Production of Sustainable Aviation Fuel from Woody Biomass via Catalytic Fast Pyrolysis and Hydrotreating

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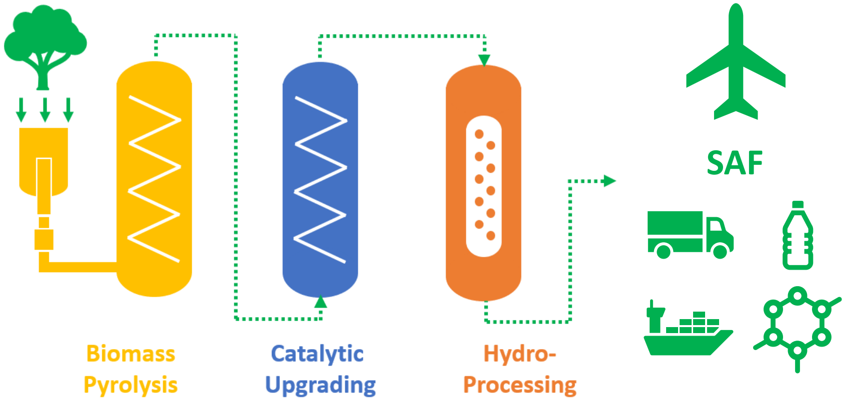
tcbiomass 2024

Background

Project Goal: Develop a technology pathway to convert woody biomass into sustainable aviation fuel (SAF) and other biogenic products via catalytic fast pyrolysis (CFP) and hydrotreating

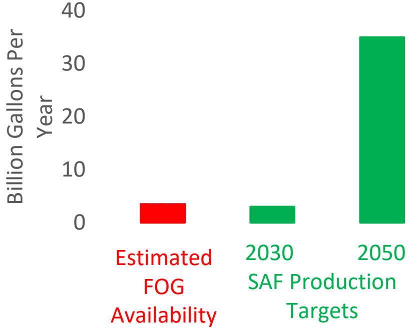


Key Advantage: Catalytic fast pyrolysis generates a stabilized bio-oil that de-risks transportation, storage, and down-stream hydroprocessing

Market Trends: Repurposing refinery hydroprocessing infrastructure for the production of renewable diesel and sustainable aviation fuel from fats, oils, and greases

Phillips 66: Rodeo, CA

Existing approach is constrained by the availability of waste fats, oils, and greases

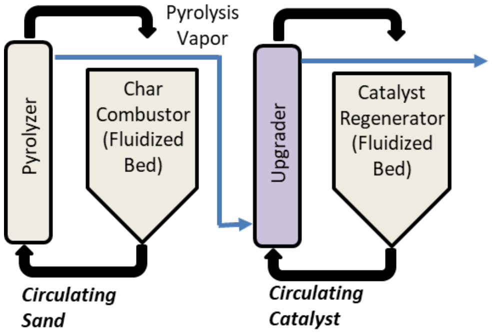


This research opens pathways for SAF production from forest resources and woody wastes

Estimated Availability of Forest Resources and Woody Wastes
133 Million Dry Tons/Yr
8 BGPY Hydrocarbon Fuel Potential

DOE Billion Ton Report, 2016, ORNL/TM-2016/160

Approach



Fluidized Bed Ex-Situ Catalytic Fast Pyrolysis

- Opportunity to individually optimize reaction conditions for pyrolysis and catalytic upgrading steps
- Reduced exposure to biomass impurities prolongs catalyst lifetimes
- Can be performed using low-cost zeolite catalysts without requiring co-fed hydrogen

Lack of end-to-end integrated data increases risk and uncertainty of process scale up

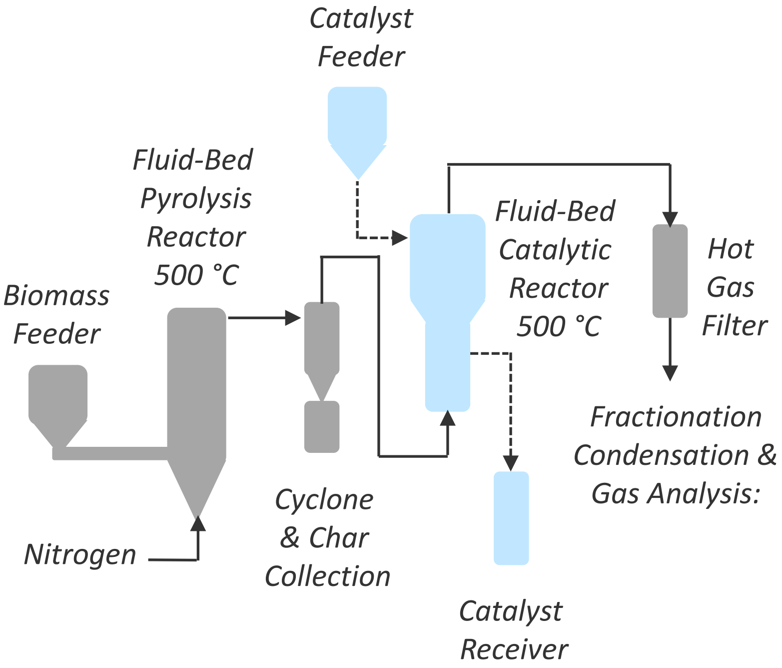
Biomass Handling and Preprocessing (INL) → **Ex-Situ CFP** Fluidized Bed ZSM-5 SAR 30 → **Hydrotreating** Fixed Bed Sulfided $NiMo/Al_2O_3$ → *Fractionation and Fuel Property Analysis*

Realistic biomass feedstocks including waste forest residues

Technical catalyst formulations for CFP and hydrotreating steps

Sufficient product volume for **fuel property analysis**

Catalytic Fast Pyrolysis



Feedstock: *50/50 Clean Pine + Forest Residues*
Catalyst: *ZSM-5 SAR 30 with Alumina Binder*
Biomass to Catalyst Ratio: *1.7-2.5*

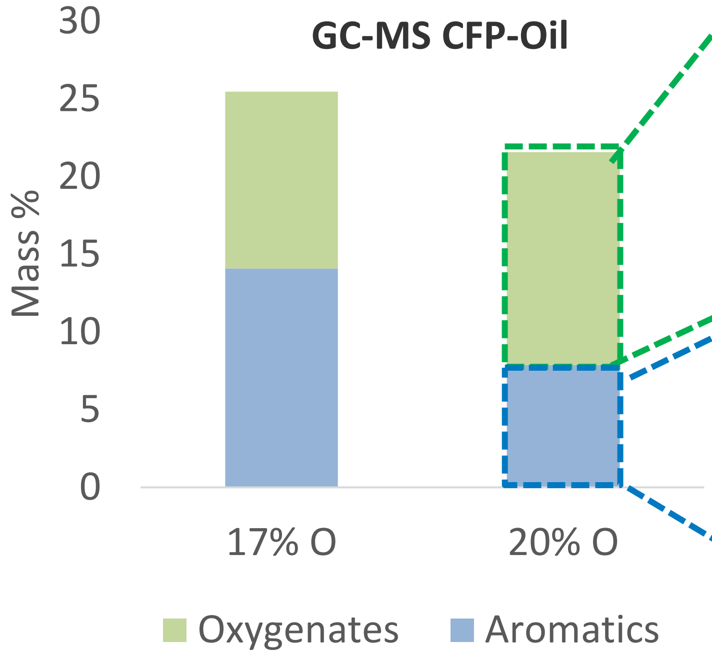
	CFP-Oils		FP-Oil
Oil Oxygen Content, wt% dry basis	17	20	48
Mass Yields, wt%			
Oil	14.1	17.8	72.7
Aqueous	28.9	27.3	
Condensables	5.0	5.6	-
Gasses	28.9	28.7	12.3
Char	12.9	13.1	9.2
Coke	9.3	7.8	-
Select CFP-Oil Properties			
H_2O, wt%	3.8	4.8	18
CAN, mg KOH/g	19	29	76

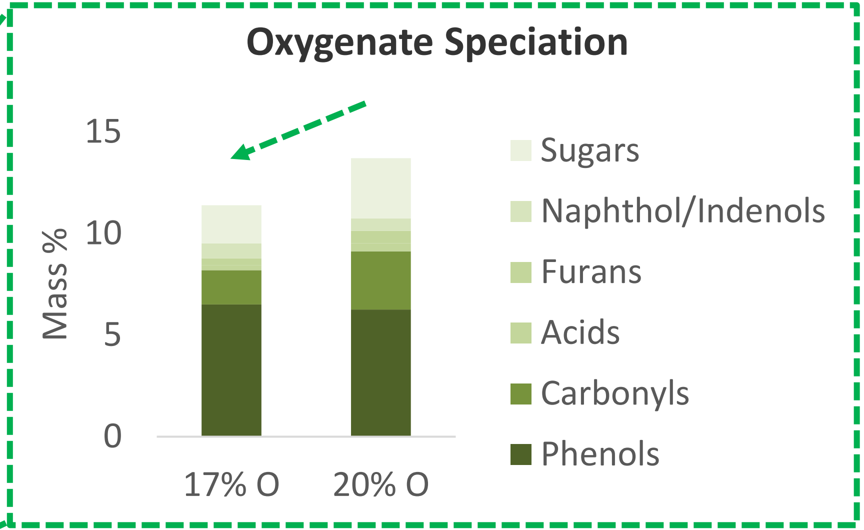
*FP-oil yield contains both organic and aqueous fractions

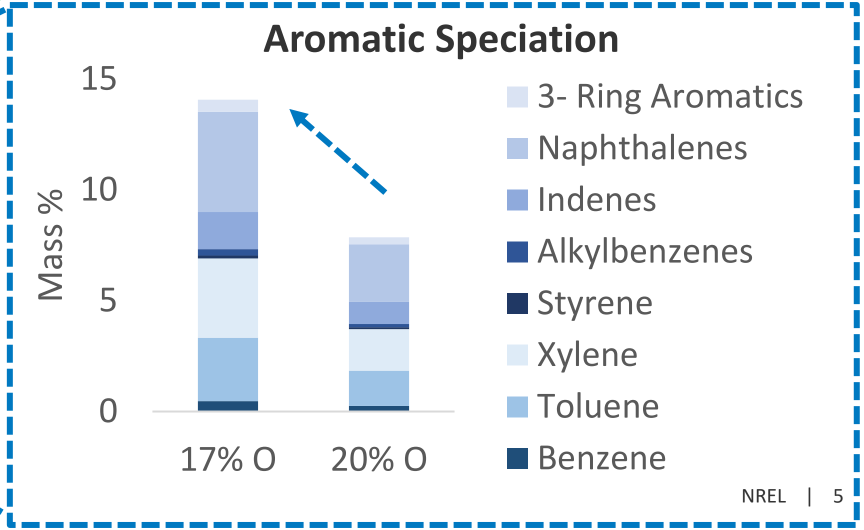
Griffin, et al., Green Chemistry, Advanced Article, 2024
Iisa, et al., Fuel, 2017, 207, 413-422

Catalytic Fast Pyrolysis – GC/MS

Catalytic upgrading reduces concentration of oxygenates and increases production of aromatics

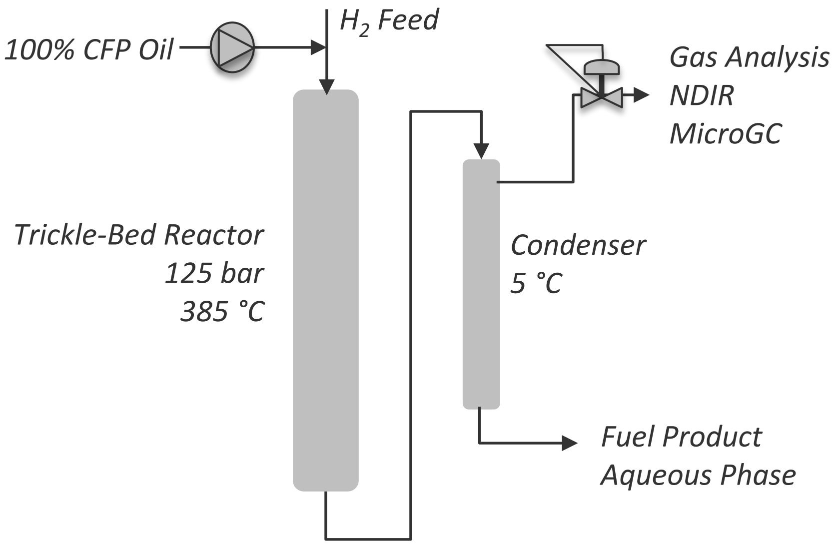






Griffin, et al., Green Chemistry, Advanced Article, 2024

Hydrotreating

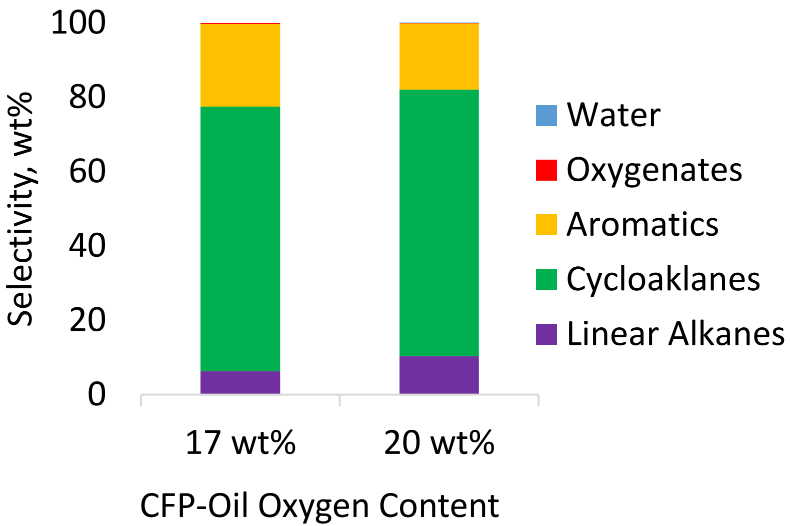


***Catalyst:** Sulfided NiMo/Al_2O_3*

***WHSV:** 0.2 h^{-1}*

Experiments performed for a minimum of 72 h time on stream at steady state conditions

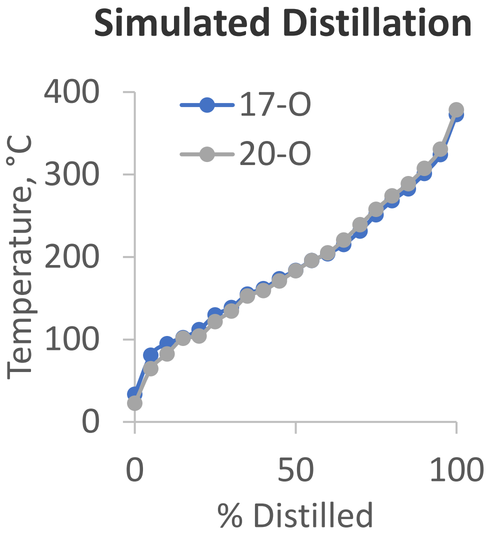
Hydrotreating at 385 °C produces a high-quality oil with oxygen levels below detection limits

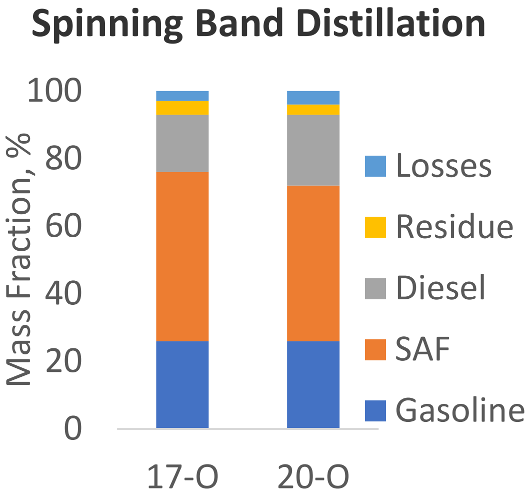


Hydrotreating Results		
CFP-Oil Oxygen Content	**17 wt%**	**20 wt%**
HT Carbon Efficiency	91%	92%
Hydrogen Consumption	7%	8%
HT-Oil Oxygen Content	<0.001 wt%	<0.001 wt%
HT-Oil H:C Ratio	1.76	1.76

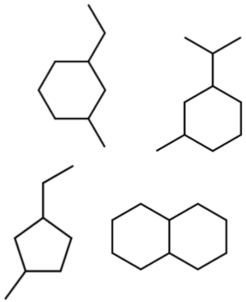
Griffin, et al., Green Chemistry, Advanced Article, 2024

Fractionation and Fuel Properties


Simulated Distillation


Spinning Band Distillation

SAF Properties		
CFP-Oil Oxygen Content, wt% dry basis	17 wt%	20 wt%
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



>70 wt% Cycloalkanes in SAF Fraction

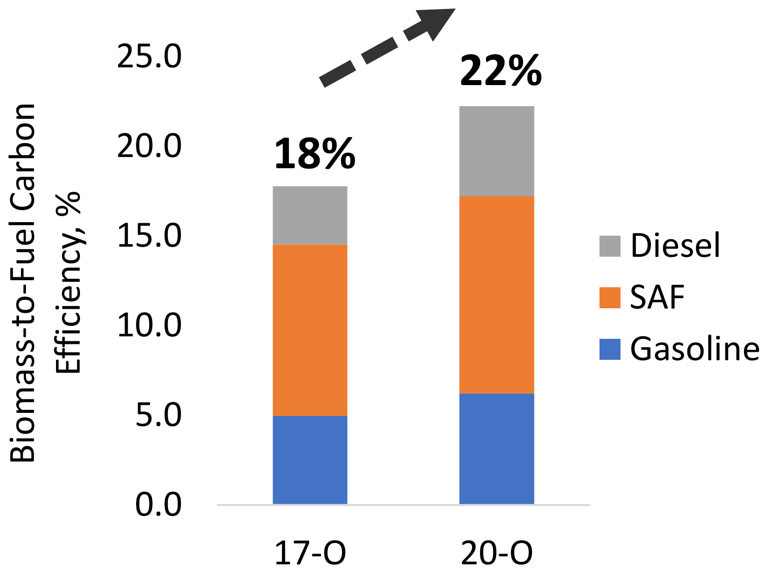
- Primary component in Jet A
- Increased energy density and cleaner burning than aromatics
- Difficult to access via other SAF pathways (HEFA, FT, ATJ)

Cycloalkane-rich SAF meets key ASTM D4054 quality guidelines

Griffin, et al., Green Chemistry, Advanced Article, 2024

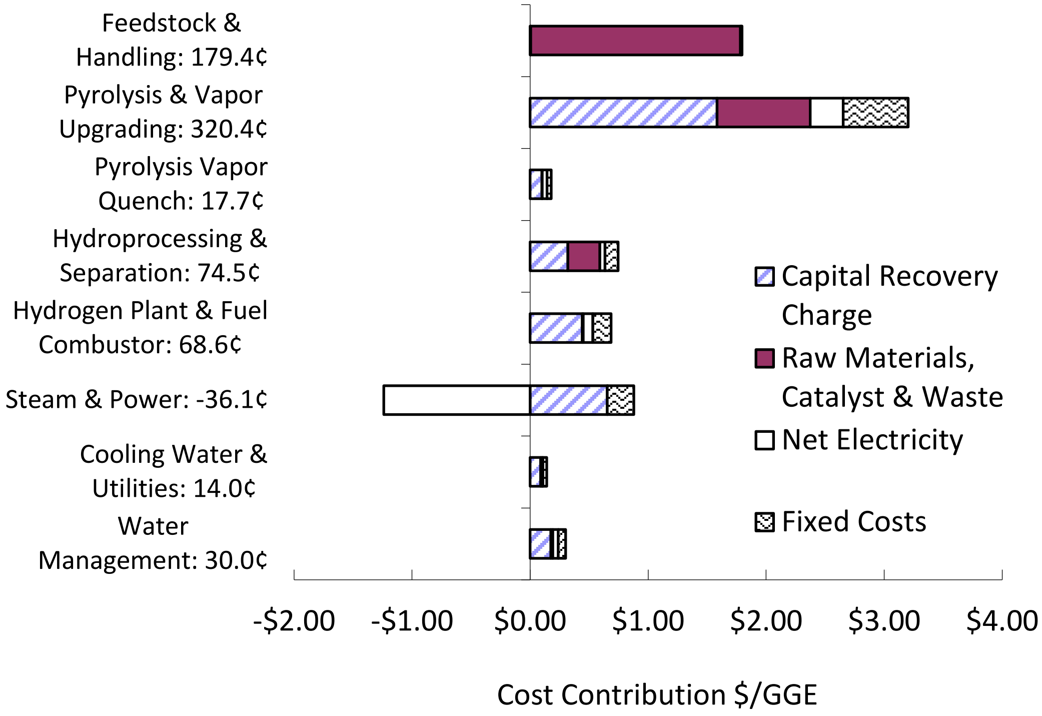
Biomass-to-Fuel Carbon Yields

End-to-end integrated experiments inform improvements in process efficiency



Griffin, et al., Green Chemistry, Advanced Article, 2024

Technoeconomic Analysis



Modelled Fuel Cost: $6.69 ⟶ $6.15 GGE MFSP

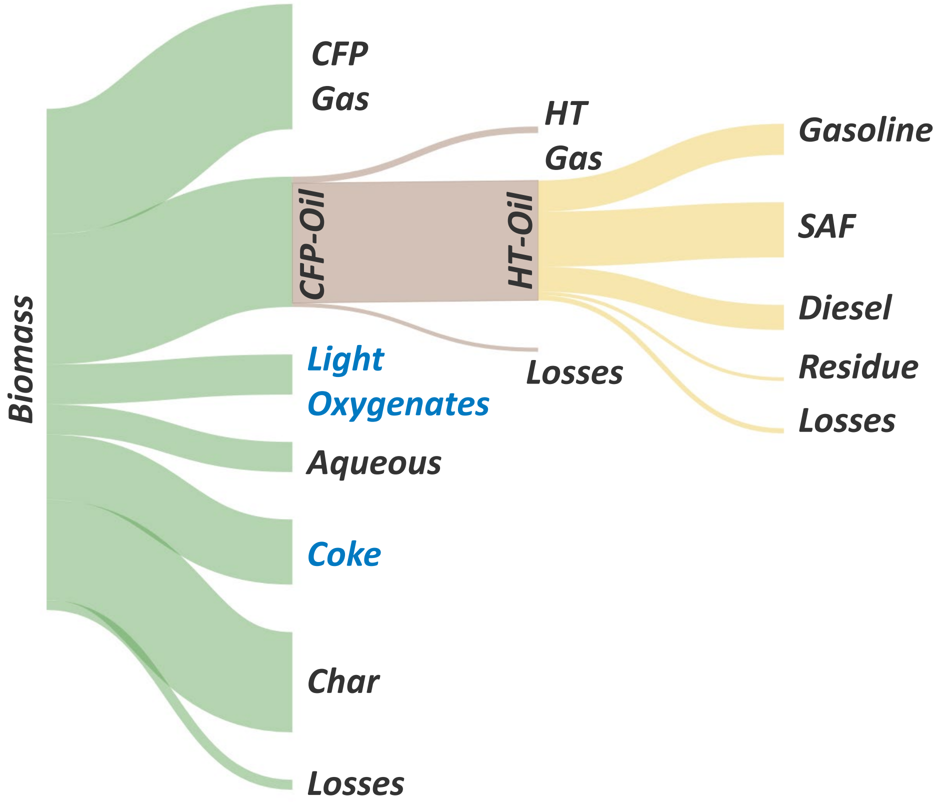
Modelled GHG Reduction Range: > 85%

2016 Dollars,

LCA based on GREET analysis with petroleum jet fuel benchmark (88.7 g CO_2e/MJ)

Improving Carbon Efficiency

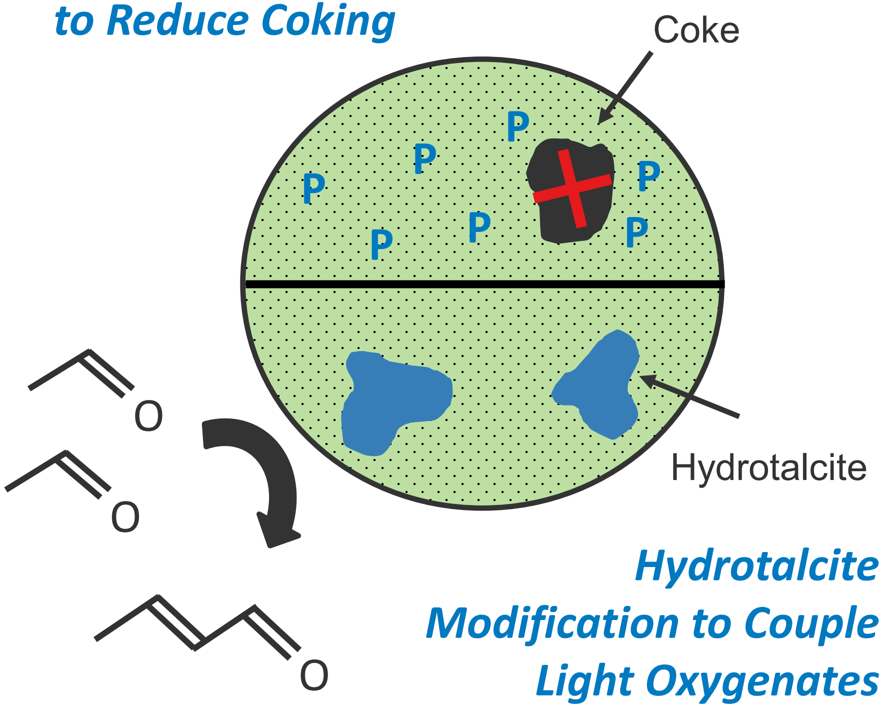
Biomass-to-SAF Sankey Diagram



Data represent normalized carbon yields for 20-O samples

Catalyst Modification Strategies

Phosphorous Doping to Reduce Coking



Hydrotalcite Modification to Couple Light Oxygenates

Van der Bij, H. E. et al. *Chem. Soc. Rev.* (2015)
Gao, L. et al. *Bioresour. Technol.* (2017)

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