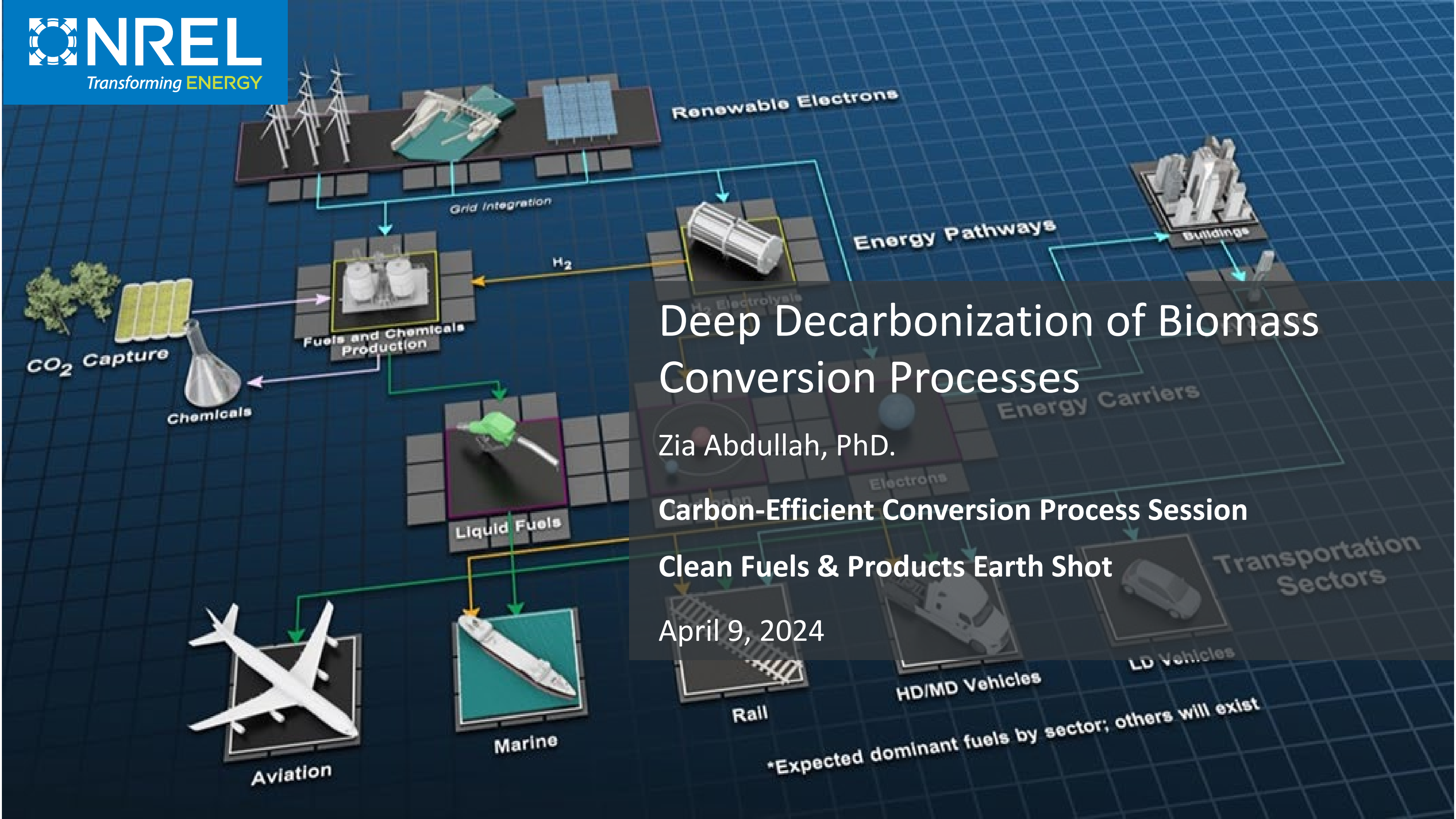


Deep Decarbonization of Biomass Conversion Processes

Zia Abdullah, PhD.

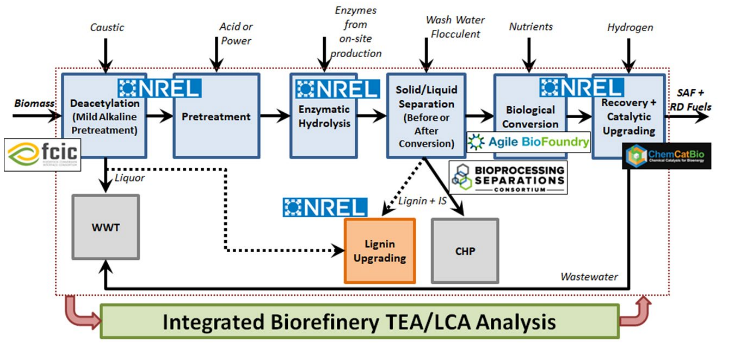
Carbon-Efficient Conversion Process Session

Clean Fuels & Products Earth Shot

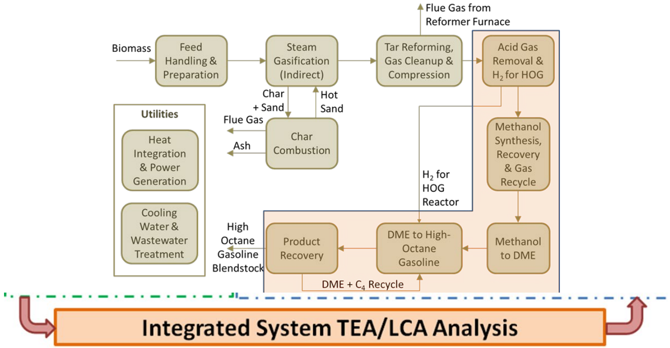
April 9, 2024

We Are Utilizing Multiple Biological And Catalytic Processes To Convert Diverse Biomass Sources To Fuels And Chemicals

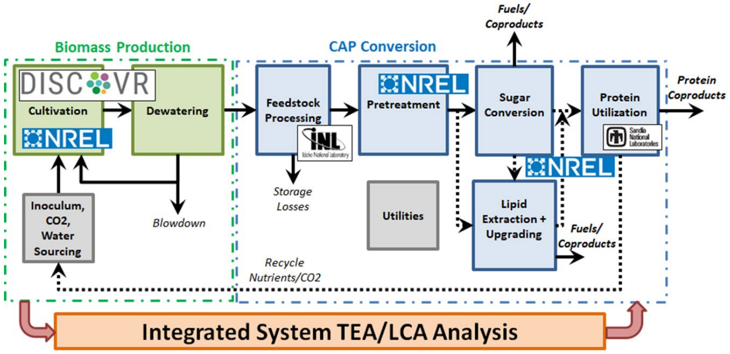
Biological Conversion Pathway



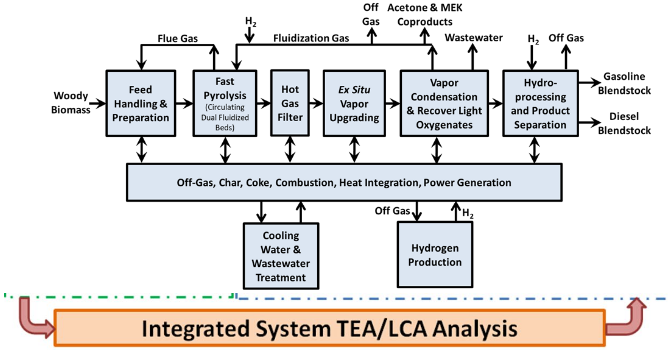
Gasification Pathway



Algae Pathway



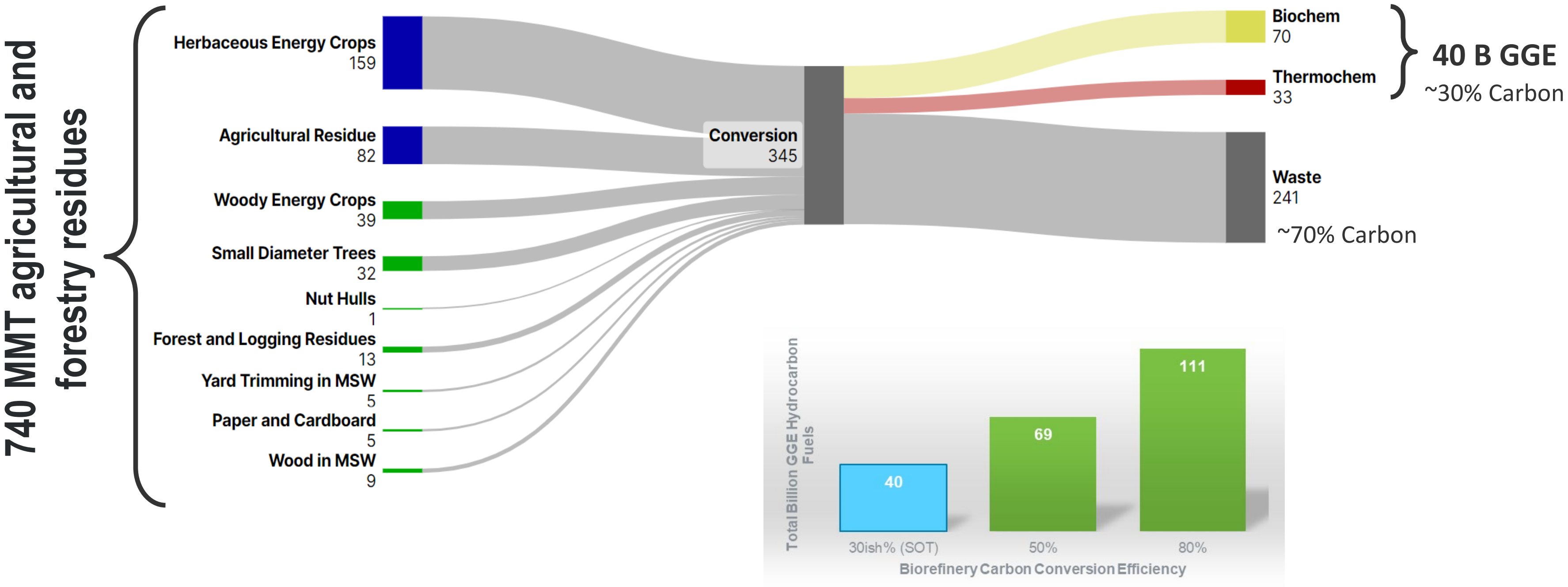
Catalytic Pyrolysis Pathway



Carbon Efficiency of Current Conversion Processes Can be Improved Significantly, Which will Reduce Feedstock Volume Needed

Current State Of Technology

345 MMT carbon → **40 Billion GGE biofuel**

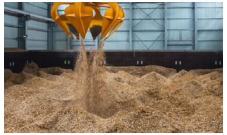


Our Near-Term Goal Is Deployment and Longer-Term Goal is to Deeply Decarbonize While Achieving Grand Challenge Volume Targets

Near Term Focus on Deployment

Longer Term Focus on Deep Decarbonization

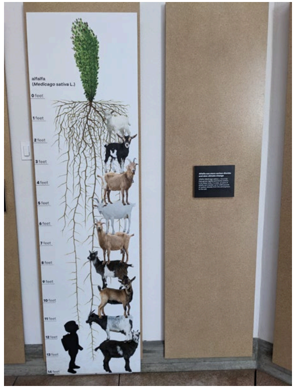
Broaden feedstock
- MSW, wet waste, CO_2, flue gases



Feedstock Conversion interface
- Reliable feeding of biomass into reactors.

Refinery integration to accelerate deployment

Gen 1 EtOH refineries
- Decarbonize
- ATJ Pathways



Purpose grown –ve carbon feedstocks
- Enable –ve carbon fuels

Carbon & energy efficient conversion
- Carbon efficiency ~30%

Electro-fuels
- Decrease Carbon Intensity
- Use CO_2 & waste gases

Negative Carbon flights

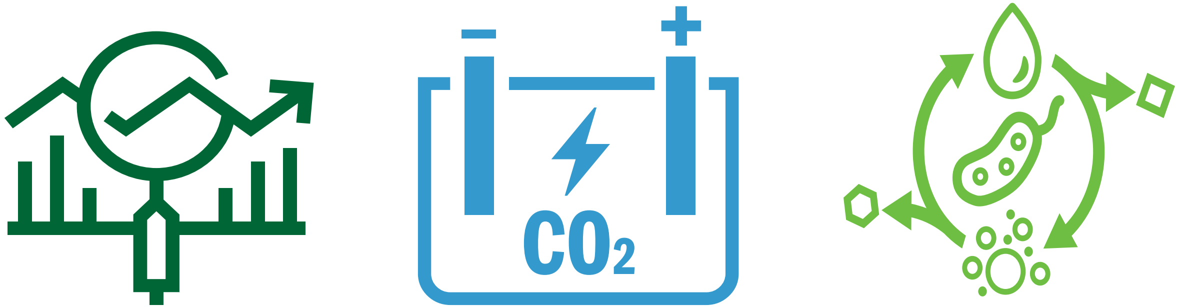
Negative Carbon shipping

CO_2RUe Consortia

Goal: *Develop bolt-on technologies that use renewable electricity to increase the efficiency of bioconversion.*

- *Leverages Inter-Lab and Industry expertise across the Conversion value chain: Feedstocks, Electro/ BioCatalysis, and Analysis*
- **12** Projects at **5** Nat'l labs

Analysis and Modeling	CO2 Electrolysis (LTE)	Biological Upgrading



- Poor carbon yields limit the Carbon Intensity reduction potential of current bioconversion pathways.
- Emerging direct electrification pathways show promise for conversion of biogenic CO_2
- Initial period of performance revealed near-term opportunities to valorize Gen1 Biorefinery CO_2 via integrated LTE-bioconversion technologies

An Example Project With Fermentation: CO as an Energy Source To allow Sugar Fermentation to Ethanol with no net CO_2 Generation

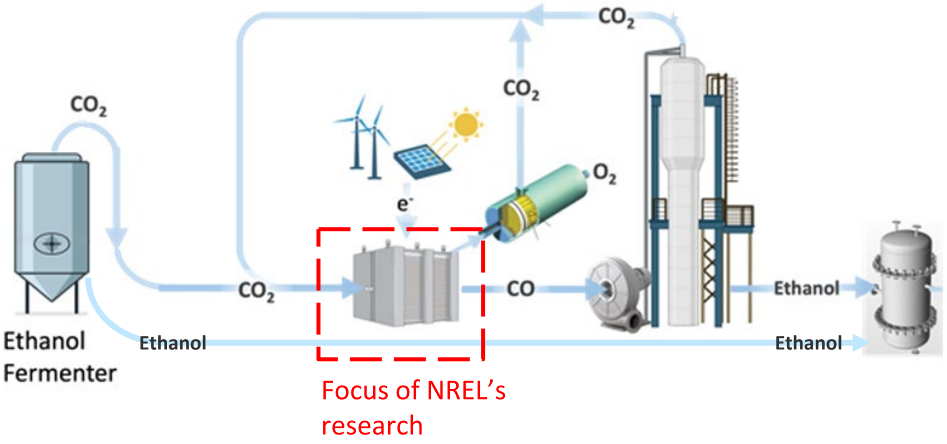
Technology Summary

- Use a CO_2 electrolyzer to reduce CO_2 to CO. Spilt water to make hydrogen.
- CO_2 and hydrogen can be fermented to produce more ethanol.
- Power can be generated using wind turbines on the same fields used to grow corn for the ethanol plant.

Technology Impact

- Generation of low cost and low carbon intensity ethanol can greatly reduce the CI of Gen 1 starch ethanol plants and enable them to contribute to the SAF Grand Challenge.
- Technology can be applied to use CO and H_2 as energy source for other products

Integrated Process That Allows CO_2-Free Fermentation



For further information contact:
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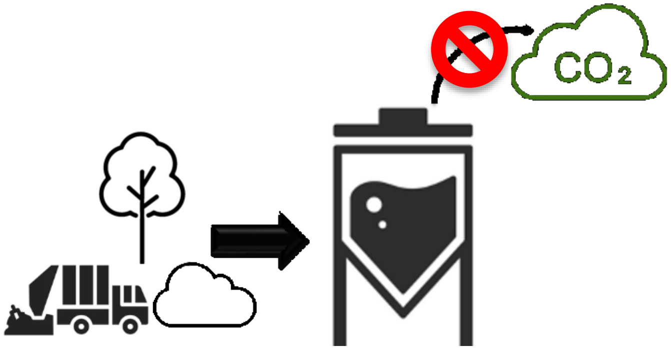
Elimination of Biogenic CO_2 During Fermentation

Leverages NREL expertise in C_1 biocatalysis, fermentation and process engineering, and chemical catalysis



- Biogenic CO_2 accounts for ~30% of input carbon.
- "CO_2 bypass" conversion strategies presents step-change potential for high-yield, carbon negative biomanufacturing
- Targets obsolescence of conventional technology
- Expands conversion portfolio to include C_1 and H_2

Carbon Efficiency of Pyrolysis And Upgrading Is ~ 30% and Can Be Improved

Demonstrating SAF Production from Biomass via Catalytic Pyrolysis and Hydrotreating

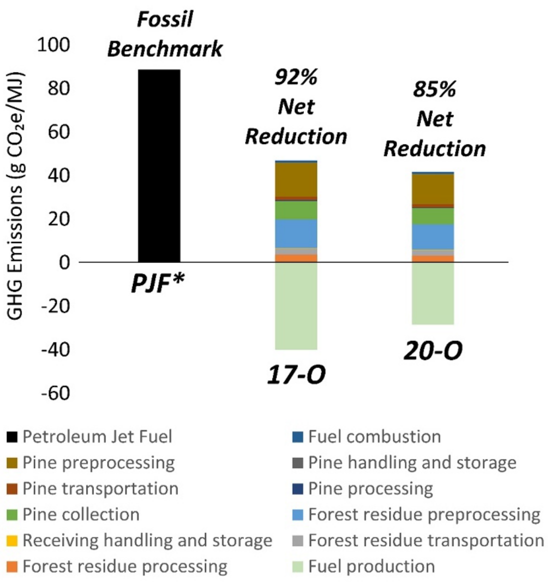
First-of-its-kind fuel property analysis revels a cycloalkane-rich SAF product that complies with key ASTM D4054 guidelines

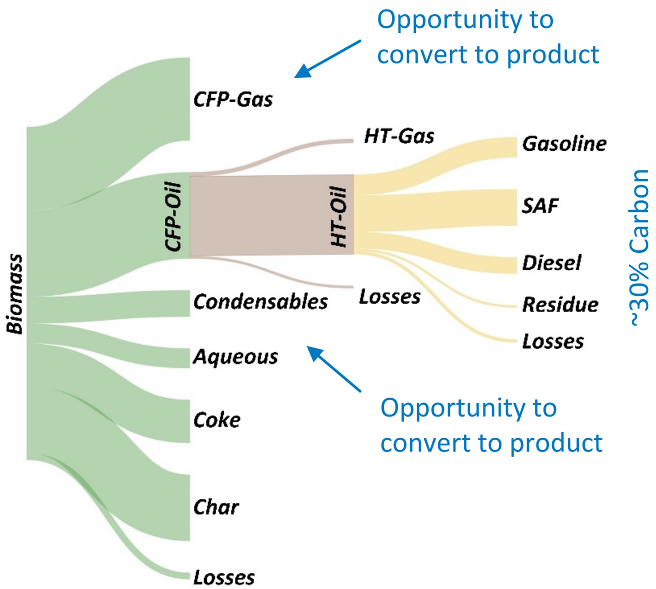
Lifecycle assessment confirms potential for ≥ 85% reduction in GHG emissions compared to fossil pathways

Integrated experimental campaigns provide end-to-end mapping of carbon utilization and identify opportunities for process development to improve yields

SAF Properties		
CFP-Oil Oxygen Content, wt% dry basis	17-O	20-O
Density @15°C, 0.730-0.880 g/ml ✅	0.854	0.843
Flash Point >38 °C ✅	41.5	41.5
Freezing Point, <-40 °C ✅	<-80	<-80
Surface Tension 22°C, 25-29 mN/m[b] ✅	28	27
Lower Heating Value, >42.8 MJ/kg ⚠️	42.5	42.7
D86 Simdis T10 150-205 °C ✅	162	162
D86 Simdis FBP <300 °C ✅	253	250

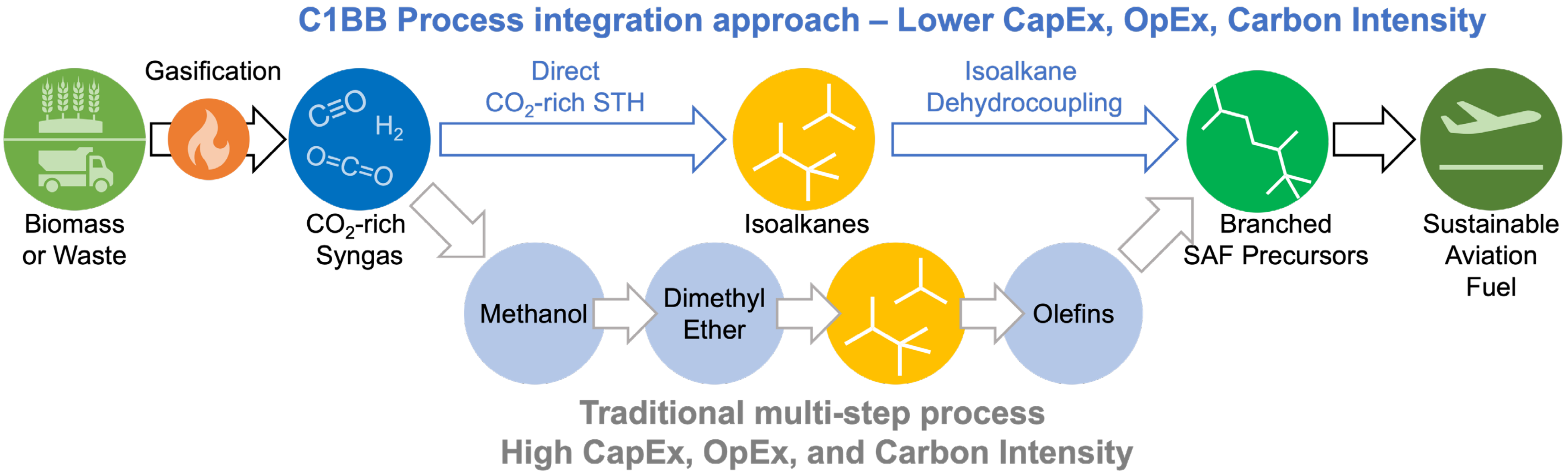
>75 wt% Cycloalkanes in SAF Fraction





Griffin, M. B., et al. "Opening pathways for the conversion of woody biomass into sustainable aviation fuel via catalytic fast pyrolysis and hydrotreating", 2024, Energy and Environmental Science, Under Review

SAF Pathway: Direct Conversion of CO_2-rich Gas To Hydrocarbons

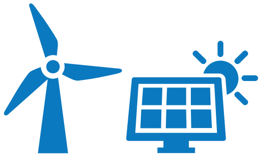


- Developing the **centerpiece technology** for direct syngas-to-hydrocarbons
- **Hydrocarbon SAF precursor product** using NREL's Cu/BEA zeolite catalyst
- Process concept translates to a variety of hydrocarbon synthesis catalysts to **target specific SAF components** (*e.g.*, iso-paraffins, cyclics)

Judicious Use of Renewable Electricity / Hydrogen Can Enable Significant Increase In Carbon Efficiency of Biomass Processes To Meet Earth Shot Goals

Aviation Fuels
Marine Fuels
BECCS
Chemicals
Materials
Pellets
Steam

Biomass



Renewable Electricity / Hydrogen

Grid decarbonization
EVs
Fuels
Hydrogen
Chemicals
Industrial decarbonization
PTL

- Improve Carbon Efficiency of biomass processes to reduce biomass volume needed for multiple uses.
- Reduce Carbon Intensity of existing biomass processes to enable deeper carbon draw-down
- Improve energy efficiency of PTL