Life Cycle Assessment of Consumptive Water Use in Biofuel Production via Thermal Deoxygenation of Woody Biomass

Mikaela Dunkin
FBRI REU Research Scholar
Mentor: **Jonathan Rubin, PhD**
University of Maine, School of Economics

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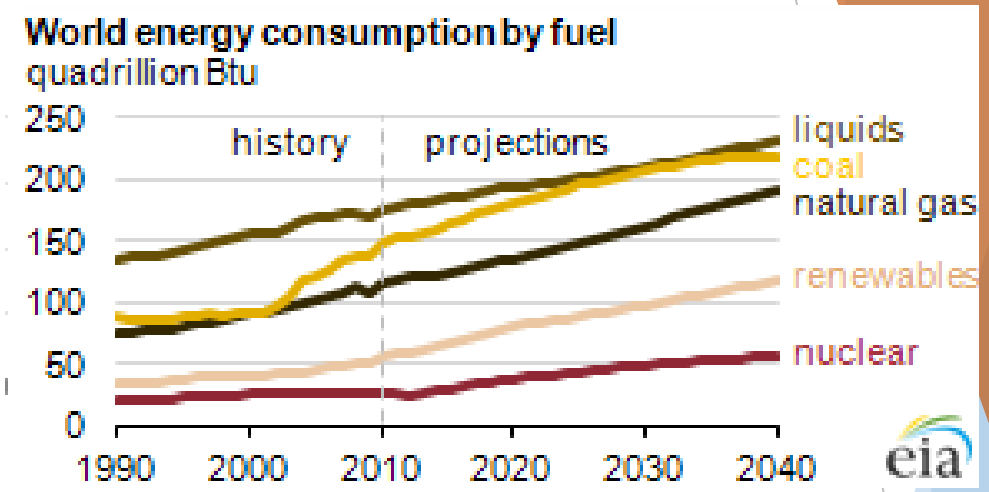
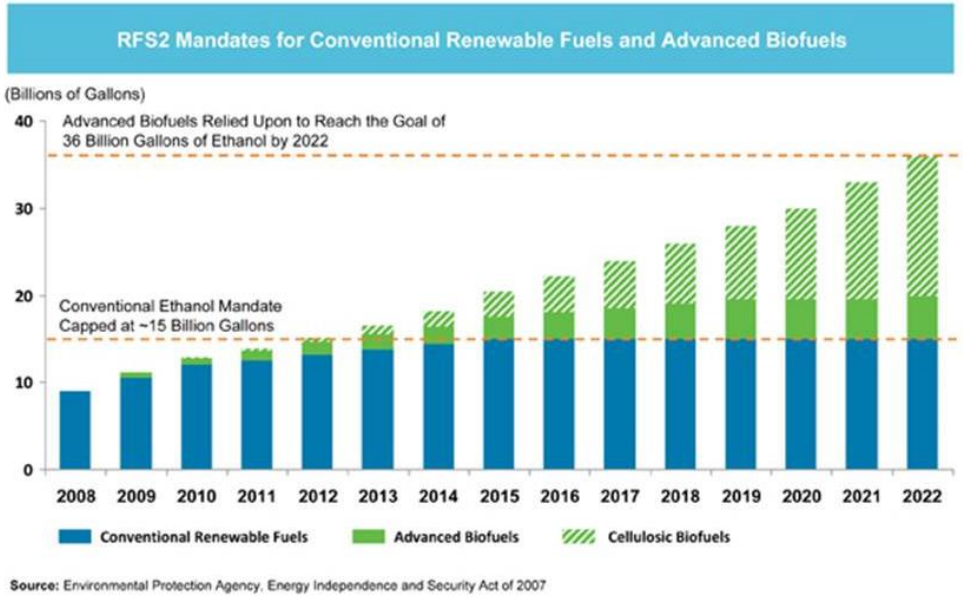
Background

- Increasing energy demands, including fuel
- United States is looking for
  - Energy security
  - Renewable fuels
  - Environmentally friendly energy

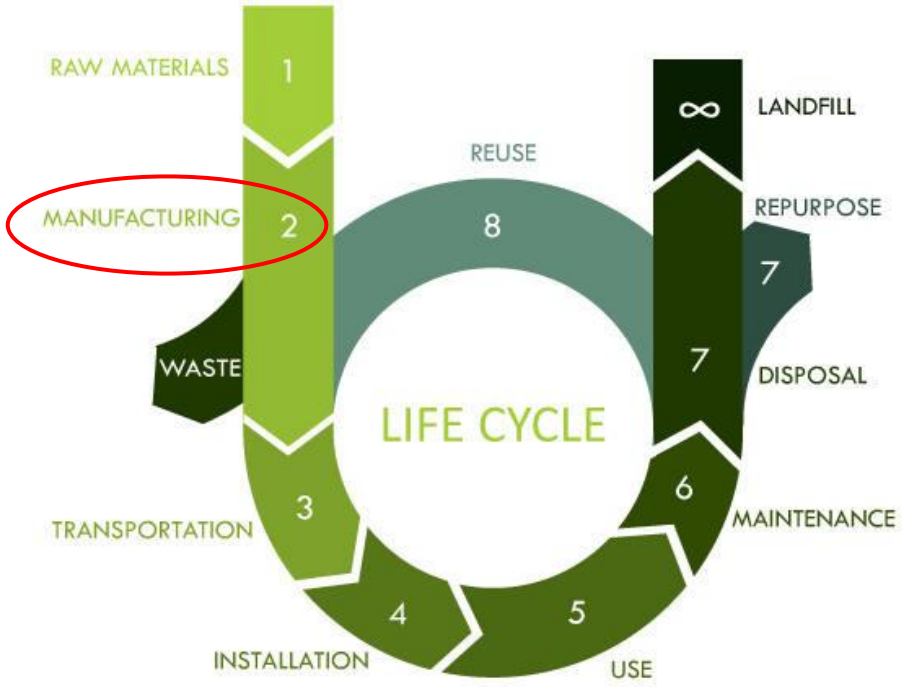




- Environmental Protection Agency (EPA) oversees the execution of the Renewable Fuel Standard (RFS2) sets mandated volume requirements for renewable fuels and incentivizes their production

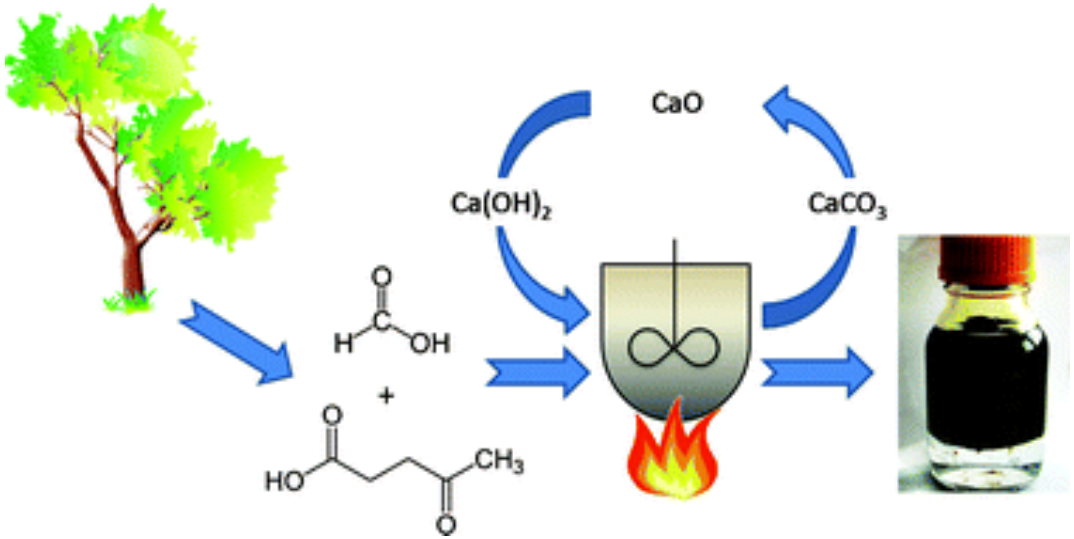
Background

- Life Cycle Assessment (LCA) is a technique used to determine the impact of a product or process
- Follows the basic guideline
  - Define a goal and scope
  - Inventory analysis
  - Assess potential impacts
  - Interpret data
- Used for greenhouse gas emissions or other pollution
- Not commonly done for water



Background

- Thermal deoxygenation (TDO), takes calcium neutralized acids from biomass and heats them to 450˚C in a bomb reactor to produce a hydrocarbon mix of fuels that have a high boiling point and energy content (Eaton 2013).



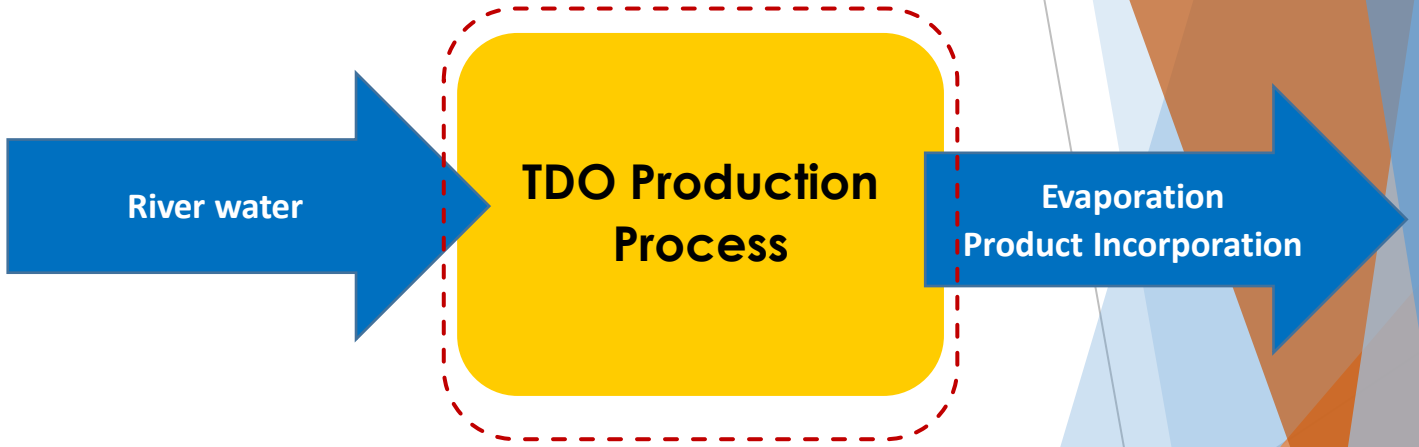
- Produces furfural, biochar, and TDO oil
- The oil can be upgraded into gasoline, diesel, and jet fuel, or used as drop-in biofuel

Purpose

- To evaluate the effect of the TDO fuel production process on water resources
- Determine where it lies on the spectrum of water consumption in common fuel production processes

Methodology

- Scope: only the water in the fuel manufacturing process is considered, AKA "in-the-pipes"
- Excludes water used upstream (growing) and downstream (wastewater treatment) because of extreme differences in pathways
  - Process water needs alone are not adequate to fully describe a pathway
- The process was analyzed as if the plant was run at full production capacity
  - However no real-world data exists for evaporative cooling and therefore was calculated



Methodology

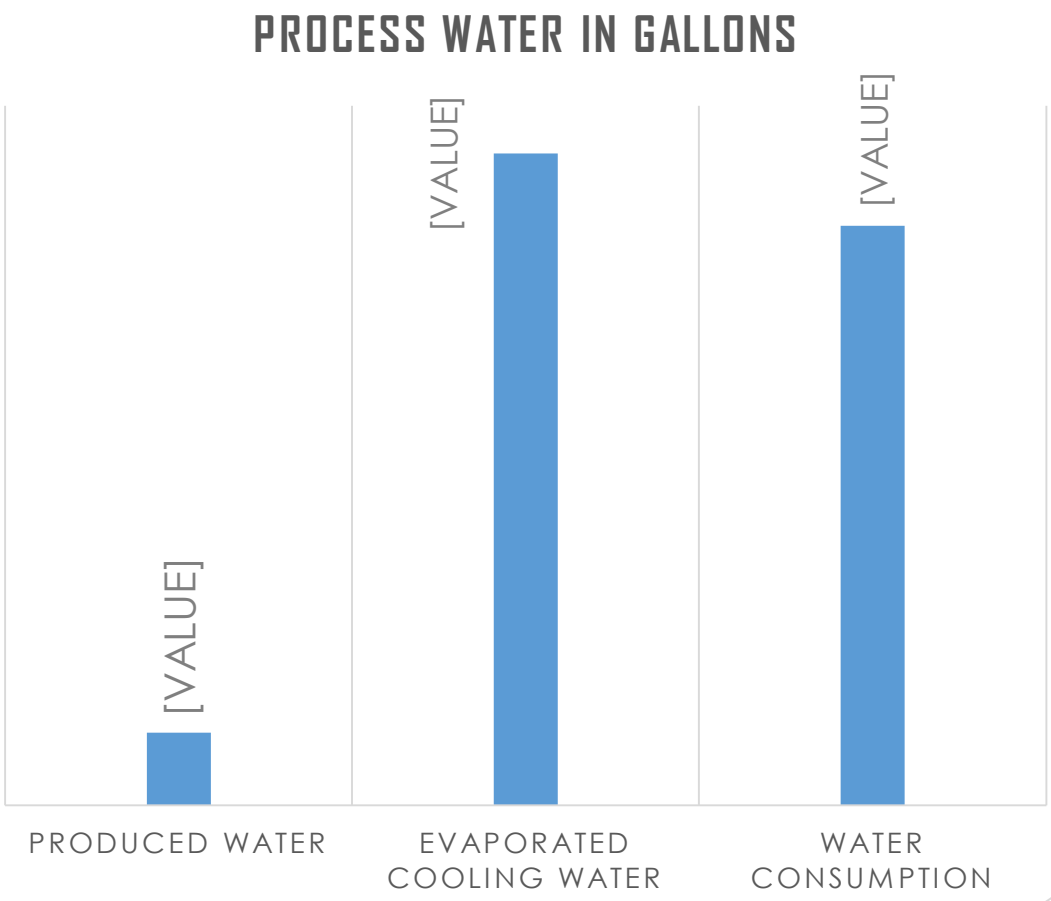
- Water balance
  - Water input – Water output
- Hypothetical evaporative water cooling value
  - Assumed two streams or pipes with largest energy value are cooled with air only
- Find overall water consumption by combining water balance and calculated water evaporation
- Co-product allocation using volume for two scenarios
  - Scenario 1: all biochar used internally
    - Products: TDO oil + Furfural
    - $Allc[\%] = {V_{oil}[\frac{tonne}{day}]} / {V_{oil}[\frac{tonne}{day}]+V_{fr}[\frac{tonne}{day}]}$
  - Scenario 2: biochar used internally, excess exported
    - Products: TDO oil + Furfural + Excess Biochar
    - $Allc[\%] = {V_{oil}[\frac{tonne}{day}]} / {V_{oil}\left[\frac{tonne}{day}\right]+V_{fr}\left[\frac{tonne}{day}\right]+V_{ch}\left[\frac{tonne}{day}\right]}$

Methodology

Table 1. Water consumption values of major fuel production processes as determined by Wu et. al in a 2011 study.		
Fuel Type	Process	Water Consumption (gal/gal)
Corn Ethanol	Dry Mill	3
		4.2
		2.45
		3.6
		2.7
	Wet Mill	3.92
Cellulosic Ethanol with switchgrass	BC process	9.8 – 5.9
		5.4
	TC process	1.9
Cellulosic Biofuel with forest wood residue	Fast Pyrolysis	2.3
Gasoline		1 gal/gal crude processed becomes 0.94 gal/gal refined product*
		Avg 1.53 gal/gal crude processed becomes 1.4 gal/gal refined product
***Assuming 42 gal crude produced generates 44.6 gal refined product**		

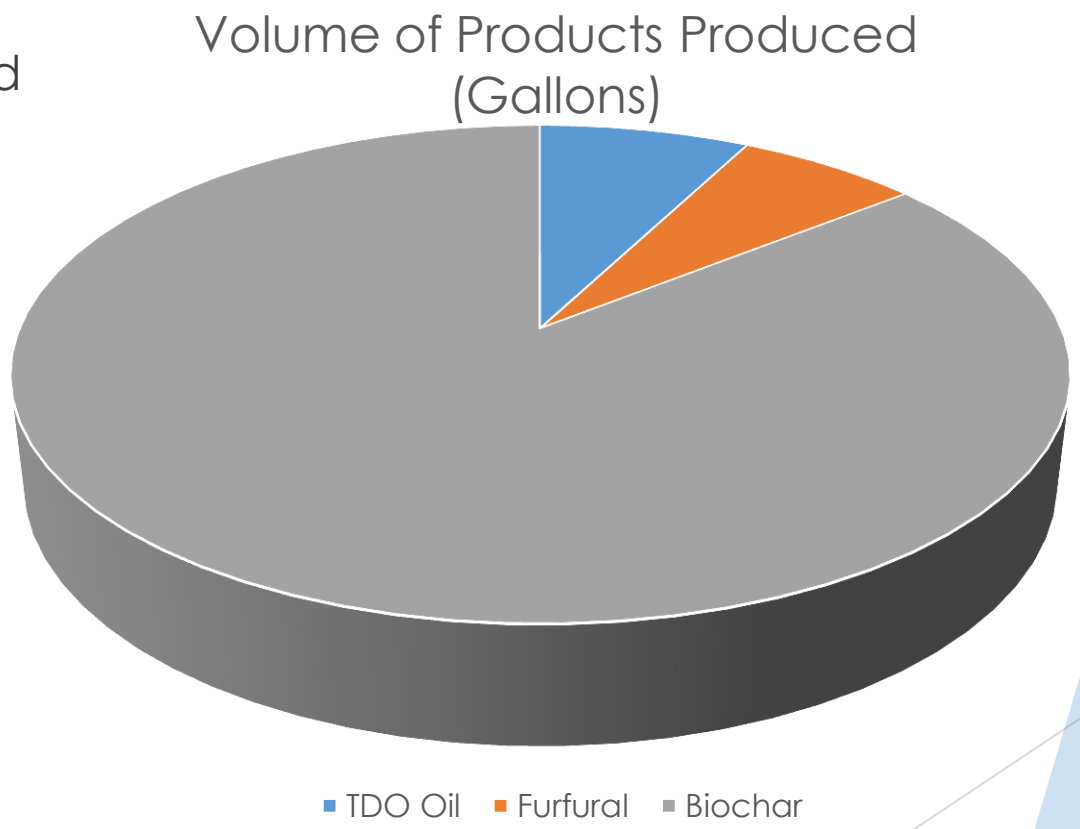
Results

- 124,000 gallons water produced per day
- 1.118×10^6 gallons water evaporate per day
- 994,000 gallons water consumed per day



Results

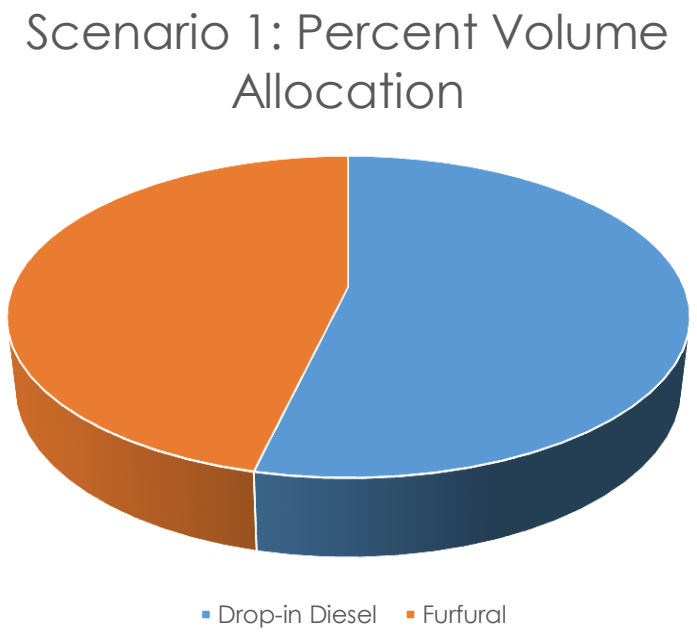
- 65,369 gallons oil produced per day
- 56,448 gallons furfural produced per day
- 730,428 gallons biochar produced per day
  - 133,206 gallons excess biochar produced per day

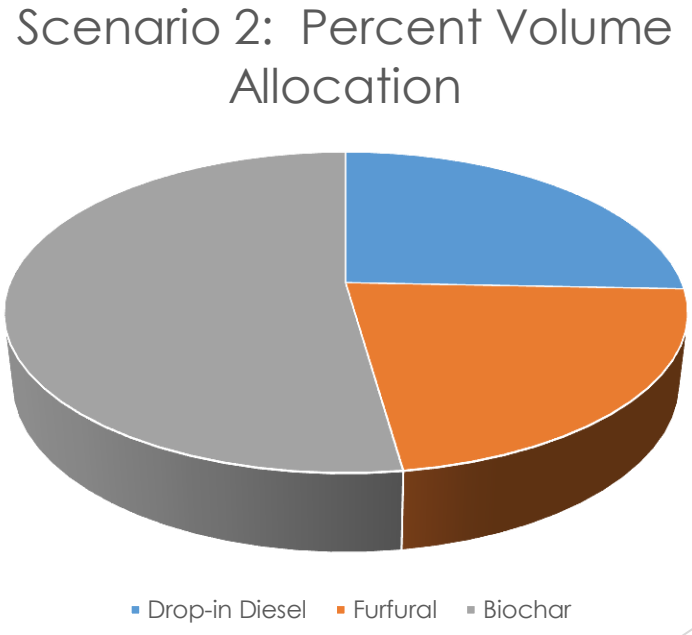


Results

- Scenario 1: TDO oil + Furfural
- 53.7 %
- 8.2 gal water / gal oil

- Scenario 2: TDO oil + Furfural + Excess Biochar
- 25.7%
- 3.9 gal water / gal oil





TDO Process

3.9 gal/gal

Petroleum

Average: **1.53** gal/gal

Lowest: **0.94** gal/gal

Corn Ethanol Dry Mill

Average: **3.2** gal/gal

Range: **2.45 – 4.2** gal/gal

Corn Ethanol Wet Mill

3.92 gal/gal

Cellulosic Ethanol BC

Range: **5.4 – 9.8** gal/gal

Cellulosic Ethanol TC

1.9 gal/gal

Cellulosic Ethanol Fast Pyrolysis

2.3 gal/gal

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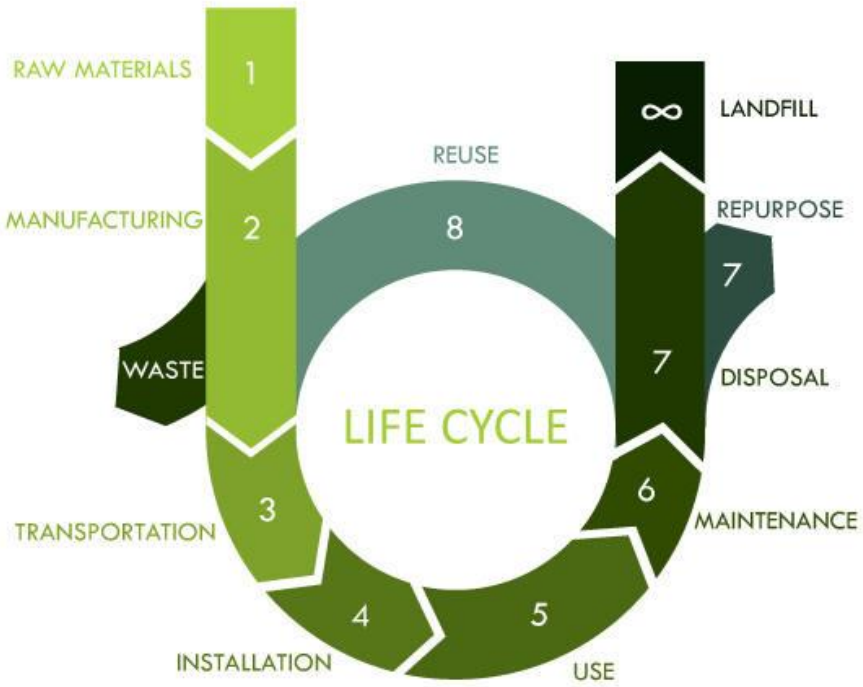
Discussion

- Petroleum vs TDO
  - TDO produces renewable fuel
- Corn Ethanol vs TDO
  - TDO does not have the same upstream water use that is used to make corn
  - TDO does not need fertilizers to produce the starting materials
- Cellulosic Ethanol vs TDO
  - Cellulosic Ethanol Plants are just entering successfully into industry, not at full capacity
- Most of these processes are established industries
- Optimize process
  - Increase water recycle
  - Improve cooling capabilities
  - Use less biochar for heating

Future work

- Full pathway LCA
  - Upstream
  - Downstream
  - Upgrading
- Fuel policies research (EPA's RFS2)
- Closer look at other pathways as well
- Include more pathways under development



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Questions