
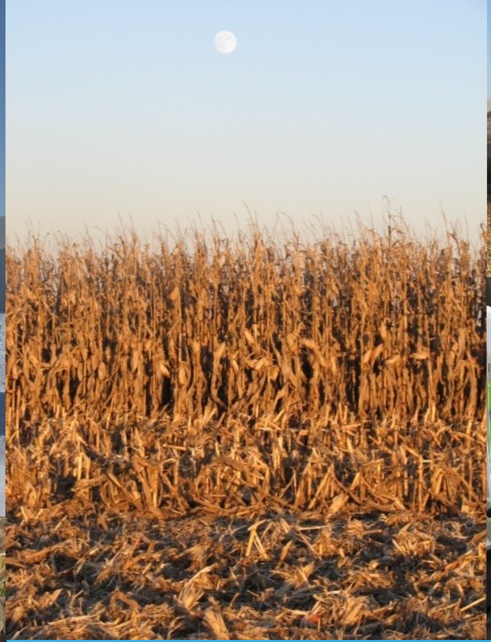

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Denver, CO

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1.1.2.1 Cover Crop Valorization for Biofuels and Products

DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Feedstock Technologies

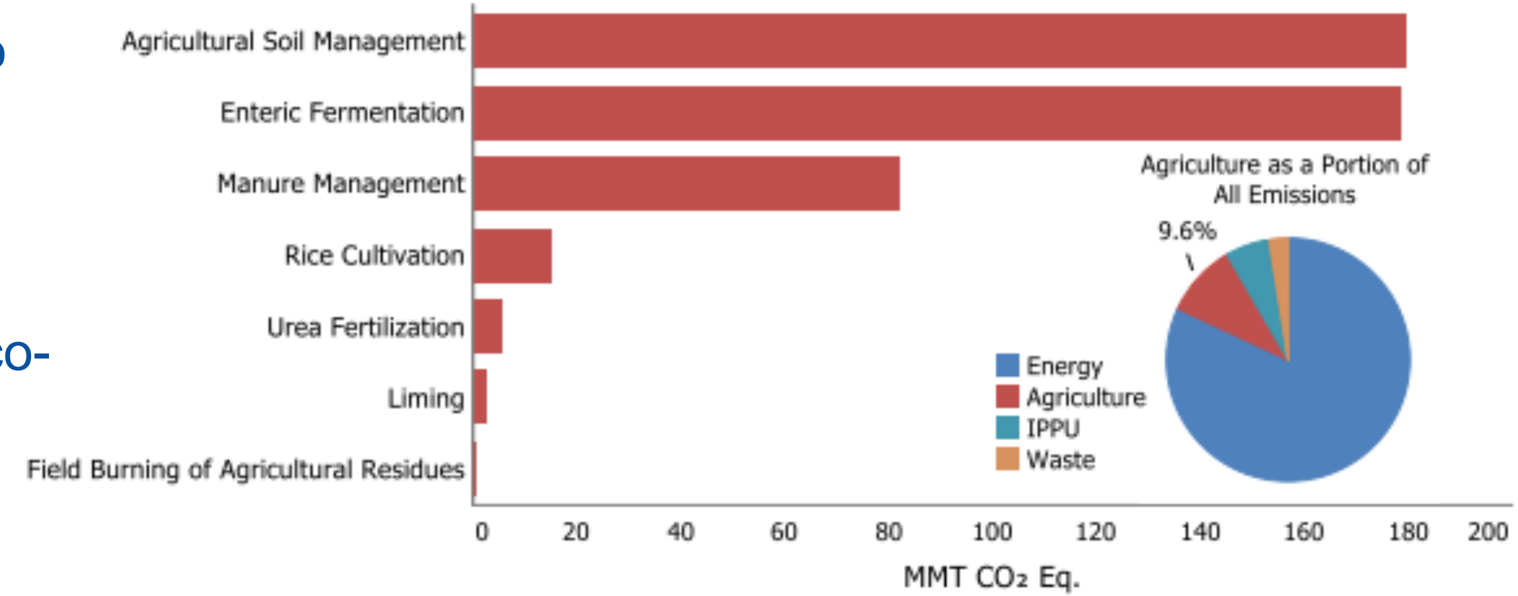
This presentation does not contain any proprietary, confidential, or otherwise restricted information

Idaho National Laboratory

Project Overview

- This is a new project as of FY22 and is approximately half-way through the first 3-year cycle
- BETO needs low-carbon resources for biofuel production
- Biofuel production **can be less carbon intensive** at every step
- Ag contributes >9% of US total greenhouse gas (GHG) emissions
  - **Nitrous oxide, CO_2**, and methane from soil management is the biggest GHG contributor

- "**Decarbonization**" is needed to reduce carbon intensity (CI) of biomass feedstocks helping to decarbonize fuel production
  - BETO Goal: "…low-carbon, cost-effective biofuels and co-products by 2030…"
  - Decarbonization starts with feedstock production



https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Project Overview

- Questions to be answered :
  - **How can cover cropping practices decarbonize biofuels production from corn stover in an economic, practical, sustainable, and verifiable manner?**
    - Do cover crops let producers sustainably remove more residues?
    - How does cover crop introduction impact farm budgets?
    - Can cover crops and biochar work together to replace the short and long term soil carbon lost by residue removal?
    - Can biochar plus cover cropping provide additional cost-offsetting ecosystems services?
    - Can we measure the effects of cover cropping, residue removal, and soil carbon *in situ* to enable spatial resolution that supports efficient and effective sub-field application of cover crops?

In-field operations during grain harvest

Technical Approach

- Consider the economic and environmental impacts on carbon dynamics
  - Determine which stover and cover crop fractions contribute to long-term stable carbon
  - Estimate char amendment rates and costs to replace long-term stable carbon
  - Provide proof of principle and local calibration models for measuring soil carbon using near infrared spectroscopic probe (INL/Antares/Hames Bale Probe)
- Use field trials to begin to fill in knowledge gaps with respect to stover removal rates, nutrient loss/replacement needs, cover crop removal potential, and collect information on local soil carbon and nitrogen dynamics to feed, refine & reevaluate models relative to new results

Technical Approach

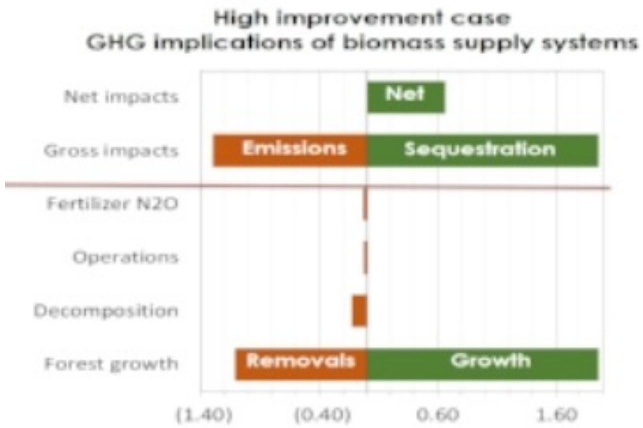
- Use technoeconomic analyses (TEA), lifecycle analyses (LCA), small-scale field trials
  - Farm budgets include ALL costs to evaluate on-farm cash flow via 10-year net present value analyses
    - Goal: show cover crops can improve on-farm cash flows above baseline and provide agricultural residues with a **15% to 25% (stretch goal) CI reduction**
    - Challenges: show that cover cropping operational costs are less than the value of residue removed including nutrient removal & replacement
  - Show how different methods of cover crop utilization impact operations, costs, cash-crop yield, soil carbon gain/loss, and value from sustainably removed stover
    - Goal: show how cover cropping methods may be modified to focus efforts on high-impact areas using landscape design concepts with **15% to 25% (stretch goal) improvement on net cash flow** over baseline; show how residue removal may be offset by carbon amendments (char) to provide long-term benefit
    - Challenges: spatial and temporal variability in soil carbon and crop performance make model verification difficult; alternative practices using sub-field design may challenge grower adoption; soil carbon development takes years; soil carbon measurement is lab-intensive effort

Management & Technical Approach

- Use external partners with experience in production agriculture and biomass logistics
  - Antares Group, Inc.—Access to commercially-relevant stover feedstocks, provide technical support with identifying and **characterizing on-farm activities** associated with conventional and cover cropping systems and residue collection
  - Continuum Ag—Access to detailed information about cover cropping and regenerative agricultural practices, farm budgets, and commercial-scale in-field cover cropping applications

ContinuumAg

ANTARES Group Incorporated (301) 731-1900 ext. 216



Management & Technical Approach

Stover baled on rye grass cover

Beans emerging through rye grass and stover

- Break analysis and laboratory tasks into operational sub-tasks with clear intermediate goals
  - TEAs are iterative—identify uncertainties/unknowns of soil C & N values, cover cropping methods, cover crop impacts on grain yield; determine sensitivity of these unknowns and prioritize high-impact factors
    - Challenges include uncertain ecosystems services values for C & N
    - Uncertainties of soil carbon permanence (*…know of any 100-year stability data?*)
    - Market volatility of grain, anthropogenic N, and fuel
  - Go/No Go milestone used to down-select factors and focus efforts on more impactful research topics
    - <u>Question:</u> Can char enhance cover crops' N retention potential? If so, to what benefit and at what cost? (Go)
    - If not, then focus on how to model the cost/benefits balance cover crop & residue off-take rates with char to offset stable carbon removal. (No Go)

Progress and Outcomes

- Attended Continuum Ag's Field Day (June 6, '22 Washington, IA); topics included:
  - Managing fertility (grain yield) with soil health
  - Getting started in regenerative agriculture
  - Data driven decisions regarding nutrient management using soil N & C *tests that can be performed in field*
- Impacts:
  - Met with local producers to identify **WHYs and HOWs of cover crops**
  - Noted grower concerns around yields, inorganic N input reductions, and interruptions to conventional ag practices **that will be incorporated into our TEAs**

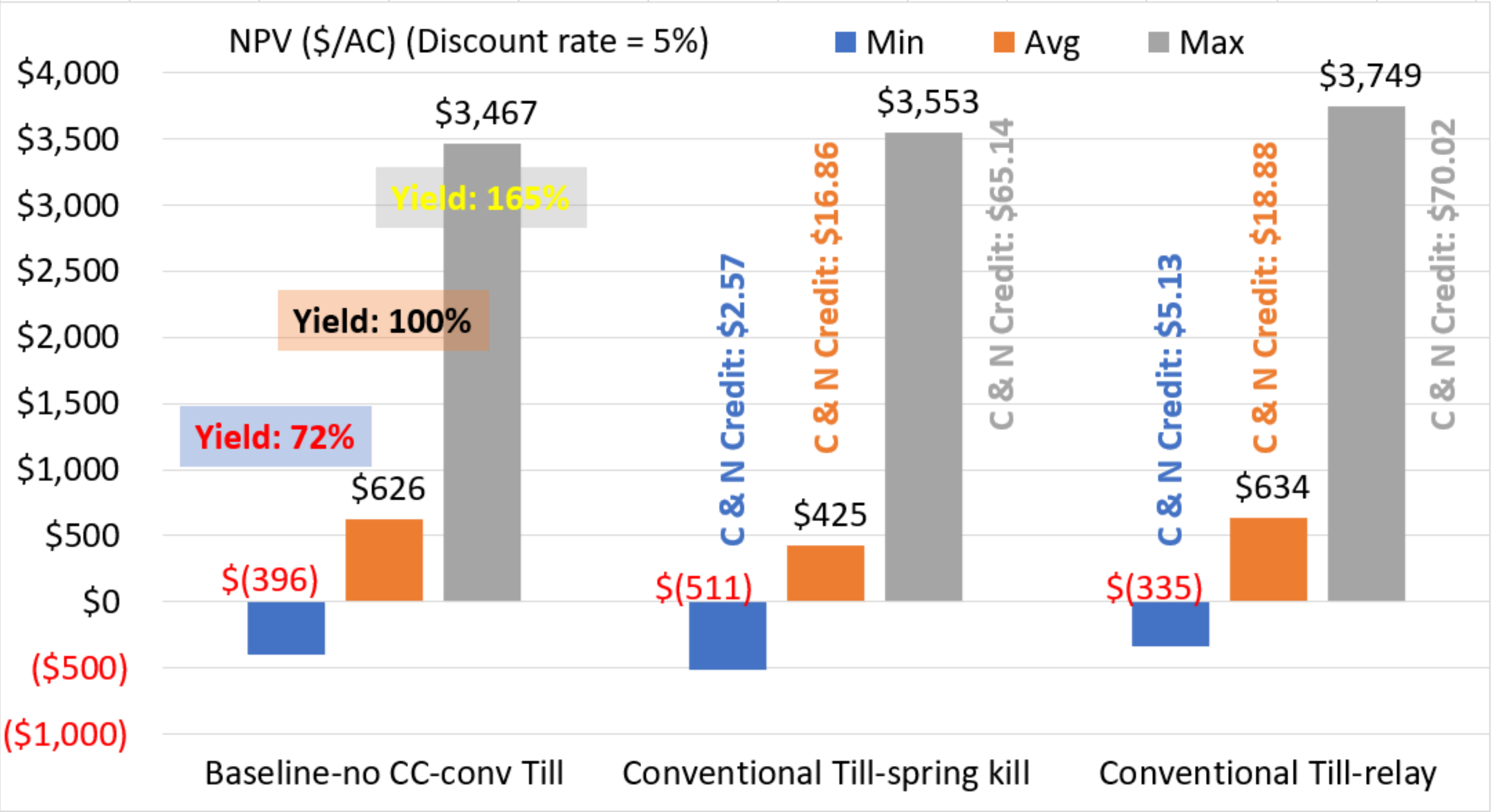
- DEI Goal: Working with student interns and post baccalaureate students from rural communities, as defined by USDA Economic Research Service

Progress and Outcomes

- **Established a baseline**–used as the reference for comparison of cover crop performance in TEAs and LCAs—of conventional corn/bean rotation with no cover crops
  - State averages, minimums, and maximums for Iowa, Illinois, and non-irrigated Nebraska and Kansas
  - Included row and cover crop management to capture grower's operations & cash flows
- Cover cropping included two methods plus conventional and reduced tillage
  - "**Spring Kill**" simulated using operations and costs of glyphosate used to terminate ryegrass cover crop (highest operational costs/lowest C & N credits)
  - "**Relay**" simulated planting corn/beans through rye grass in the spring (lowest cost/highest C & N credits)
- **Value of C and N credits vary:** a range was used based on high, low, and median values
- **No direct revenue was given for residue removal as removal rates with cover crops are to be determined (FY23 Q4)**
- 10-year cash flow analysis was used to reflect the impact of crop rotation to on-farm revenue
  - Uncertainties exist with respect to yield impact—positive or negative—of cover crops, which will be considered in FY24

Progress and Outcomes—Initial TEA: 10-yr Net Present Value (NPV) cash flow analysis ($/acre average for case)

- Loses occur during periods of lowest reported grain yields
- 1% increase in value for relay crops (Avg)
- 32% loss in value for spring killed (Avg)
- Spring kill uses additional resources, thus reduces profits
- Differences between average and maximum values largely reflects uncertainties in C & N values

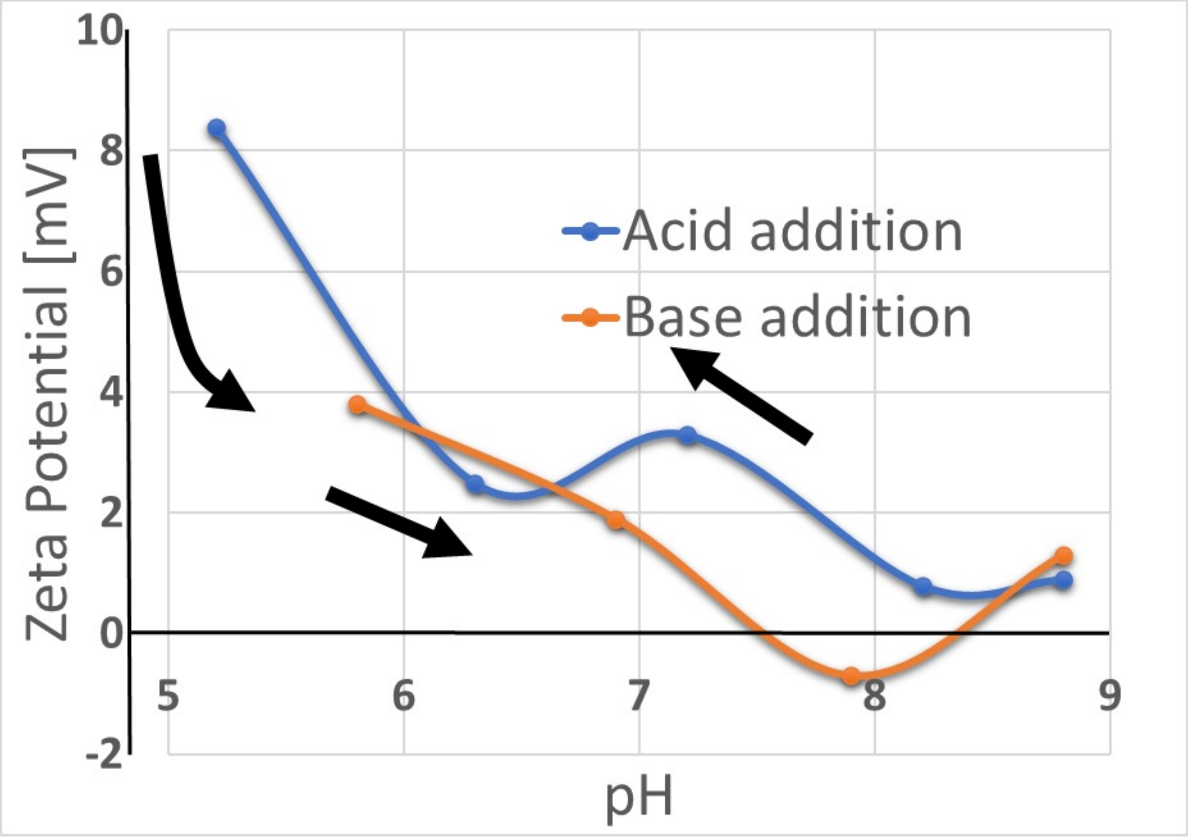


Progress and Outcomes

- Char can complement cover crops and be more than just a long-term carbon sink
  - Biochar may help retain soil nitrate and nitrite, thus lowering inorganic N needs
  - Results show that biochar from corn stover fractions has anion exchange capacity
  - Future analyses can be used to show the economic sensitivity to N retention
- Zeta Potential
  - Shows charge that charge is pH dependent but not long-lasting
  - More char options will be tested before Go/No Go decision (FY22 Q3)
- <u>Impact:</u> Results show that biochar can be more than stable carbon; when combined with cover crops the retained N has potential to reduce inorganic N inputs and allow more stover to be removed while maintaining soil C

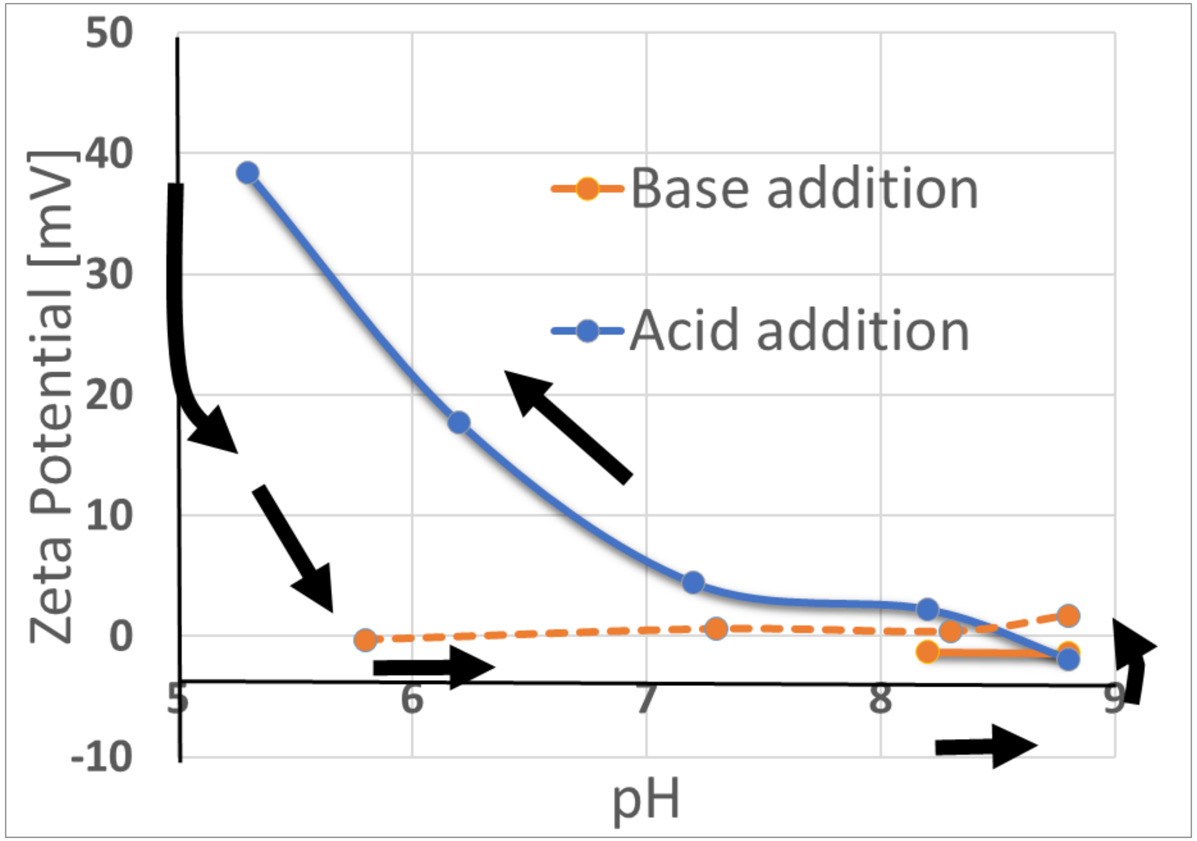
Progress and Outcomes— Zeta Potential: "Heavy" fraction

- Heavy fraction of corn stover: stalks and cobs
  - Easily separated by air classification
  - Anatomical fractions differ in composition
- This char has a weak positive surface potential at low pH
- The surface potential goes to zero as the pH increases
- Char from heavy fraction has a weak anion exchange capacity in acidic environments (potential for nitrate & nitrite retention)
- **Heavy fraction is more valuable for conversion for its carbohydrates**



Progress and Outcomes—Zeta Potential: “Light” fraction

- Light fraction of corn stover: leaves, husks, and “fines”
  - Easily separated by air classification
  - Fraction high in ash including silica and soil components
- Stronger anion exchange potential in acidic soils than the heavy fraction
- However, it loses all surface potential after initial acidification
  - Some component—possibly carbonate—may be consumed at low pH
- **Less valuable fraction may be better suited for biochar, but successful candidate must survive repeated cycles**



Progress and Outcomes NIR Bale Probe for Soil Carbon

- Foundational work necessary to enable high-fidelity soil carbon measurements that provide data that will enable sub-field application of cover crops and/or char
  - Engaged staff at USDA National Laboratory for Agriculture and the Environment (NLAE)
  - Obtained access to well-characterized soil samples for chemometric calibrations
    - Positive reception by USDA suggests agency interest in collaboration—formal or informal—which strengthens our ability to attack the problem of decarbonization of agricultural residues from both the soil health and **biofeedstock supply** directions
  - Analytical spectral sample analysis planned for FY23 Q3
- Impact: Joint work with NLAE provides opportunities to speed development and deployment to give end users and producers access to valuable, quantitative soil carbon data in support of their decarbonization efforts & **provide confidence in their efforts to supply low CI residues**

Cover crop emerging after stover collection

Impacts

- TEAs show how **risks/returns of cover crop and residue removal can be balanced**
  - Sale of residue vs. potential grain yield and soil carbon losses
  - Evaluate potential benefits using models before performing any field trials
  - Communicate results via peer-reviewed publications, Ag engineering conferences, & webinars
- Field data provides initial results of **residue removal rate on soil C & N** in cover cropping
  - Use cover crops to offset carbon and nutrients removed in residue
  - Show how cover crops/variable residue removal rates can reduce the need for inorganic N additions, thus improving **on-farm cash flow and environmental benefits** that lower CI
- Evaluation of char as more than just sequestered carbon
  - Retain nutrients in the field rather than lost to leaching—again, **managing nutrient costs**
  - Add environmental benefit to soils at risk of nitrate leaching
- Adapt NIRS Probe for evaluating soil carbon
  - Rapid, in-field deployable tool for spatially and temporally variable and critical soil component to show decarbonization potential—**enables R&D via high resolution in-field monitoring**
  - Publish results in high-impact peer reviewed publications

Summary

- BETO is working to decarbonize ag residue collection to enable low CI feedstocks
- Working with Antares, local producers, and Continuum Ag to evaluate emerging cover cropping practices relative to on-farm costs & environmental benefits
- Comparing a range of alternatives—including landscape design—to a baseline obtained from "conventional" corn-bean rotations in high-yielding region (Iowa)
- Using the lab to evaluate biomass (stover & cover crop residue) quality relative to critical material attributes defined by the Feedstock Conversion Interface
- Starting with a range of operations/costs/environmental benefits from peer reviewed sources; use sensitivity analyses to find greatest impact & largest knowledge "gaps"
- Evaluating the use of biomass fractions to make char more than just long-term soil C
- Will publish results in peer-reviewed venues; distill findings into "white papers" for producers and biomass users (i.e., the Pioneers) ease their "learning curves"
- Building on BETO-funded Biomass Probe to develop rapid, field-deployable tool for measuring soil carbon to improve soil C measurement spatial and temporal fidelity
- **Project combines TEA, lab testing, and residue removal in field plots to show decarbonization and grower benefits**

Quad Chart Overview

Timeline

- *Project start date: 10/1/2021*
- *Project end date: 9/30/2024*

	FY22 Costed	Total Award
DOE Funding	*$480,915*	*$2,250,000*
Project Cost Share *	n/a	n/a

TRL at Project Start: 2
TRL at Project End: 4

Project Goal

Results of this work will provide a technical and economic evaluation of emerging cropping systems that will identify the magnitude of the potential benefits above and beyond ecosystem services. Residue removal will be evaluated for its sustainable nutrient removal capacity, yield, and value to a conversion process. This information can be used to demonstrate the feasibility of cover cropping and biomass removal to generate on-farm economic benefits as well as provide a lower carbon intensity agricultural residue for conversion to sustainable aviation (SAF) and/or marine fuels (SMF).

End of Project Milestone

Using metrics of costs, carbon use intensity, yield, and biomass quality (relative to FY22 SOT) evaluate two cover crop/residue removal scenarios that meet or exceed the performance of the baseline system defined in FY22. Stretch goal: use "ground-truthed" field data for one or both scenarios.

Funding Mechanism

Funded through DOE-BETO Annual Operating Plan (AOP)

Project Partners*

- Antares Group, Inc. (Bill Belden, Tim Rooney)
- Continuum Ag, Inc. (Mitchell Hora)

*Only fill out if applicable.

Thanks to:

- Tammy Lin, Pralhad Burli, Rajiv Paudel, Damon Hartley, and David Thompson at INL in the execution of this work and preparation of this presentation.
- Bill Belden, Tim Rooney, and Bonnie Hames at Antares Group for technical support, ideas, and guidance in the planning of this work.
- Mitchell and Brian Hora of Hora Farms LLC and Continuum Ag for technical support, producer insight, and their patience with my questions about cover cropping operations.
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- Doug Karlen for many of the photos used today.

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Additional Slides

Responses to Previous Reviewers' Comments & Go/No Go Description

- This is this projects first Peer Review; no direct comments to address
- In general, our project presentations have been identified as too "tech heavy"; we've made a point of focusing on the outcomes and impacts in this presentation
- Go/No Go will occur in FY23 Q3 to permit time to evaluate a wider range of sources of biochar
  - Decision will be made to either pursue quantifying the economic and environmental benefits of char for nutrient retention, or…
  - Drop the nutrient retention value estimation and focus on char solely as a long-term carbon source in our TEAs and LCAs
  - Purpose is to either capitalize on this property to offset—thus avoid—carbon intensity of inorganic N addition (novel proposal) or use existing and emerging literature values for biochar costs (production and application) and values (estimates of long-term carbon stability)
- Criteria for Go/No Go: Identify char materials with >40 meq/100g (nominal ion exchange capacity of soil)
  - If Go, then **quantify benefit** relative to additional value for nutrient retention potential
  - If No, then use char only for carbon amendment in TEAs

Publications, Patents, Presentations, Awards, and Commercialization

- New start in FY22 (starting in Q2)
- No publications to date.
  - FY23 End of Year milestone will provide the results for a planned peer review manuscript
    - "*The use of sub-field cover cropping strategies to improve the yield and reduce the carbon intensity of corn stover residue removal*"
- Working with Antares Group and Dr Bonnie Hames on Biomass Probe adaptation for soil carbon measurements and other potential commercial uses to evaluate biomass feedstocks and soil additives

Project Overview—Why Cover Crops & Soil Carbon?

- "BETO is focused on technologies to efficiently convert organic materials and biomass into affordable biofuels and bioproducts. These bioenergy technologies will help **decarbonize the transportation sector**, while mitigating greenhouse gas emissions to combat climate change." (*https://www.energy.gov/eere/bioenergy/about-bioenergy-technologies-office*)
- Environmentally sustainable renewable biomass feedstocks rely on **soil & nutrient management** plus soil **carbon storage** (*March 28, 2022 BETO Workshop: Bioenergy's Role in Soil Carbon Storage*)
- BETO uses Greenhouse gases, Regulated Emissions, and Energy used in Transportation (GREET®) Carbon Calculator for Land Use Change from Biofuels (CCLUB) to evaluate energy and environmental effects (*https://www.energy.gov/eere/bioenergy/articles/greet-greenhouse-gases-regulated-emissions-and-energy-use-transportation*)
- Farming, fertilizers, pesticides, and land use change contribute to feedstocks CI score
  - Includes N, P, K, $CaCO_3$, herbicide, and insecticide plus on-farm operations
- Practices of **cover cropping** and **biochar** amendment to agricultural soils have potential improve environmental sustainability (*as does tillage, but that's outside this scope*)
  - We must enable an ample & sustainable **supply** of bio-based feedstocks

Abstract

- This task identifies technically feasible but currently underutilized cover cropping systems with potential to decarbonize agricultural activities associated with corn stover harvest as a feedstock for conversion to sustainable fuels. The project focuses on the economics, biogenic carbon use, and biomass quality impacts of using cover crops where the stover residues are used as feedstock for fuel production. The novelty of this work is that it goes beyond traditional ecosystems services and uses existing consensus values of those services as a baseline monetary value from which we will measure success. Objectives include: 1. economic evaluation of combining cover crops with agricultural residues to improve on-farm economics with and without cover crops, 2. decarbonization potential of combining cover crops with residue removal relative to conventional agrichemical application and field operations, 3. laboratory-scale evaluation of cover crop materials, 4. evaluation of economically advantaged biochar to modify soil carbon, and 5. testing of INL's bale probe to measure soil carbon. Results will be used to populate and expand INL's feedstock logistics models. The outputs will be used to show how cover cropping, residue removal, and integrated land management have potential to provide growers with a sustainable additional income stream and supply biorefineries with a high-quality and sustainable biomass resource.