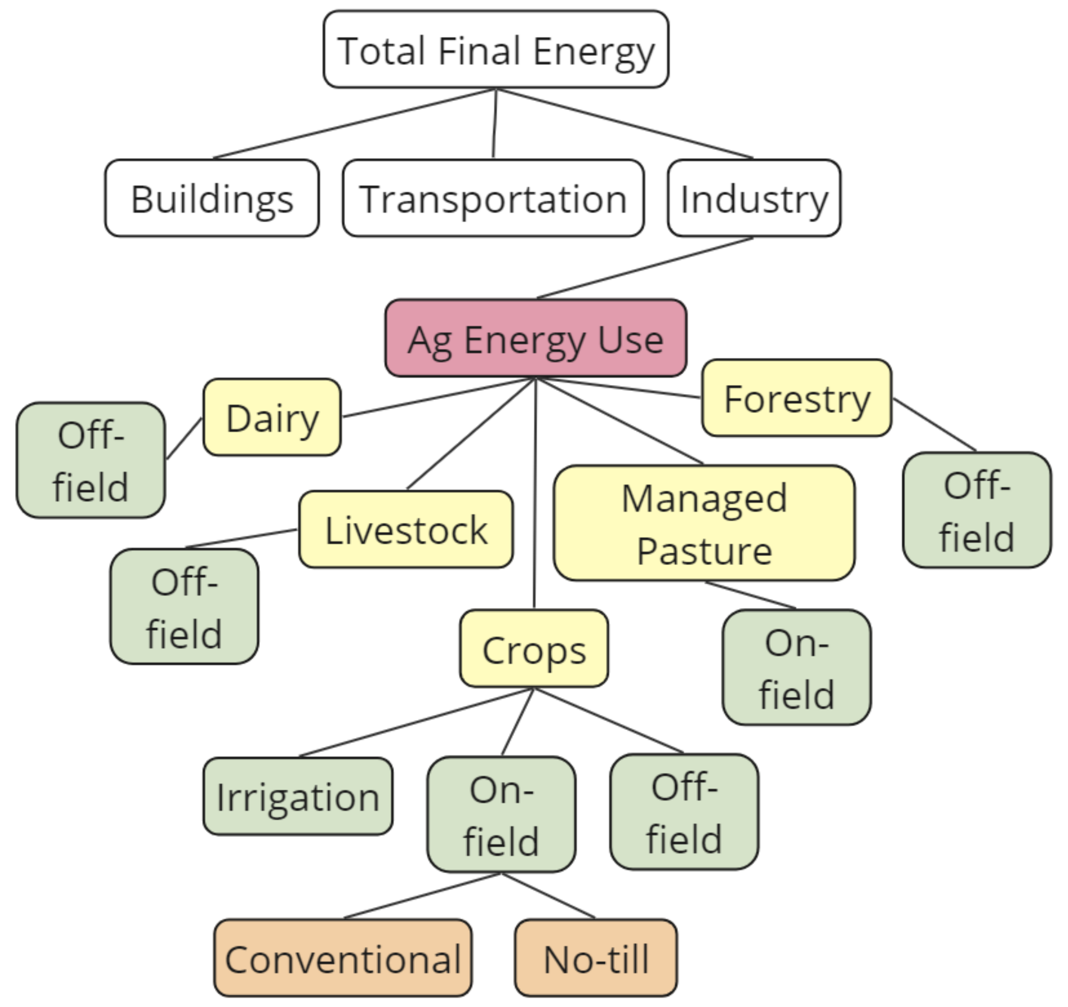
- The Global Change Analysis Model (GCAM) is a global, long-term, integrated assessment model (IAM).
- Links economic, energy, land-use, water, and climate systems.
- Base year of 2015, runs in 5-year time steps to 2100.
- 32 energy/economy regions, 235 water basins, and 384 land regions.
- Core operating principle: market equilibrium

- Full documentation: https://jgcri.github.io/gcam-doc/index.html
- Download GCAM: https://github.com/JGCRI/gcam-core/releases/tag/gcam-v7.0



# GCAM Developments – Detailed Energy for Agriculture

- **Global data** for ag direct energy consumption at the **crop/fuel level does not currently exist**.
- Wide variation in energy used for ag operations between countries. Key factors include **level of mechanization, dominant crop types, cropping practices, and climate.**
- Constructed a global dataset of energy use in ag by country, product, fuel, and selected technologies for historical years based on bottom-up estimates.
- Will allow modeling future technological developments in agriculture and decarbonization in GCAM.

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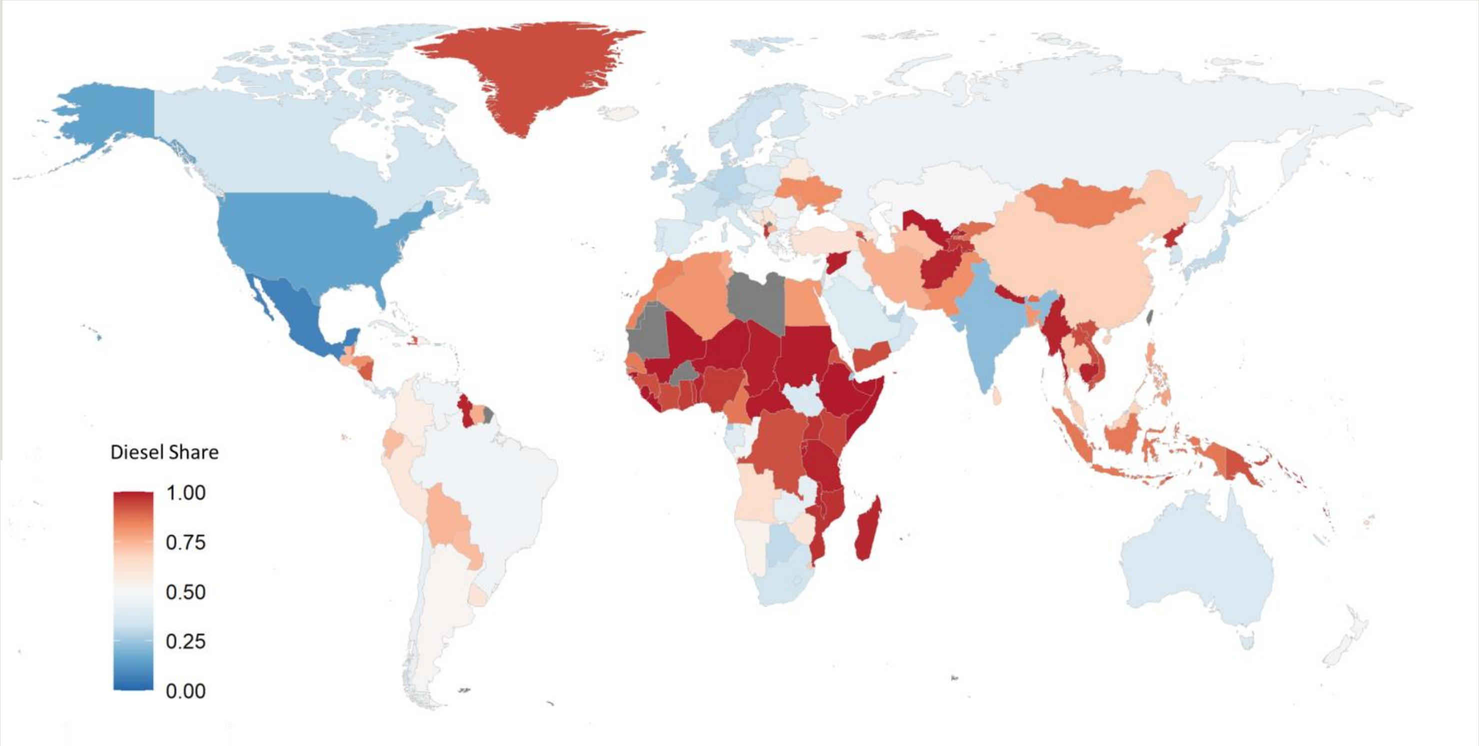
# GCAM Developments – Irrigation Energy Consumption

- GCAM currently only considers irrigation **electricity consumption**, while other fuels used for pumping are ignored (e.g., diesel, solar PV).
- Constructed a global dataset of country-level irrigation energy consumption **by multiple fuel types** based on bottom-up estimates.
- Understanding the existing situation of energy consumption in irrigation can help **achieve economic security, energy, and climate mitigation goals**.

Estimated irrigation energy consumption share by diesel (2015)

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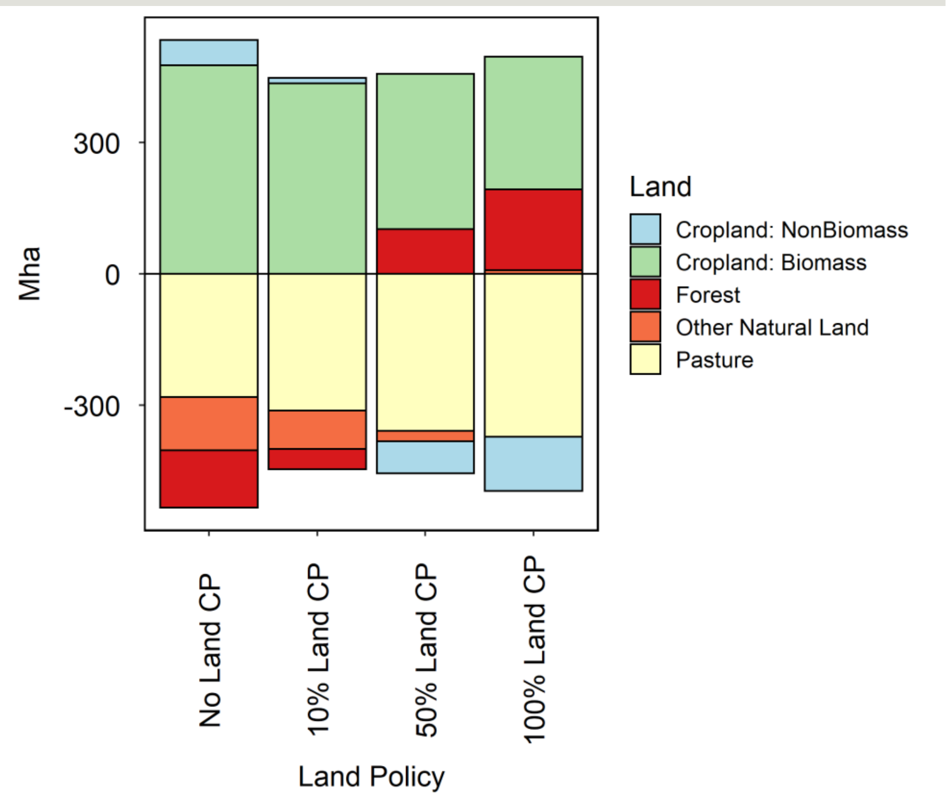
# GCAM Applications – Land-based Carbon Removal

- Used GCAM to provide insights into
  - How much land-based CDR, BECCS & A/R (AFOLU) particularly, contribute to mitigation goals
  - How do they compete for land?
  - How do various policy choices affect their mitigation contributions?
- Scenarios included varying land carbon taxes and policies, emissions targets, and bioenergy limits.

Average land use (2020 – 2100) decomposition

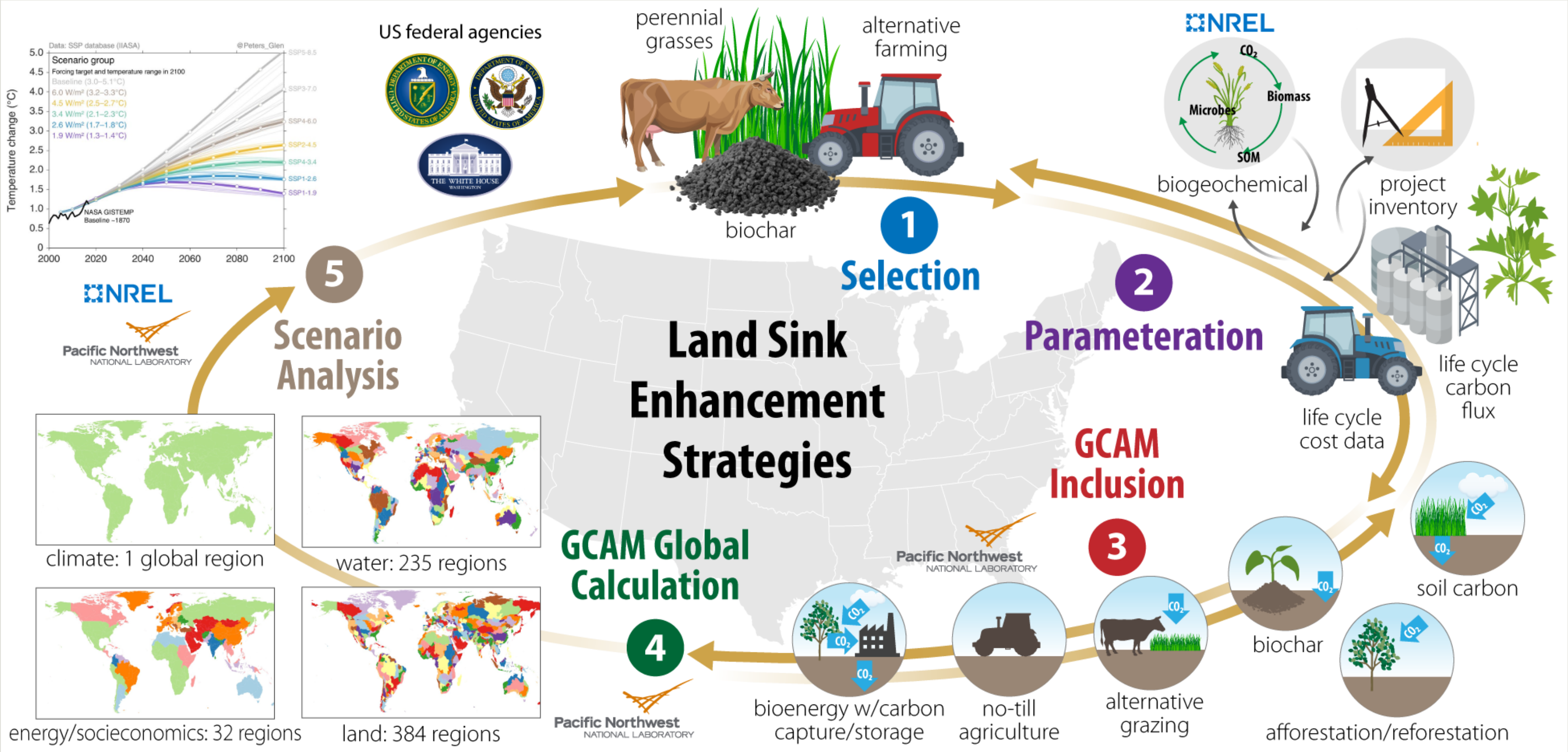



- Key Findings
  - Significant BECCS deployment in all cases, A/R deployment depends on extent of land pricing.
  - **Land-based CDR could be more effective with more use of nonland-based BECCS, earlier deployment of CCS, and more effective A/R (on currently low-carbon-density land).**

Contact: Xin Zhao (xin.zhao@pnnl.gov)

Zhao, X., Mignone, B., Wise, M.A., and McJeon, H. Trade-Offs in Land-Based Carbon Removal Measures under 1.5°C and 2°C Futures. Nature Communications. In Press.

# Deep Dive – GCAM Agricultural Technologies




Weber, M.A., Wise, M.A., Lamers, P., Wang, Y., Avery, G., Morris, K.A., and Edmonds, J.A. Potential long-term, global effects of enhancing the domestic terrestrial carbon sink in the United States through no-till and cover cropping. Carbon Balance and Management. In Press.

This research is based on work supported by the Bioenergy Technologies Office (BETO) of the United States Department of Energy (DOE).

Contact: Maridee Weber (maridee.weber@pnnl.gov)

# 1 Selection – No-till and Cover Cropping

- Previously conducted a study on biochar addition to croplands as a decarbonization strategy. (Paper in review at ERL)
- Agricultural practices like no-till and cover cropping can enhance total soil organic carbon (SOC) content and crop yields.

- **How does an adoption of domestic (USA) no-till farming and cover cropping practices impact land use, agricultural trade, and global land use change emissions?**

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# 2 Parameterization – DayCent

**Treatments – aligned with GCAM**

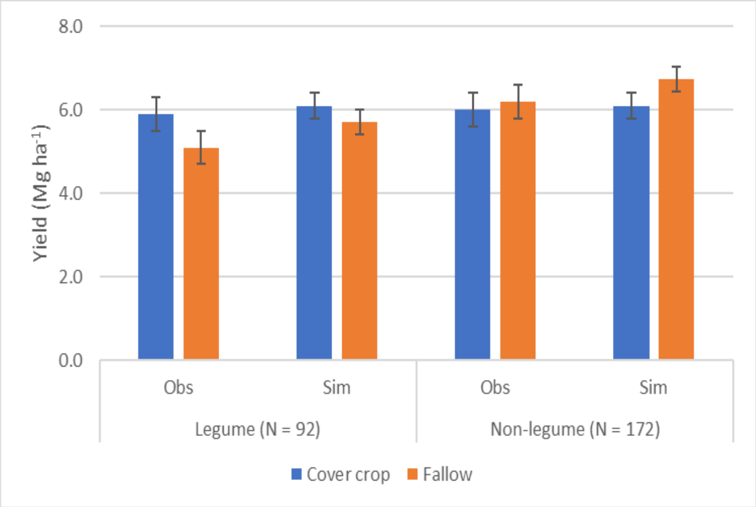
- 2 irrigation levels: rainfed, irrigated
- 2 fertilization levels: low and high
- 2 tillage options: conventional, no-till
- 3 cover crop options: fallow, legume, non-legume

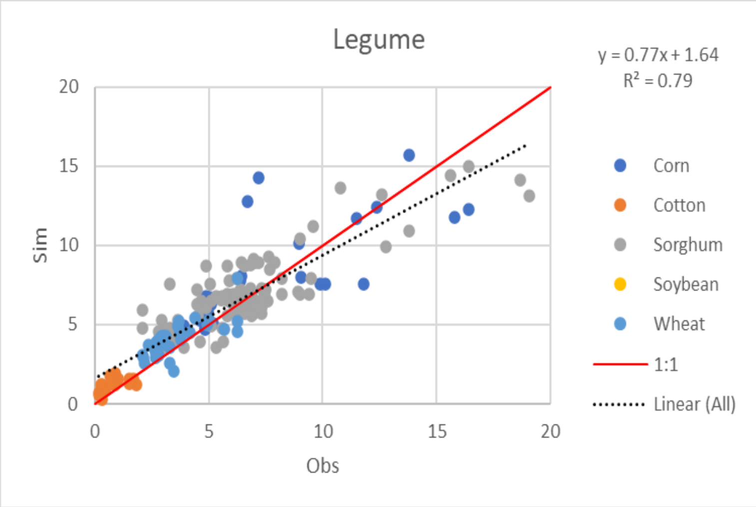
→ 31 crop-regions x 2 irrigation x 2 fertilization x 2 tillage x 3 cover crop = **744 run combinations**

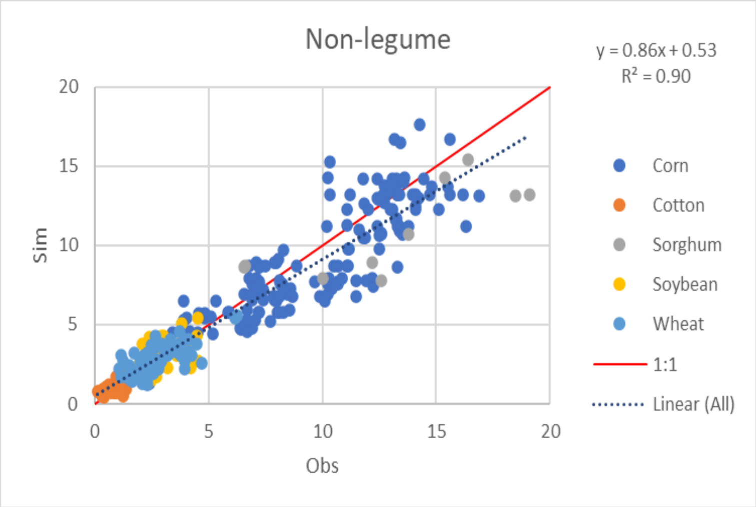
**DayCent**

- 5,000 years spin-up runs with temperate grassland (-3150 to 1850).
- 165 years base runs to 2015 with 2000-2015 using GCAM fertilizer and irrigation amount associated with conventional till.
- 85 years projection runs to 2100 using GCAM fertilizer and irrigation amount comparing conventional till and no till.
- Weather data: DAYMET.
- Soil data: representative loamy textured (40% sand, 40% silt, 20% clay).

**Yield**

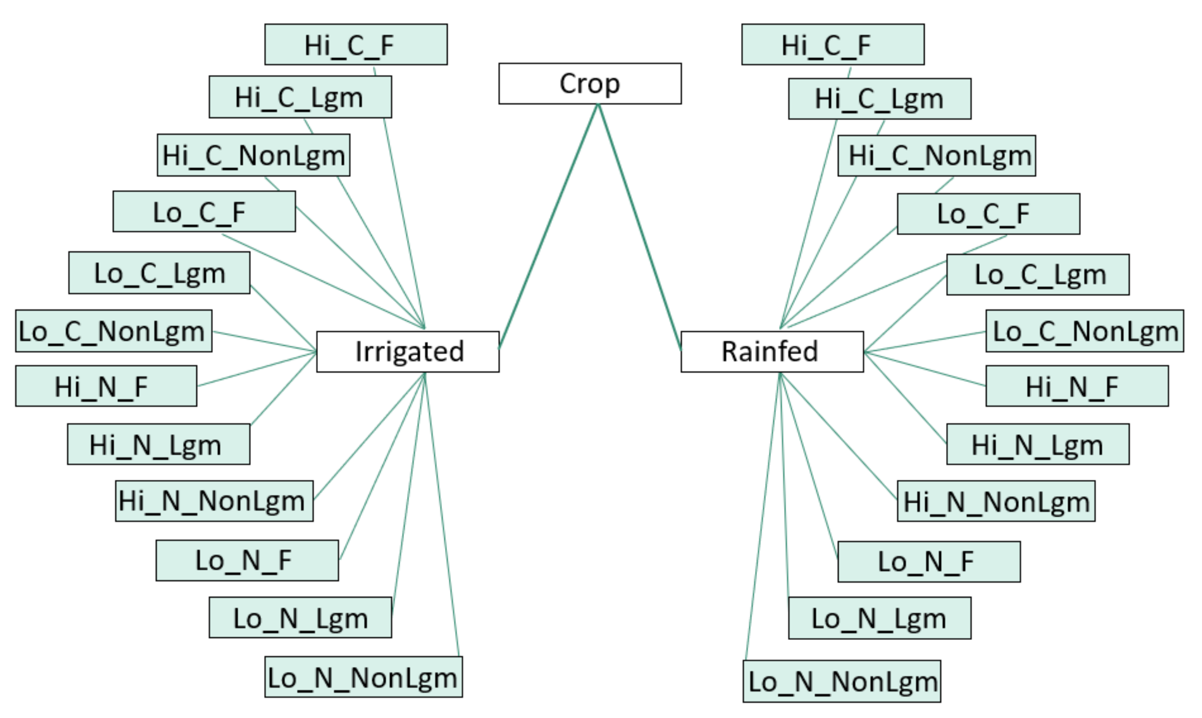


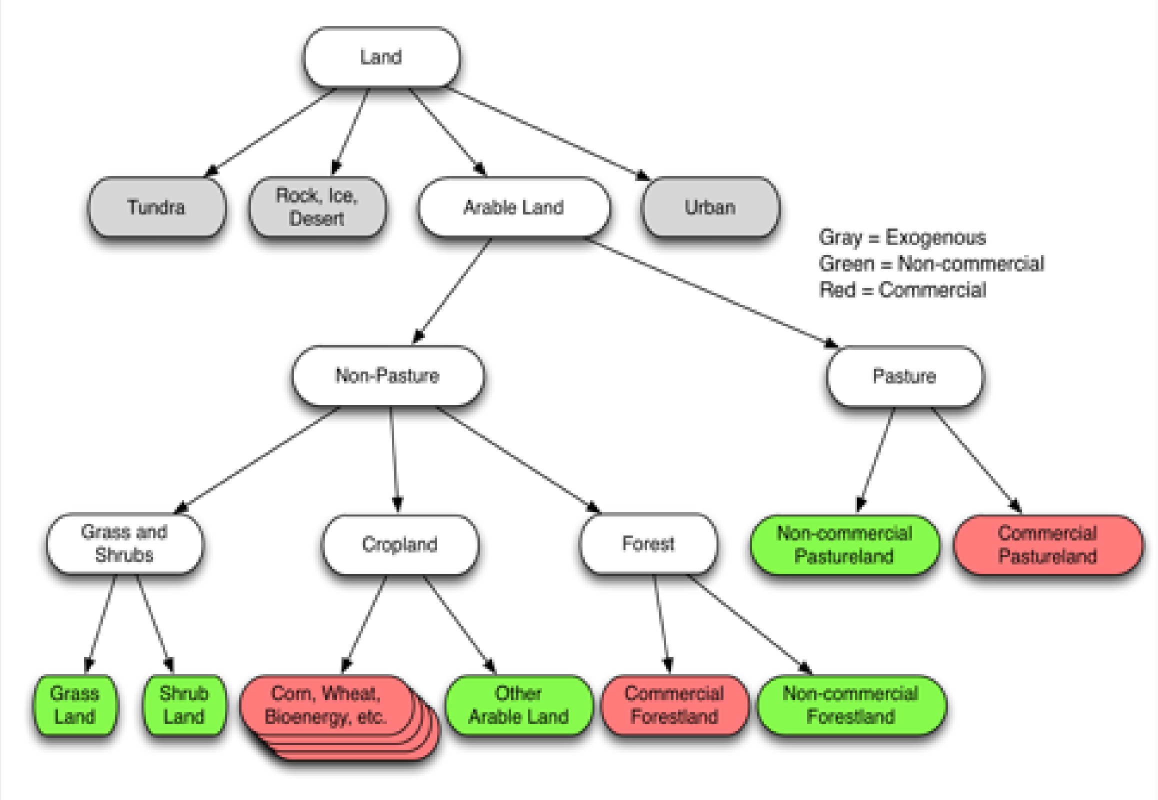



# ③ GCAM Inclusion – Land System

- Created 20 new crop-technology options that compete with the existing conventional-fallow technologies based on yields, soil carbon, prices, and valuation of carbon.




- Additional competition between cropland and other land types, like forest, based on profitability and substitutability.



# 4 GCAM Global Calculation – Scenarios

| Scenario | Description |
|---|---|
| Reference with Protected Land (REF) | A reference scenario where no-till and cover crop agricultural practices are implemented into GCAM in the US. 90% of previously undeveloped lands are protected from expansion of managed land-use in the US, with **no fiscal incentive for carbon storage**. |
| Cropland Carbon with Protected Land (CCPL) | A US-based carbon policy that **values soil carbon in agricultural systems** in the US, with 90% of previously **undeveloped lands protected** from expansion of managed land-use in the US. |

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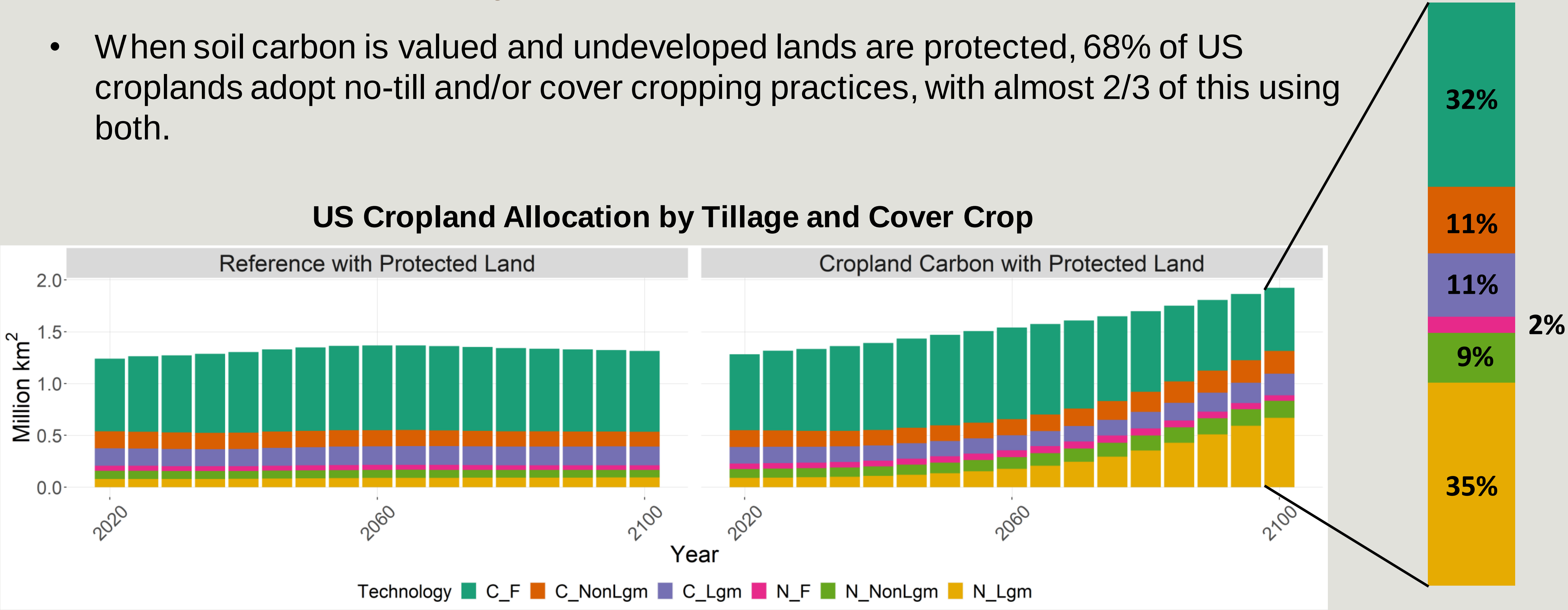
# 5 Scenario Analysis – Results – Land Use

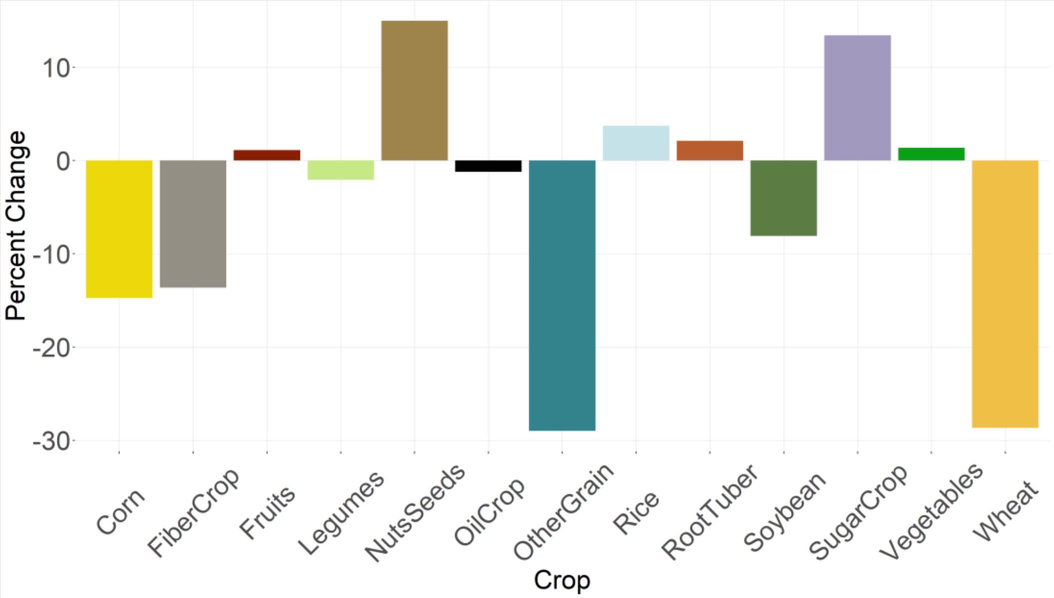
- When soil carbon is valued and undeveloped lands are protected, 68% of US croplands adopt no-till and/or cover cropping practices, with almost 2/3 of this using both.

**US Cropland Allocation by Tillage and Cover Crop**

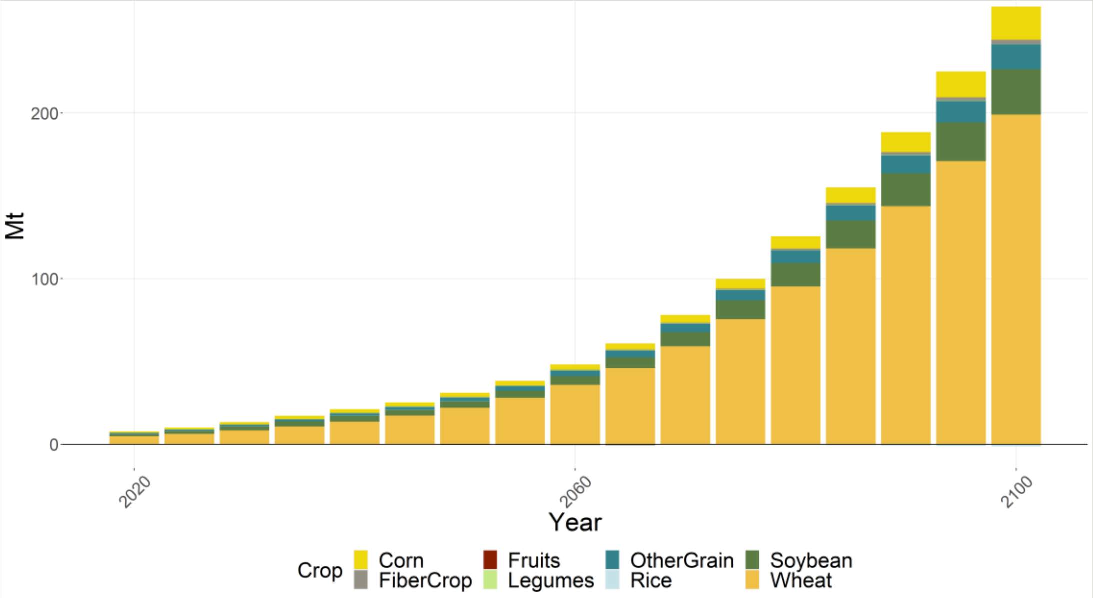


# 5 Scenario Analysis – Results – Production and Trade

**Percent Change in US Crop Prices from REF to CCPL (2100)**




**Difference in US Net Exports for Crops from REF to CCPL**




- Valuing soil carbon reduced crop prices, as the carbon-price incentives are an additional source of revenue to landowners. Opportunity cost of not growing a crop that has higher SOC potential.
- Higher yields associated with no-till and cover crops allow the US to grow more crops without allocating additional land, leading to higher export volume.
- These changes in export, and import, volume in the US are counterbalanced by changes in production in the rest of the world.

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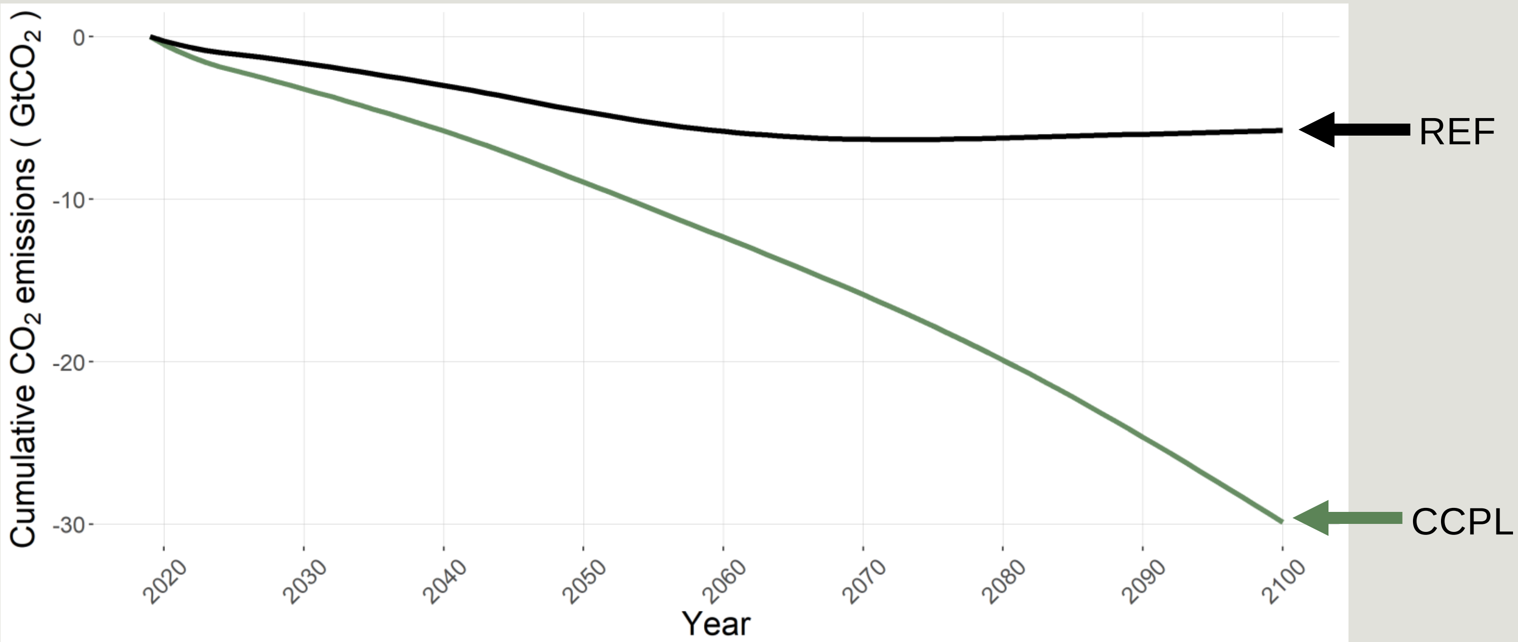
# ❺ Scenario Analysis – Results – Emissions

- Terrestrial carbon impacts on just US cropland.
- Change in carbon stored in agricultural soil in the US is **increased by 24 $GtCO_2$** cumulatively to 2100, roughly 0.3 $GtCO_2$/year on average.
- Does not consider the effects of cropland expansion.

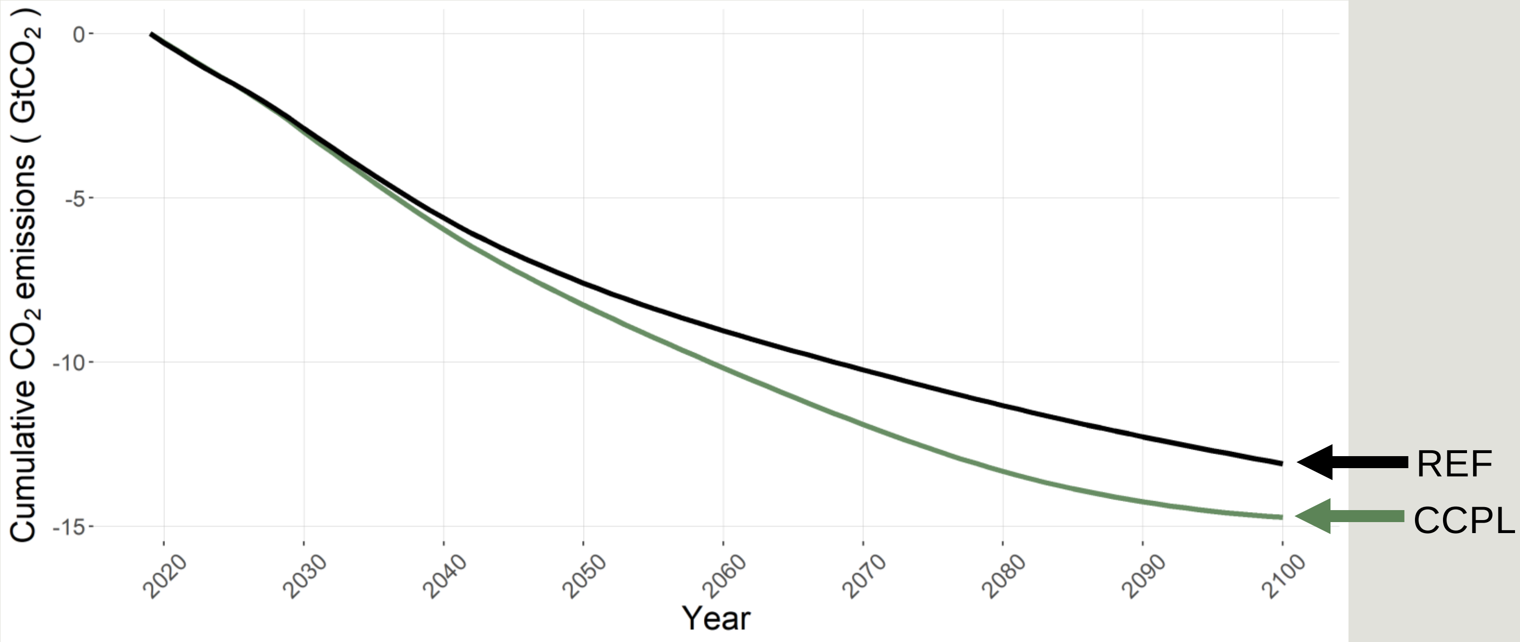
**US LUC Emissions from Cropland**



# 5 Scenario Analysis – Results – Emissions

- Cumulative change in terrestrial carbon for all land in the US.
- Change in carbon stored in soil in the US is **increased slightly by 2 $GtCO_2$** cumulatively to 2100.
- Reduced impact attributable to increased LUC emissions from deforestation and reductions in other natural lands in the US.

**US LUC Emissions from All Land**



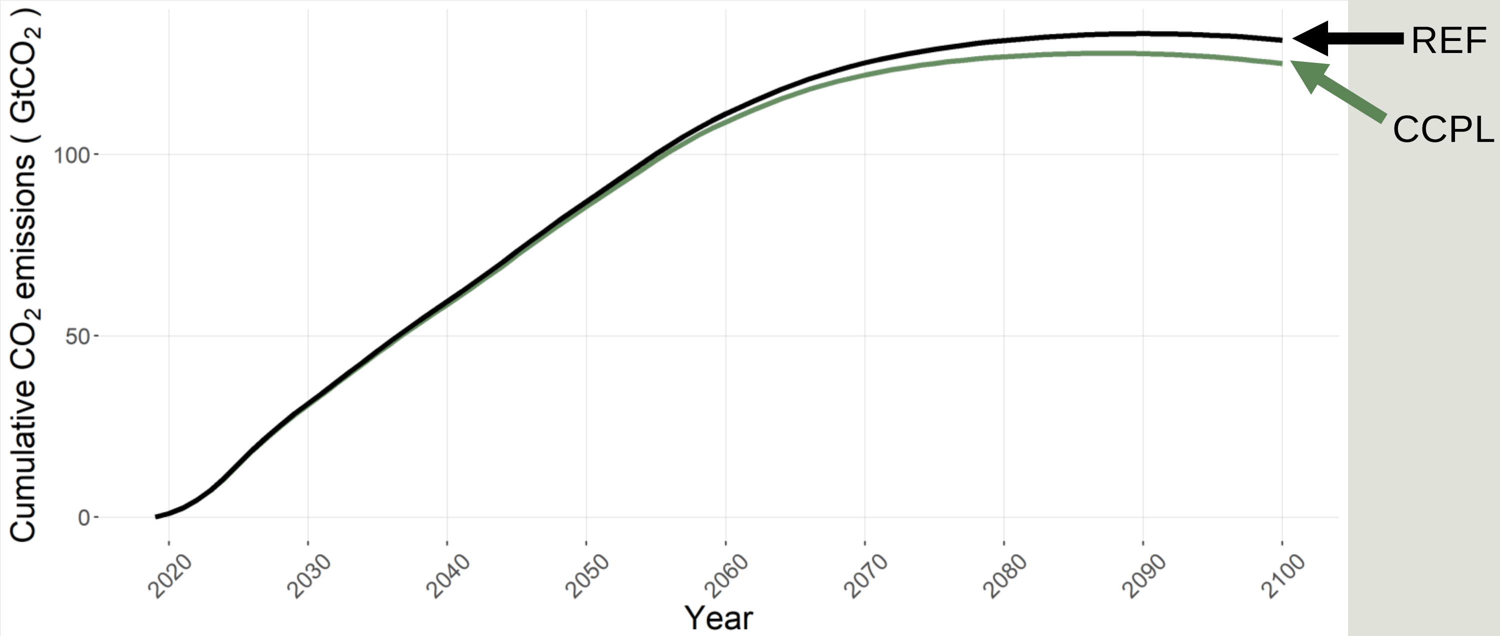
# 5 Scenario Analysis – Results – Emissions

- **Globally, emissions are reduced 6.5 $GtCO_2$** cumulatively to 2100 in CCPL.

- Increase in cropland in US results in reduced crop production in other regions globally, **allowing an increase in natural land, like forests**.

- Net global **impact from US cropland actions in CCPL is 0.16 $GtCO_2$/year** on average over 40 years, a plausible US proportion of the global estimates of 1.4-2.3 $GtCO_2$eq/year (Griscom et al, 2017).

**Impact of US CCPL on Global LUC Emissions**

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# Conclusions

- A shift to no-till and cover cropping in the US could increase the terrestrial carbon sink with limited effects on crop availability for food and fodder markets.

- The increased terrestrial carbon sink under CCPL should be considered for the global carbon budget.

- Future work could include adjustments to water demands and production costs.

- Paper accepted to a special issue of Carbon Balance and Management.

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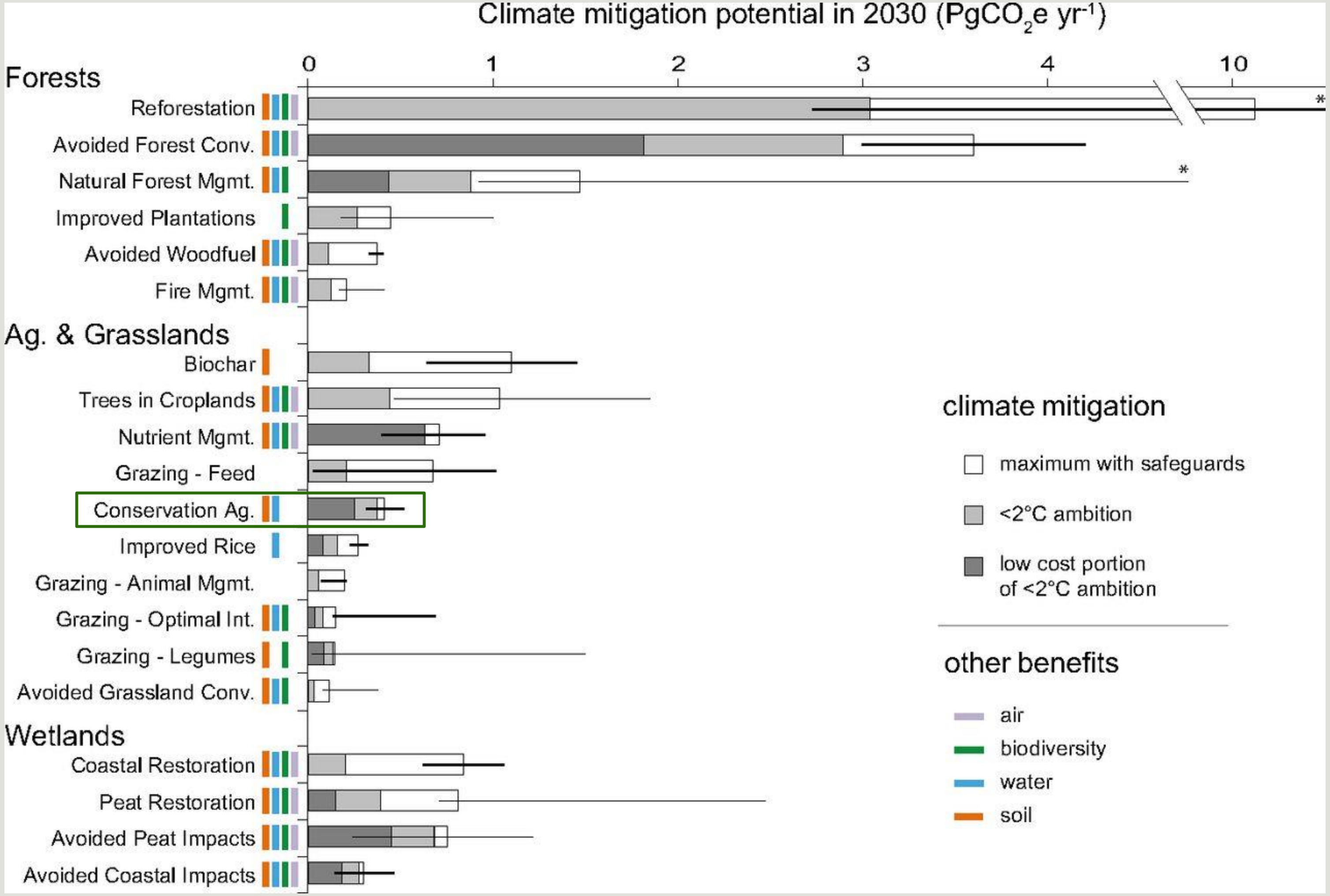
# Literature Context for Terrestrial Carbon Options

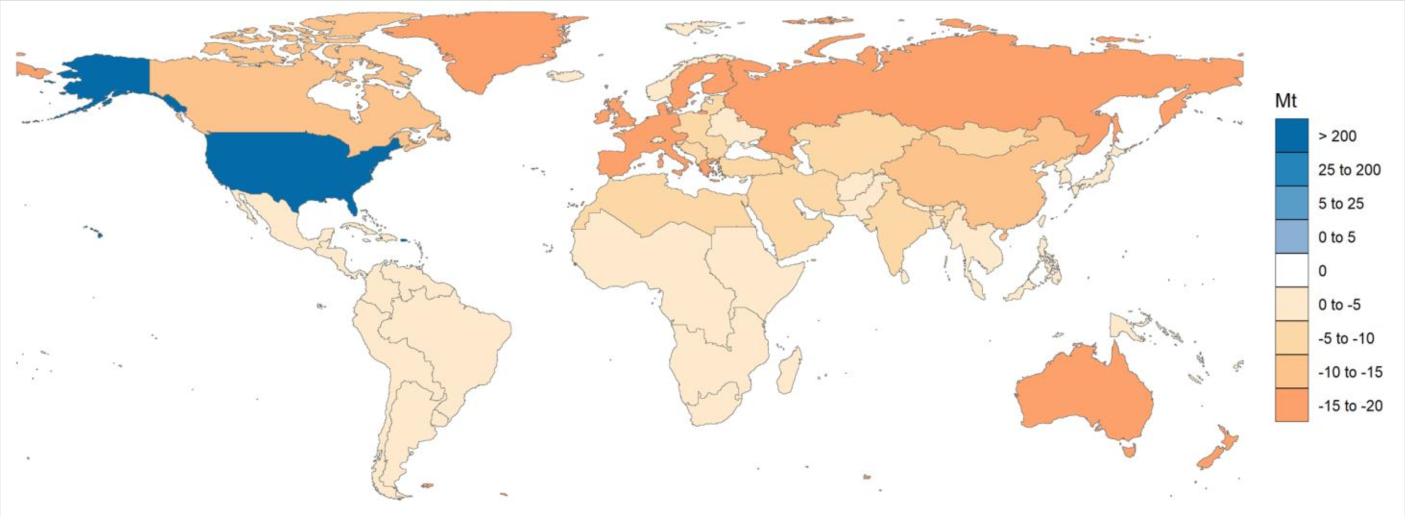



Griscom et al, 2017. “Natural Climate Solutions.” *PNAS.*

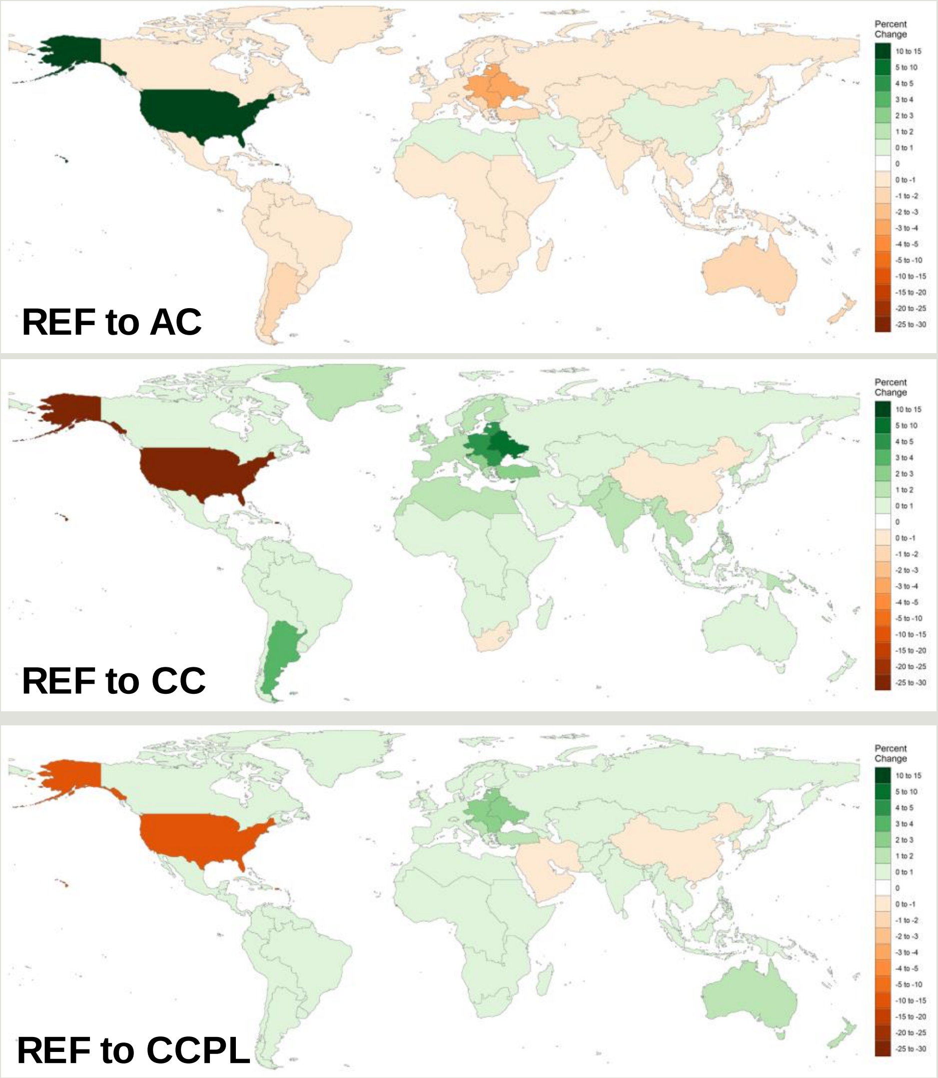
- These are well-founded but mainly static estimates considering sustainability without changing cropland and other boundary conditions.
- Our approach here is to use integrated economic modeling that considers trade-offs and dynamic responses in agriculture to carbon incentives.

# Global Production and Land Allocation

**Change in Global Wheat Production from REF to CCPL (2100)**




**Change in Regional Forest Allocation (2100)**




- Increase in wheat production in US mostly offset by decreases in production in all other regions, but still resulting in a net increase in global wheat production.
- In AC, +19% forest in US, +0.07% to -4% in other regions.
- In CC, -23% forest in US, -0.3% to +6% in other regions.
- In CCPL, -6% forest in US, +0.5% to +3.5% in other regions.