Life Cycle Assessment

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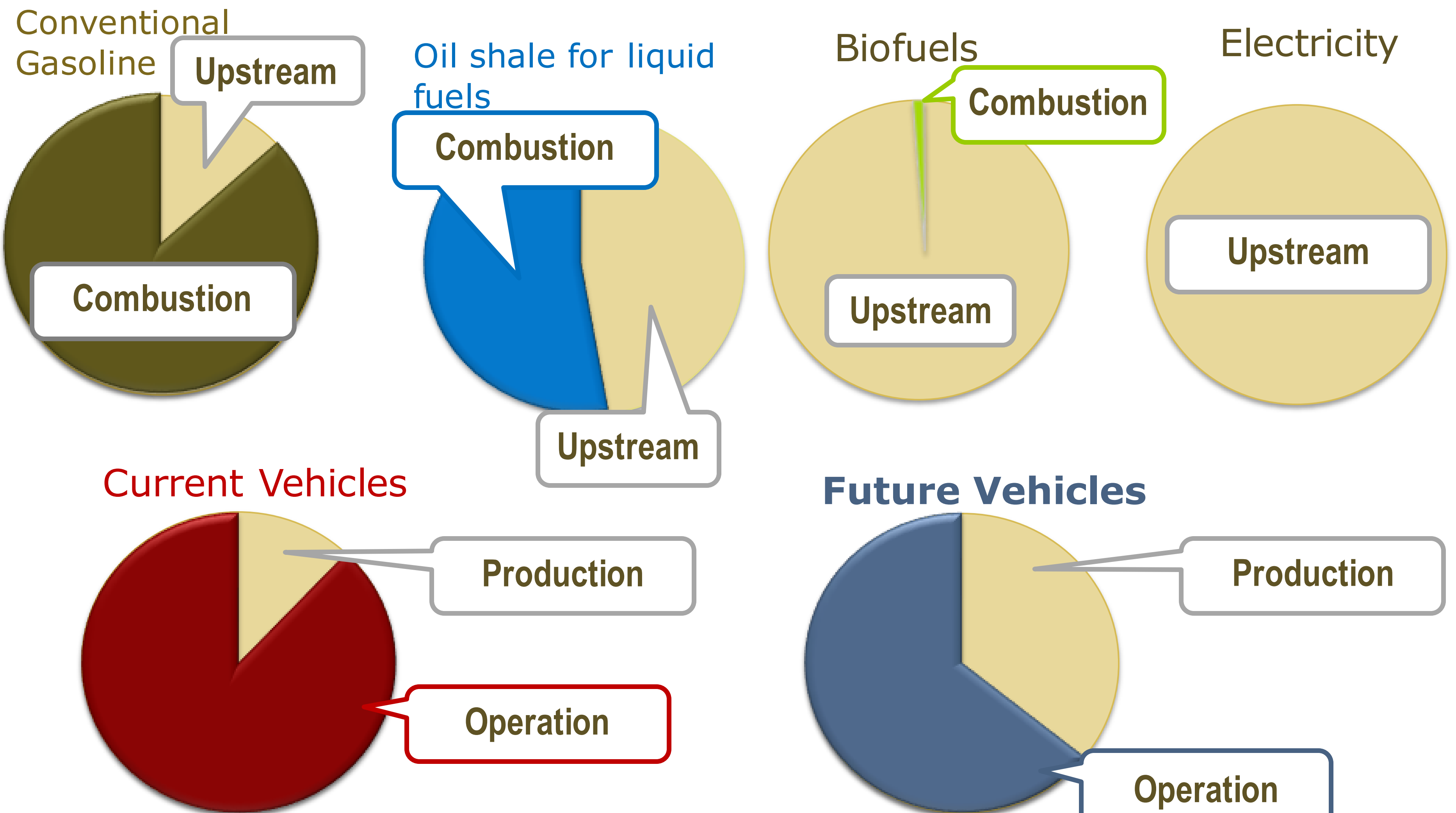
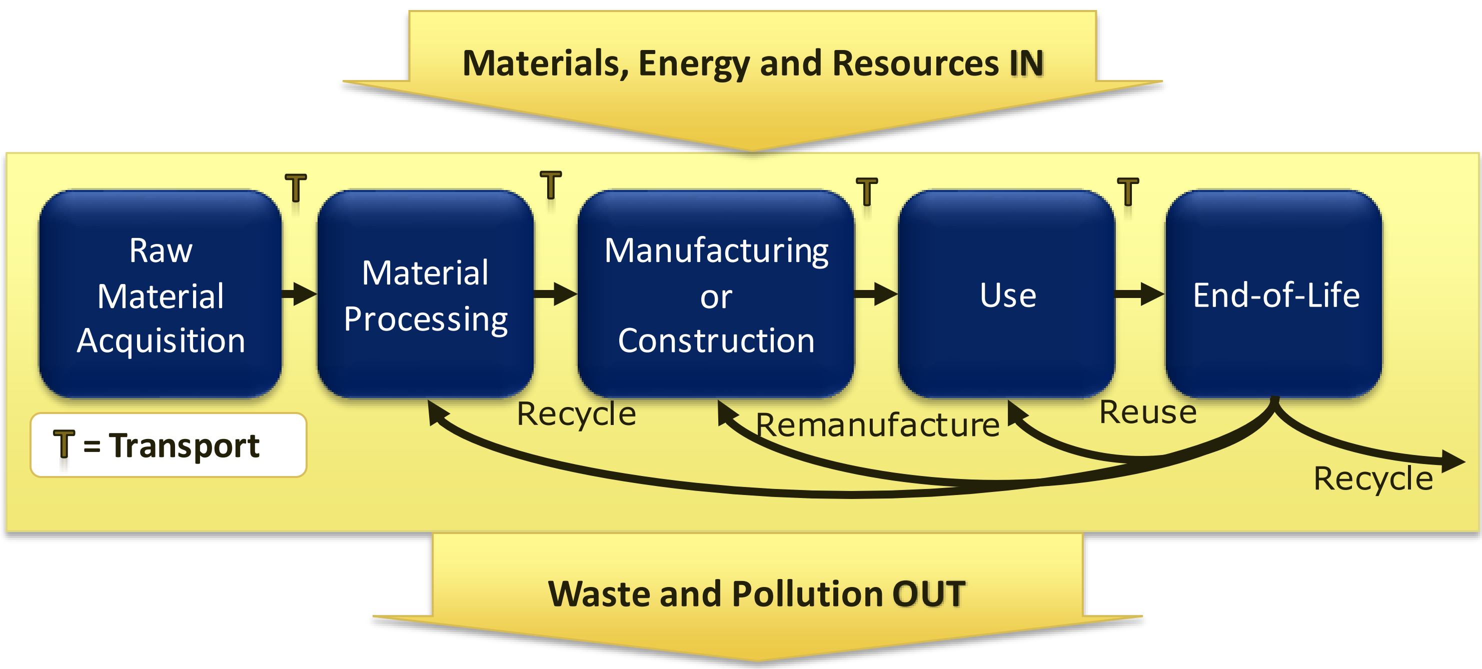
Why we (increasingly) need a life cycle approach for evaluating energy and emissions

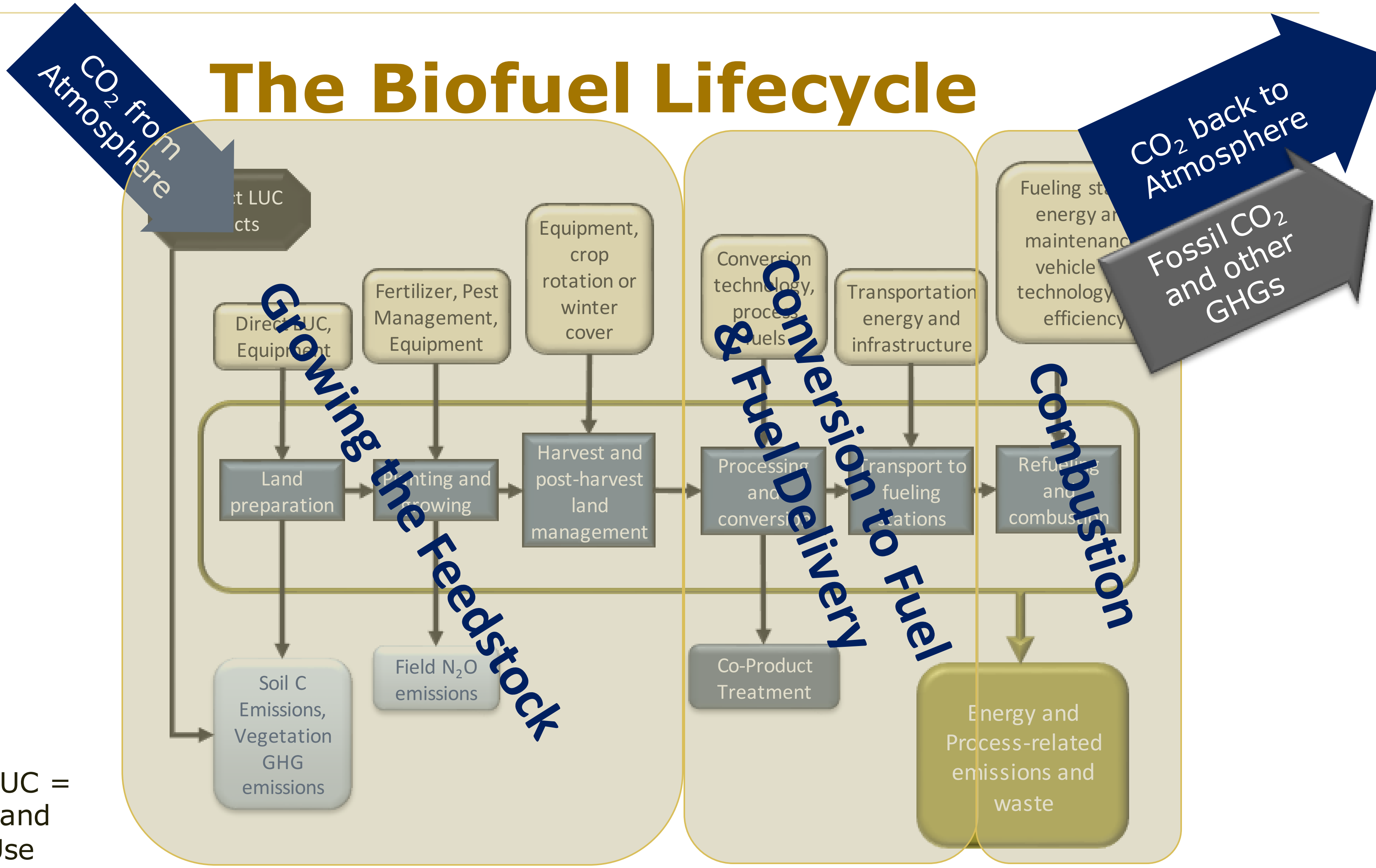


Lifecycle Assessment (LCA)

- A method for characterizing and quantifying and interpreting environmental flows for a product or service from a "cradle-to-grave" perspective

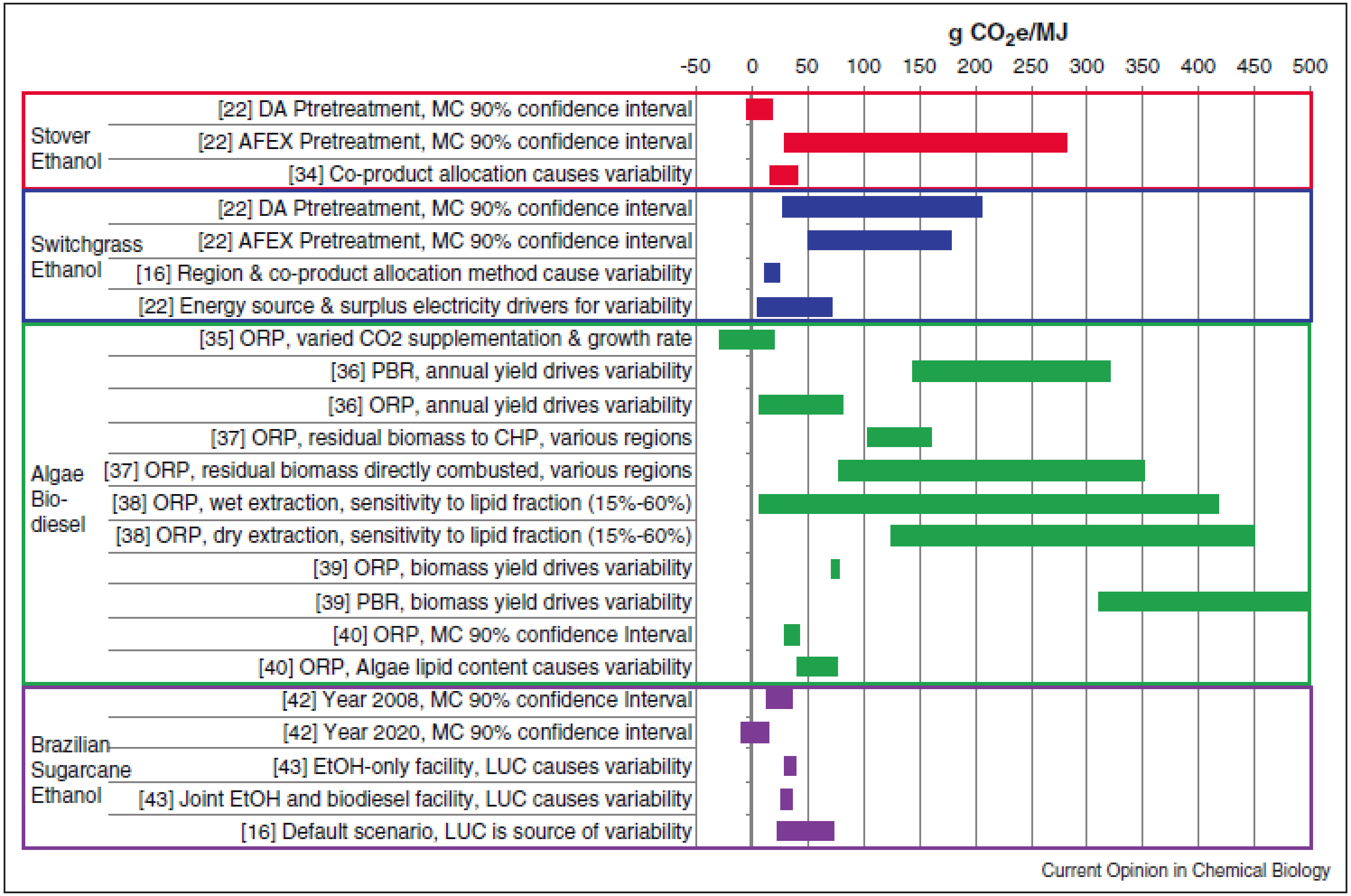


The Biofuel Lifecycle



LUC = Land Use Change

Biofuels LCA shows great variability between and within pathways



Kendall and Yuan (2013) Current Opinion in Chemical Biology 17:439-443

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Where does this variability come from?

Steps in an LCA

Source of Variability or Uncertainty

	Goal and Scope Definition	Life Cycle Inventory	Impact Assessment
Model and Methods-Induced Variability	(1) Attributional vs. Consequential (2) System Boundary Selection (3) LUC and cut-off rules (4) Impact Categories Modeled	(1) Age and quality of background LCI datasets (2) Co-product allocation methods	(1) Impact assessment method and reporting (2) Treatment of time and biogenic GHG emissions
Actual Variability and Uncertainty in Biofuel Pathway Performance	(1) Retrospective vs. Prospective (2) Spatiotemporal heterogeneity • Assumptions about climate, soil, cultivation practices, yields and regional energy systems (3) Technology selection or technology configurations	(1) Spatiotemporal heterogeneity as reflected in LCI datasets (2) Differences in co-product utilization (3) Real or projected performance differences in production technologies reflected in assessed environmental flows	(1) Spatiotemporal heterogeneity as reflected in impact assessment (2) Real or projected performance differences among production technologies as reflected in impact assessment

Current Opinion in Chemical Biology

Sources of variability and uncertainty at each stage of a biofuel LCA.

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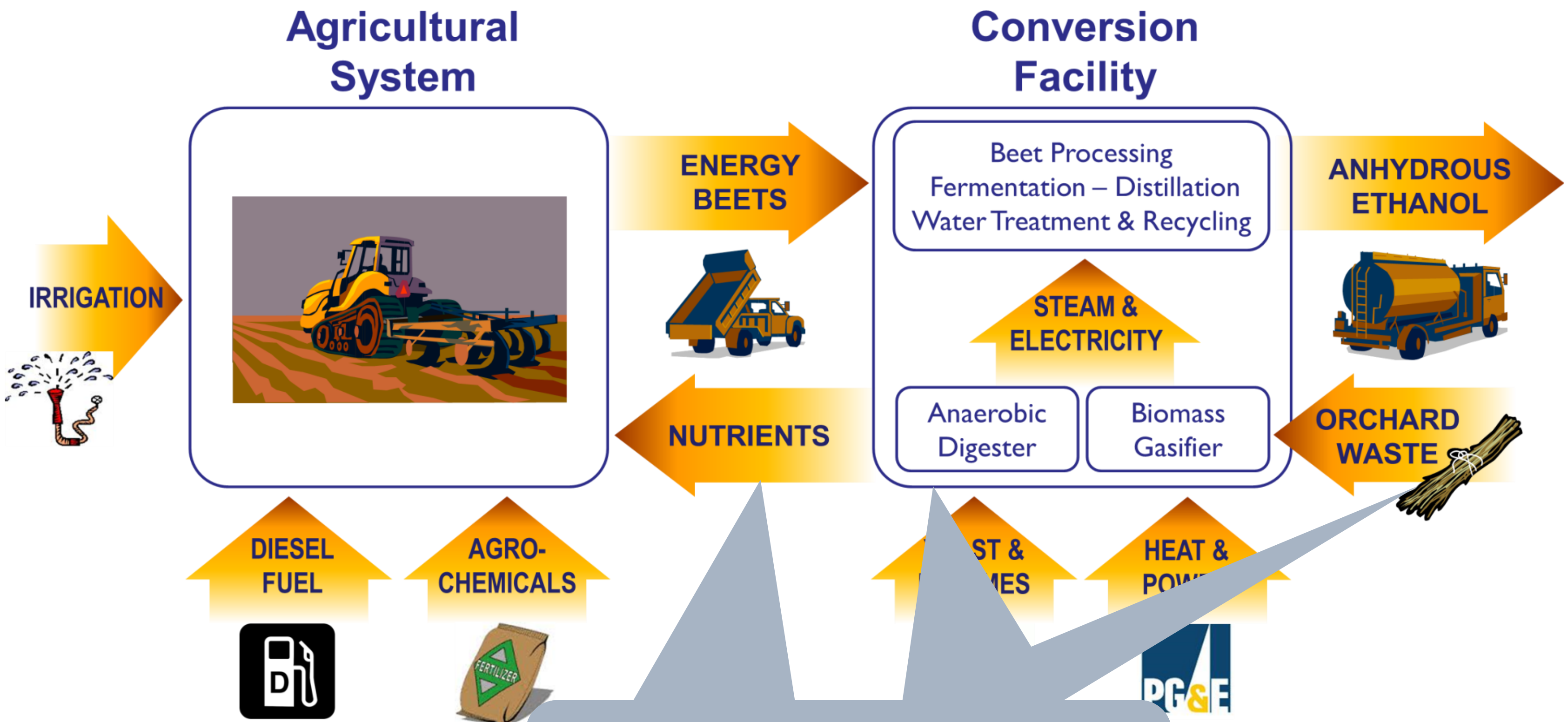
Current Research

- Philosophy: Integrating systems and "closing loops" to improve the environmental performance of biofuels
- Feedstocks
  - First generation feedstock (sugar beet)
  - Second generation feedstocks (cellulosics)
  - Advanced biofuels (algae)

How can we close loops?

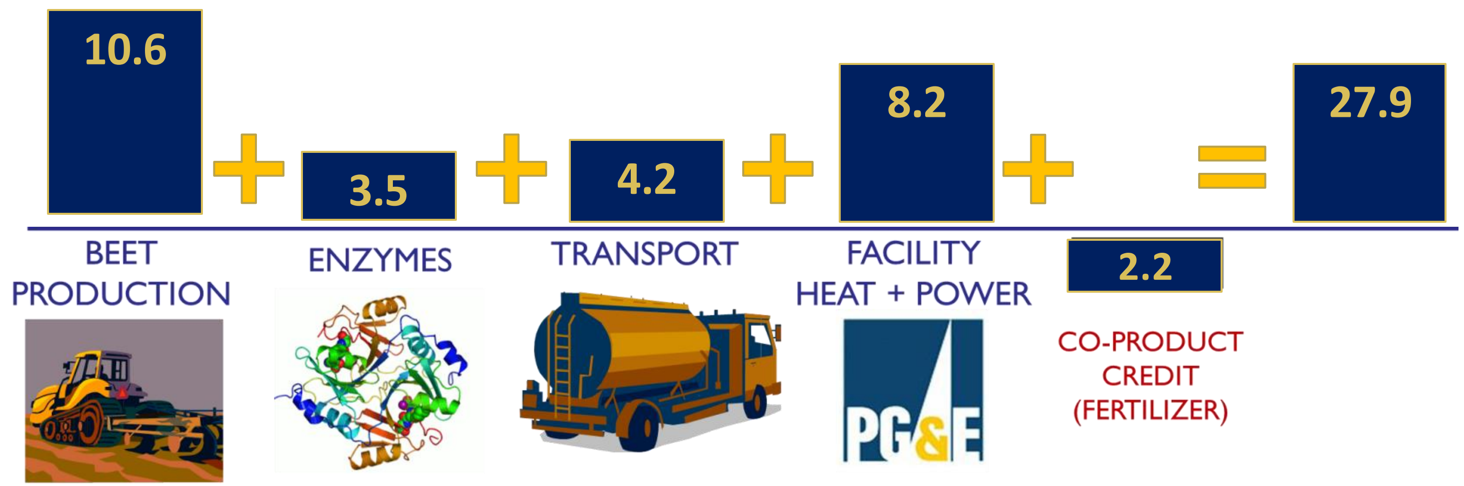
- Internal to production systems and external to productions systems
  - Internal Example: Recycling water, carbon, energy within a production site
  - External Example: Valorizing waste flows to find higher uses of co-products

First Generation: Sugar beet in California



Closing carbon, water, and nutrient loops

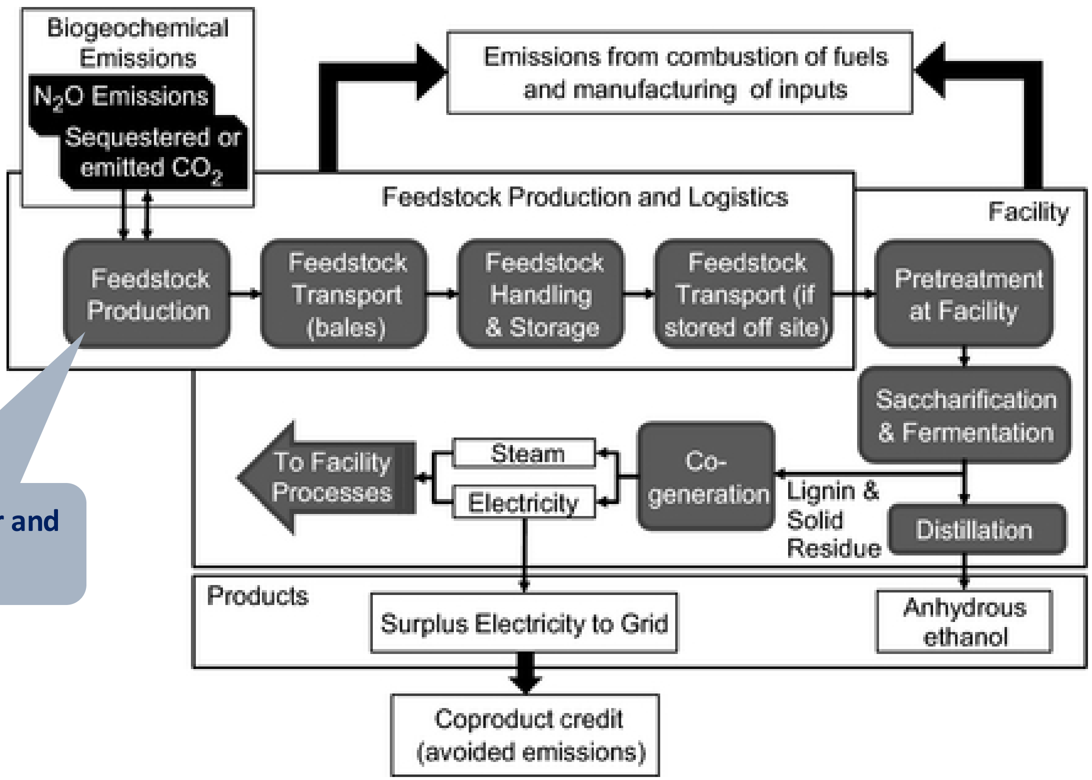
Results – deep reductions in GHG intensity



- 44% lower than weighted average CI for California ethanol
  - This excludes land use change for all the ethanol pathways
  - No iLUC estimates for sugar beets

Alexiades, A; Kendall, A; Winans, K.S., Kaffka, S.R. Sugar beet ethanol (Beta vulgaris L.): A promising low-carbon pathway for ethanol production in California ***Journal of Cleaner Production*** (in press)

Life cycle analysis of biochemical cellulosic ethanol under multiple scenarios



Examined corn stover and switchgrass

Murphy, C., Kendall A. ***GCB Bioenergy*** Volume 7, Issue 5, pages 1019-1033, 14 JUN 2014 DOI: 10.1111/gcbb.12204

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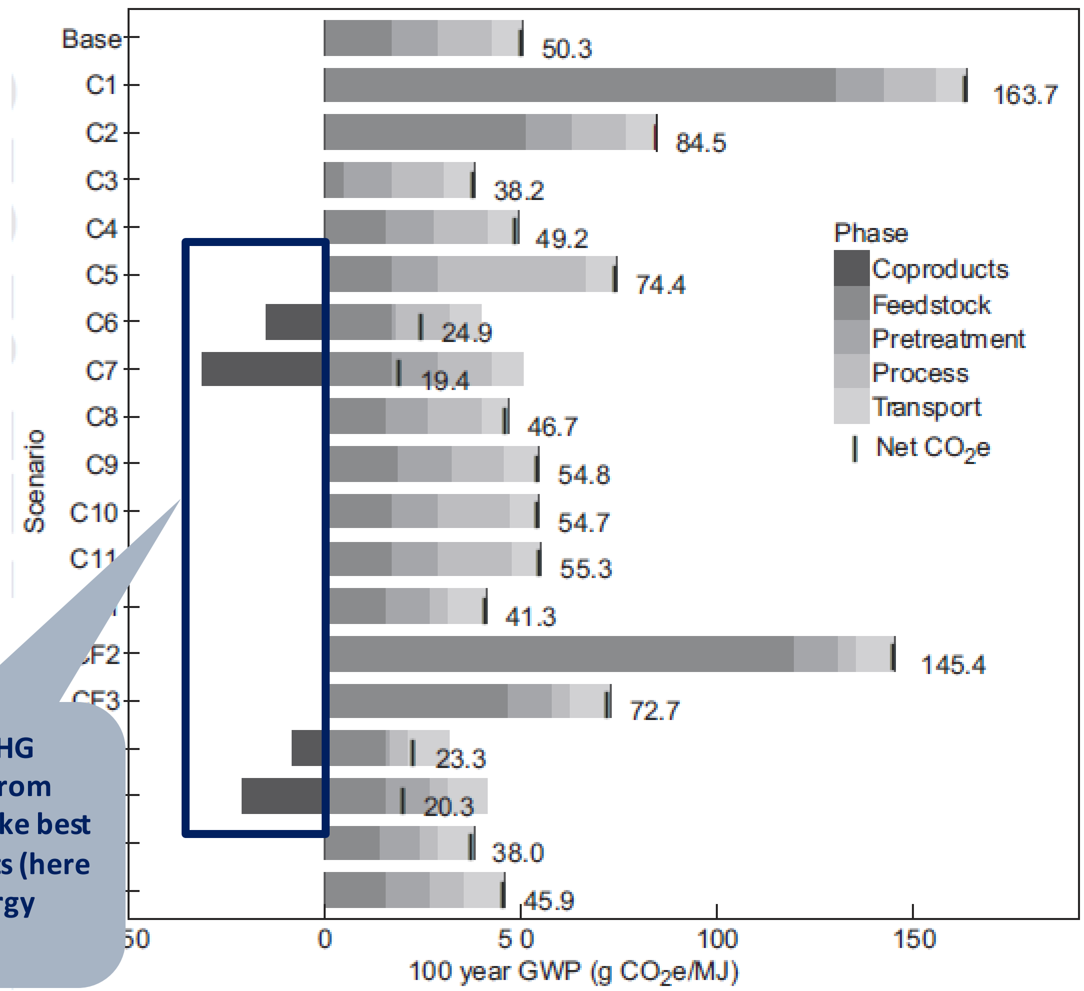
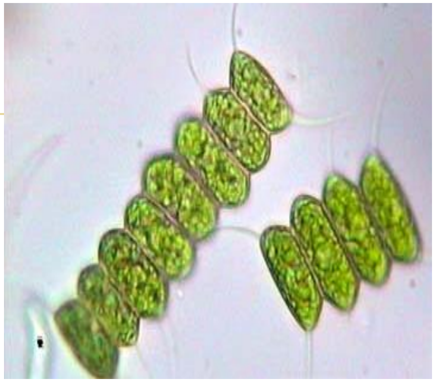
Results for Corn stover ethanol



Lowest Net GHG Emissions are from scenarios that make best use of co-products (here lignin for energy recovery

The Potential of Microalgae



- Short growth and harvest cycle (~ 10days)
- High biomass yield and high lipid content – potential for 10X the oil production per area than soybeans
- Avoids competition with cropland, grow anywhere with CO_2, water (high or low quality) sunlight, and nutrients
  - No indirect land use change
- Use waste streams

Microalgae's Reality

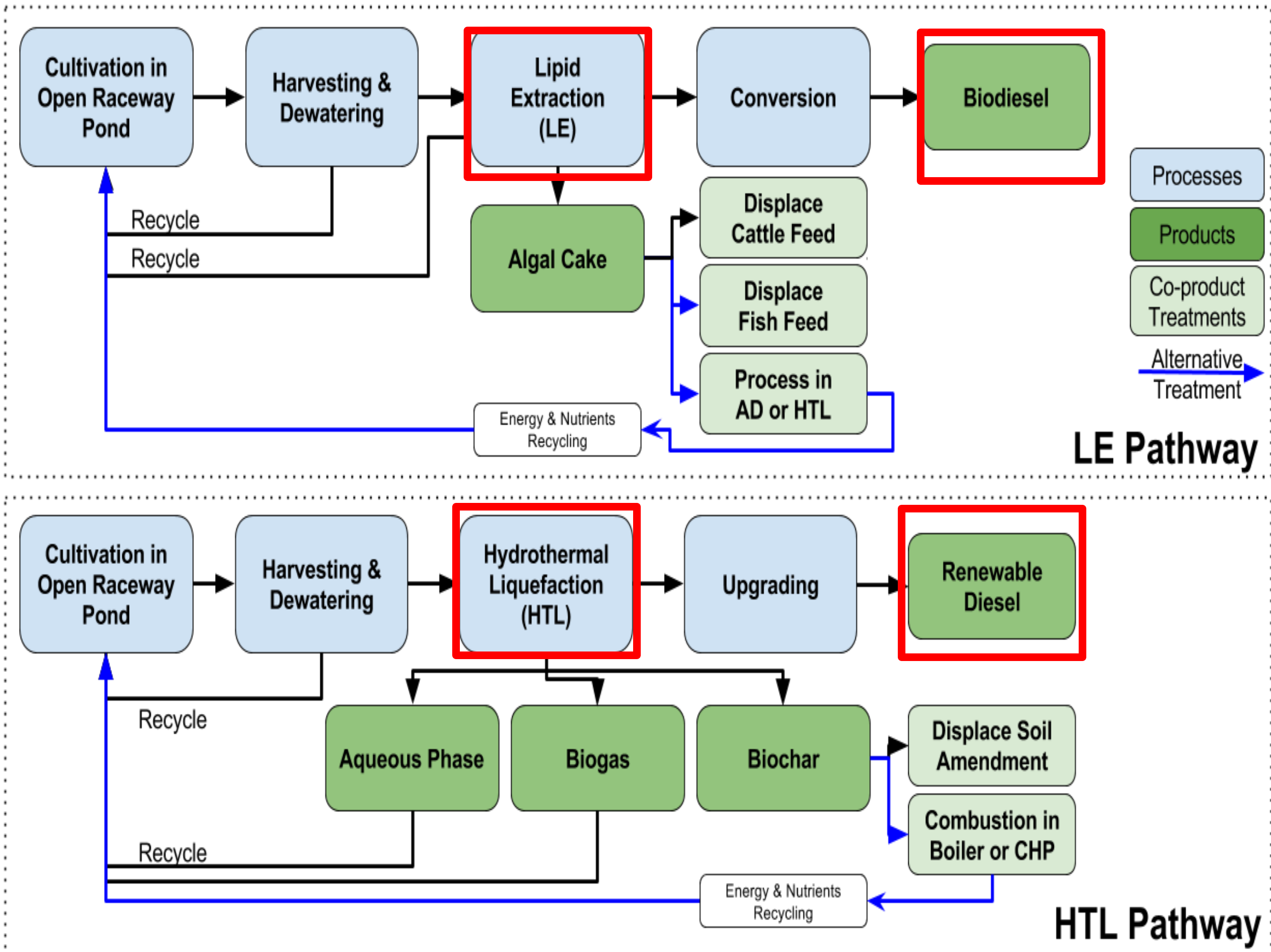
- Life cycle greenhouse gas (GHG) emissions
  - **10 to 500** g CO_2e/MJ
- Primary energy input
  - **0.2 - 6** MJ/MJ biodiesel
- Cost-effectiveness
  - **$1.64 - $30**/gallon biodiesel

Definitions

- **Biodiesel** is produced by extracting oil and transesterification process
- **Renewable Diesel** is chemically the same as petro-diesel, with no esters in the chemical composition. May be produced a number of ways from "green crude" – here we model green crude from hydrothermal liquefaction

System Description

Oil Extraction/Conversion Technologies



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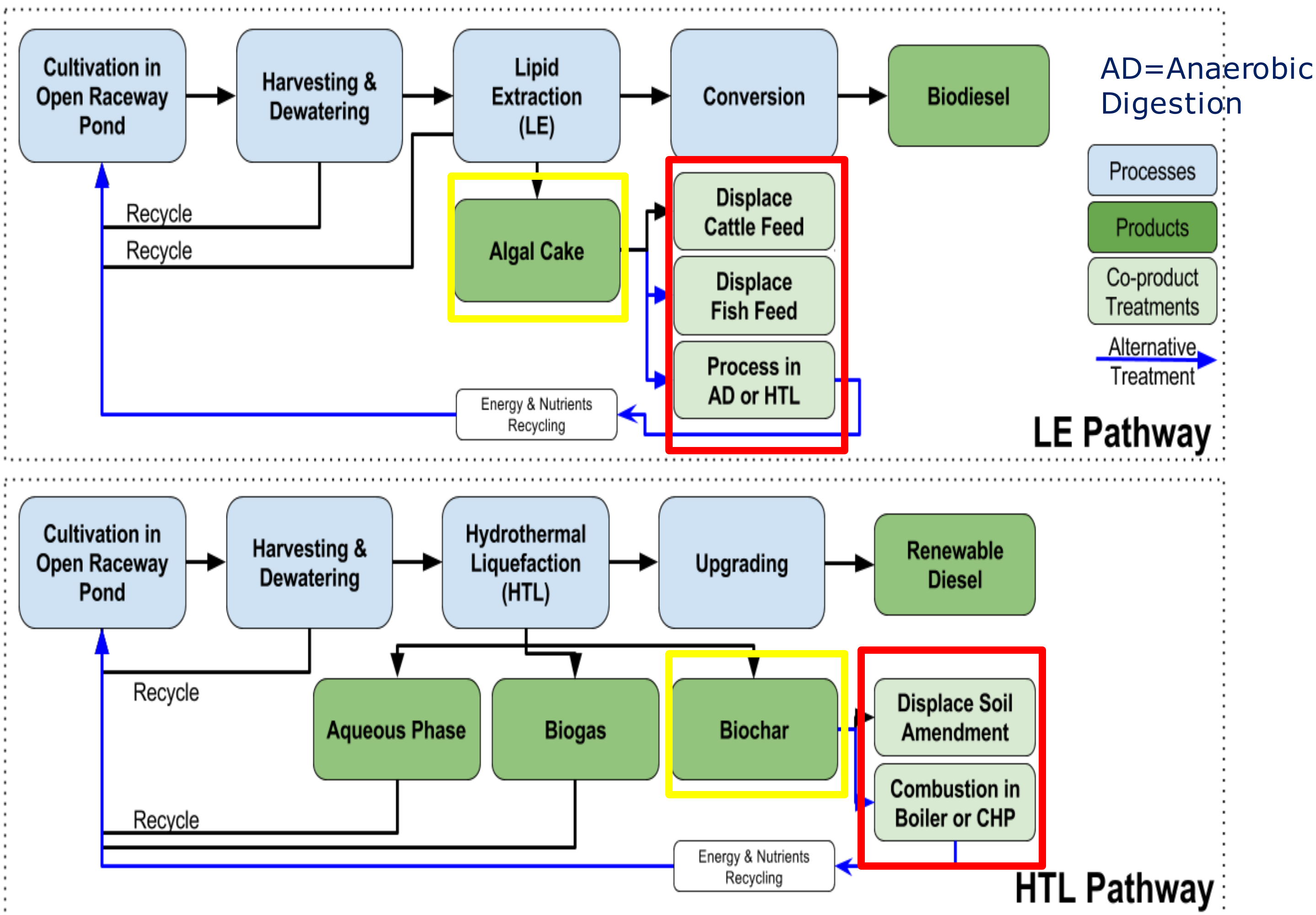
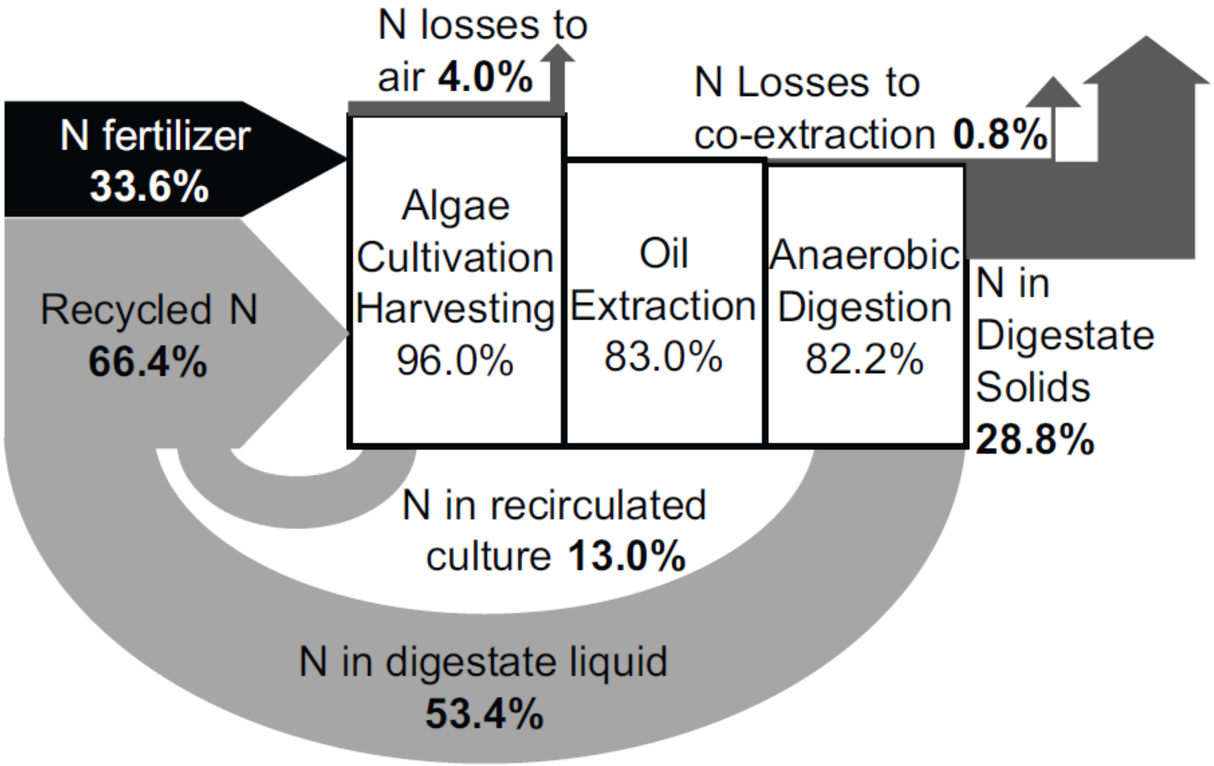
System Descriptions

Co-products and Treatment strategies



Example of nutrient and water cycling



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LE or HTL -- Which technology recycles better?

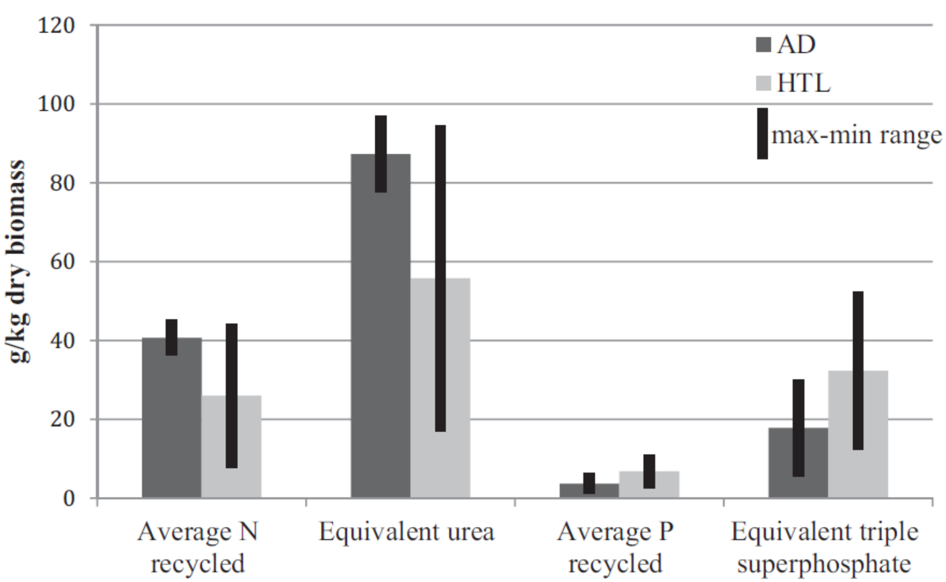


Fig. 2. Nutrient recycling rate through AD or HTL of algal cake.

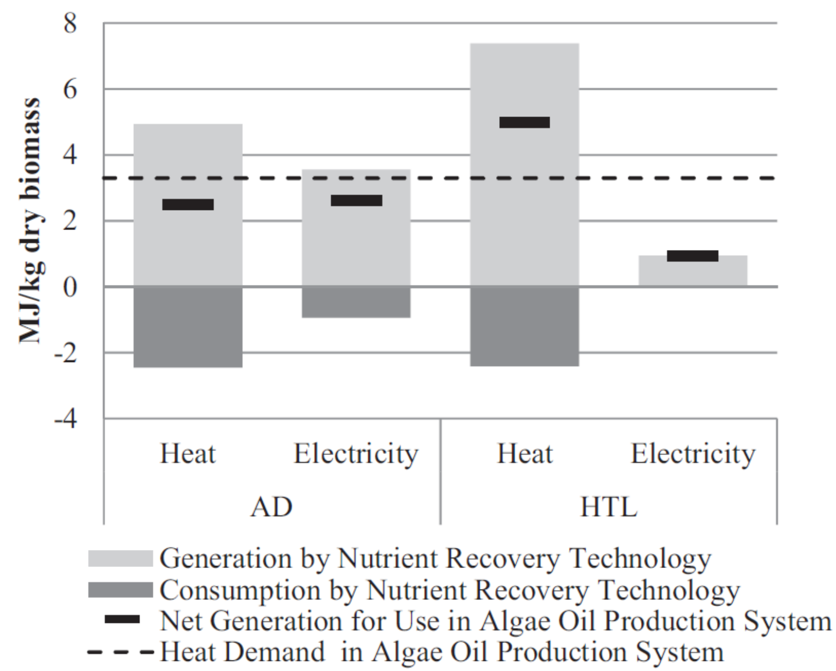


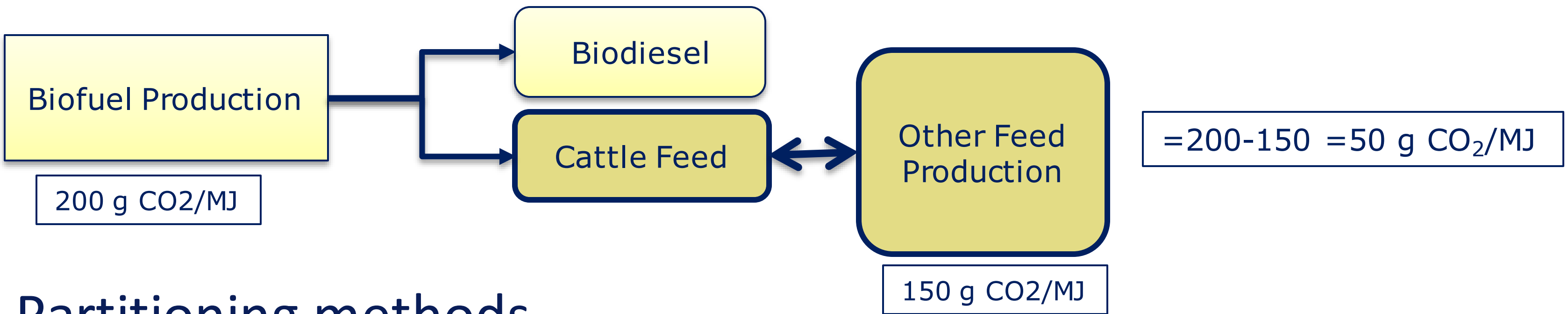
Fig. 3. Energy recovery from algal cake through AD or HTL.

Are internal or external loops better?

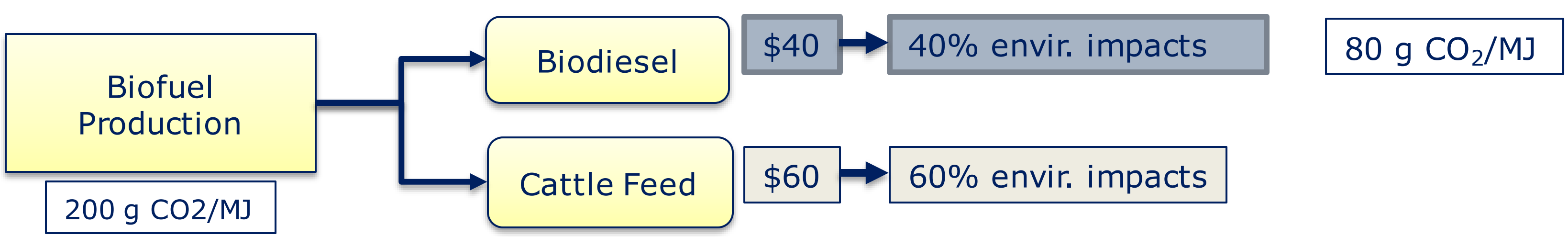
- I've just shown you results focused on internal recycling
- What happens if we include the export of algal cake for uses outside of the algae biofuel production system?
- Algal cake is nutrient and protein rich…makes a great potential feed for livestock and aquaculture

Co-Product Allocation Choices

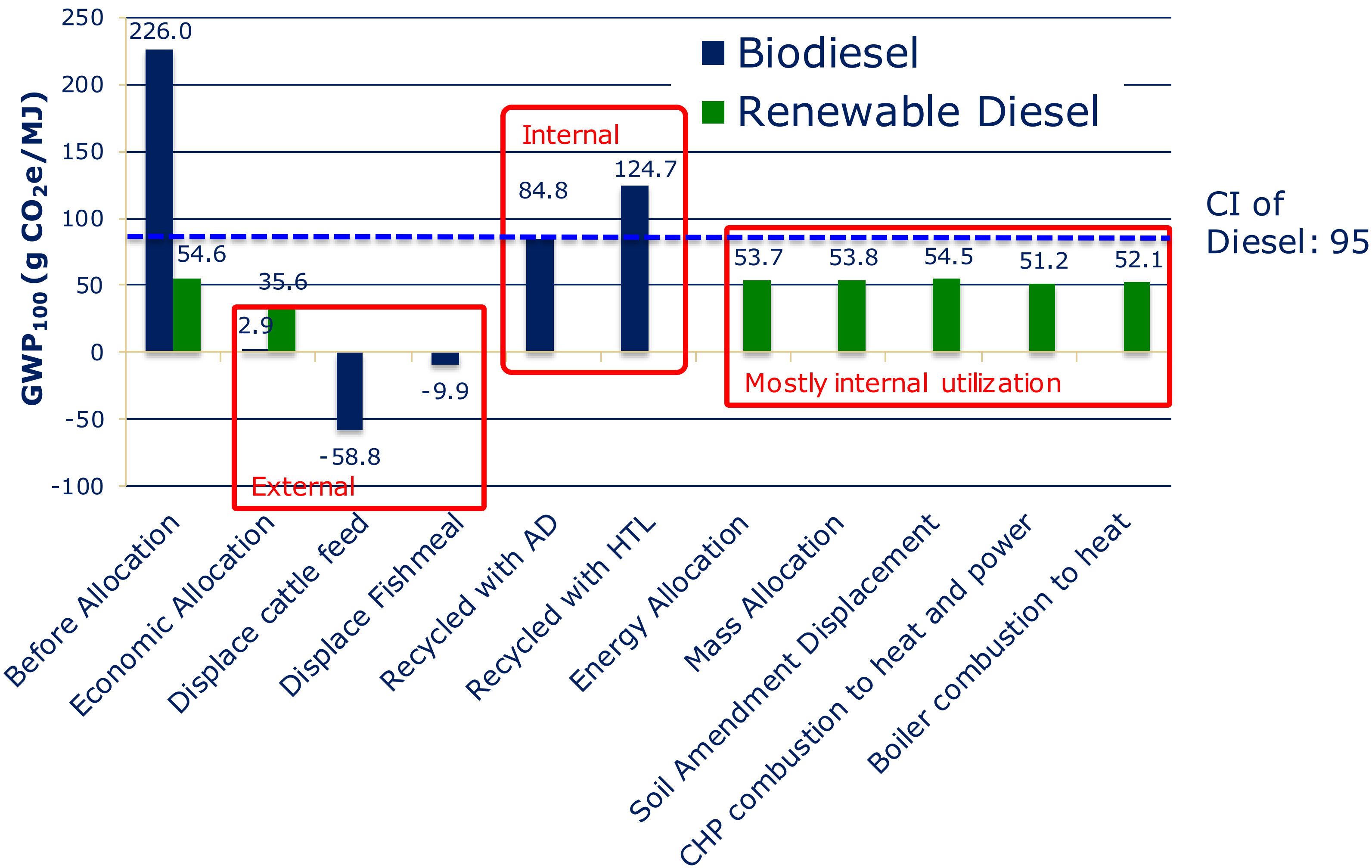
- System expansion (displacement method)
  - expands the product system to include additional procedure related to the co-product



- Partitioning methods
  - allocation which divides the environmental flows for the system based on physical causality or on value such as mass, energy content, or economic value



GHG emissions from Biodiesel and Renewable Diesel Production with Co-product Treatment



External Recycling

- While external recycling has a chance of leading to displacement of high impact substitutes and thus generating ultra-low or negative impacts, it also is highly uncertain and subject to market forces
- Internal recycling actually eliminates demand for resources, making calculations reliable and free of market assumptions and methodological choices (around allocation).

Current work

- A current project with colleagues at UCD looking to close loops on the anaerobic digester here on campus, using the nutrient-rich effluent and the CO_2 from biogas combustion to grow algae and reduce nutrient loads in the effluent (provide water treatment).

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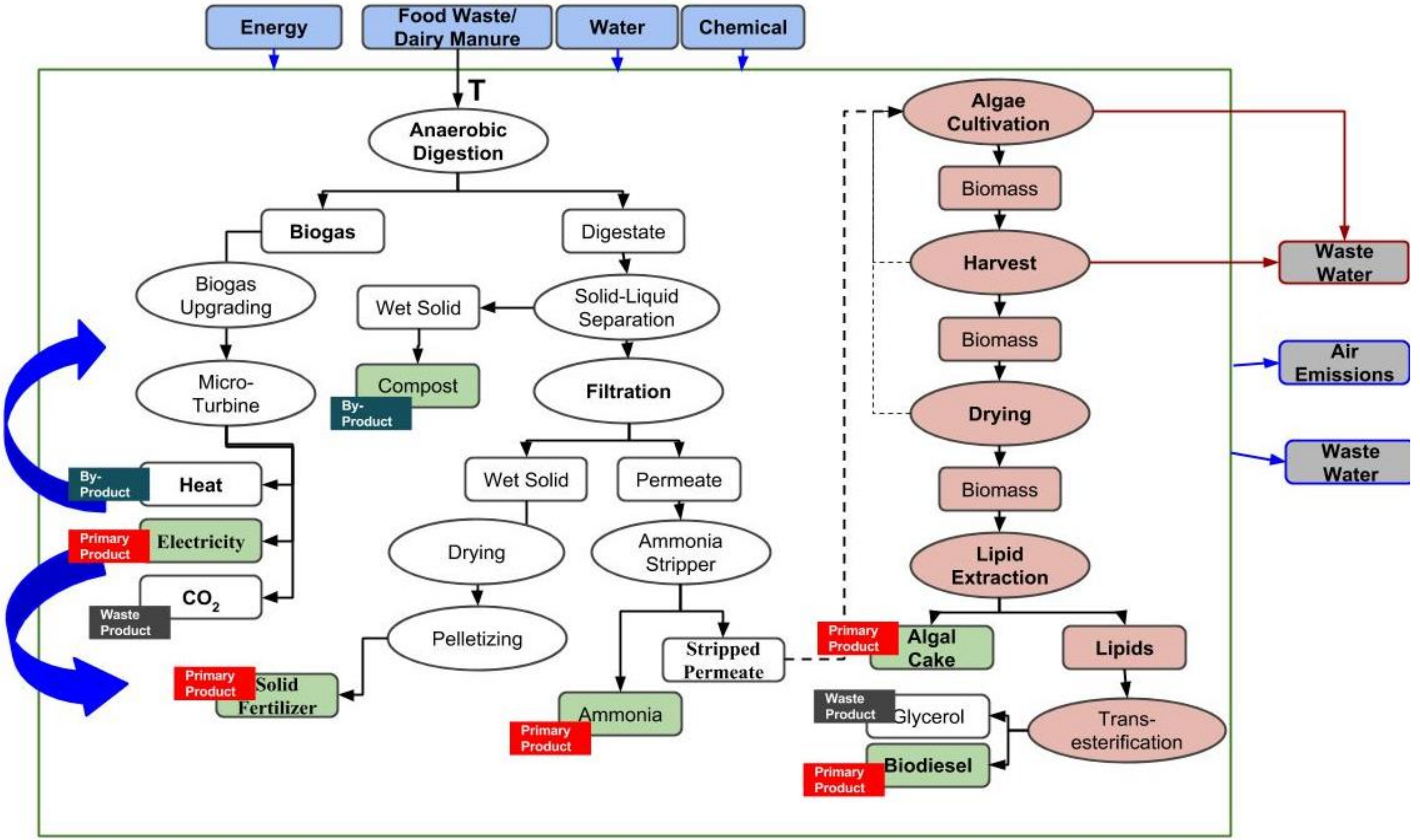
System Description



Question?

- Contact information

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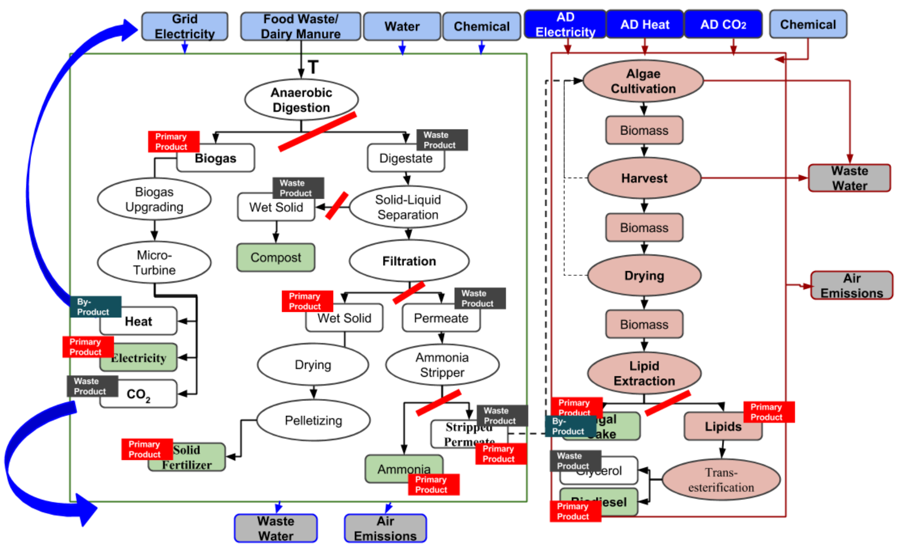
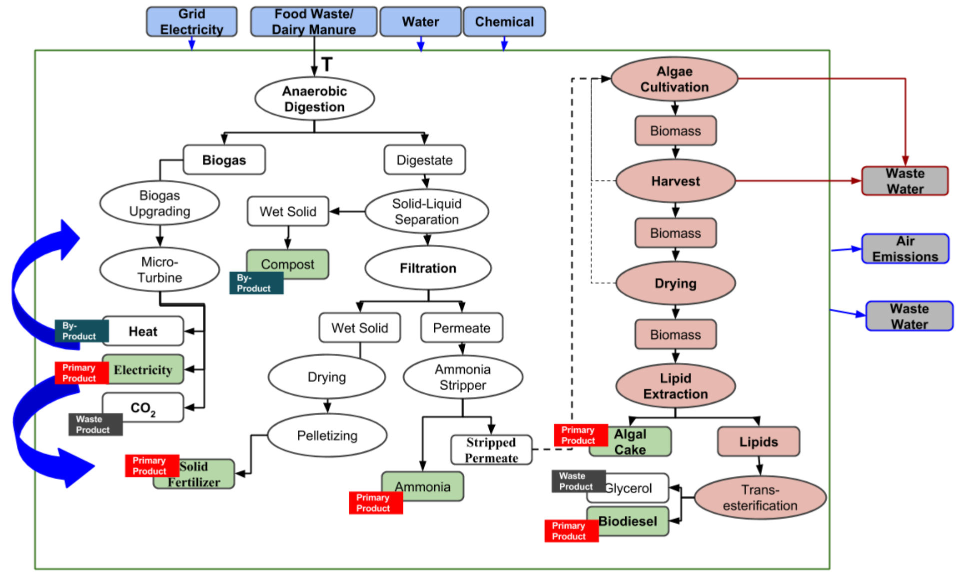
Next: Test allocation effects in different system boundaries

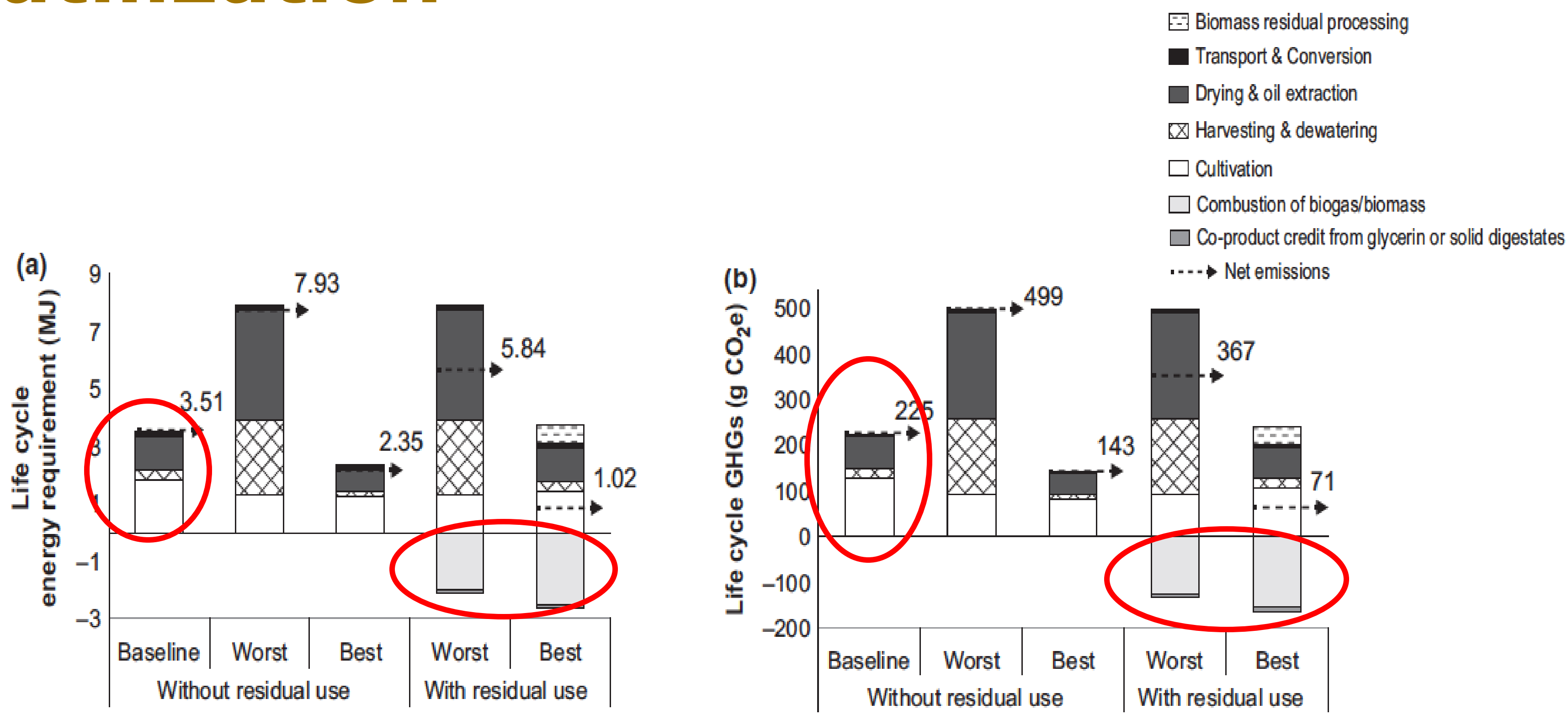
Framework 1: Algae biodiesel production as co-located independent production system





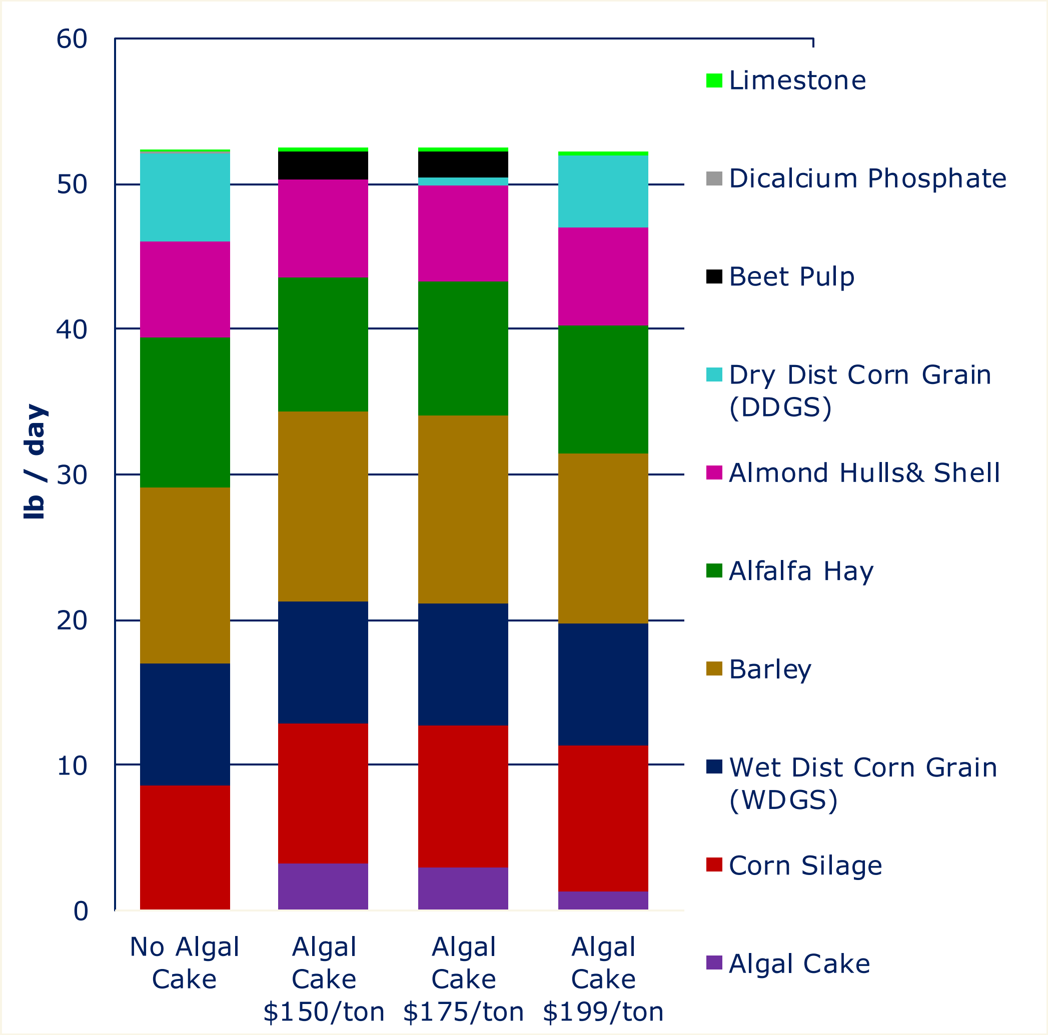
Framework 2: Consider AD and Algae Biodiesel as one integrated system.

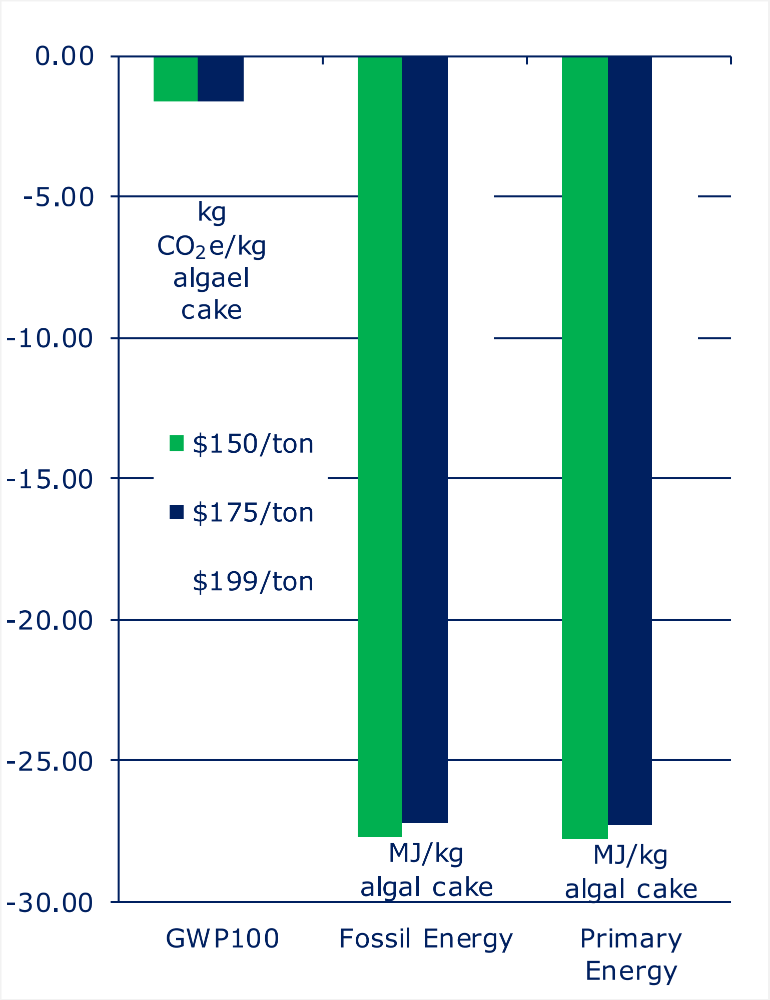
Life cycle performance of Algal Biodiesel: a function of residual utilization



Yuan, J, Kendall, A, and Zhang, Y. GCB Bioenergy (2014), doi: 10.1111/gcbb.12229

Estimation of Dairy Feed Displacement by Algal Cake





LE Co-product Treatment Strategies

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Utilization of Algal Cake	Economic Allocation	Displace CA Dairy Cattle Feed	Displace Fishmeal	Process in Anaerobic Digester (AD)	Process in Hydrothermal Liquefaction (HTL)

LE Results

Effects of Co-product Treatments on GWP and Total Energy of Biodiesel

	GWP_{100} (g CO_2e/MJ)	Primary Energy (MJ/MJ)
Before Allocation	226	3.52
Displace Cattle Feed	-58.80	-1.24
Displace Fishmeal	-9.88	0.05
Recycled with AD	84.77	1.06
Recycled with HTL	124.73	1.77
Economic Allocation (as feed)	2.89	0.05

Renewable Diesel Results

Effects of co-product treatment on Algal Renewable Diesel

	Primary Energy (MJ/MJ)	Carbon Intensity (g CO_2e/MJ)
Economic Allocation	0.62	35.64
Energy Allocation	0.93	53.75
Mass Allocation	0.93	53.76
Soil Amendment	0.76	54.49
Heat and Power	0.88	51.16
Heat Generation	0.89	52.13
Before Allocation	***0.95***	***54.59***