Using Life Cycle Assessment to Inform CBI Research Priorities

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Motivation

- Life cycle assessment (LCA) is a methodology for evaluating the environmental impacts associated with providing products or services.
- Within CBI, LCA is used to evaluate and compare the environmental impacts of CBI biorefinery and feedstock systems and to identify and prioritize future research directions.
- This poster gives an overview of the LCA methods used within CBI, identifies data connections between the TEA/LCA team and other CBI teams, and gives several examples of how LCA has previously been applied to inform CBI research.

Methods: Impacts and Indicators

Global Warming Potential (GWP), and Carbon Intensity

- **Impact** calculated from the total of all greenhouse gases released by the life cycle expressed on a CO_2-equivalent basis using GWP factors.
  - Emissions can be either *net* (difference between releases and uptake – see Accounting for Net Carbon) or *gross* (uptake and biogenic releases are excluded). Carbon intensity uses gross emissions. (Prussi et al., 2021)
- **Range:** Net emissions can be negative for life cycles that include carbon uptake via biomass growth, soil carbon changes, and/or carbon capture.
- **Interpretation:** Lower values are preferred.

Cumulative Energy Demand (CED)

- **Indicator** calculated as the total of all primary energy inputs to the life cycle including fossil, renewable, biomass, and nuclear energy sources.
- **Range:** CED is always greater than zero.
- **Interpretation:** Lower values *may be* preferred: higher use of renewable sources can outweigh decreases in the use of fossil sources.

Available WAter REmaining (AWARE)

- **Indicator** that represents regional water stress caused by a life cycle.
  - AWARE is not equivalent to water use, water consumption, or water footprint and does not include emissions to water. Values depend both on water requirements in a life cycle and existing regional water stresses. (Boulay et al., 2018)
- **Range:** A value of 1 indicates no change in water stress is caused by the life cycle under study; higher values indicate more stress.
- **Interpretation:** Lower values are preferred.

Conclusions

- CBI LCAs draw on input from all teams to provide an accurate accounting of environmental impacts associated with the biorefineries and feedstocks being developed.
- LCA has been used to identify environmental hotspots, evaluate feedstock variants, quantify environmental benefits of CBI products over fossil products, and identify impactful biorefinery parameters.

References

Prussi, Matteo et al. "CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels." *Renewable and Sustainable Energy Reviews,* 150 (2021): 111398.
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Klein, Bruno C. et al. "Impact of co-product and feedstock selection on the economics and global warming potential of a commercial-scale biomass-fractionating biorefinery based on CELF pretreatment." *Energy & Environmental Science*. Under review.
Bartling, Andrew W. et al. "Techno-economic analysis and life cycle assessment of a biorefinery utilizing reductive catalytic fractionation." *Energy & Environmental Science* 14, 8 (2021): 4147-4168.
Boulay, Anne-Marie et al. "The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE)." *The International Journal of Life Cycle Assessment* 23 (2018): 368-378.

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TEA/LCA

Methods: Data Inputs from CBI Teams

- Calculating life cycle impacts and indicators requires assembling a life cycle inventory: an account of all processes, material and energy inputs, and emissions required to produce, use, and dispose of a product.
- For CBI LCAs, the inventory includes CBI-developed biorefineries, switchgrass and poplar farming practices, and feedstock logistics, and is developed with input from researchers throughout CBI.
- Each of the boxes below represents actual or potential data exchanges with other CBI teams.

Agricultural Practices (Poplar, Switchgrass, TEA/LCA)
- Fertilizer and chemical use
- SOC changes and carbon uptake
- Equipment specifications and use
- Biomass yield

Feedstock Logistics (TEA/LCA)
- Transport equipment specifications
- Fuel use in equipment

Biorefinery Simulation (TEA/LCA, Deconstruction, CompBio, C-CBP, LigVal, Catalysis)
- Chemical inputs
- Fuel and electricity inputs
- Water use
- Process level emissions

Biorefinery Products (TEA/LCA, C-CBP, LigVal)
- Amount and type of fuels and products
- Equivalent fossil-derived products, if known

Methods: Accounting for Net Carbon

Carbon is both removed from and released to the environment in a biofuel supply chain. How do we tell if the biofuel is carbon-neutral or carbon-negative?

Increasing collaboration and data needs →

Standard Assumption	Basic Accounting	Full Accounting
Assume that biogenic carbon releases and carbon uptake throughout the life cycle are equal.	• Include biogenic carbon emitted by the biorefinery. • Include carbon uptake by growing biomass using a static factor. • Include carbon released during biofuel use.	• Include biogenic carbon emitted by the biorefinery. • Include simulated changes in carbon stocks for viable agricultural locations. • Include carbon released during biofuel use.

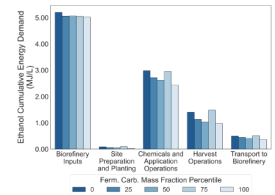
Applying LCA to Inform Research Priorities

Environmental Hotspots

The largest portion of switchgrass-to-ethanol life cycle impacts is due to the biorefinery, and biorefinery impacts are relatively insensitive to cell wall composition.

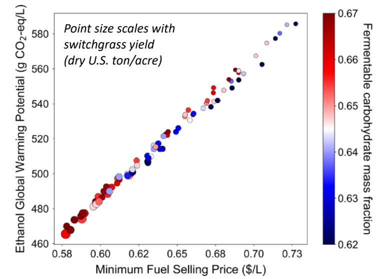
Context: Switchgrass natural variant study with TEA/LCA performed on 84 switchgrass variants converted to ethanol. (Happs et al., in preparation)

Outcome: Because switchgrass was assumed to be grown with minimal inputs and particularly no irrigation, the biorefinery inputs contribute the largest share of total CED. Switchgrass cell wall composition, indicated by shades of blue at right, had little effect on the overall impacts. This indicates that reducing the impact of biorefinery inputs needs to be done via biorefinery optimization rather than switchgrass variant selection.



Economic and Environmental Co-Benefits

High switchgrass yield provides both economic and environmental benefits. Cell wall composition has a less significant impact.



Context: Switchgrass natural varient study with TEA/LCA performed on 84 switchgrass variants converted to ethanol. (Happs et al., in preparation)

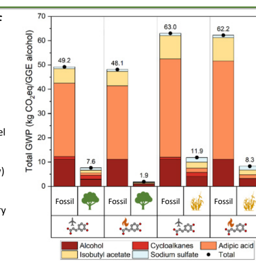
Outcome: Ethanol GWP and minimum fuel selling price (MFSP) are strongly correlated for these switchgrass variants. High switchgrass yields (lower left corner of graph) provide both low GWP and low MSP. Cell wall composition (red-blue color scale) appears to have less of an impact, but this may be because the higher-yield variants all had similar cell wall compositions.

Comparison to Equivalent Fossil Products

Using CELF to co-produce a slate of products provides environmental benefits over the equivalent fossil products.

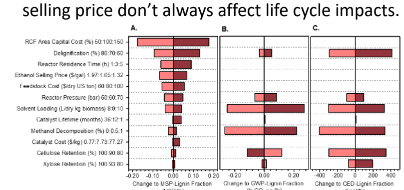
Context: Co-solvent enhanced lignocellulosic fractionation (CELF) biorefinery configurations that either produced jet fuel or burned lignin and used either corn stover or poplar as a feedstock are compared to each other and to production of the equivalent fossil product slate. (Klein et al., under review)

Outcome: All CELF biorefineries offer large environmental benefits over the fossil products. Overall, the CELF biorefinery using poplar and burning lignin instead of producing jet fuel had the lowest life cycle GWP.



Biorefinery Parameters Sensitivity Analysis

The biorefinery parameters with the greatest effect on minimum selling price don't always affect life cycle impacts.



Context: Reduced catalytic fractionation (RCF) TEA/LCA (Bartling et al. 2021) single point sensitivity analyses for change to the **A.** Minimum lignin fraction selling price (MSP) **B.** GWP, and **C.** CED.

Outcome: Parameters that strongly affect MSP do not necessarily have a strong affect on GWP or CED. Reducing solvent loading or reactor pressure provide reasonable co-benefits.

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