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Analysis of the Bioeconomy for Carbon Drawdown

DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

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Analysis & Sustainability

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Project Overview

- The National Academy of Sciences has concluded that bioeconomy pathways are among the largest potential contributors to carbon drawdown, which is essential to avoiding the worst long-term impacts of climate change
- The goal of this project is to quantify the technical and economic potential of multiple, diverse bioeconomy pathways that draw down carbon dioxide from the atmosphere.
  - BETO began investing in quantitative drawdown analysis in FY19
- Current approaches carbon drawdown analysis include lifecycle assessment (LCA) and technoeconomic analysis (TEA) that do not appropriately account for atmospheric, biogenic, and sequestered carbon
- Incentivizing inefficient or ineffective carbon drawdown pathways endangers medium- and long-term greenhouse gas emissions goals.

Carbon drawdown is one of the hottest topics in climate technology/policy today.

Management (1/2): Roles and Responsibilities

- This project is managed by LLNL (prime) with significant effort by UC Berkeley (subcontract). It combines the systems analysis expertise at LLNL with the subject matter expertise at Berkeley
  - LLNL is responsible for project management, reporting, strategic direction, TEA, and coordination with other Carbon Drawdown efforts at DOE.
  - UC Berkeley is responsible for intellectual leadership, LCA, geospatial analysis, and informal collaborations.
- Journal submissions and DOE reports are jointly prepared by the performers

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Management (2/2): Collaborations

- Formal collaborations
  - Comparative analysis of fuel production pathways for USDRIVE's Net Zero Tech Team (NZTT) with NREL, PNNL and ANL coordinated via bi-weekly meetings and annual report.
  - Development of atmospheric/biogenic carbon accounting methods for LCA with the GREET team at ANL via ad-hoc meetings.

- Informal Collaborations
  - This project maintains a dialogue with the biomass resource assessment and utilization group at ORNL
  - We have a non-funded collaboration with U. Calgary to assess innovative carbon capture at biorefineries

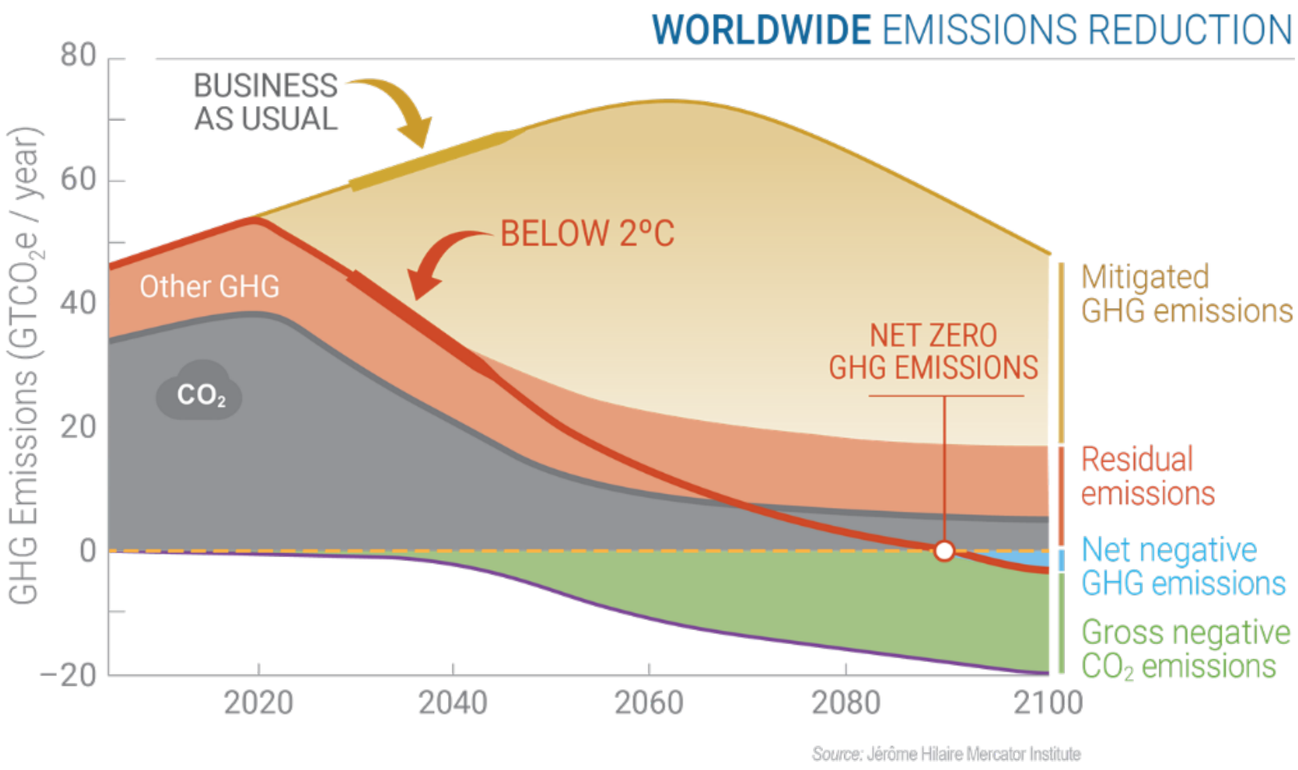
Approach

- Enumerate the bioeconomy pathways that can lead to carbon drawdown
  - Challenge: Permutations of feedstock, conversion technology, product and byproduct create a large number of potential pathways
  - Challenge: "product" and "byproduct" are not well defined
  - Strategy: focus on pathways that permanently immobilize carbon from the atmosphere; collaborate and exchange information with the large community* of researchers working on carbon capture, utilization and storage (CCUS)
- Develop lifecycle assessment (LCA) and technoeconomic analysis (TEA) of select pathways using DOE-developed tools
  - Challenge: LCA models do not consistently track and account for biogenic carbon
  - Strategy: Build an analysis framework atop existing LCA input/output, and continuously engage with tool developers*
  - Go/No-Go: Approval, Adoption, or Acceptance of carbon drawdown analysis framework by key stakeholders in the LCA community

* Recommendations from 2019 Peer Review

Impact (1/3): Alignment with BETO's Mission

- BETO Mission: Develop and demonstrate transformative and revolutionary bioenergy technologies for a sustainable nation.
- BETO Goal (2): Encourage the creation of a new domestic bioenergy and bioproduct industry.



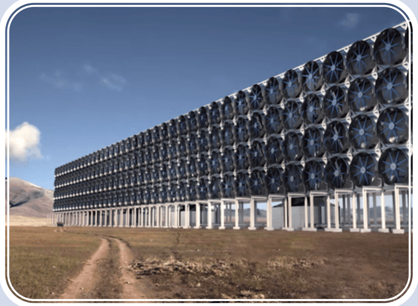
How do we harness the bioeconomy to achieve net emissions reductions?

Impact (2/3): Bioeconomy pathways are a critical component of the Negative Emissions Technology (NET) portfolio

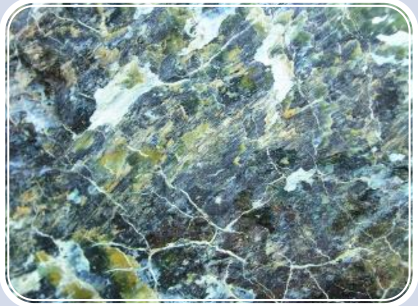
Coastal Blue Carbon

Terrestrial Carbon Removal and Sequestration

Biomass Energy with Carbon Capture and Sequestration



Direct Air Capture

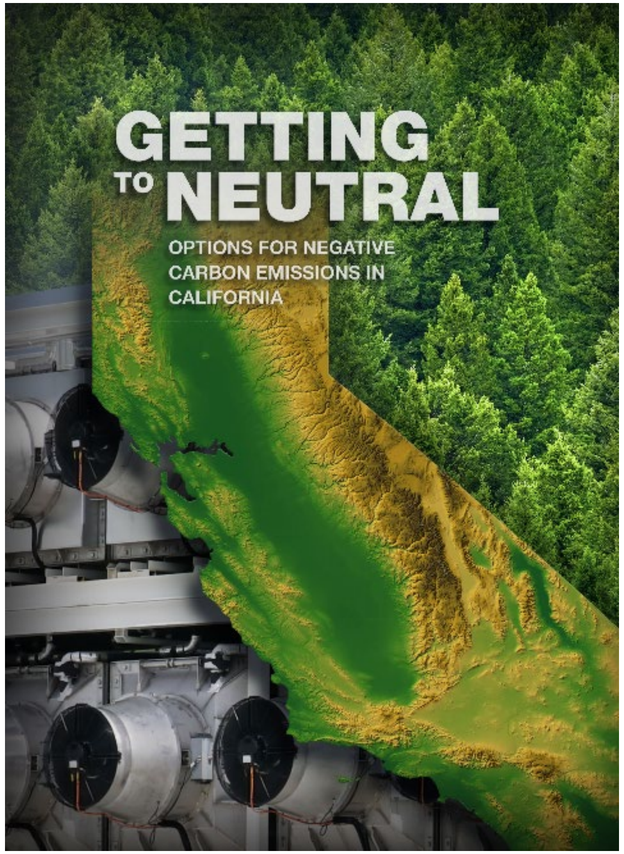


Carbon Mineralization of CO_2

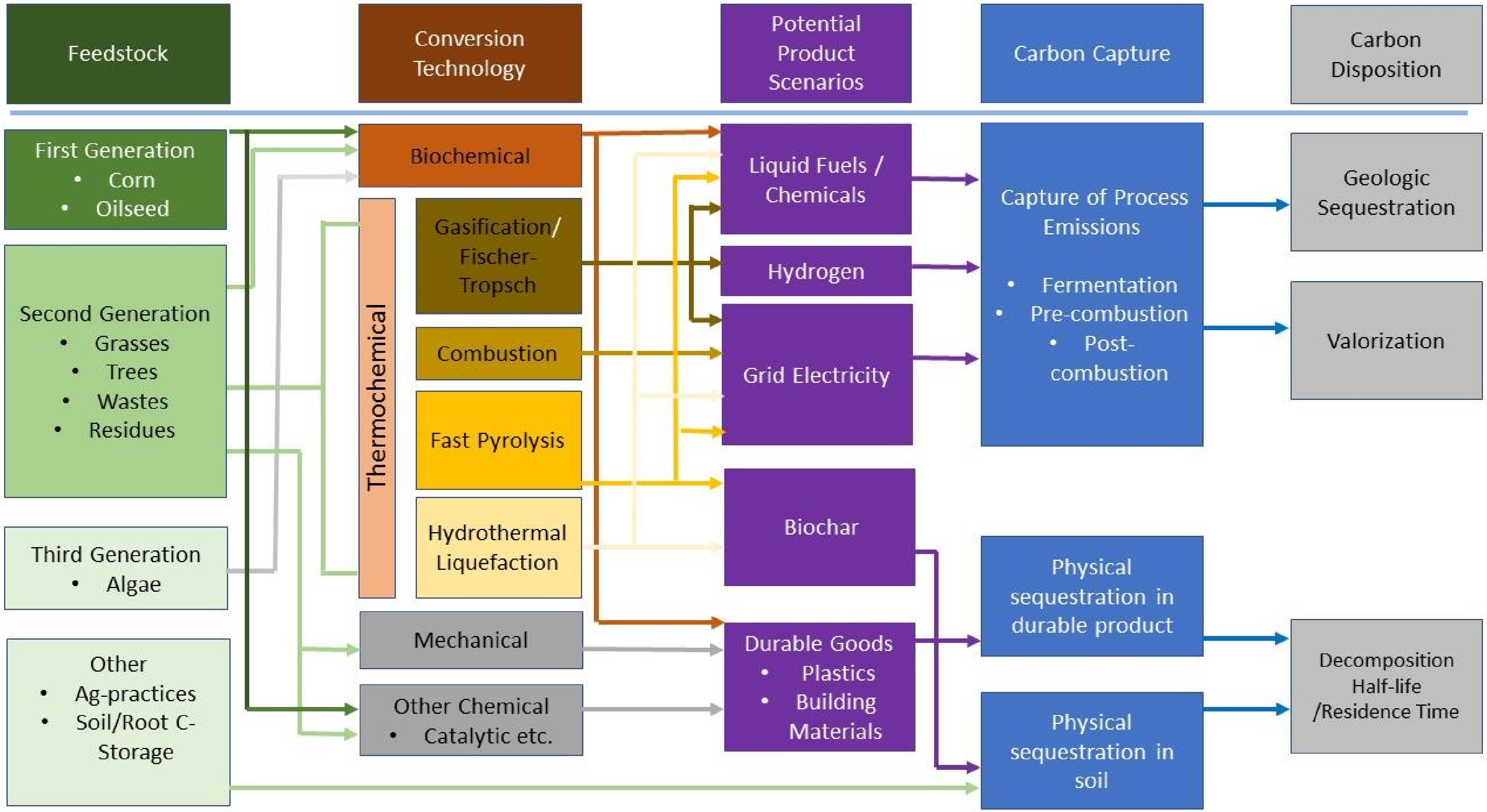
Negative Emissions Technologies and Reliable Sequestration – A Research Agenda (National Academies Press, 2019)

Impact (3/3): Engagement with Negative Emissions Community

- Journal Publications
  - 1 paper submitted to Environmental Science & Technology: “Leveraging the bioeconomy for carbon drawdown”
  - 2 planned submissions joint with other leaders in the field
- Joint Reporting: NZTT
  - LCA/TEA community: NREL, PNNL, ANL
  - Industry guidance, review & engagement
- LLNL Leadership
  - California “Getting to Neutral” framework



Progress and Outcomes (1/8): Pathway Enumeration



Balance feedstock, conversion and product coverage with near-term TRL

Progress and Outcomes (2/8): Assessed Pathways (2019 – 2020)

- Corn to ethanol with capture and sequestration of fermentation CO_2
  - Conventional, widespread biological feedstock/conversion technology
  - Carbon capture technology in limited practice today
- Corn stover to polyethylene with capture and sequestration of fermentation CO_2
  - 2^{nd} Generation (lignocellulosic) feedstock/conversion technology
  - Straightforward carbon capture; proven chemical transformations
- Switchgrass to electricity with pre-combustion capture (IGCC) and sequestration of fermentation CO_2
  - 2^{nd} Generation feedstock
  - Demonstrated (advanced) energy conversion
- Forest Residue to biochar with capture of carbon in agricultural soils
  - Multi-value feedstock
  - Emerging carbon immobilization technology
- Forest Products to Oriented Strand Board (OSB – a building material)
  - Conventional feedstock for a NON-ENERGY bioproduct
  - Complex end-of-life analysis , non-linear release of bio-carbon over decades - centuries

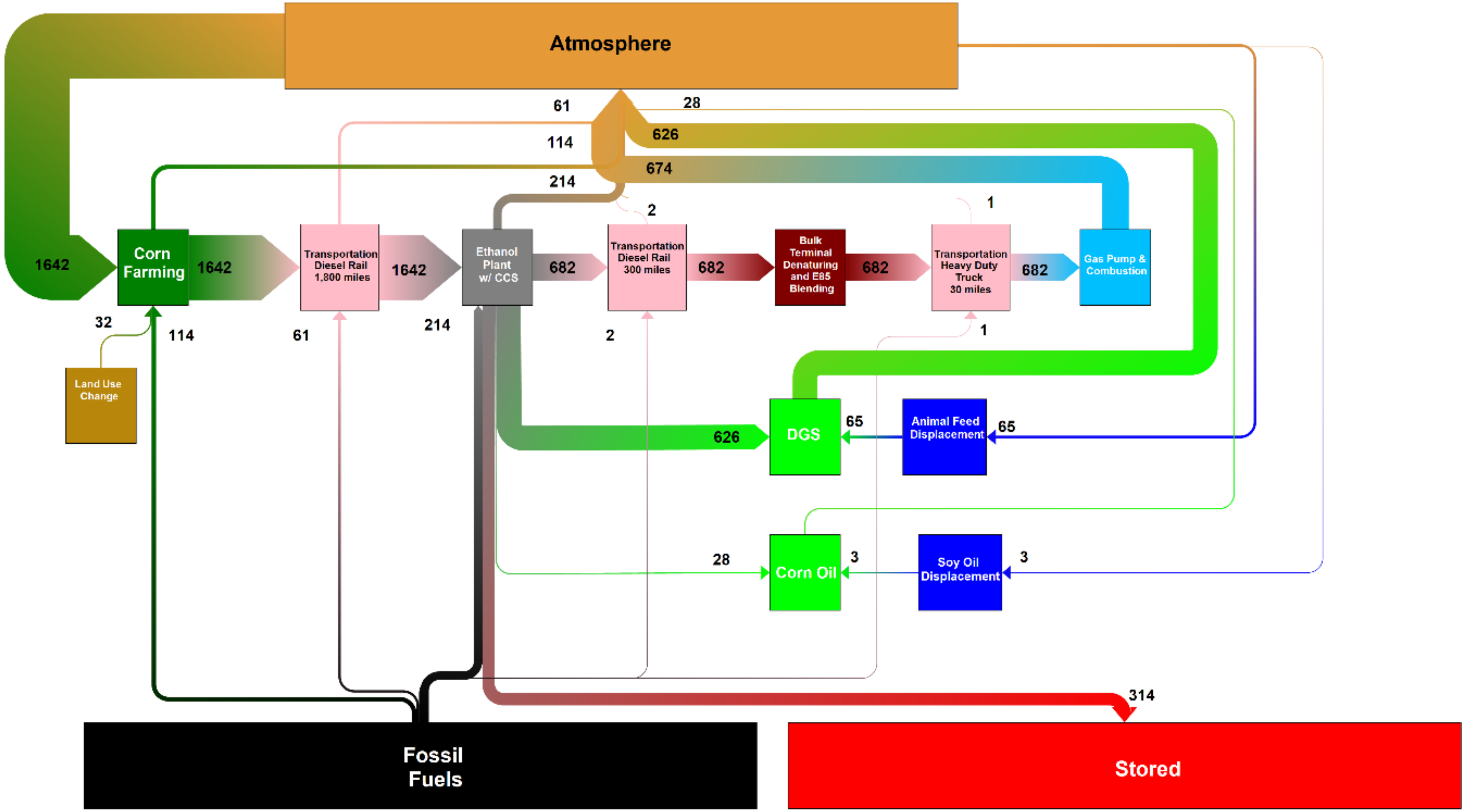
Progress and Outcomes (3/8): Pathway Visualization

Sankey Diagrams illustrate the magnitude of carbon flows, and depict the extent of net carbon emissions.

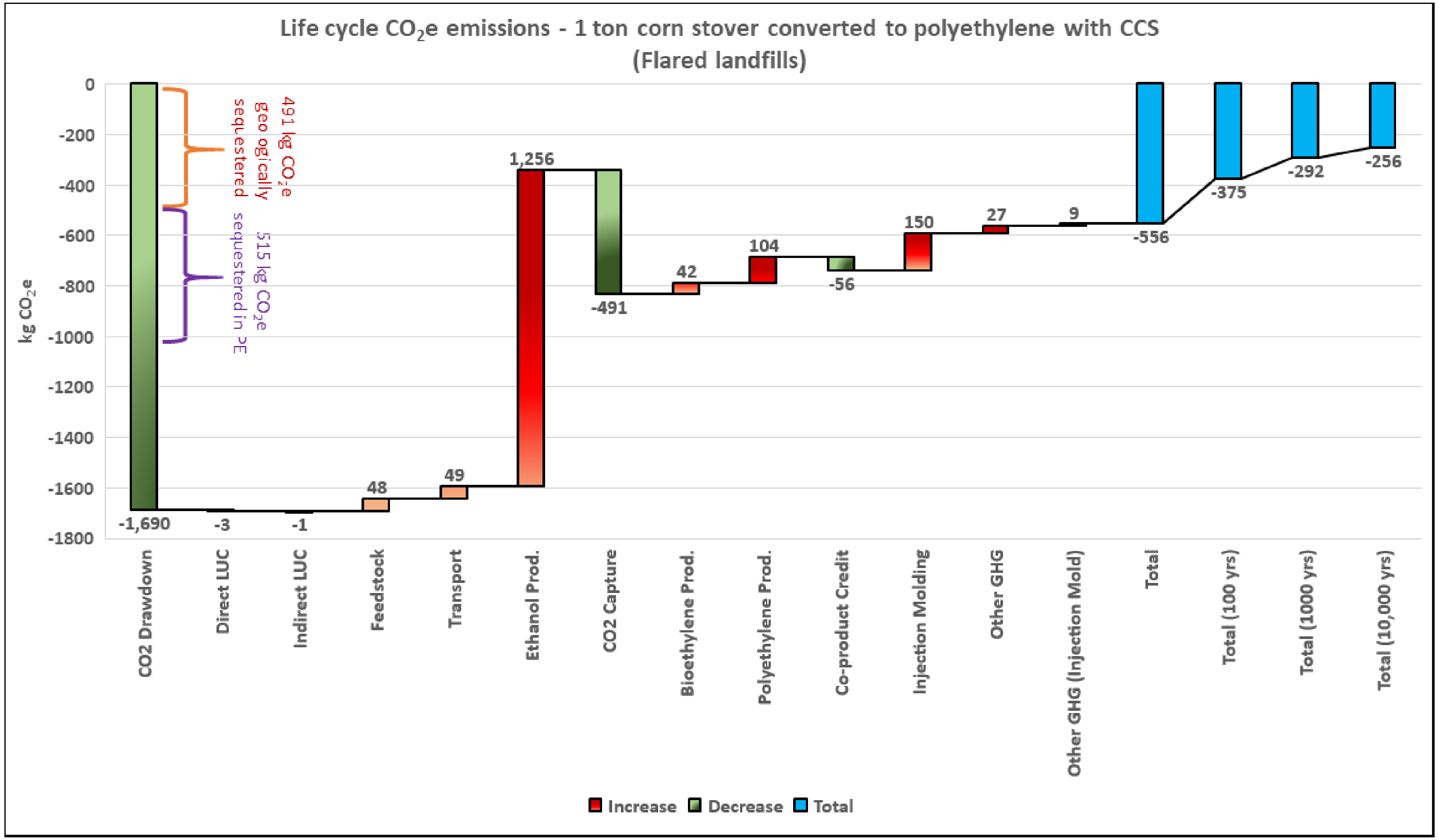
This diagram depicts CORN STARCH TO ETHANOL WITH CCS.

Similar diagrams for four other pathway are included in our annual report

Baseline Ethanol w/ CCS: Carbon Dioxide Flow (kg)



Progress and Outcomes (4/8): Lifecycle Assessment and Carbon Accounting

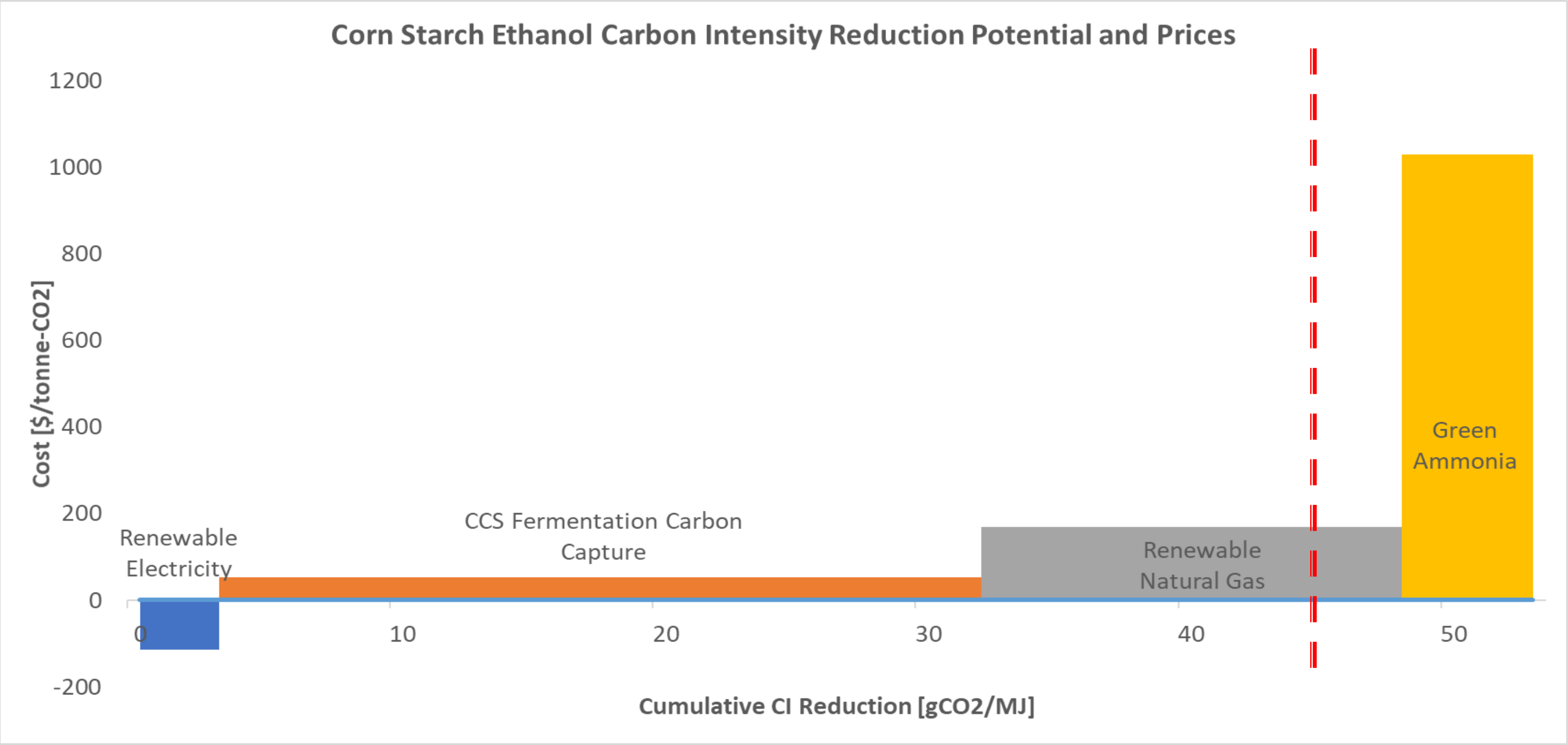


Waterfall diagrams depict gross carbon flows from each step in a bioeconomy pathway.

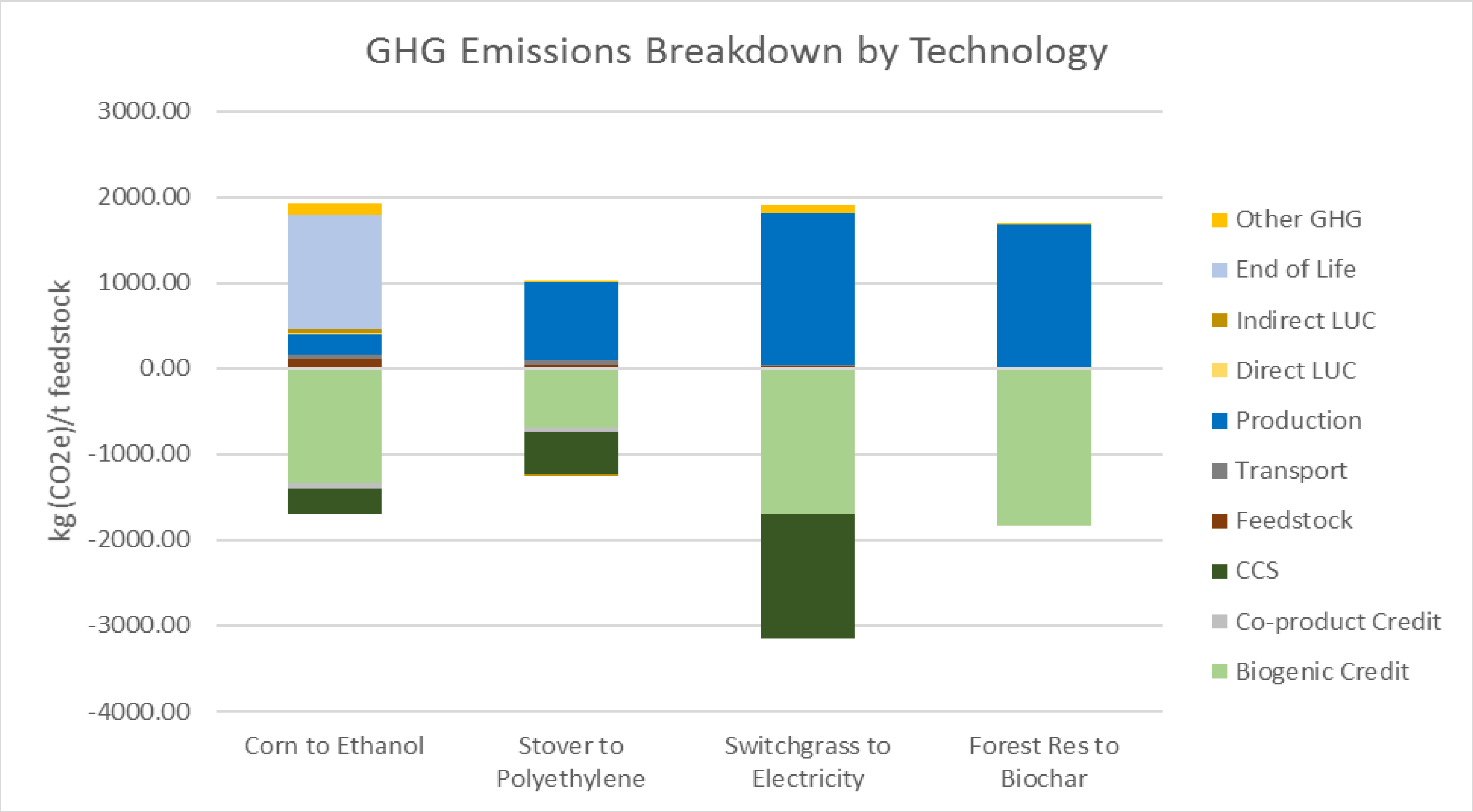
This diagram depicts CORN STOVER TO POLYETHYLENE WITH CCS.

Progress and Outcomes (5/8): Technoeconomic Analysis

This "supply curve"-style visualization depicts the cost and opportunity to reduce the INTENSIVE carbon intensity of ethanol production.



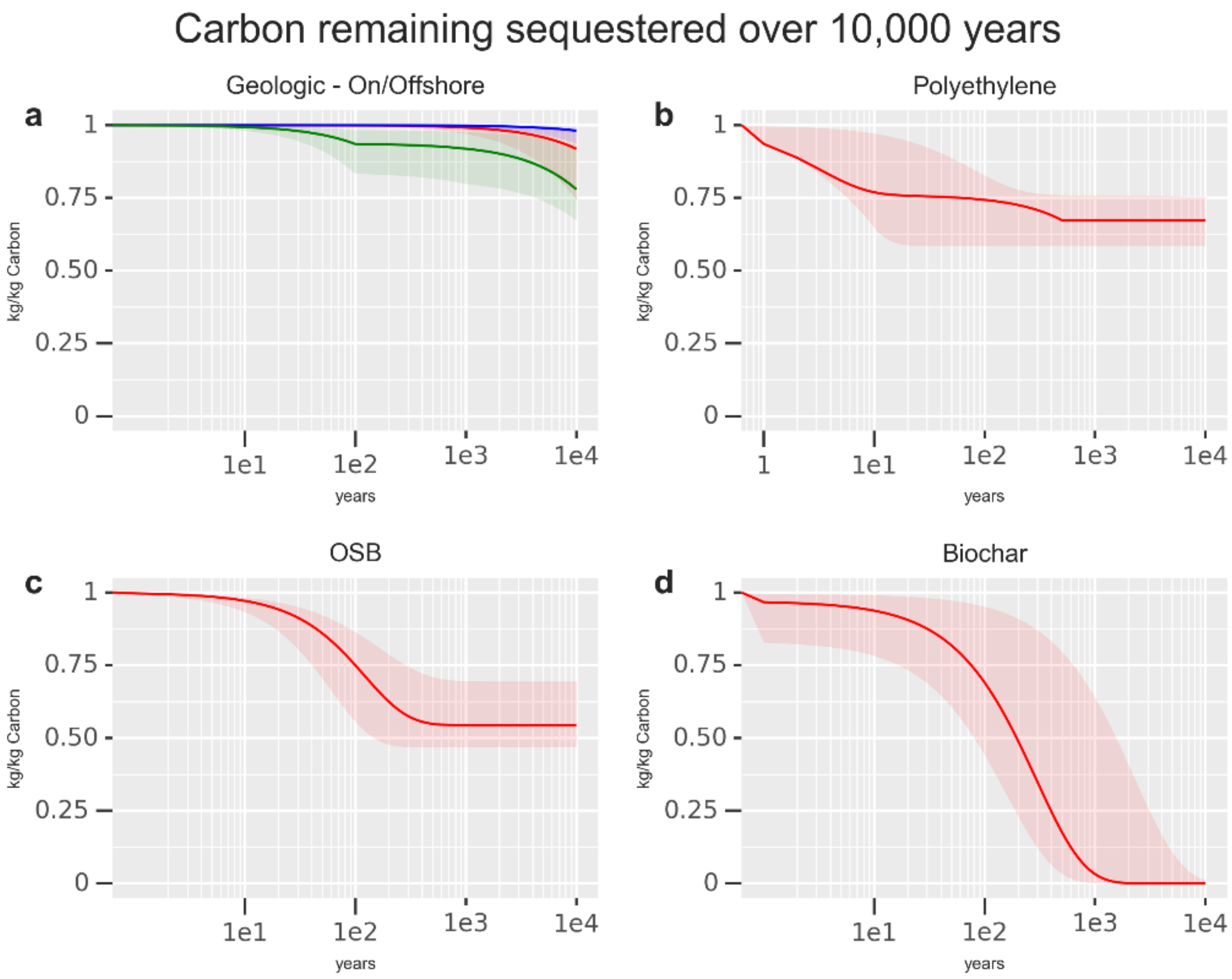
Progress and Outcomes (6/8): Pathway Intercomparison – Net emissions



Lifecycle emissions are evaluated on a per-unit-***feedstock*** basis, enabling intercomparison of bioeconomy pathways with diverse products (and co-products).

Progress and Outcomes (7/8):
Pathway Intercomparison – Carbon product end-of-life

Drawdown requires assurance that carbon remains locked away underground, in landfills or in products. CCS, bioplastic, wood products and char have different projected end-states and wide bounds of uncertainty.



Progress and Outcomes (8/8): Future Work

- Carbon capture of combustion emissions (fossil & biogenic) at biorefineries
  - MAJOR carbon drawdown opportunity (comparable to fermentation emissions)
  - Oxy-firing, solvent capture, and other options
  - LCA and TEA to determine cost/benefit
  - Informal collaboration with Sean McCoy at University of Calgary
- Corn stover to liquid fuel pathway
  - Ethanol and ethanol-to-drop-in-fuels options
  - BETO-requested work, integrates with existing geospatial analysis of stover-derived fuels
- Direct Air Capture (DAC) analysis
  - Integration of DAC with bioeconomy pathways
  - DAC-offset fossil pathways as a Net-Zero counterfactual
  - Requested by industrial members of Net Zero Tech Team

Summary

- Capture, Utilization and Storage of biogenic carbon (CCUS) is one of the most active areas of research in climate technology.
- Pathways with geologic storage and/or durable carbon products are the ONLY way to achieve carbon ***drawdown.***
- Lifecycle assessment and technoeconomic analysis have identified the ***relative*** merits of several drawdown technologies applicable to the bioeconomy.

Quad Chart Overview

Project Timeline

- **Start Date: Oct 1, 2019**
- **End Date: Sept. 30, 2022**

	FY20	Active Project
DOE Funding	$200k	FY19: $160k (seedling) FY20: $200k FY21: $200k FY22: $200k

Project Partners

- **UC Berkeley** (Dr. Dan Sanchez)

Barriers addressed

At-A - Analysis to Inform Strategic Direction: Analysis is needed to better understand factors influencing the growth and development of the bioenergy and bioproducts industries, identify the most impactful R&D strategies, define BETO goals, and inform BETO strategic direction.

Project Goal

The goal of this project is to quantify the technical and economic potential of multiple, diverse bioeconomy pathways that ***draw down carbon dioxide*** from the atmosphere.

End of Project Milestone

By the end of this project, our team will publish results from several geospatially explicit bioeconomy-enabled carbon drawdown pathways. We will post the data to the bioenergy knowledge discovery framework, submit multiple journal articles, and contribute to DOE reports on net-zero (and net-negative) fuel pathways. We are well on our way to meeting these goals.

Funding Mechanism

This project is funded at $150k per year under the FY20 AOP. We have received an additional $50k each year to extend our work in a collaboration with NREL, PNNL, ANL and the DOE/USDRIVE Net Zero Tech Team (NZTT).

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