Project 01

Alternative jet fuel supply chain analysis

Massachusetts Institute of Technology & UHasselt (subaward)

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Cost Share Partner(s): Byogy, World Energy, Oliver Wyman, MIT

Objective:

Analyze lifecycle GHG emissions, costs, and availability of Sustainable Aviation Fuels (SAF), considering a wide range of production pathways and feedstocks. Research is conducted in support of efforts under ICAO CAEP.

Project Benefits:

1. Analysis of future GHG reduction potential from SAF and economic analysis of SAF
2. Analysis of potential SAF uptake scenarios over the coming decades, including regionalized analyses
3. Provide expert support on SAF to the U.S. delegation to ICAO CAEP, esp. FTG

Research Approach:

Lifecycle GHG emissions

Conduct **well/field-to-wake (WTW) analysis of lifecycle GHG emissions** per unit fuel energy [gCO_2e/MJ]

Costs

Apply **discounted cash flow analysis** to compute the minimum selling price of the fuel.

SAF availability

Analyze **future scenarios** of feedstock availability, market adoption and investment

Major Accomplishments (to date):

- Applied LCA to SAF pathways to obtain default LCA values, incl. defining method for PtL SAF
- Developed stochastic methods for assessing lifecycle GHG emissions and economic viability
- Studied SAF production scenarios and associated GHG emission reductions out to 2050
- Analyzed US-based SAF production scenarios for the 2030s, incl. PtL-based SAF
- ***Today:*** Pathways for reducing the emissions footprint of SAF production

Future Work / Schedule:

- Detailed PtL fuel potential analysis
- Policy analysis for U.S.-based SAF production

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Objectives for Today

SAF Grand Challenge

DOT, DOE & USDA signed MoU on government-wide activities to:

- reduce cost for SAF
- enhance SAF sustainability
- expand the production and use of SAF

Goal:

Increase SAF availability to:

- 3bn gallons/yr (2030)
- Sufficient supply to meet jet fuel demand (2050)

Qualifying SAF:

At least 50% reduction in GHG emissions

Focus for today

Assess the emissions footprint of US-based SAF production, considering the most available and scalable pathways.

Guiding questions:

1. Understand lifecycle GHG impacts for SAF from crops with significant potential
2. Assess approaches for further mitigation:
   a. To meet Grand Challenge goals
   b. To make sure investments are made in technologies which, in the long-term, can live up to aviation's decarbonization ambitions (>>50% reduction).

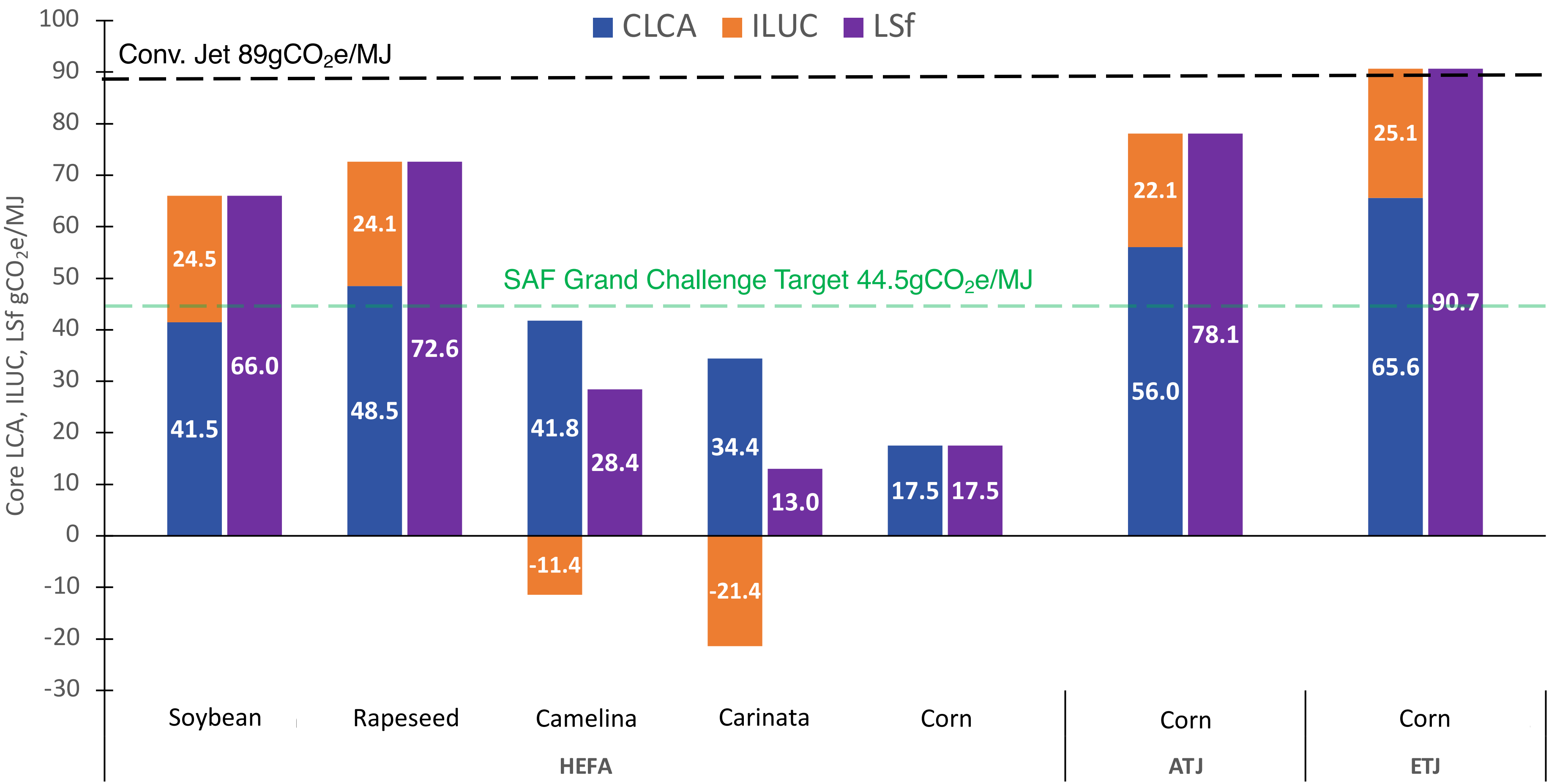
Scope of emissions footprint following the CORSIA approach

For our analysis, we leverage data and structure from the CORSIA process, leading to the following breakdown of the emissions analysis:

Core LCA	Induced Land-Use Change (ILUC)
Attributional LCA to capture:	*Consequential approach to capture carbon stock changes and emissions associated with LUC:*
Cultivation	***Vegetation*** *(natural, agricultural, unused land)*
Feedstock transport	***Foregone sequestration***
Conversion	***Soil organic carbon***
Fuels transport	***Peatland oxidation***
Distribution	*CORSIA: Amortized over 25 years:* $ILUC\ emission\ intensity = \frac{\sum_{i,j,k,r} E_{i,j,k,r}}{AP \times EO}$
Combustion ***(- biomass credit)***	
Based on Prussi et al. (2021)	*Based on Taheripour et al. (2021)*

Pathways with significant US production potential: Soybean & Rapeseed HEFA, Corn ATJ & EtJ - *current CORSIA default LCA values*

Note: *LCA values reflect default values. Individual companies may have improved process designs leading to different LCA values.*



ICAO, 2021. CORSIA supporting document - CORSIA Eligible Fuels – Life Cycle Assessment Methodology. Retrieved from https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V4.pdf

ICAO, 2021. ICAO Document - CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels. Retrieved from https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20November%202021.pdf

Pathways with significant US production potential: Soybean & Rapeseed HEFA, Corn ATJ & EtJ - *current CORSIA default LCA values*

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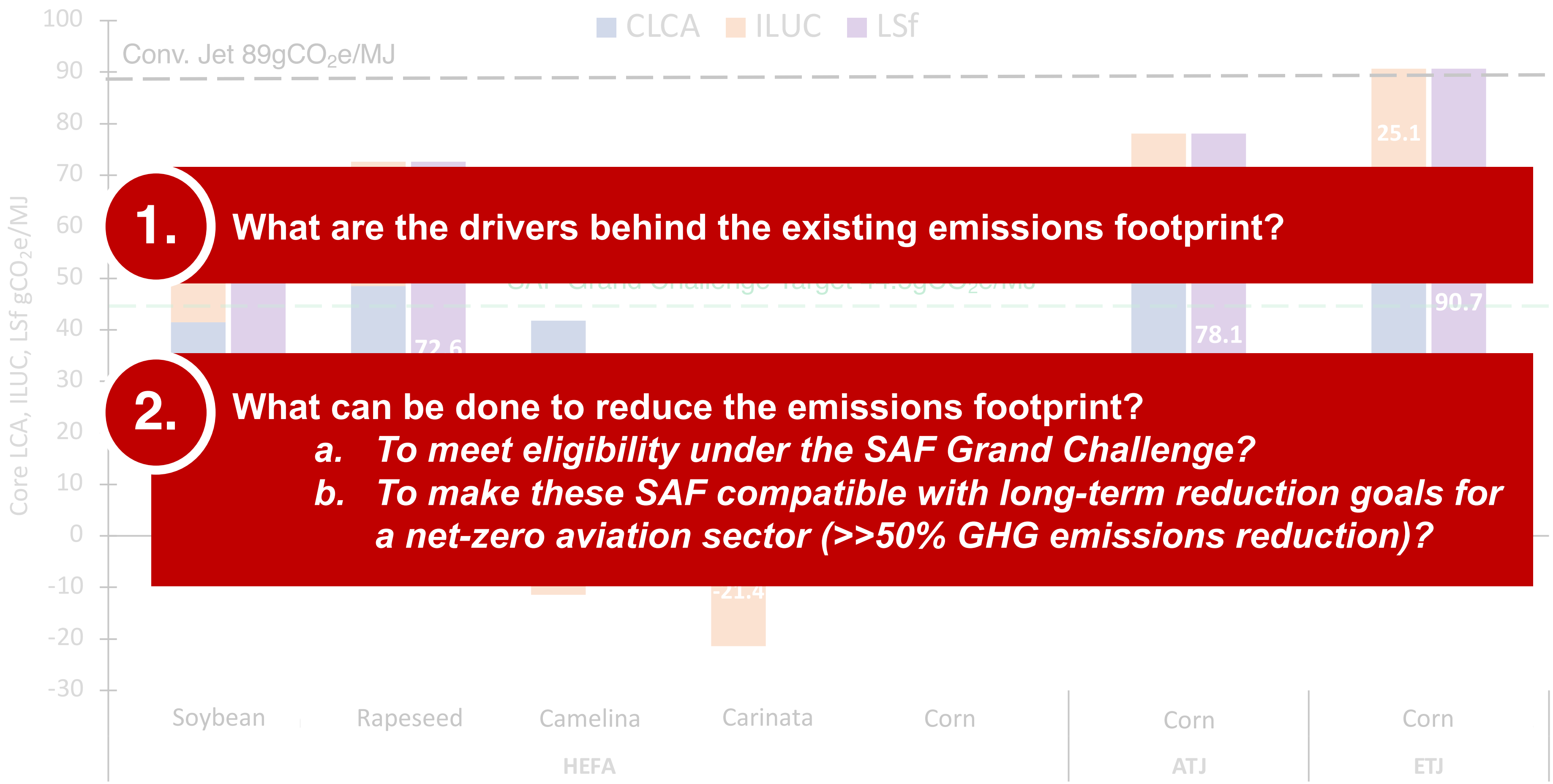
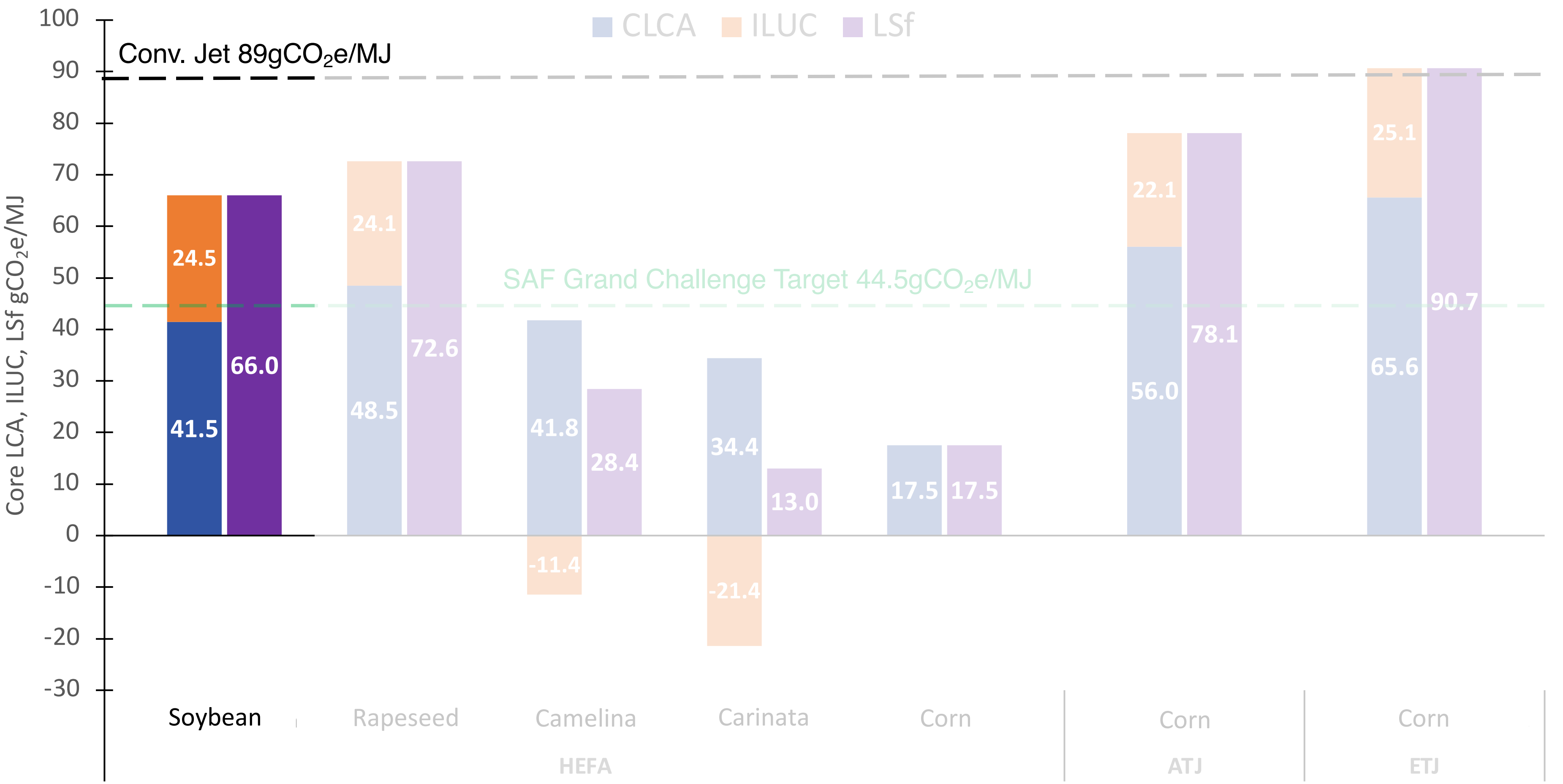


1. What are the drivers behind the existing emissions footprint?

2. What can be done to reduce the emissions footprint?

- ***a. To meet eligibility under the SAF Grand Challenge?***
- ***b. To make these SAF compatible with long-term reduction goals for a net-zero aviation sector (>>50% GHG emissions reduction)?***

Current CORSIA default values: Soybean HEFA

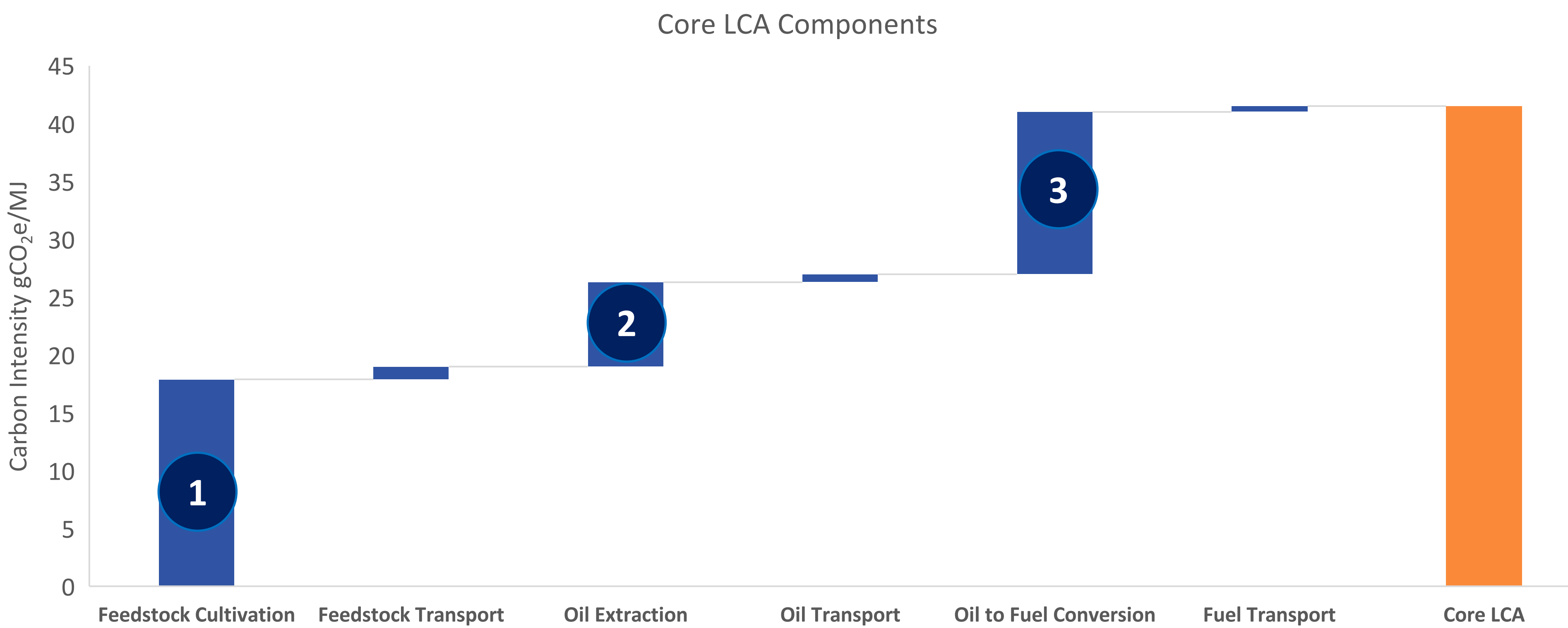


Preliminary.

Soybean-HEFA: Core LCA shows significant impact from feedstock cultivation, oil extraction and conversion

(in gCO_2e/MJ)

$\sum$ Feedstock Cultivation 17.9 〉 Feedstock transport 1.1 〉 Oil Extraction 7.3 〉 Oil Transport 0.7 〉 Oil to Fuel Conversion 14 〉 Fuel transport 0.5 = Core LCA 41.5



Argonne National Laboratory. *GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Technology) Model*; Argonne National Laboratory, **2019**.

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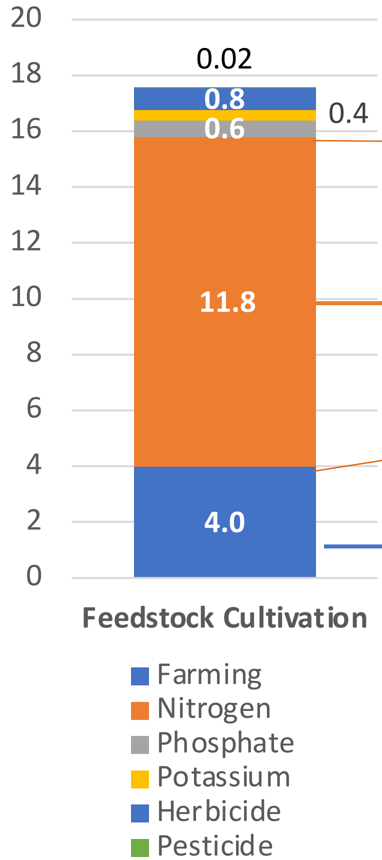
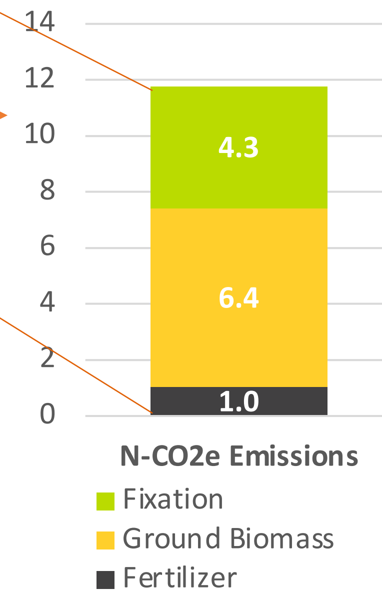
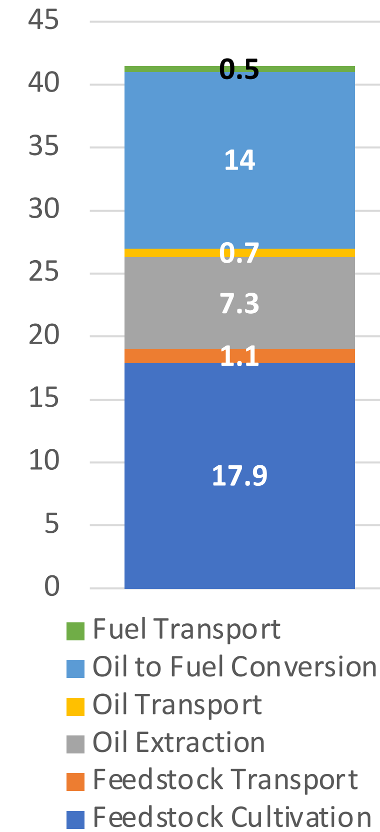


Fixation, existing N in biomass above and below ground, fertilizer leads to N_2O emissions

Farming uses:
- Diesel
- Gasoline
- LNG
- NG
- LPG
- Electricity



N Fertilizer
Soybean: 49g/bushel
Corn: 383g/bushel

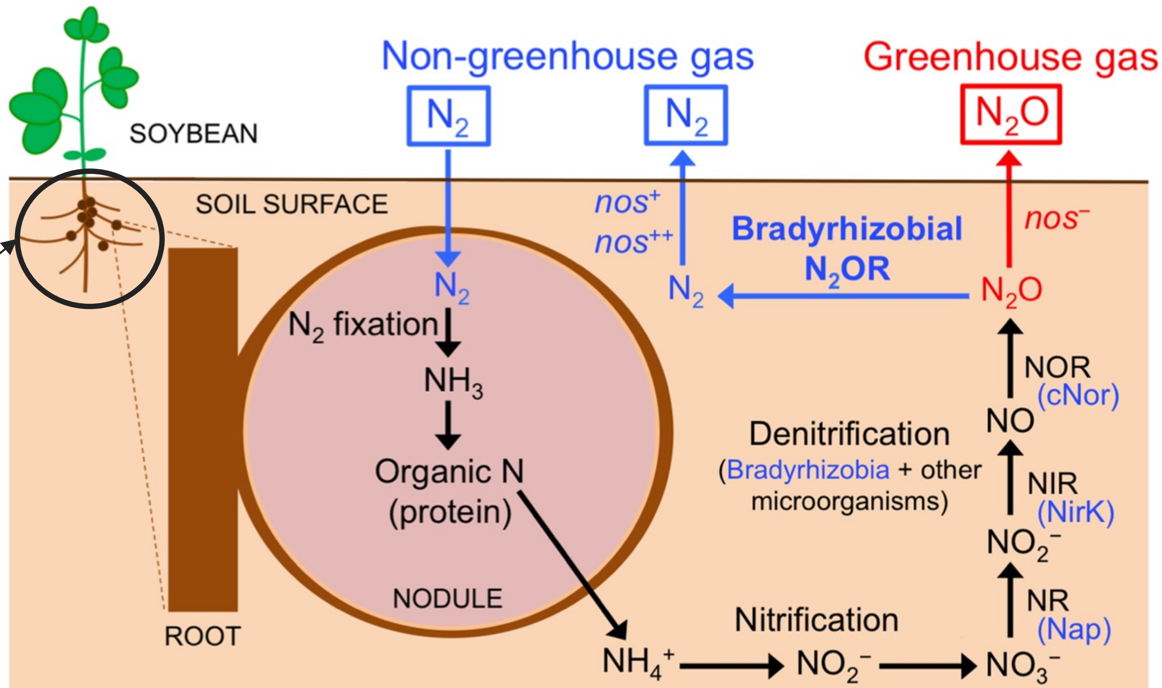


(component bars not to scale w/ CLCA total)

Preliminary. * Deviation between default core LCA values and detailed breakdown analyses due to differences in GREET.

Soybean-HEFA: Nitrogen fixation

Nitrogen fixation occurs in the rhizosphere of the soybean; which is the region closest to the plant roots



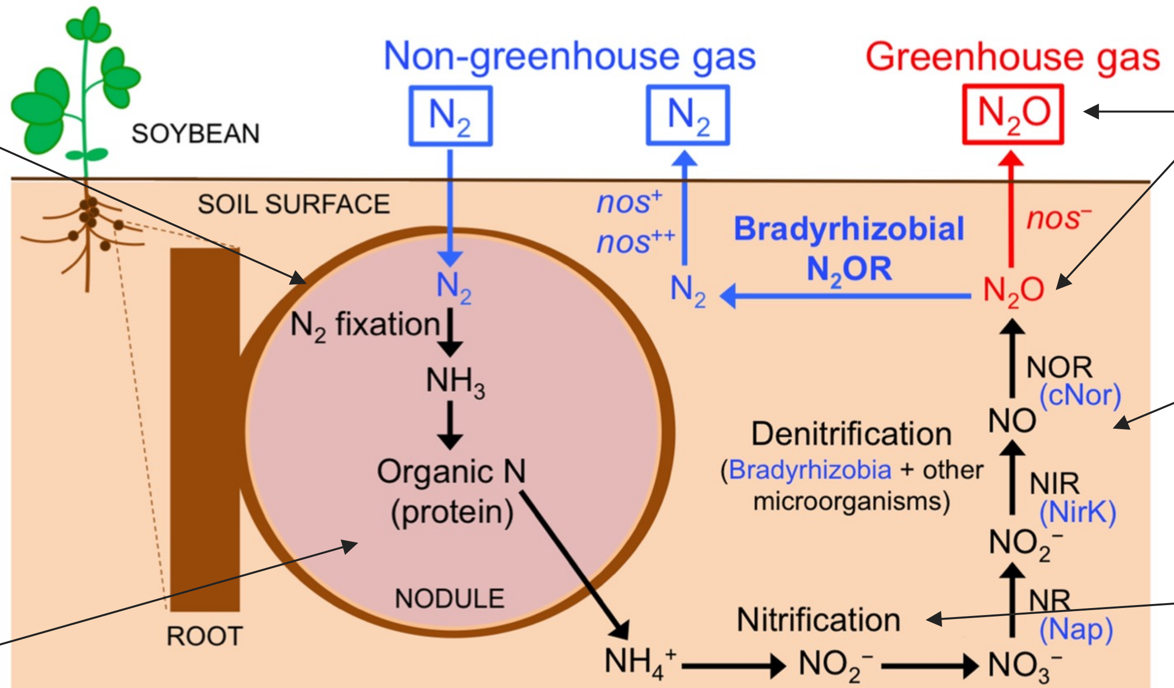
Nitrogen Cycling in Soybean Rhizosphere: Sources and Sinks of Nitrous Oxide (N_2O), Frontiers in Microbiology, 2019.

Preliminary.

Soybean-HEFA: Nitrogen fixation

1. Dinitrogen is converted to NH3 by rhizobia (endosymbiotic bacteria) encountering oxygen-limiting conditions

2. Organic nitrogen then combines with NH3 to form NH4+ in the root nodule (mineralization process)



5. N2O is emitted as a GHG, OR reduced to N2 by soybean bradyrhizobias

4. NO3- is converted to N2O via dentrification

3. NH4+ is converted to NO3- via nitrification

Nitrogen Cycling in Soybean Rhizosphere: Sources and Sinks of Nitrous Oxide (N_2O), Frontiers in Microbiology, 2019.

Preliminary.

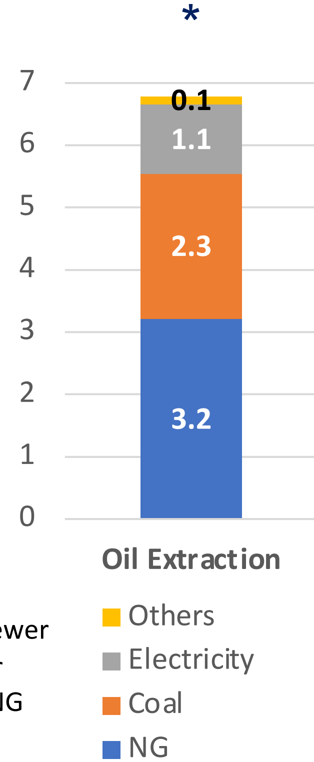
Soybean-HEFA: Oil extraction largely driven by heat requirements which can be met with lower carbon footprint

(in gCO_2e/MJ)

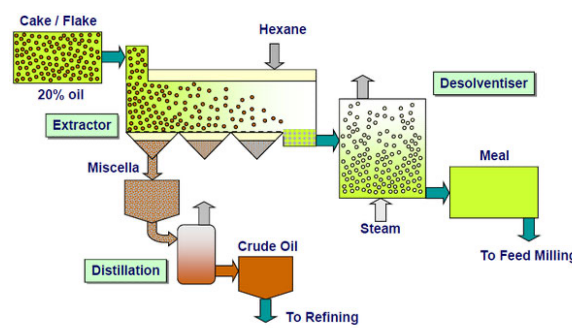
Σ Feedstock Cultivation 17.9 › Feedstock transport 1.1 › **Oil Extraction 7.3** › Oil Transport 0.7 › Oil to Fuel Conversion 14 › Fuel transport 0.5 = **Core LCA 41.5**

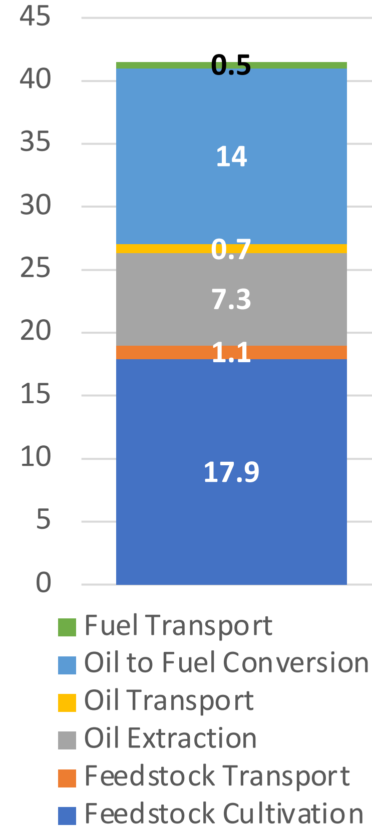
Oil solvent extraction uses:

- NG (heat) or coal (heat) (or combination)
- Electricity
- n-Hexane (solvent)
- Biomass, LFG, Residual oil, diesel



Adds to 6.7 due to newer GREET version (lower CH_4 emissions from NG combustion)





(component bars not to scale w/ CLCA total)

Admin. (2018, December 6). *Small edible oil extraction equipment*. Cooking oil production line,Edible oil extraction equipment,Edible oil refining plant. Retrieved May 20, 2022, from http://www.cnoiltreatment.com/small-edible-oil-extraction-equipment.html

Preliminary.

* Deviation between default core LCA values and detailed breakdown analyses due to differences in GREET.

Soybean-HEFA: Natural gas and hydrogen requirements drive footprint

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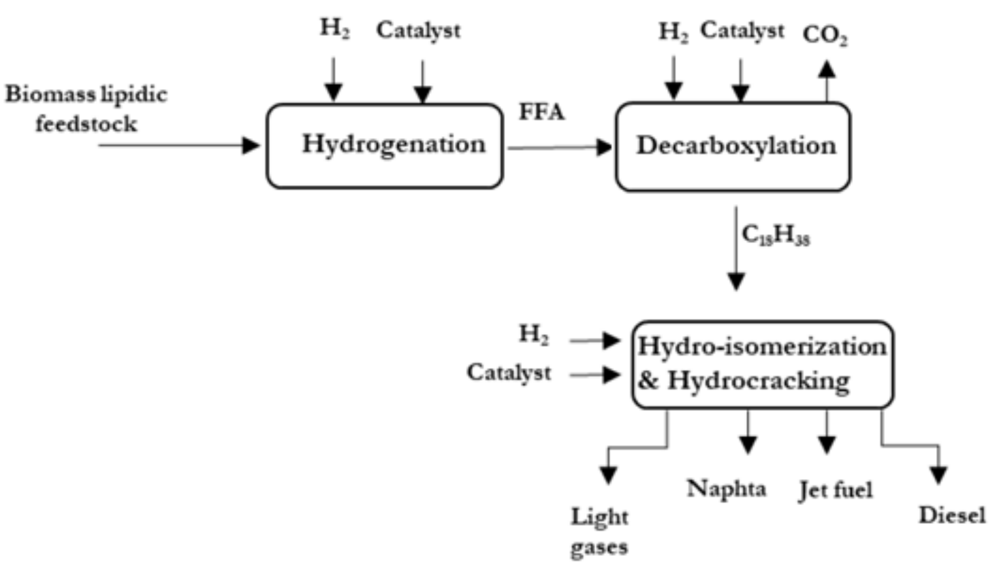
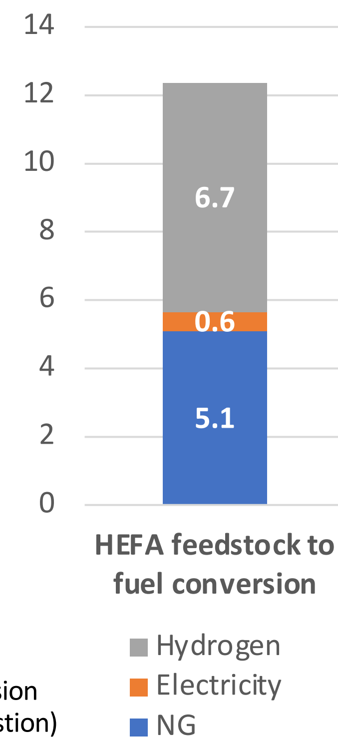
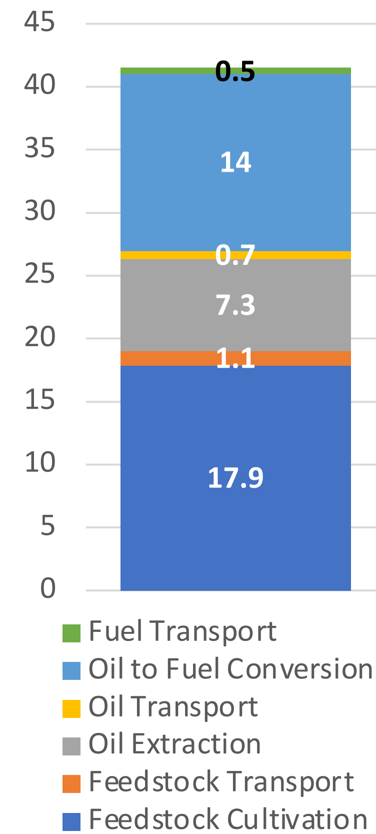
(in gCO_2e/MJ)

Σ Feedstock Cultivation 17.9 › Feedstock transport 1.1 › Oil Extraction 7.3 › Oil Transport 0.7 › **Oil to Fuel Conversion 14** › Fuel transport 0.5 = **Core LCA 41.5**





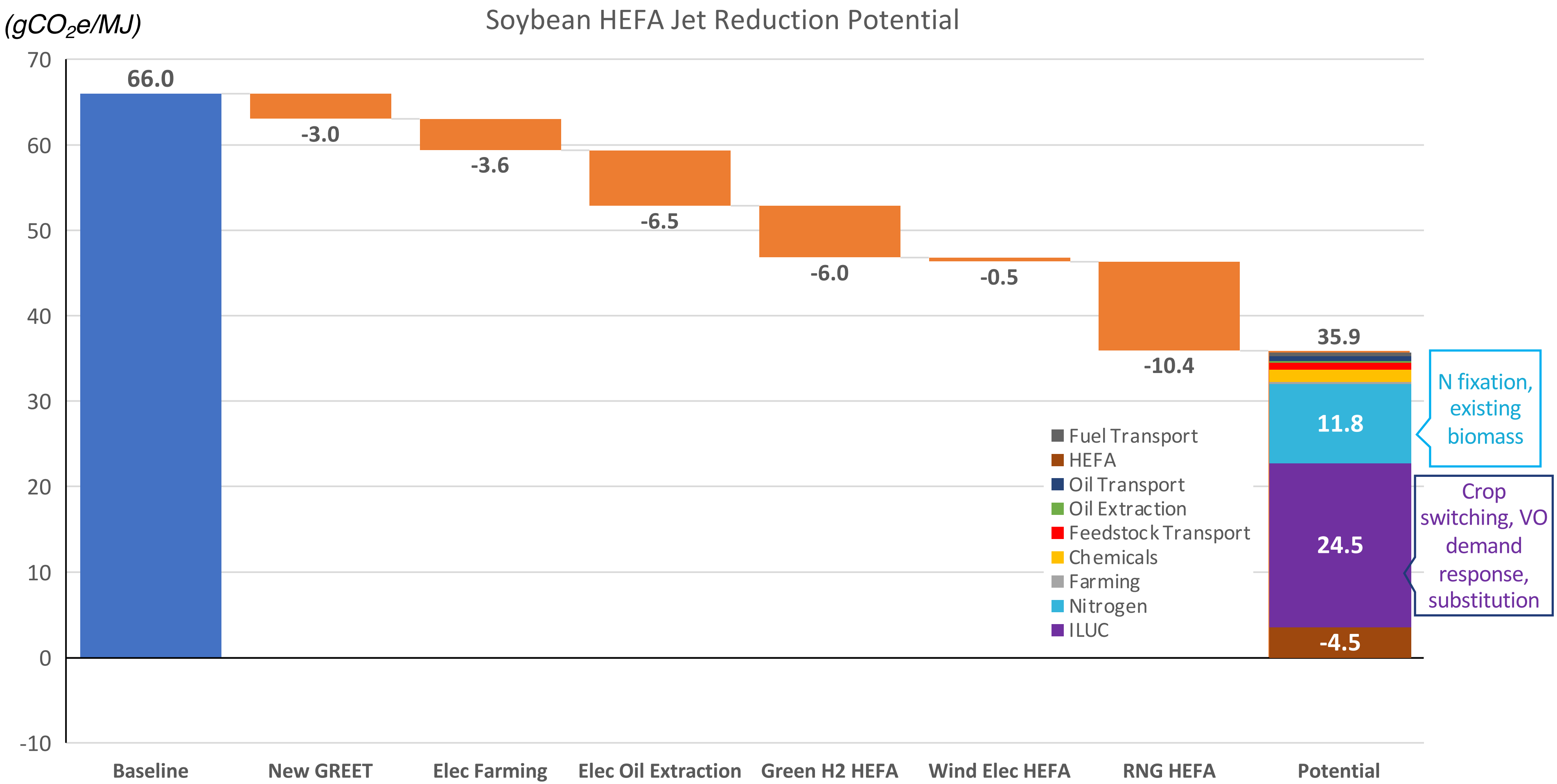


Adds to 12.4 due to newer GREET version (lower CH_4 emissions from NG combustion)

(component bars not to scale w/ CLCA total)

Preliminary.

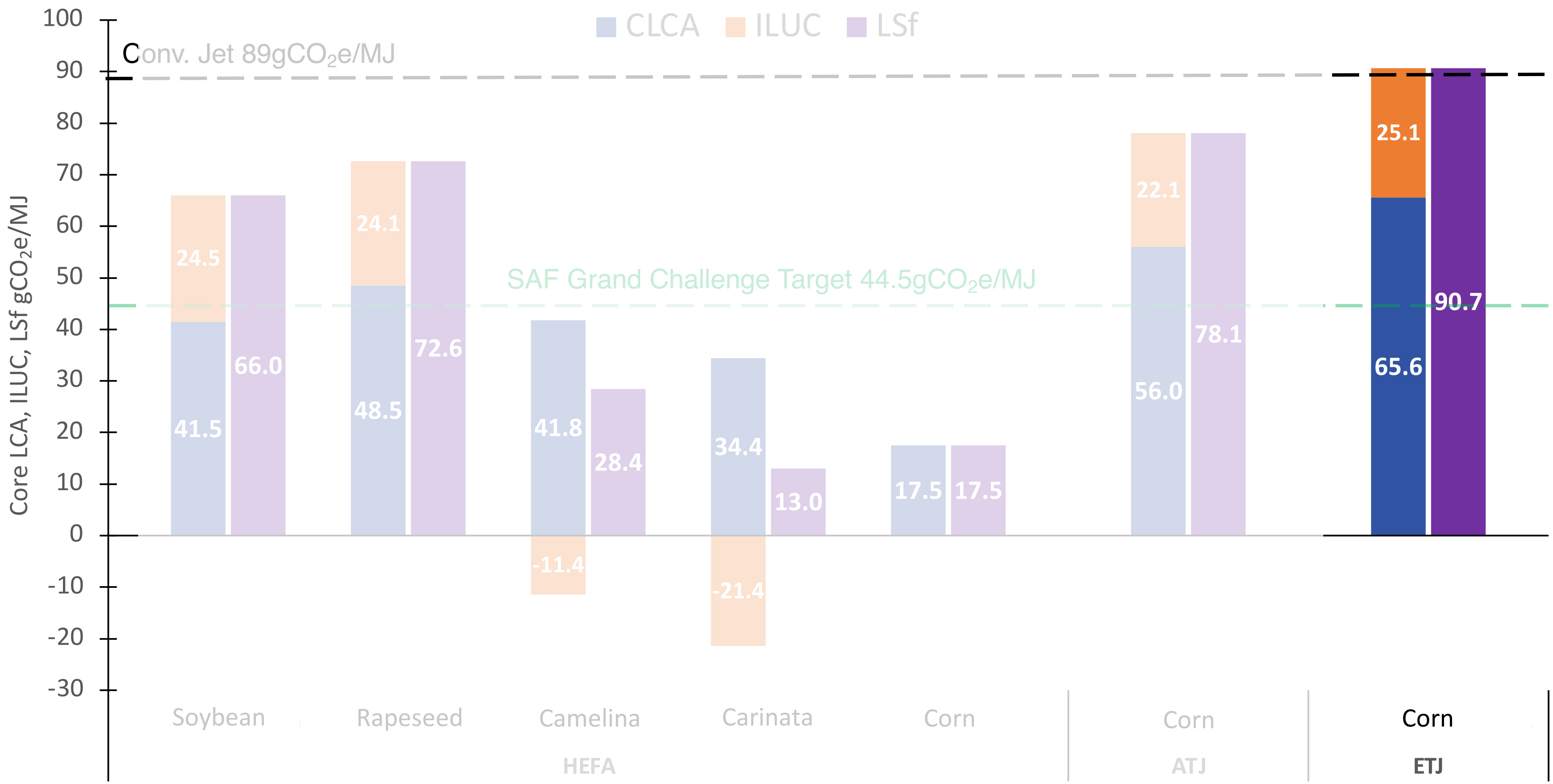
Soybean-HEFA: Significant reduction potential in core LCA exists; ILUC emissions provide next important target



Assumptions:
- 100% Wind: 11gCO2e/MJ
- Green H2: 90% reduction from SMR
- Same fossil energy reallocated to 100% electricity
- RNG from MSW

Preliminary.

Current CORSIA default values: Corn EtJ

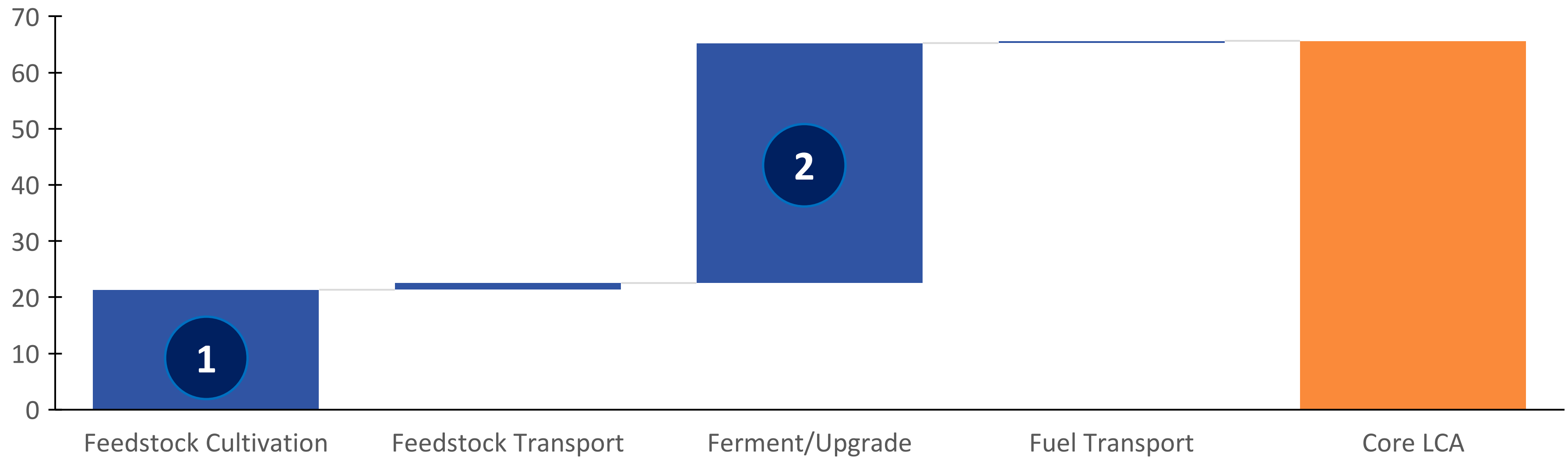


Preliminary.

Corn-EtJ: Core LCA emissions driven by feedstock cultivation and fermentation & upgrading

(in gCO_2e/MJ)

Σ Feedstock Cultivation 21.3 〉 Feedstock transport 1.2 〉 Ferment/ Upgrade 42.7 〉 Fuel transport 0.4 = Core LCA 65.6



Preliminary.

Corn-EtJ: Feedstock cultivation emissions largely driven by fertilizer impacts

(in gCO_2e/MJ)

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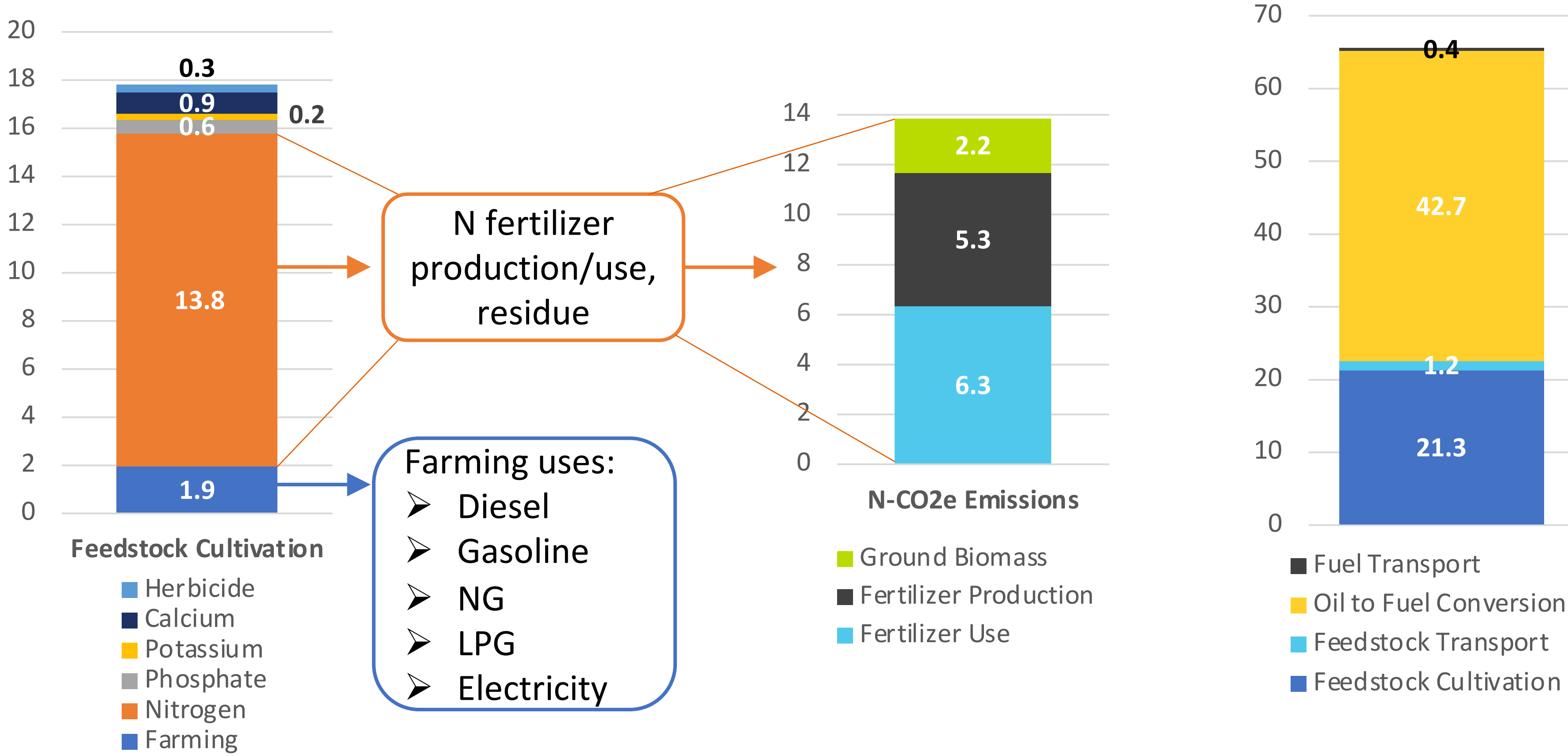
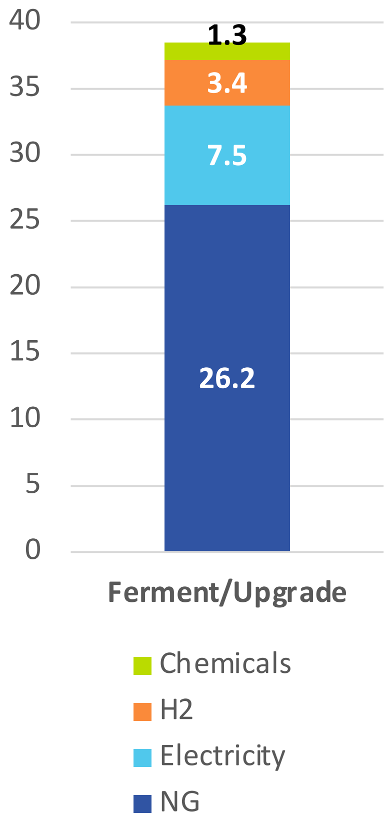


Preliminary. * Deviation between default core LCA values and detailed breakdown analyses due to differences in GREET.

Corn-EtJ: Fermentation/Upgrading emissions driven by natural gas, electricity, and H_2 use

(in gCO_2e/MJ)

Σ Feedstock Cultivation 21.3 〉 Feedstock transport 1.2 〉 Ferment/ Upgrade 42.7* 〉 Fuel transport 0.4 = Core LCA 65.6



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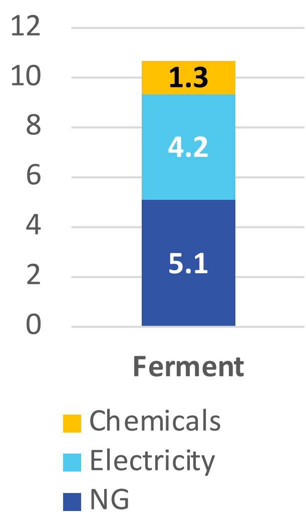
Additional biogenic CO_2 emissions!



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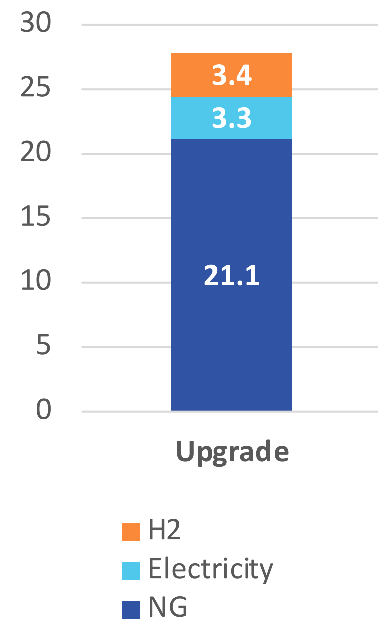
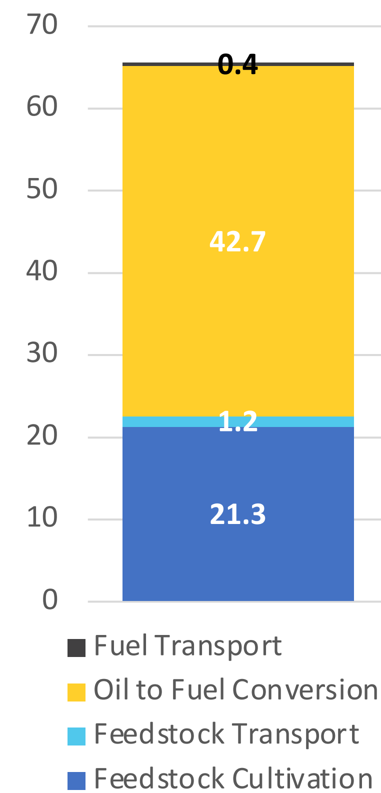
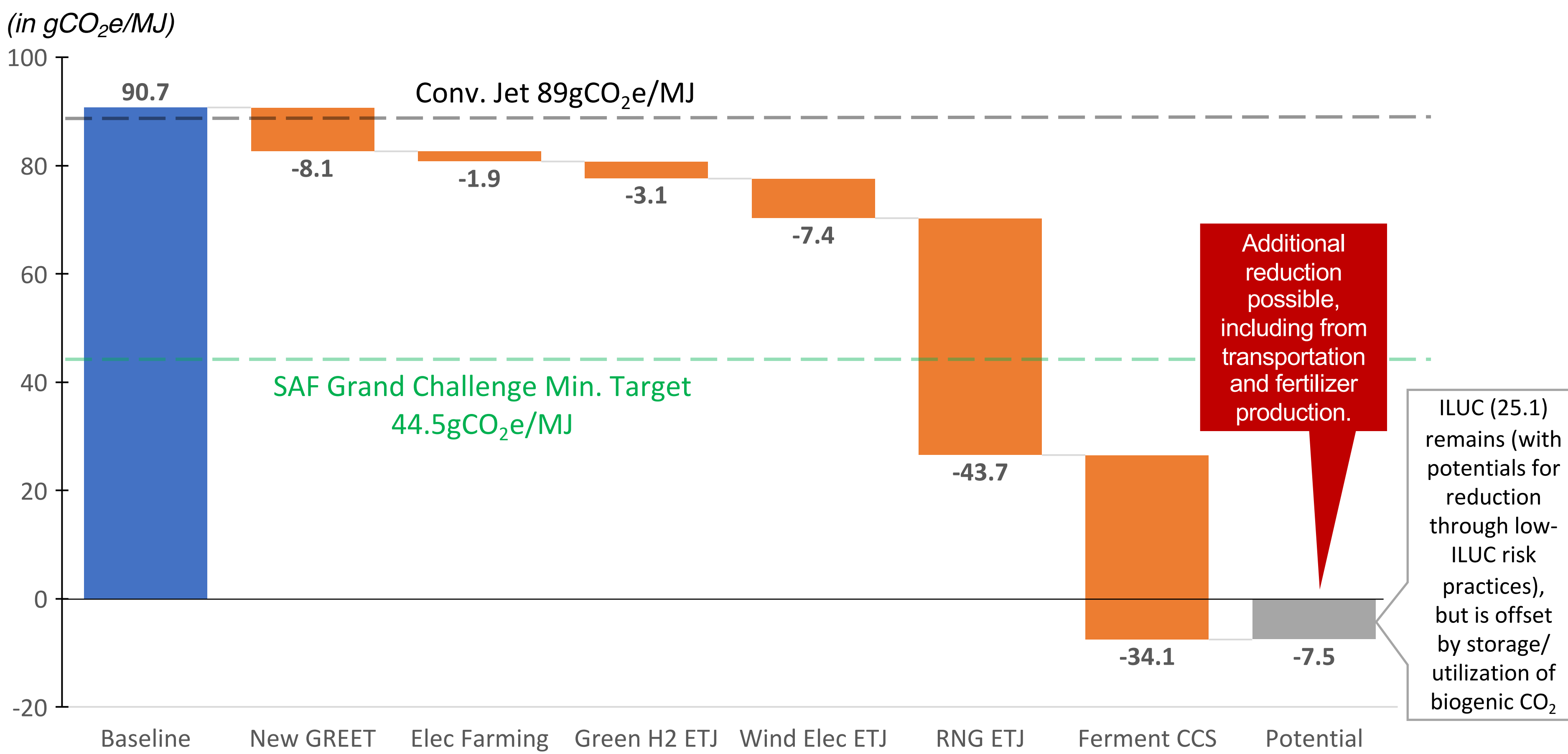




Preliminary.

* Deviation between default core LCA values and detailed breakdown analyses due to differences in GREET.

Corn-EtJ: Reduction potential could lead to negative emissions with CCS implementation

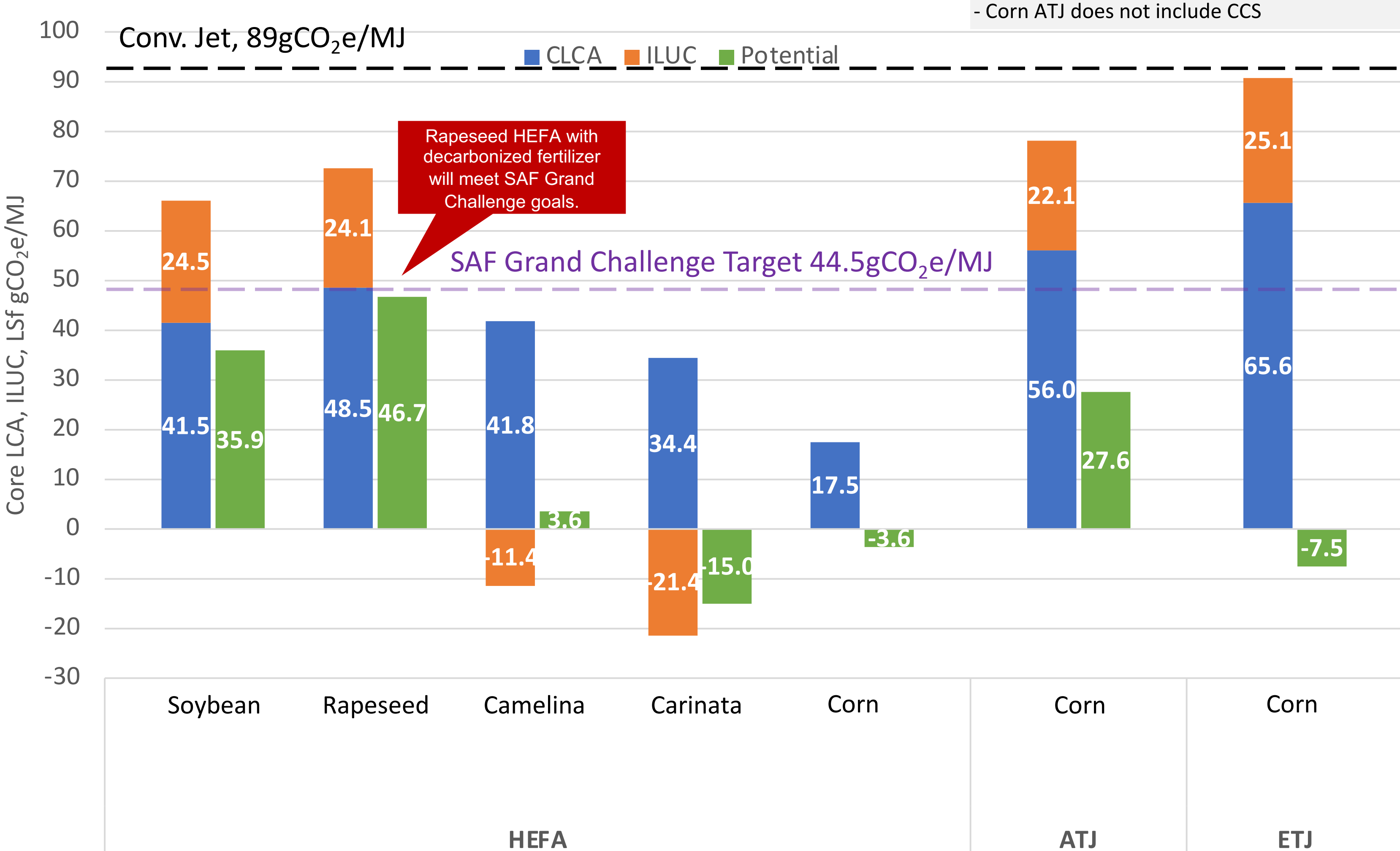


*Spaeth, J. (2021, October 20). *Sustainable aviation fuels from low-carbon ethanol production*. Energy.gov. Retrieved May 20, 2022, from https://www.energy.gov/eere/bioenergy/articles/sustainable-aviation-fuels-low-carbon-ethanol-production

Preliminary.

Core LCA Reduction Potential:
Summary for all pathways considering Core-LCA; additional ILUC potentials may exist

Note:
- Reductions from core LCA only
- Alternate ILUC scenarios may bring additional benefit
- Corn ATJ does not include CCS



Reduction potentials not exhaustive.

Example: All pathways have add. 1-2 gCO_2e/MJ reduction potential from transportation using zero-carbon fuels. Low-carbon fertilizer not yet considered which will benefit all pathways (the least: Soybean)

Conclusions

- Major feedstock/conversion pathways for the U.S. have the **potential for significant LCA reductions**, making many SAF pathways compatible with SAF Grand Challenge goals and long-term ambitions for decarbonization in the aviation sector.
- Leveraging the reduction potentials will require additional effort in the production process, especially using **non-fossil inputs** (RNG, electricity etc.) and **CCS**. To support the trend, **new supply chains to support SAF production** will be needed. This could also entail supply of chemicals and other inputs, e.g. fertilizer.
- **Sustainable land use practices** are another key driver towards significant improvements, especially for soybean-HEFA. This requires further research. Double-cropping strategies leverage a natural advantage in that context.
- **Future research is needed to understand both the scalability and cost of the strategies presented here. This will be key to implementation!**

Preliminary.