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1.1.2.2

Maximizing the Value of Cover Crops in the Pacific Northwest

DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review
Feedstock Technology Session

Daniel Santosa (PI), Aye Meyer, Francesca Pierobon
Pacific Northwest National Laboratory (PNNL)

Chad Kruger, Teal Porter, Doug Collins, Steve Norberg, Aaron Esser, Jonathan Male
Washington State University (WSU)

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Project overview: **COVER CROPS AND BIOFUELS**

- Cover crops have multiple benefits—<u>soil health is the most important benefit</u>.
- Cover crops as a feedstock for biofuels?

Cover crop from cropland in Washington

Commercial feedstock

supply and logistic system

Biofuel production [hydrothermal liquefaction (HTL) and biocrude upgrading]

BIOFUEL

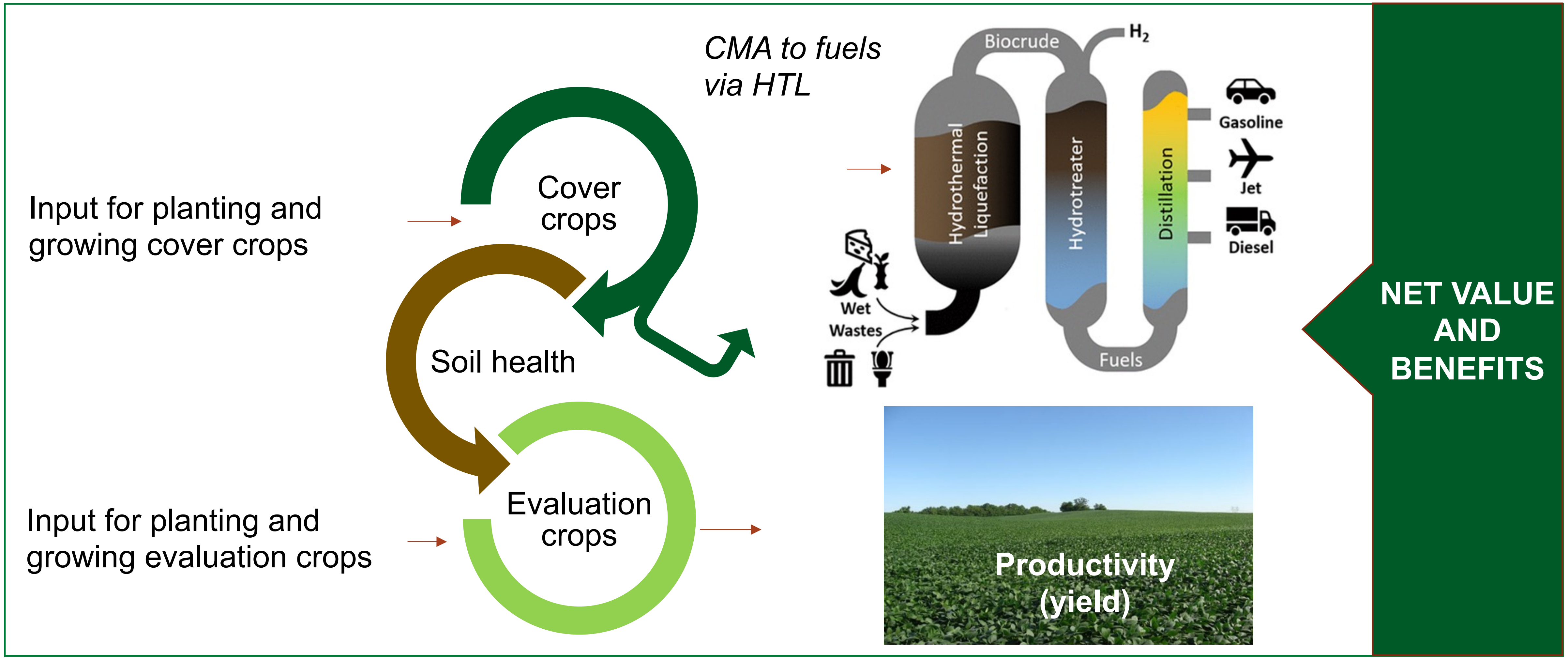
7% of the U.S. biofuel production in 2021[1]

- This effort aligns with BETO's mission to improve agricultural and agronomic practices within DOE Energy Efficiency and Renewable Energy Office's effort to decarbonize *agricultural* and *transportation* sectors.
- Economic opportunity to benefit local and regional farmers that are part of minority groups and for energy production (<u>used only in 3.9%[2]</u> of all U.S. cropland in 2017; <u><1% in Washington state[3]</u>).
- Primary challenges to adoption are uncertainties in use of cover crops across states and includes relative roles of *climate*, *soil type*, *production practices*, and *policy*[2].

❑ Cover crops could be a significant element in biofuel feedstock supply and logistics.

(1) In 2021, U.S. ethanol production totaled about 15 billion gallons and combined biodiesel/renewable diesel production totaled about 2.5 billion gallons.
(2) Cover Crops, 2017 U.S. Census of Agriculture (3) https://agr.wa.gov/departments/land-and-water/natural-resources/agricultural-land-use

1. Approach: MAXIMIZING THE VALUE OF COVER CROPS



- Grow cover crops in at least two growing seasons to understand seasonal variability in three weather systems.
- Characterize critical materials attribute (CMA) for fuels production via HTL pathway.

https://www.feedipedia.org/node/294

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1. Approach: PROJECT STRUCTURE

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOENERGY TECHNOLOGIES OFFICE

- Maintain synergies in BETO project portfolios
- Make decisions on resource distribution/allocation

- Project updates
- Quarterly milestones
- Annual milestones
- GO/NO GO report

Monthly and quarterly meetings

- Resources
- High-level direction for the technology area
- Technical feedback

Engaging farmers from under-represented regions and rural communities [Diversity, Equity, Inclusion, and Power (DEIP)].

Field day(s) meeting for demonstration

WASHINGTON STATE UNIVERSITY

WSU Center for Sustaining Agriculture and Natural Resources

- Establish and harvest cover crops and cash crops
- Evaluate soil property/health

- Crop yields
- Chemical usages
- Soil properties

Biweekly project meetings

- Technical feedback

PNNL

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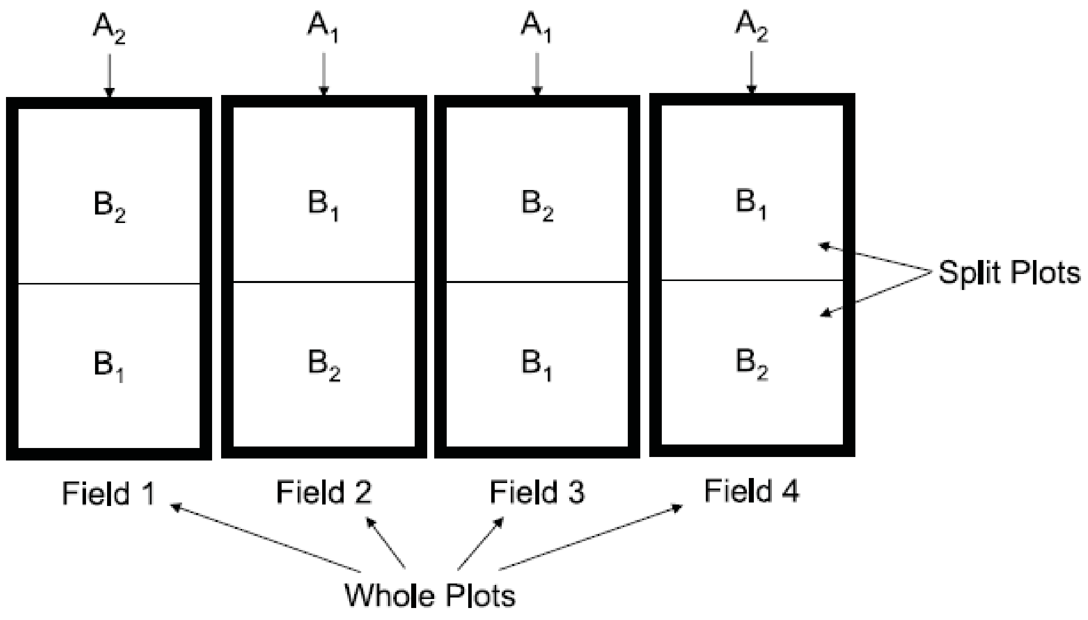
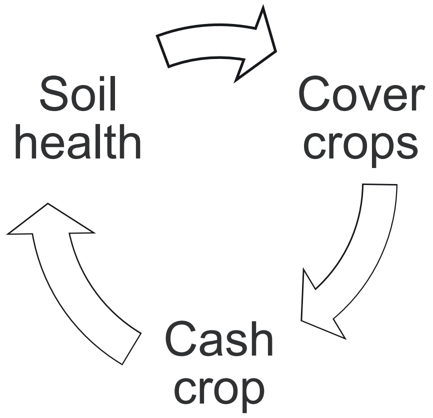
- Project management
- Biomass analysis
- Cost and environmental impact analysis [technoeconomic analysis (TEA) and lifecycle analysis (LCA)]

❑ The project brings together detailed knowledge from WSU (growing crops, sustainable agriculture, and soil characterization) with PNNL's expertise in biomass conversion, techno-economic analysis, and life cycle assessment.

1. Approach: COVER CROP SELECTION AND PLANTING



Split plot agricultural layout. (**Factor A** is the whole-plot factor (i.e., cover crop type) and **Factor B** is the split-plot factor (i.e., cover crop harvested and removed versus left in the field).



Site Location	Puyallup (Western WA)	Othello (Central WA, Irrigated)	Davenport (Eastern WA, Dryland)
Cover Crops	triticale	triticale (flex 719)	triticale
	hairy vetch	hairy vetch	
	red clover	red clover	
	winter pea or fava bean	winter pea	pea
Planting Date	Sept. 1-15	Sept.1-15	Sept. 1 - March 31 (depending on rain)
Biomass termination date	May 15	April 15	May 14-31
Follow-up evaluation crop	Sudan grass	soybean (hay)	winter wheat (following fallow)
Plot size in feet	12 x 50	10 x 50	25 x 200
Treatments	No cover crop	No cover crop	No cover crop
	Cover crop - full biomass removal	Cover crop - full biomass removal	Cover crop - full biomass removal
	Cover crop - no biomass removal	Cover crop - no biomass removal	Cover crop - no biomass removal
	Cover crop - partial biomass removal (potentially)		

- The experimental design is to isolate the effects of cover crops and their removal on cash/evaluation crop performance

Bradley Jones et al. Journal of Quality Technology (2009)

1. Approach: EVALUATE COST BENEFITS FROM COVER CROPS

Farmer: Possible profit from cover crop farm management

+ Revenues

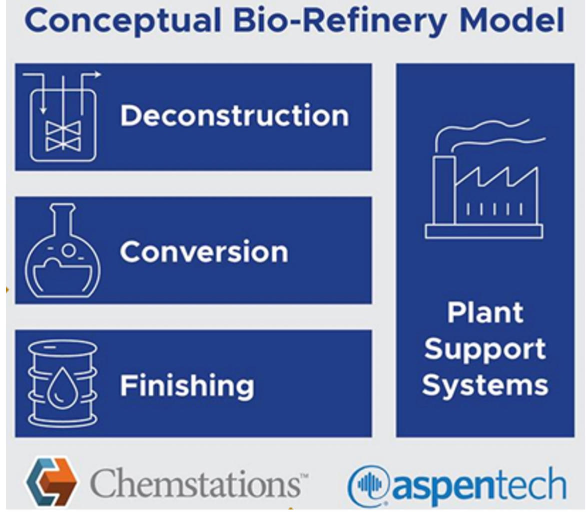
- Cash crop revenue
- Cover crop revenue (to biofuel plant)

- Costs

- Cover crop planting and harvesting
- Cash crop planting and harvesting
- Soil improvement

Biofuel producer: Competitive biofuel price from cover crop feedstock

Yield and process performance



Adopting HTL and biocrude upgrading[1] process design

Mass and energy balances

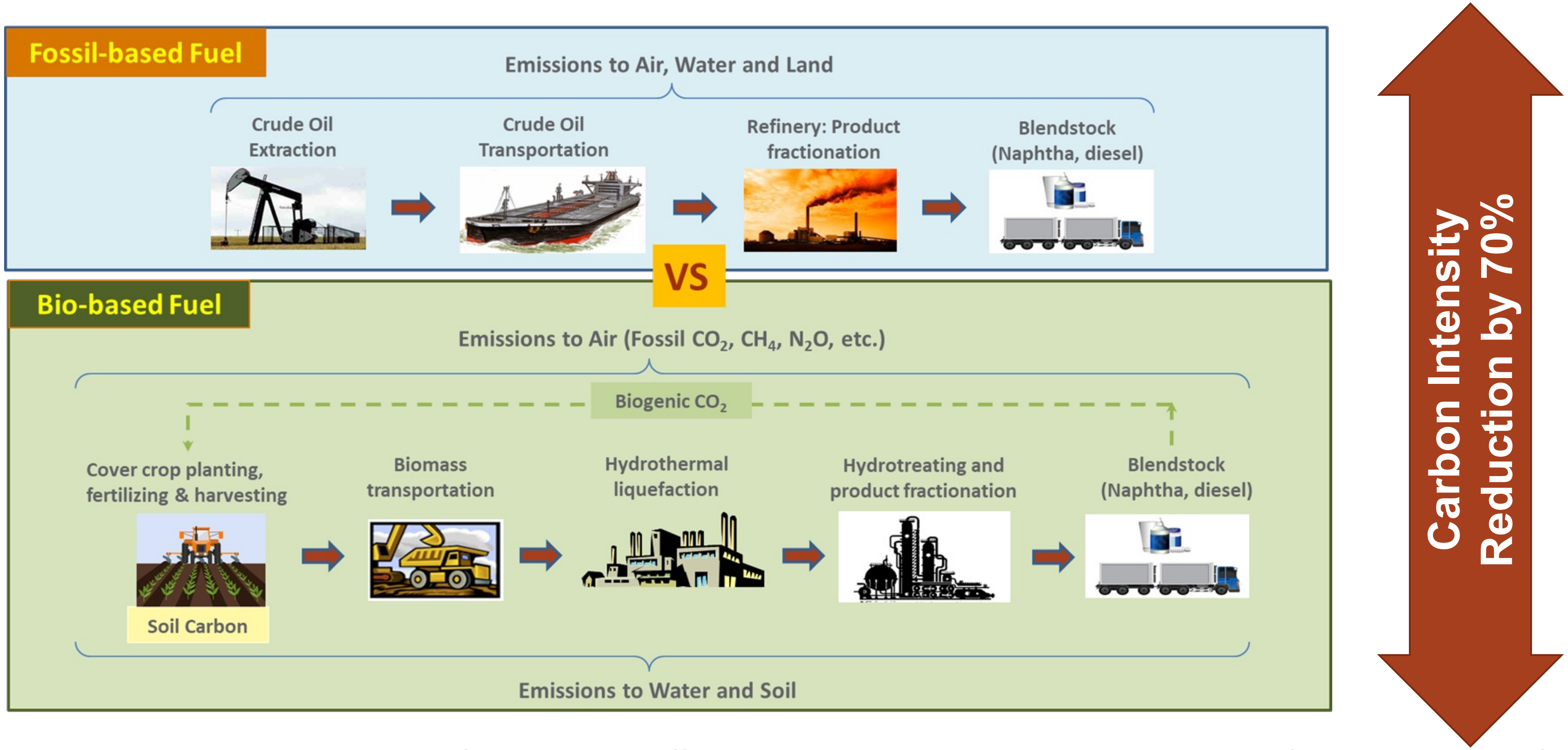
Biofuel price

Using common BETO TEA financial assumptions for CAPEX and OPEX evaluation

- ❑ This work will optimize the economic trade-off between growing for soil health (cash crop as proxy) and growing for biofuels.

[1]Snowden-Swan LJ, Y Zhu, MD Bearden, TE Seiple, SB Jones, AJ Schmidt, JM Billing, RT Hallen, TR Hart, J Liu, KO Albrecht, SP Fox, GD Maupin, and DC Elliott. 2017. Conceptual Biorefinery Design and Research Targeted for 2022: Hydrothermal Liquefaction Processing of Wet Waste to Fuels, PNNL27186, Pacific Northwest National Laboratory, Richland, WA.

1. Approach: CRADLE-TO-GATE LIFECYCLE ANALYSIS



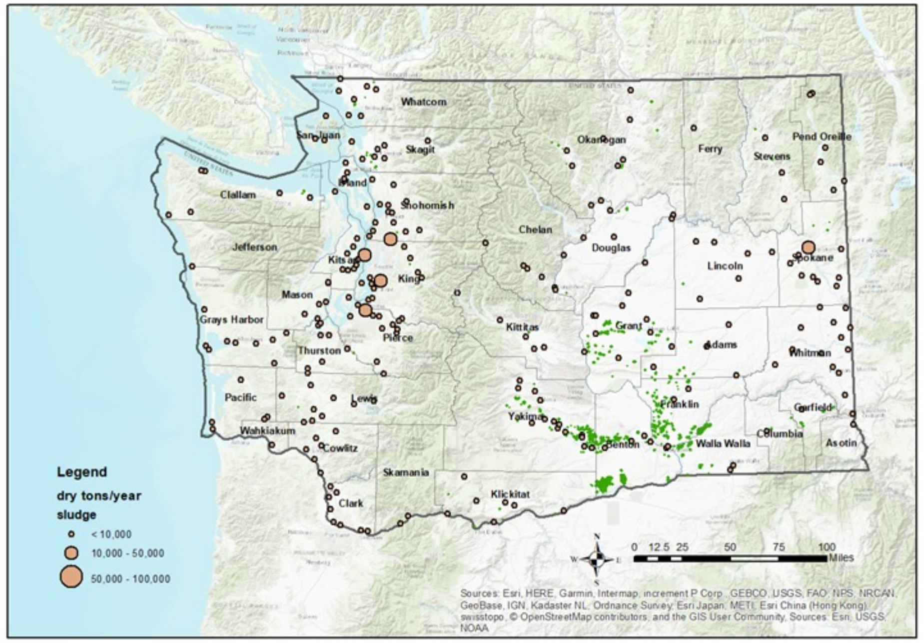
- This project seeks to understand factors that affect overall global warming potential of the bio-based fuel system, including cover crop practice, feedstock transportation, conversion, and final fuels distribution (cradle-to-gate).

1. Approach: GO/NO GO

Assessing the initial technical, environmental, and economic feasibility of cover crops to be harvested to produce biofuels (3/31/23).

DESCRIPTION	CRITERIA
TEA and LCA will show the net impact of harvesting the biomass cover crop and whether it is equal to or better than not harvesting the biomass cover crop in one season.	▪ CMA on cover crops biomass to biocrude and biofuels via HTL. ▪ TEA and LCA for two cover crops in one of three locations shows not (-) to the cash crop. ▪ Soil health/fertility to assess productivity in cash crop.

Sludge and cover crop availability in Washington State



Leveraging waste to energy 2.1.0.113: Enhancing the model based on co-locating waste treatment plants with current cover crops farms.

❑ GO/NO GO IS COMPLETED: Net impact of cover crops in at least one of the three location was (+) in terms of revenue and environmental impact.

1. Approach: RISKS AND MITIGATION STRATEGIES

Risk	Mitigation strategies
Weather can delay and diminish cover crop production	The crop production design is over several years to capture variability in weather.
Cover crop has low yield of bio-oil via HTL	Establish CMA of the feedstock and how it effects bio-oil production; explore blending of cover crops with wet waste streams.
Cover crops and subsequent cash/evaluation crop yields can be variable	Cover crops are grown in replicates of four for each treatment (no cover crop, leave cover crop on field, harvest cover crop) at each site and at least two cover crops are grown at each site.

2. Progress and Outcomes

Key Technical Milestones	TIME	Status
Complete cover crop selection and planting - first year	12/1/2021	Completed
Complete subsequent evaluation crop selection and planning	3/1/2022	Completed
Complete harvesting of cover crops	6/1/2022	Completed
Determine how cover crops will convert to bio-oils	9/1/2022	Completed
Start to engage surrounding rural communities at sites in Washington state (DEIP)	9/1/2022	DEIP-Completed
Complete cover crop selection and planting - second year	12/1/2022	Completed
Complete subsequent evaluation crop selection and planning	3/1/2023	Completed
Go/No Go	3/1/2023	Completed
Complete harvesting of cover crops	6/1/2023	On track
Complete second year of rotational effects of cover crops and assessment of benefits from converting cover crops into biofuels	9/1/2023	On track
Complete seasonal effects on cover crops and assess economic and environmental benefits of converting cover crops into biofuels – third year	9/1/2024	On track
Within tradeoffs of biomass production and ecosystem services, derive greater value from at least one of four most promising cover crops compared to the off-season oil crop as a baseline	9/1/2024	On track
Engage surrounding rural communities and communicate findings to increase inclusiveness in latest research	10/1/2024	DEIP-on track

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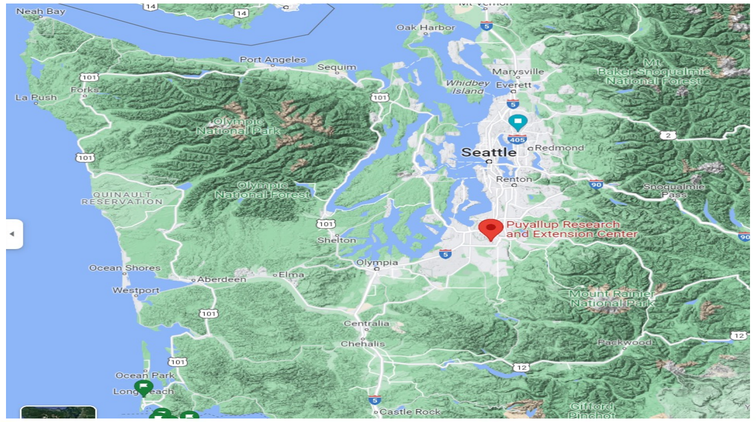
2. Progress and Outcomes: **COVER CROP GROWTH AND HARVESTING IN THREE LOCATIONS WAS *SUCCESSFUL***

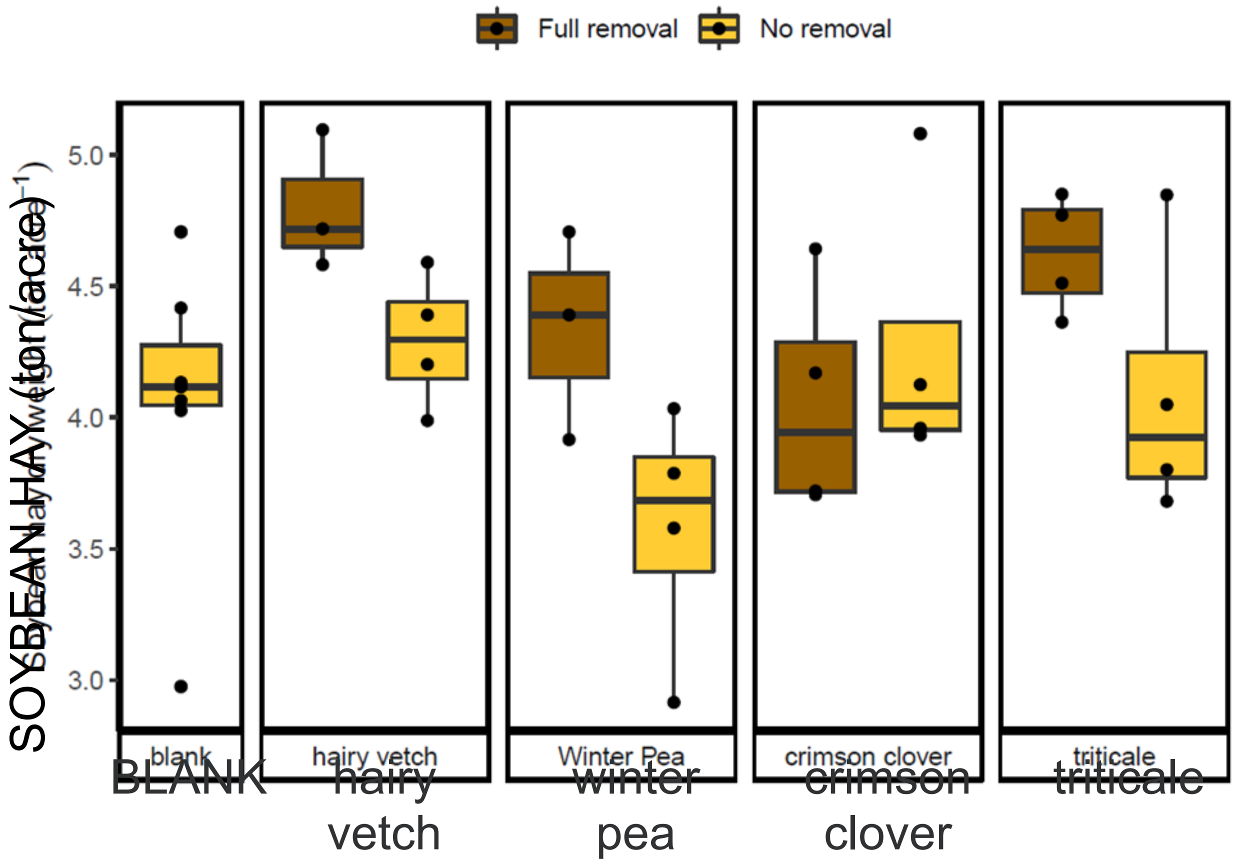


- Weeds are suppressed by cover crops.
- Biomass CMA is evaluated based on lipid, protein, carbohydrate, ash, and moisture content.

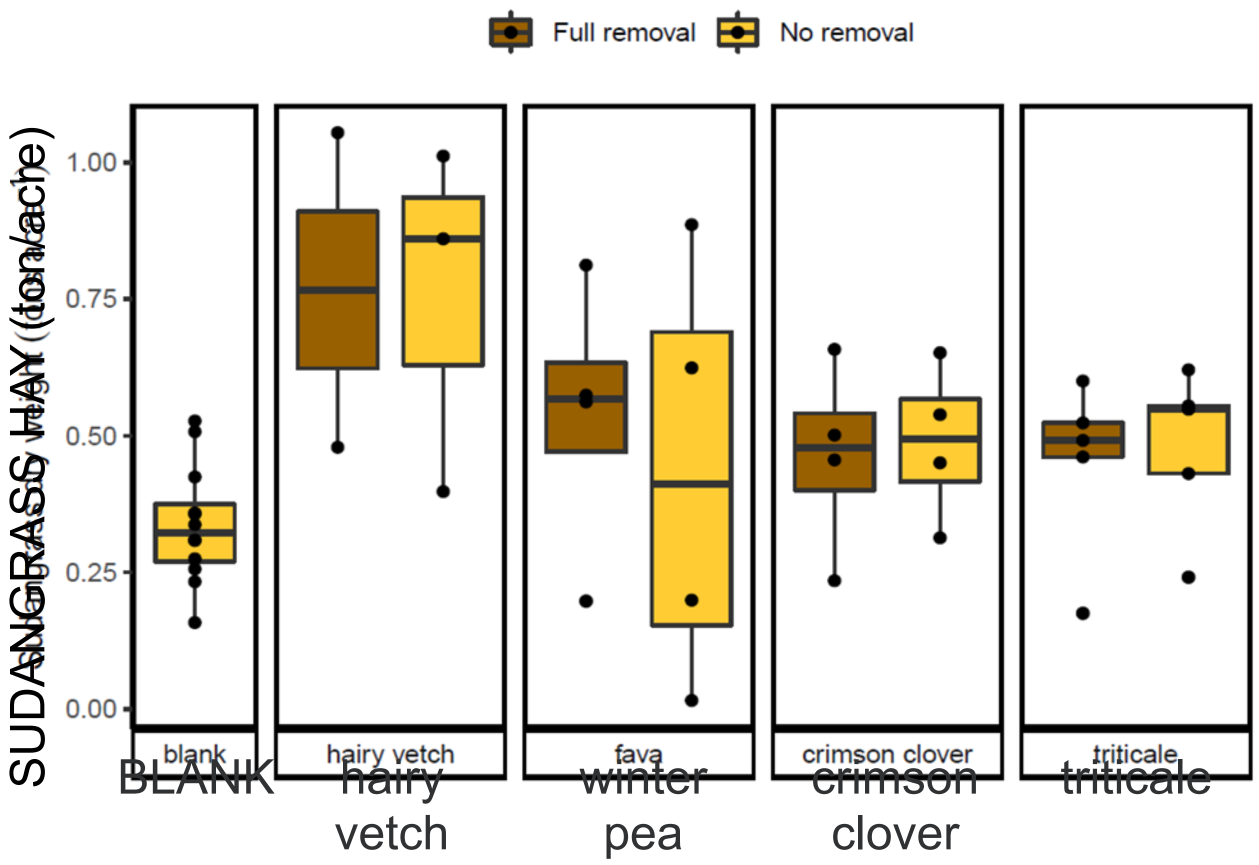
1ST YEAR RESULT:

Triticale and Vetch produced the most biomass above ground in the high precipitation area.

2. Progress and Outcomes: COVER CROPS DO NOT HURT CASH CROP PRODUCTION



Irrigated – Othello, WA



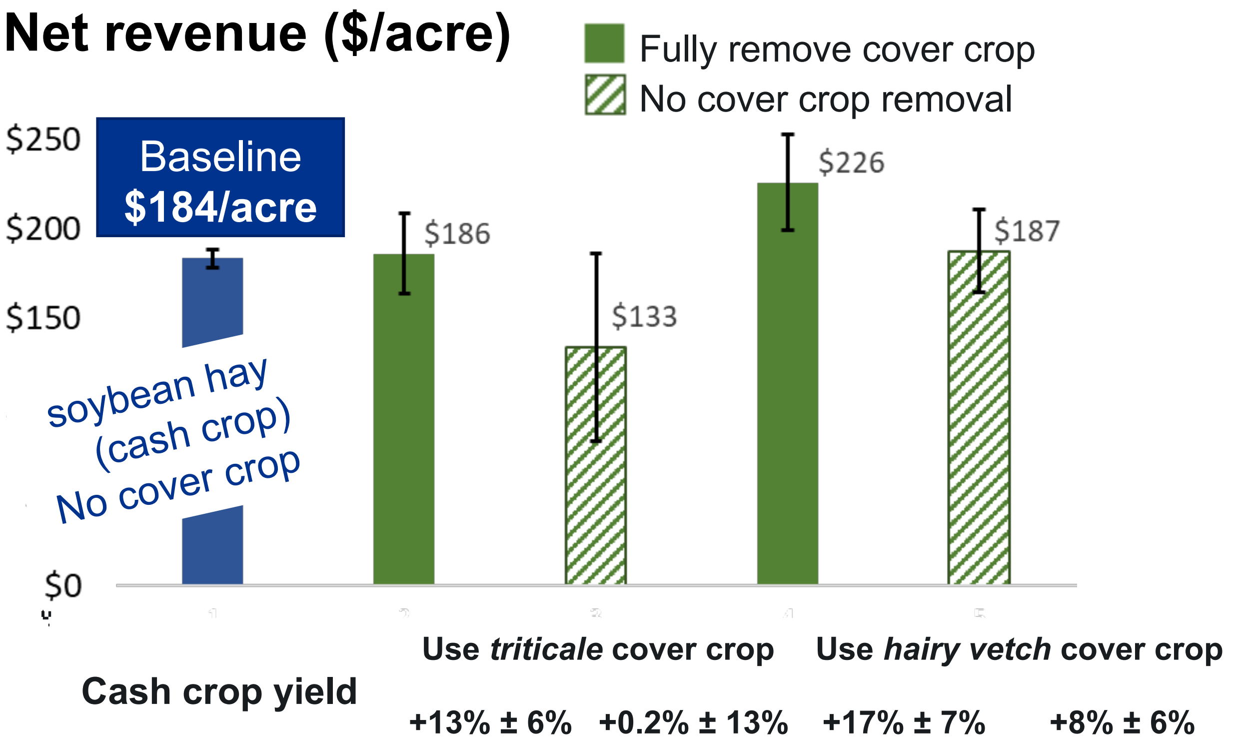
High precipitation – Puyallup, WA

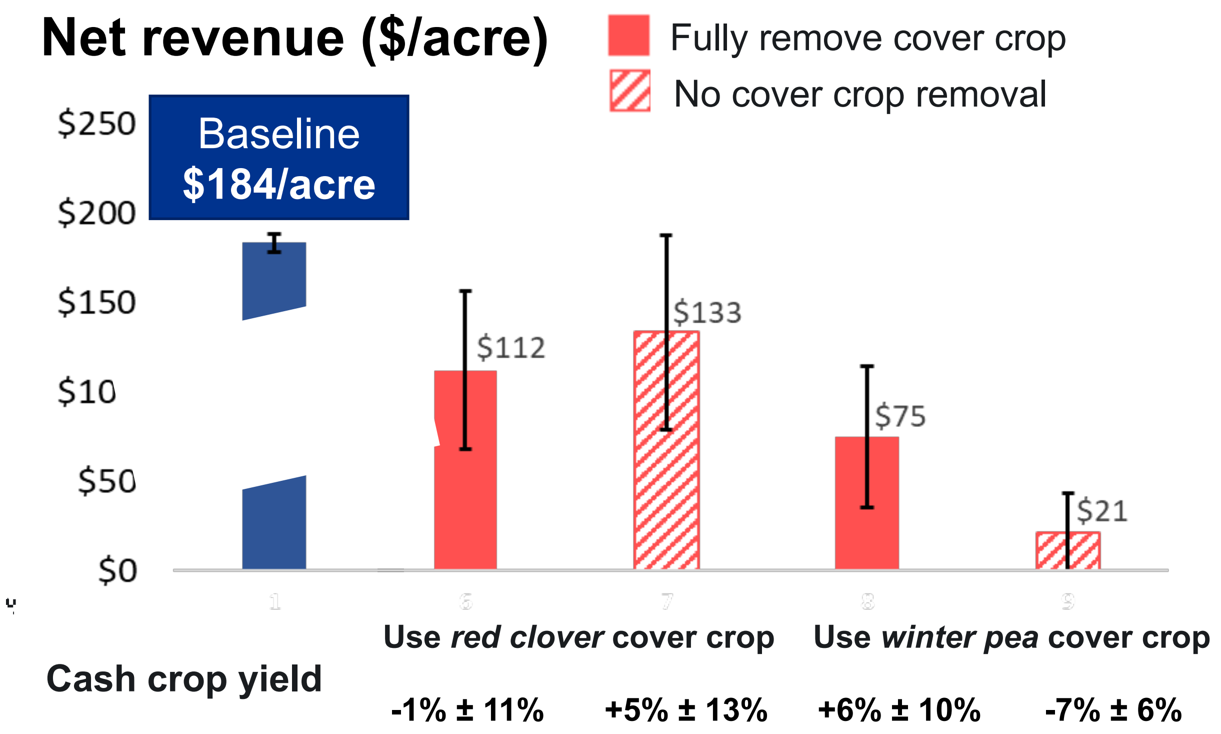
- ❑ Hairy vetch – highest impact on cash crop yields across two sites.
- ❑ Full removal (highest potential for biofuels) is equal to or better than not harvesting the cover crop with regards to net impact on the evaluation/cash crop.

2. Progress and Outcomes: FIRST YEAR TEA SHOWS POTENTIAL (+) *COST BENEFITS* FROM COVER CROPS

Othello, WA (Irrigated land) site; Cash crop: soybean hay

Revenue* = cash crop revenue – expense (growing and harvesting crops)



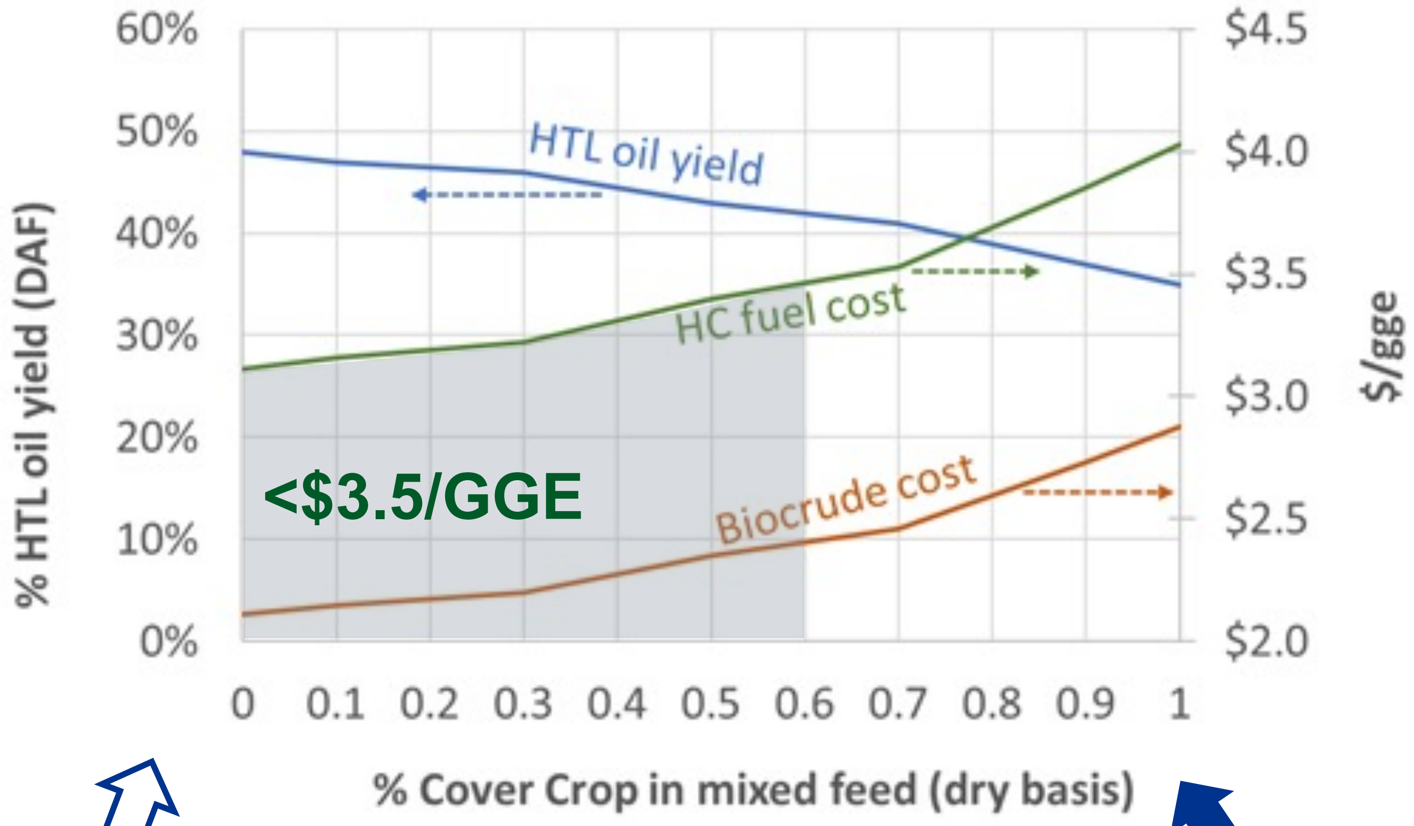


Improved cash crop yields. Net revenue ≥ $184/acre

Yield improvement didn't compensate for expense to manage cover crops. Net revenue ≤ $184/acre

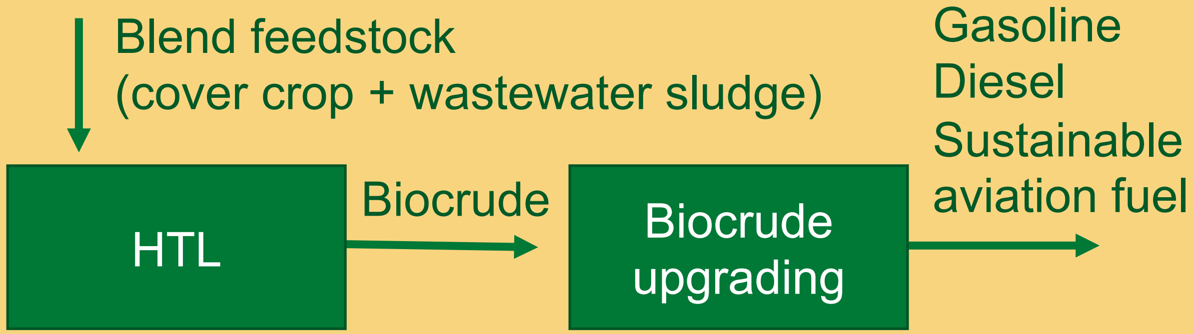
- ❑ Revenue from cash crop is (+) due to increased yield, especially for triticale and hairy vetch.
- ❑ *Not including biofuels revenue. Additional revenue as biofuel can further increase revenue to farmers.

2. Progress and Outcomes: **BLENDING COVER CROPS FOR BIOFUEL FEEDSTOCK IS PRACTICAL TOWARD ACHIEVING <$3/GALLON PER GASOLINE EQUIVALENT**



100% wastewater treatment sludge in biofuel feed

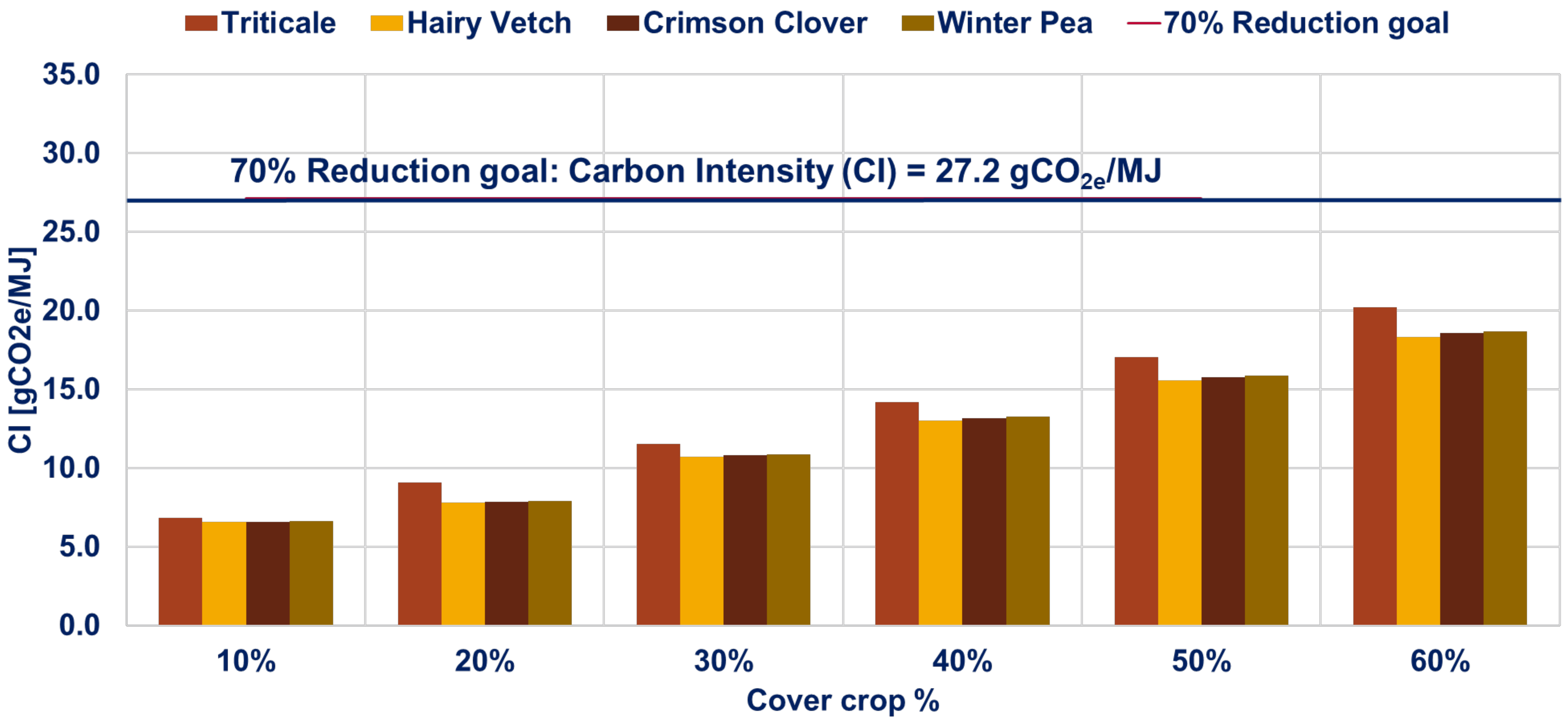
100% cover crop material in biofuel feed



- Cover crop has high carbohydrate and lignin content and limited seasonal availability.
- Blend is key to promote sustainability.
- < $3.50/GGE model cost achieved from blending up to 60% of cover crop.

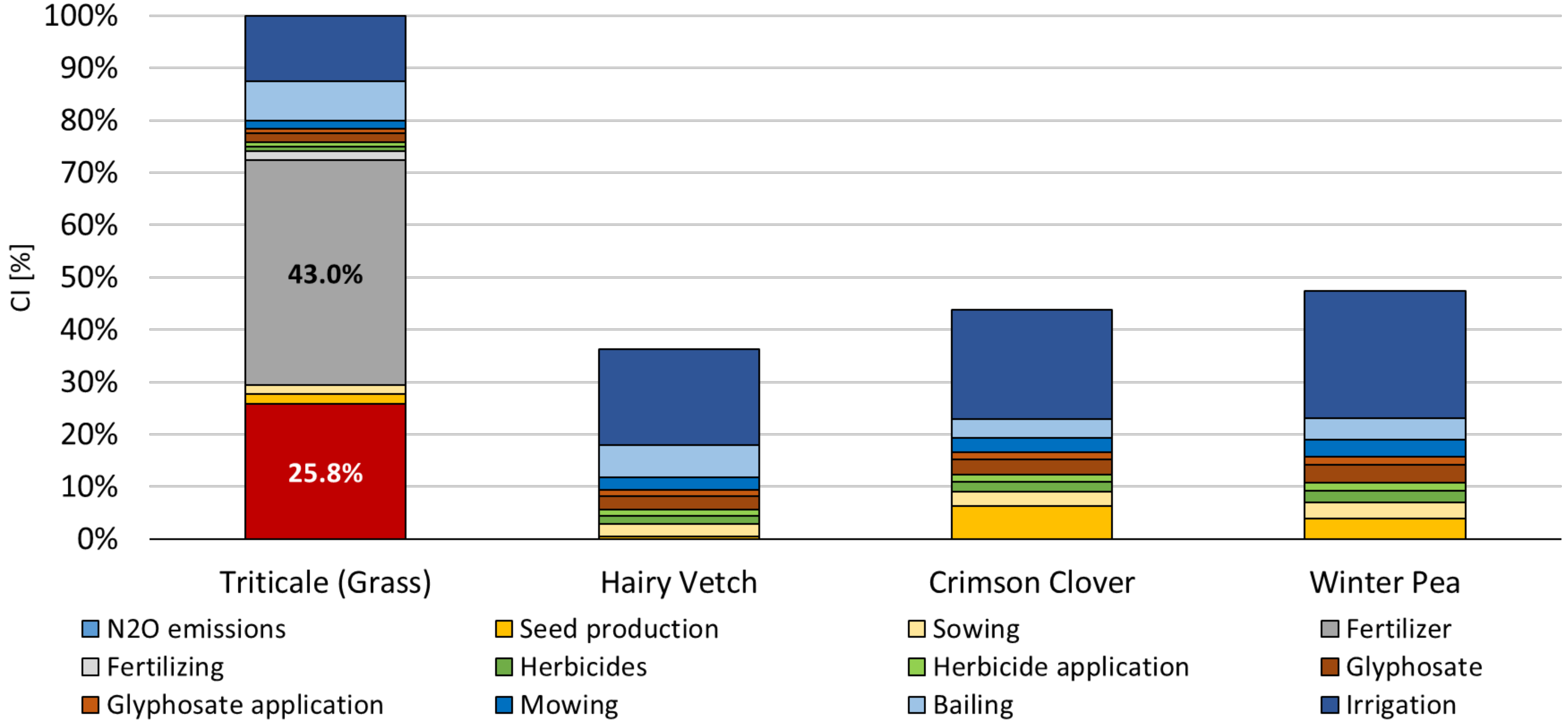
- ❑ Feedstock cost and availability is key driver in fuel production cost.
- ❑ Blending cover crops with other abundant biofuel feedstock is a sustainable way to meet < $3.5/GGE.

2. Progress and Outcomes: BLENDING COVER CROPS IS KEY TO MEET CARBON INTENSITY TARGET



- ❑ Blending with sewage sludge is advantageous in meeting carbon intensity and stabilizing feedstock supply.
- ❑ Blending up to 60% of cover crop achieved the best carbon intensity reduction and < $3.50/GGE.

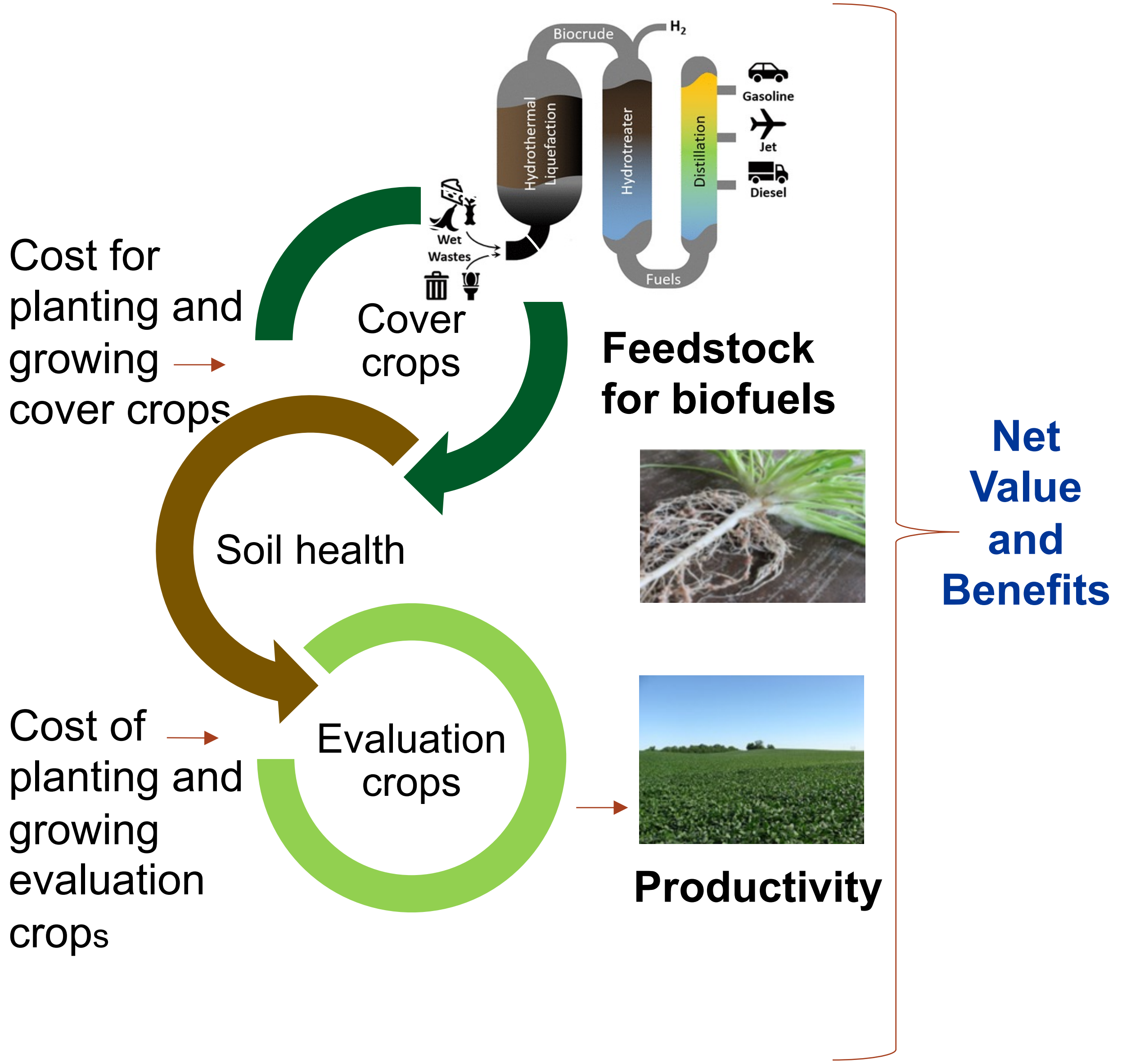
2. Progress and Outcomes: **MINIMIZING FERTILIZER USE IS KEY IN REDUCING CARBON INTENSITY**



- ❑ Fertilizers and the N_2O emissions associated contributed to >50% of CI in Triticale production.
- ❑ Using legume cover crops resulted in the lowest carbon intensity.

3. Impact: COVER CROPS CAN INCREASE OVERALL PRODUCTIVITY OF LAND AND PROVIDE (+) BENEFIT FOR BIOFUELS PRODUCER

- **Field experimental data from first year shows positive impact on growing cover crops**
  - No negative impact on cash crop or soil health
  - (+) revenue from cover crops when sold as biofuel
  - Legume cover crops shows the lower carbon intensity due to less or no fertilizer requirement.
- **Preliminary analysis shows up to 60% blending of cover crops with sewage sludge can achieve modeled cost < $3.5/GGE and > 70% carbon intensity reduction**
  - Increased cover crops adoption can help fill gap of feedstock availability to enable deployment of additional conversion pathways such as HTL to help meet sustainable aviation fuel volume goal by 2030
  - Enable HTL pathway to produce 3.9 billion gal/year of sustainable aviation fuel (> 20% of 2019 U.S. aviation demand) from wet wastes with > 70% carbon intensity reduction at $3.15/GGE.
- In 2022, more than 50 growers attended the field day at the Davenport, WA extension research farm. Growers commented **"Excited to see impact of cover crops on the cash crops and for biofuels."**



SUMMARY

Goal	Derive greater value from cover crops in cropping systems.
Approach	Grow and harvest cover crops, characterize CMA for fuels to understand final potential revenue for farmers and overall reduction of carbon intensity.
Progress and Outcome from First Year	▪ Some cover crops provide significant increased yield of cash crops. ▪ Full removal versus no removal of cover crops show equal or better overall cash/evaluation crop yield. ▪ Blending cover crops with other wet wastes achieves both cost target and carbon intensity reductions.
Impact	Commercially relevant field experimental data for adoption of cover crops and addressing volumetric requirement for biofuels of the sustainable aviation fuel grand challenge.

Future Work	▪ Assess seasonal variability and crop rotation timing from second year biomass growth and cash crop performance.
	▪ Next field days:
	    ▪ June 27, 2023 - dryland (Davenport, WA)
	    ▪ September 2023 - high precipitation (Puyallup, WA)

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THANK YOU!

QUAD CHART OVERVIEW

Timeline

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

	FY 22	Total Award
DOE Funding	$490,000	$1.47M (FY 2022 - 2024)

TRL at Project Start: 3
TRL at Project End: 5

Project Goal

Deliver a deeper understanding of the compromise of optimal growth of cover crops for biofuel and bioproduct production and desire to have no negative impact on the land and subsequent cash crops by growing over two growing seasons and using TEA and LCA.

End Of Project Milestone

Understand trade-off impacts of at least two cover crops at three locations in Washington state for biomass in more than one growing season and characterize CMAs of biomass and its suitability to be converted to bio-oil either alone or in a blend to assess economic and environmental benefits of cover crops.

Funding Mechanism

AOP Topic 2A-2. Valorization of Cover Crops Beyond Soil Health and Ecosystem Services.

Project Partners

Washington State University

Additional Slides

Additional slides: ABBREVIATIONS

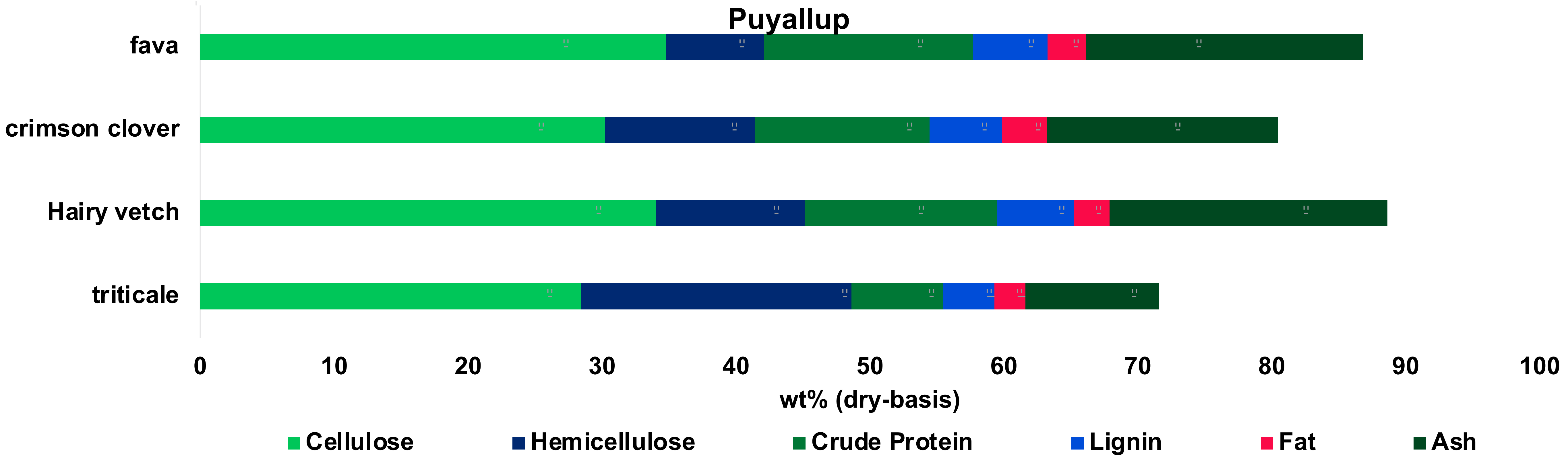
- AOP: Annual Operating Plan
- BETO: Bioenergy Technologies Office
- CMA: Critical Materials Attribute
- DOE: Department of Energy
- DEIP: Diversity, Equity, Inclusion and Power
- GGE: Gallons per gasoline equivalent
- HTL: Hydrothermal liquefaction
- LCA: Lifecycle analysis
- TEA: Technoeconomic analysis
- PNNL: Pacific Northwest National Laboratory
- WSU: Washington State University

Additional slides: PUBLICATIONS, PATENTS, PRESENTATIONS, AWARDS, AND COMMERCIALIZATION

This study actively publishes data for biofuels producers

- Cover crops composition data to be incorporated into Bioenergy Knowledge Discovery Framework.
- Inter-Agency Biomass R&D Board Working Group (U.S. Department of Agriculture and DOE) special topics on cover crops - 2022
- Soil carbon workshop (DOE) - 2022
- Biochar workshop - 2022
- Field days for farmers in Puyallup, WA (2021) and Davenport, WA - 2022
- American Chemical Society Spring Meeting, Indianapolis, IN - 2023
- American Society of Agricultural and Biological Engineers Annual International Meeting, Omaha, NE - 2023

Additional slides: **FIRST YEAR - COVER CROPS COMPOSITION (CMA)**

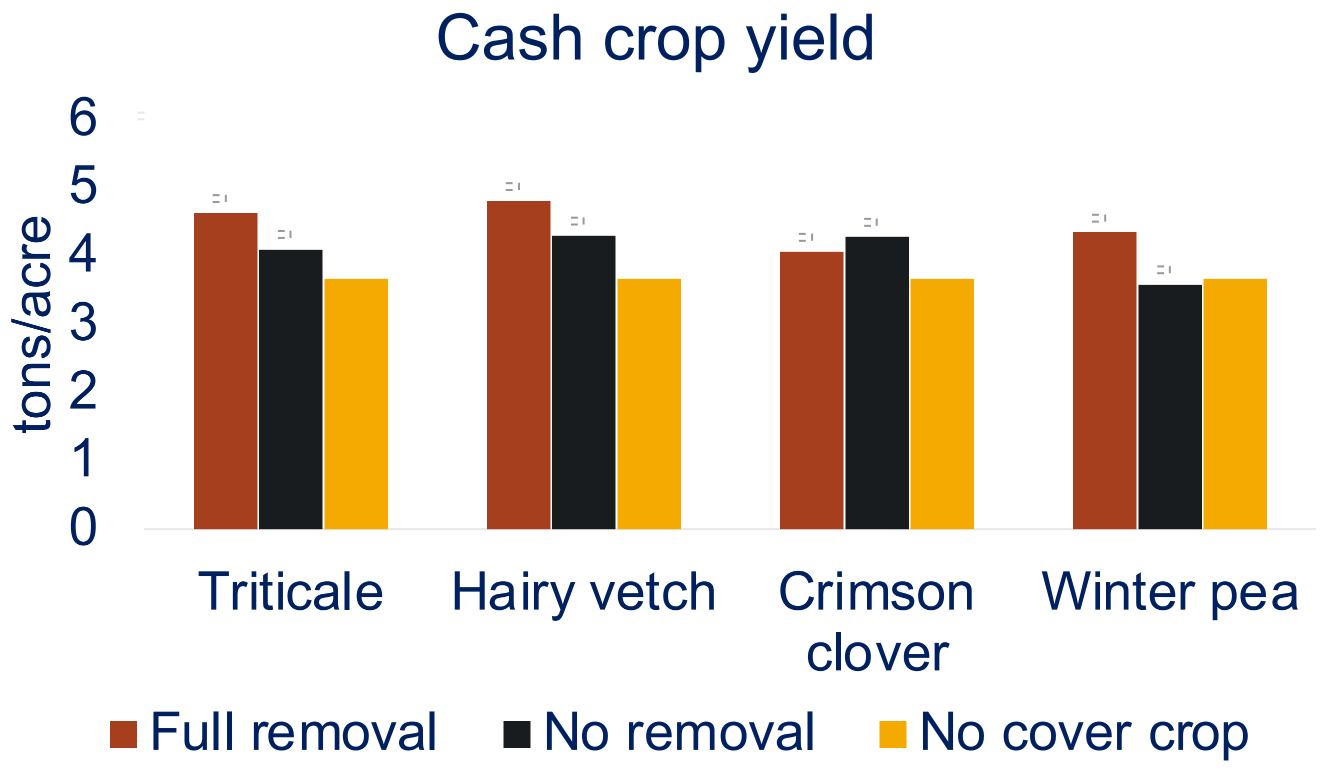


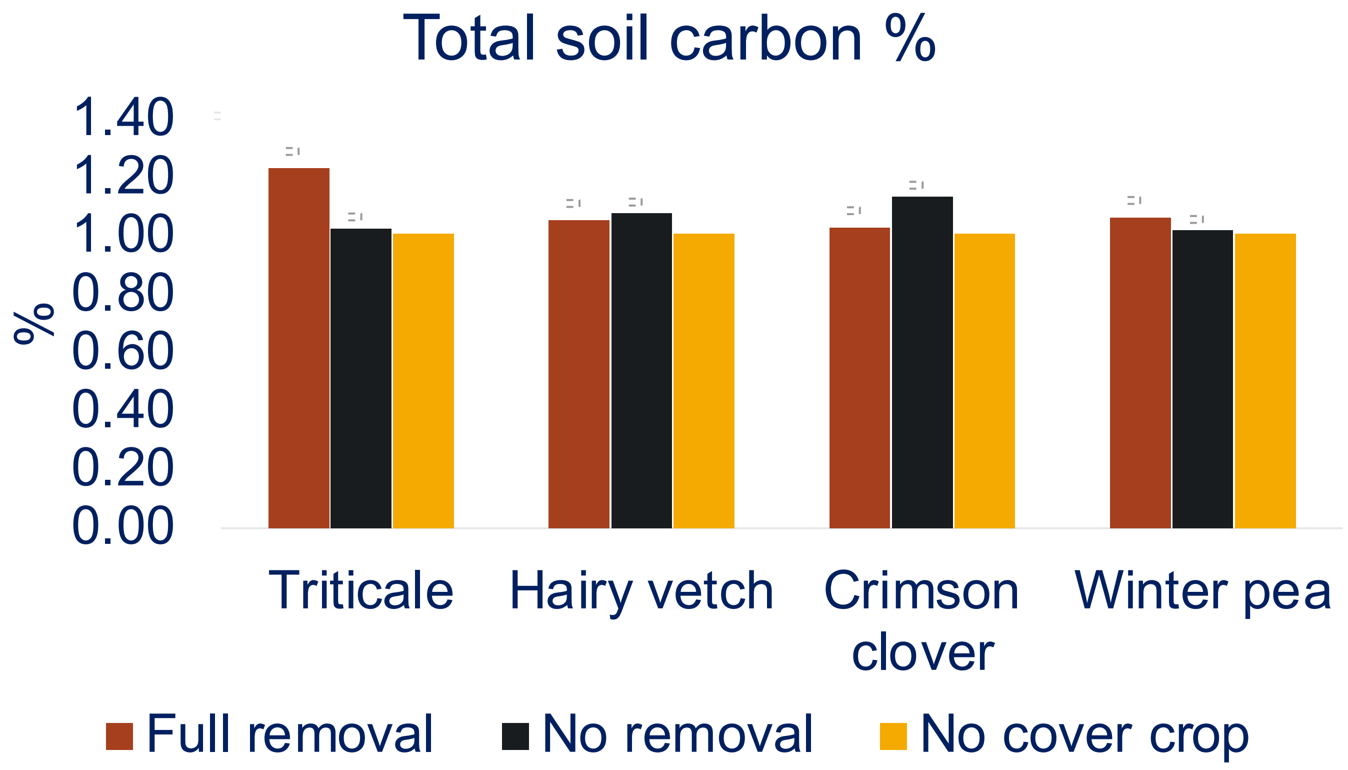
Samples were from biomass removed from field. Samples were dried, ground, and analyzed for forage analysis panel.

- ❑ Fat and protein contributes to higher biocrude yield and literature values were used to calculate final biocrude yield[1,2].
- ❑ Ash, a CMA, is highest in shorter plants such as legumes (closer to the ground).

[1] Li S., et al. 2021. *Applied Energy* 283.
[2] Jiang Y. 2019. *Algal Research* 39.

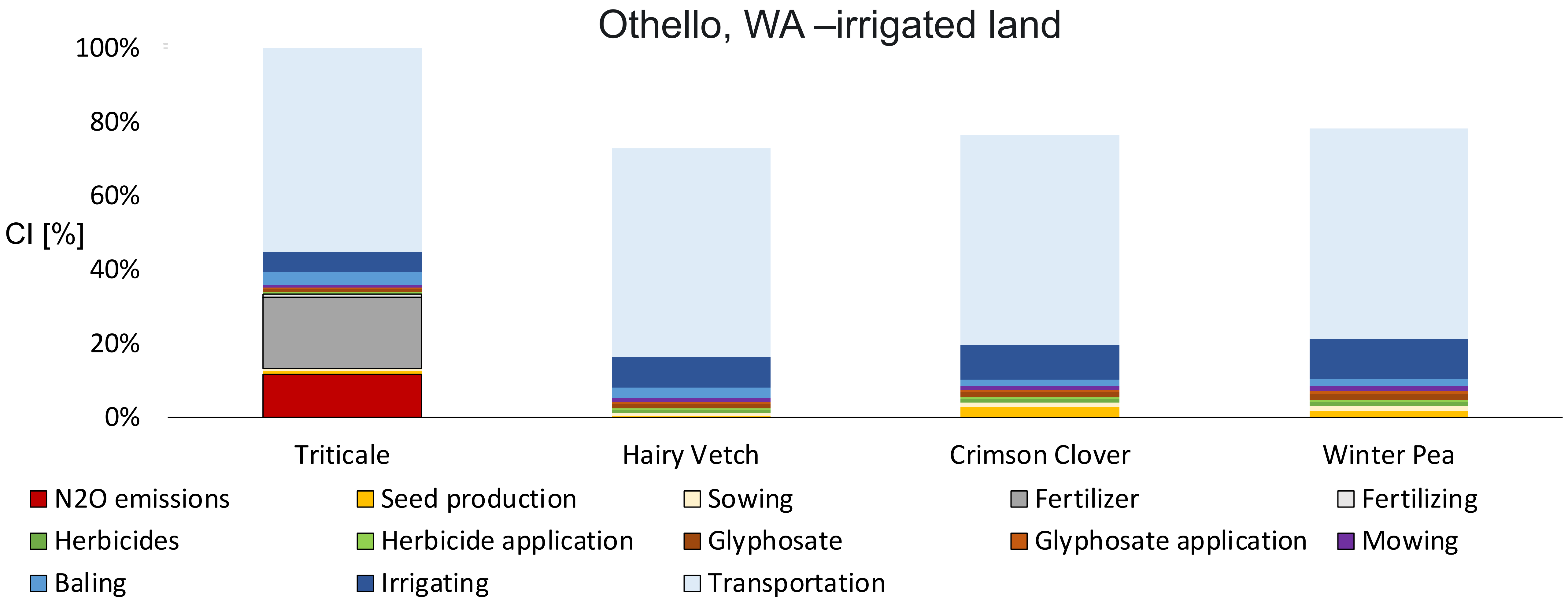
Additional slides: FULL REMOVAL OF COVER CROPS FOR BIOFUELS DOES NOT SIGNIFICANTLY IMPACT GLOBAL WARMING POTENTIAL AND SOIL CARBON





- Cover crops provide significant increased yield of cash crop and total soil carbon.
  - Triticale has the largest effect.
- Full harvesting versus no harvesting of cover crop shows no significant differences in overall cash crop yield and total soil carbon.

Additional slides: MINIMIZING TRANSPORTATION DISTANCE AND FERTILIZER USE ARE KEY IN REDUCING CARBON INTENSITY



- ❑ Transportation has the highest impact; 55-78% of total CI.
- ❑ Fertilizers and the N_2O emissions associated contributes to >25% of CI in Triticale production.
- ❑ Using legume cover crops resulted in the lowest carbon intensity.

Additional slides: COLLABORATIONS WITH OTHER BETO PORTFOLIOS

Title	WBS
Process Development Unit for HTL	3.4.2.301
Bio-Oil Co-Processing with Refinery Streams	3.4.3.306
Bench Scale HTL of Wet Wastes Feedstocks	2.2.2.302
Analysis Supporting Conversion Research for Fuels and Products	2.1.0.301
Hydrothermal Processing for Algal-Based Biofuels and Co-Products	1.3.4.101
HTL Model Development	1.3.5.101
Waste-to-Energy: Optimized Feedstock Aggregation and Blending at Scale	2.1.0.113

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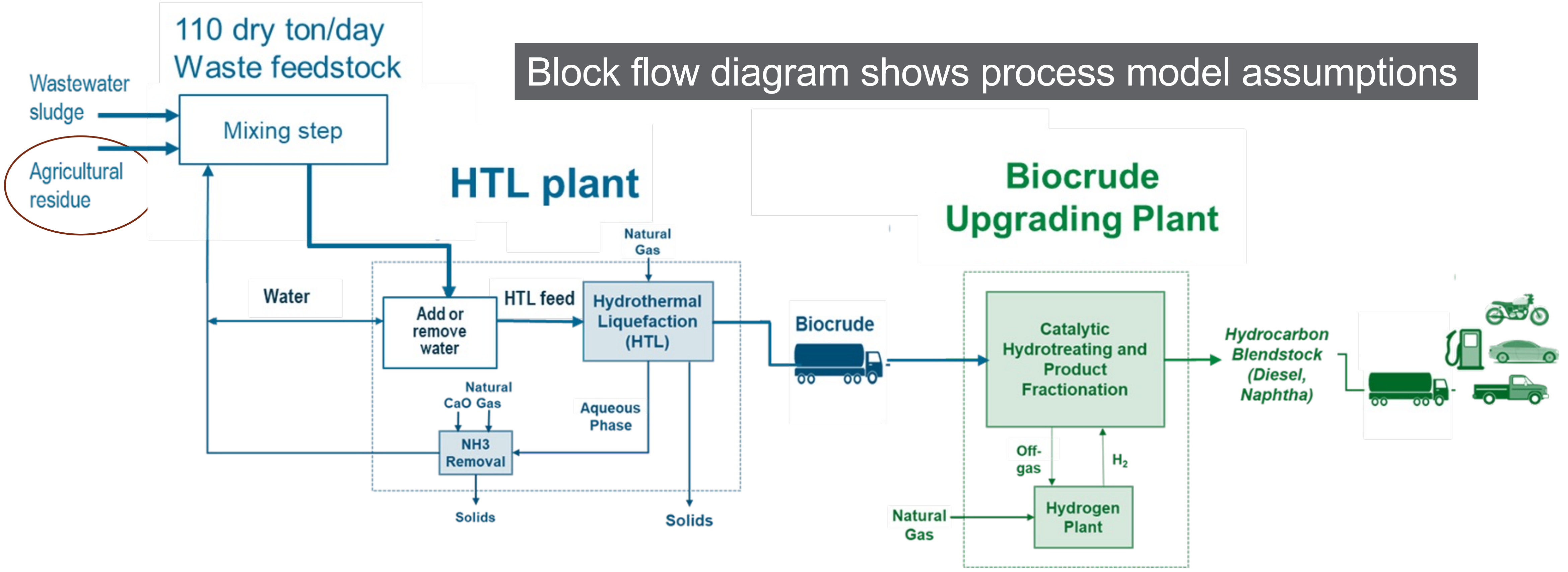
Additional slides: COVER CROPS POTENTIALLY ADD REVENUE FOR FARMERS AND HELP MEET SUSTAINABLE AVIATION FUEL VOLUME TARGET

Block flow diagram shows process model assumptions

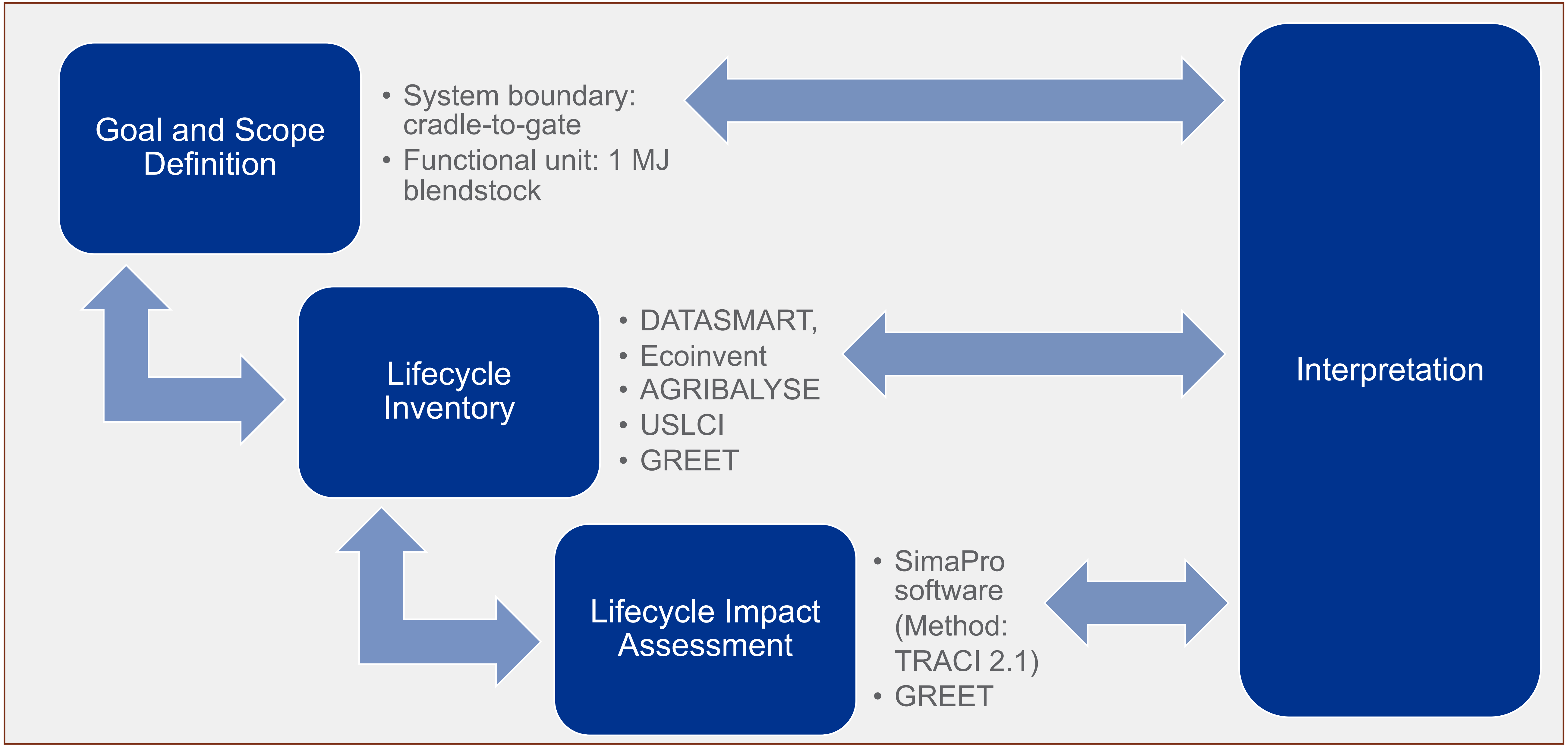


- BETO's wet waste HTL design case is used as baseline model (assumption: HTL plant is co-located at wastewater treatment facility).
- HTL pathway can handle wet feedstocks without drying step.
- Feed compositions are used to estimate biocrude or HTL oil yields (cost driver) and calculate model costs.
- Hydrocarbon blendstocks are final products. Optimizing sustainable aviation fuel product volume can be done by tuning the upgrading step.

Additional slides: **GOALS OF THE LCA STUDY**

1. Compare Global Warming Potential of different crop systems (three locations, at least two cover crops at each site).
2. Evaluate Global Warming Potential and impact on soil carbon of the following treatments:
   - No cover crop (current practice)
   - No harvesting of cover crop (current practice if cover crops are used in farmer's rotation)
   - Full harvesting of cover crop (to achieve the highest amount of feedstock for biofuels).
3. Compare the Global Warming Potential of bio-based versus fossil-based hydrocarbon blendstock (diesel, naphtha).
   - Reduction goal: 70%.

Additional slides: LIFECYCLE ASSESSMENT METHODOLOGY



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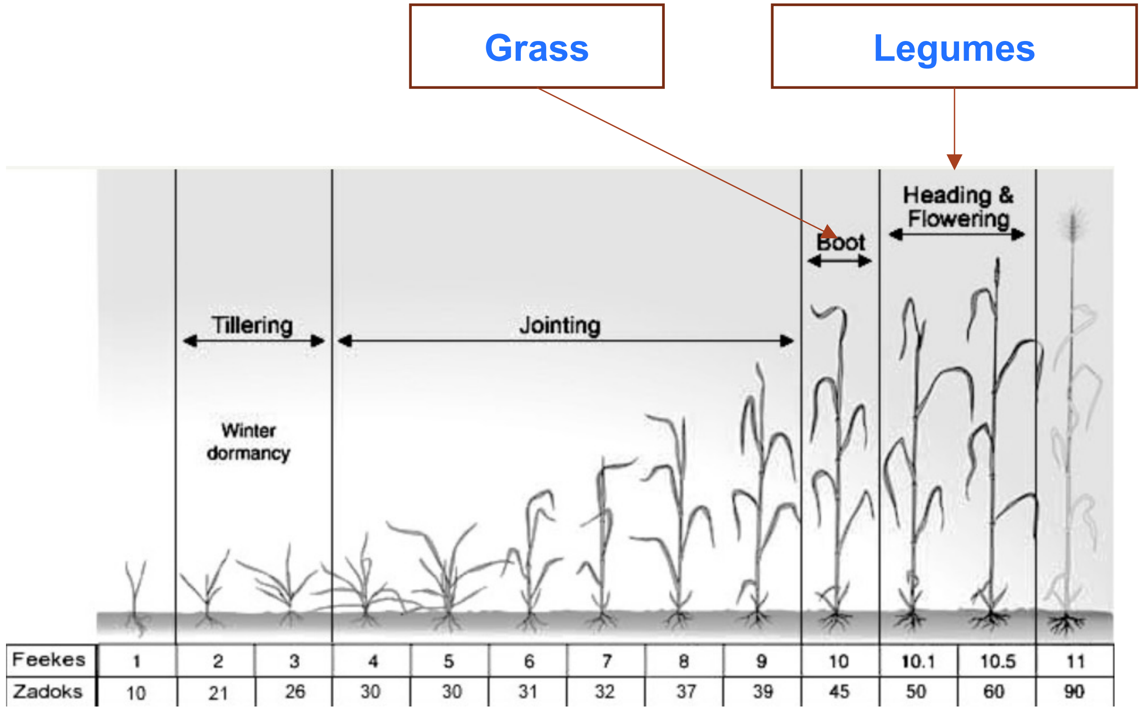
Additional slides:
HARVESTING METHOD

- Harvesting of the plants at the peak of the biomass production considering the aspect of timing and phenology of grass versus legumes.

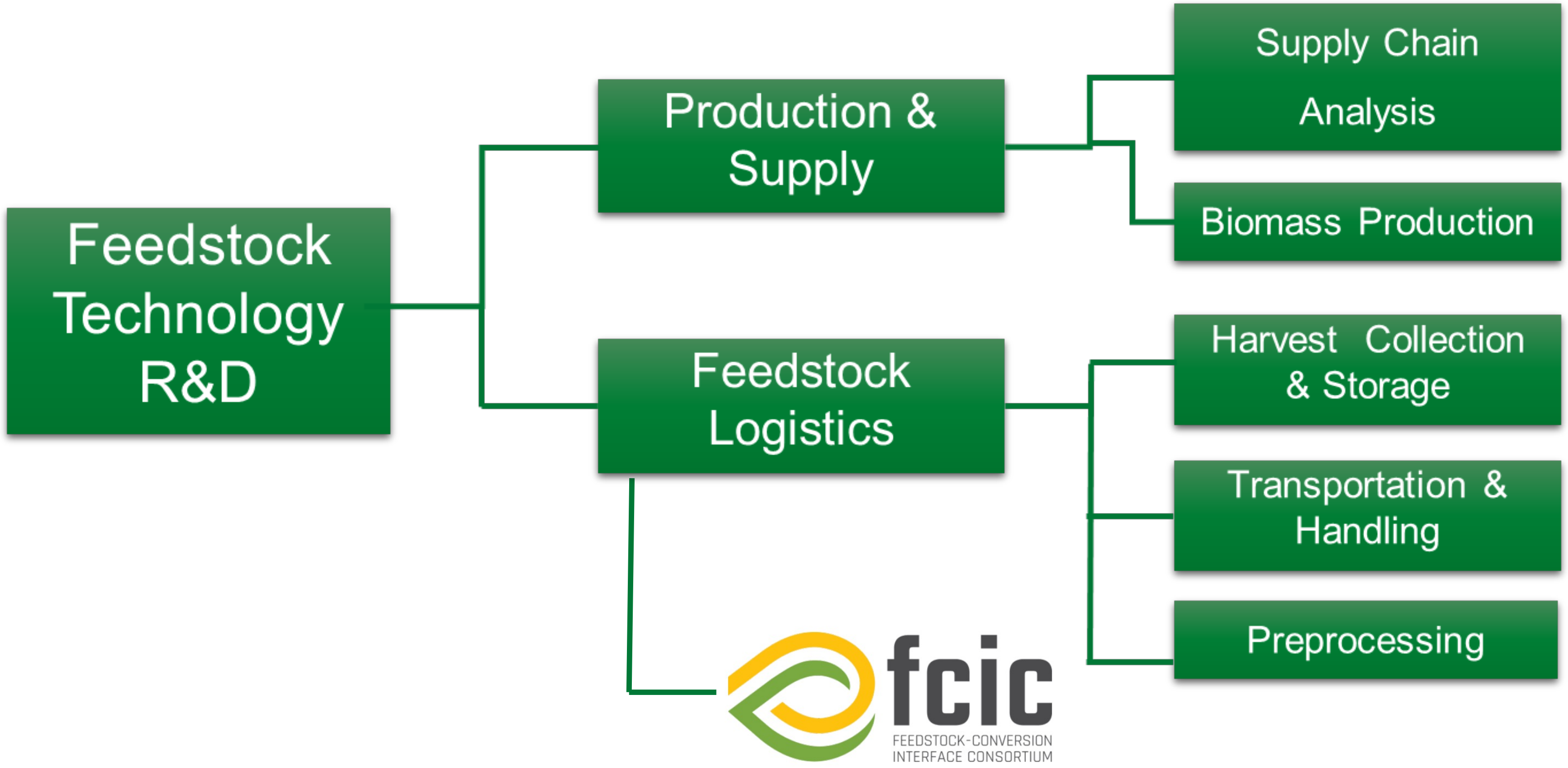
- Harvesting used a power harrow; 1-3” deep disturbance.

- Some weeds are combined with cover crops.

- Reduced inorganic (i.e., soil contamination), but some seemed to be inevitable with plot harvester and mole hills.



Additional slides: DATA ENABLING ONGOING COLLABORATION TO FACILITATE TECHNOLOGY DEVELOPMENT



MISSION

- ✓ Assesses the potential availability and quality characteristics.
- ✓ Evaluates all the operations, associated costs, and sustainability issues.

Adopting industrial practice and actual field data to support at least two pillars in feedstock technologies program structure.