NREL
Transforming ENERGY

Biomass Resources and Biomass Conversion Technologies in the USA

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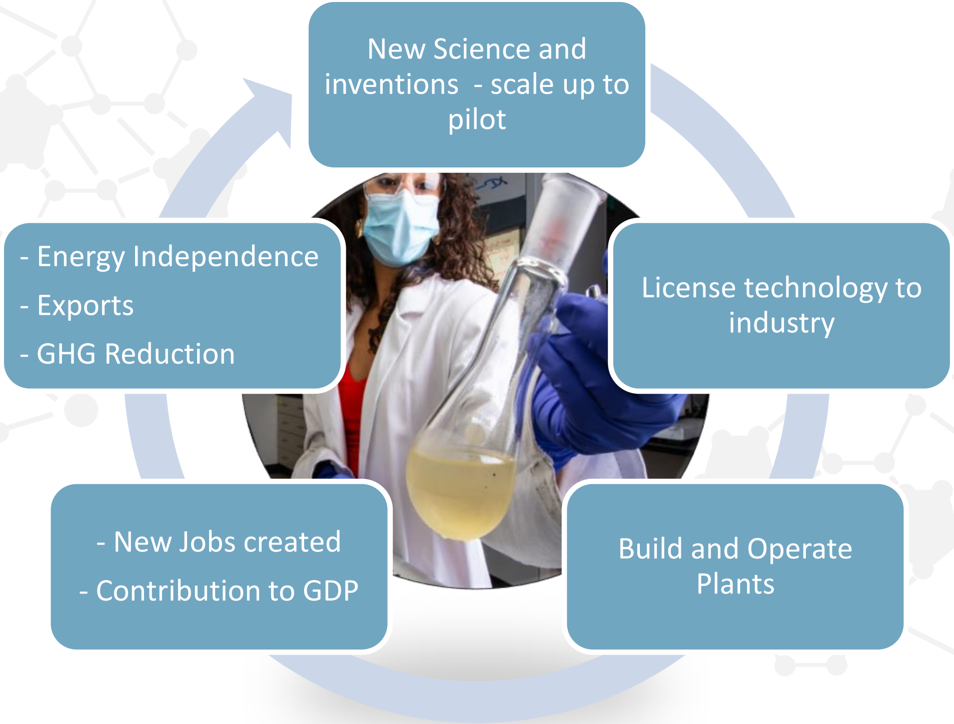
Our DOE BETO Funded Program Develops Cost-competitive, and Performance-Advantaged Fuels, Materials, and Chemicals From Renewable and Waste Carbon

Research Focus:

Use **foundational science** to design, upcycle, and manufacture renewable and carbon efficient fuels materials and processes.

- Cost competitiveness
- Performance advantaged
- Fuels for heavy-duty truck, marine and aviation sectors.
- Materials and chemicals.
- Electricity to upgrade renewable and waste carbon.



New Science and inventions - scale up to pilot

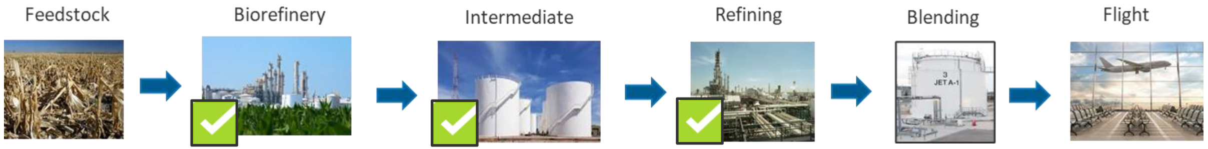
License technology to industry

Build and Operate Plants

- New Jobs created
- Contribution to GDP

- Energy Independence
- Exports
- GHG Reduction

NREL's DOE - BETO Program Is Developing Pathways Across Multiple Feedstocks And Deployment In Partnership With Industry



Market Impact via Industry Partners Across SAF Supply Chains

Feedstock Suppliers – Harvesters – Preprocessing – Conversion - SAF

Tech-to-Market Pipeline, Stage-Gate Processes, Piloting Facilities

Cross Cutting Techno-Economic Analysis and Life Cycle Analysis

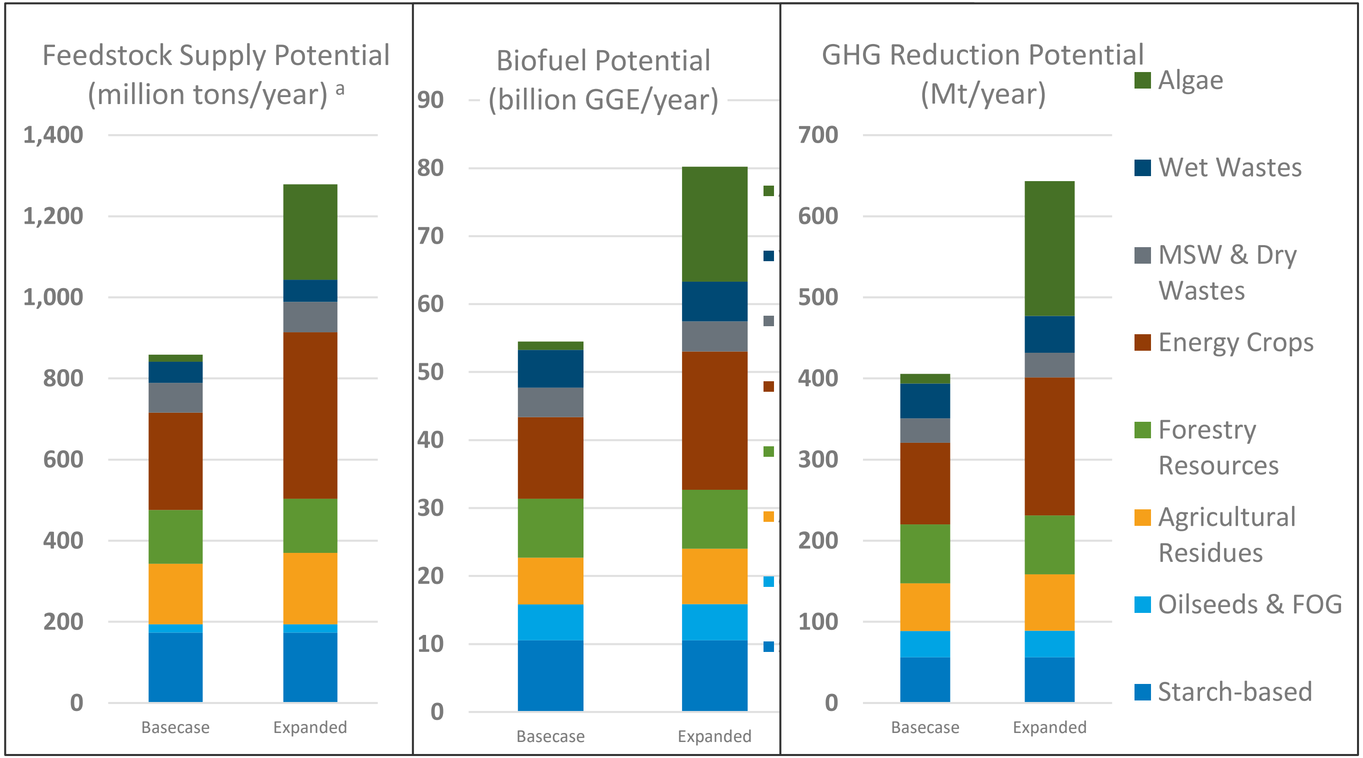
Foundational Science / Science &Technology Focus Areas

- Pretreatment & Biological Conversion
- Lignin to Fuels & Products
- CO_2 & Waste Gas to Fuels & Products
- Catalytic Conversion
- Algal Biofuels & Bioproducts
- Polymers & Bioproducts

✓ NREL's focus areas along the supply chain.

US Biomass Feedstock Supply and Biofuel Potential

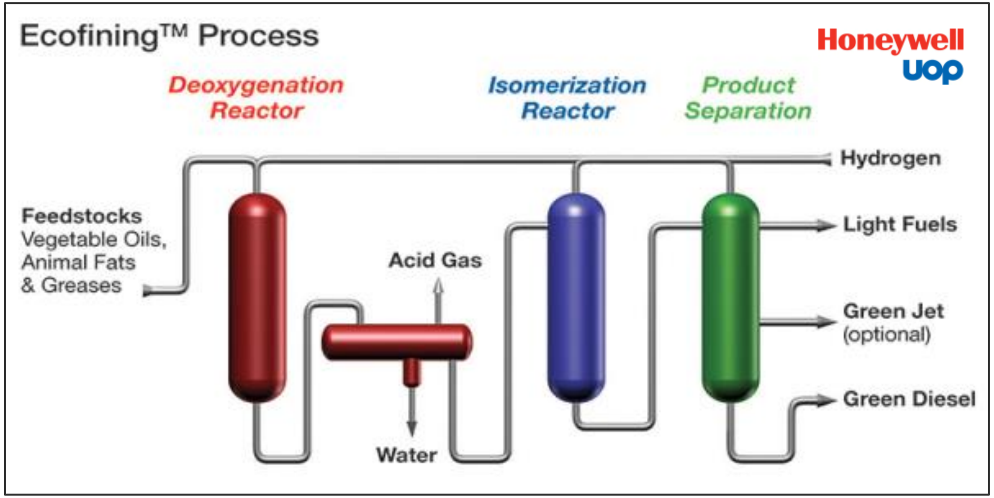
- Carbon feedstocks
  - 858 to 1,279 million tons/yr.
- Fuel production
  - 55 to 80 billion GGE/yr.
- Total GHG emissions saving
  - 406 to 644 million tons/yr.

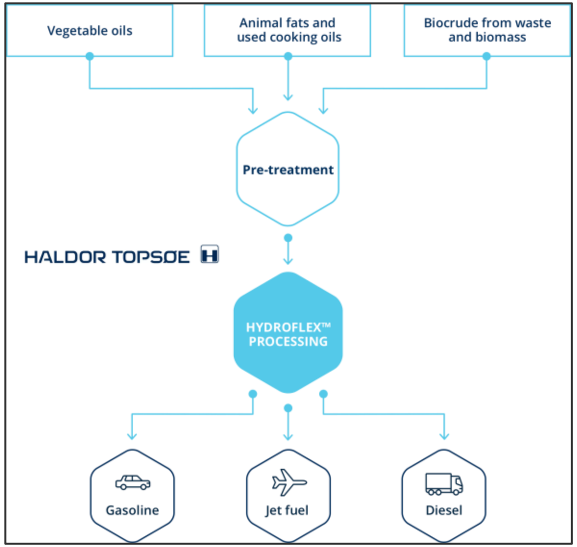


[a] Dry and wet waste feedstocks are reported on a dry basis. Algae is reported on an AFDW dry basis. Starch-based, oilseed, and waste FOG are reported on an as-received basis.

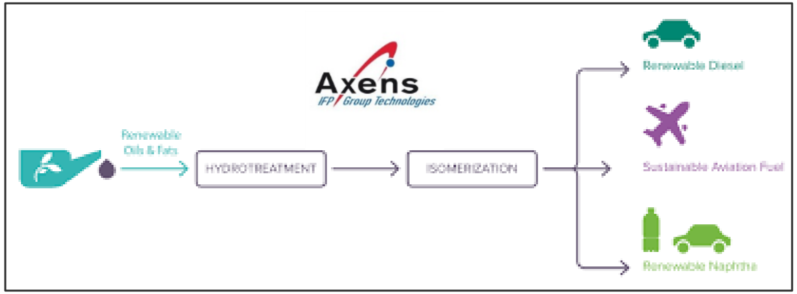
Source: https://www.osti.gov/biblio/2202642

Renewable Diesel and Sustainable Jet Fuel from Lipid Feedstocks





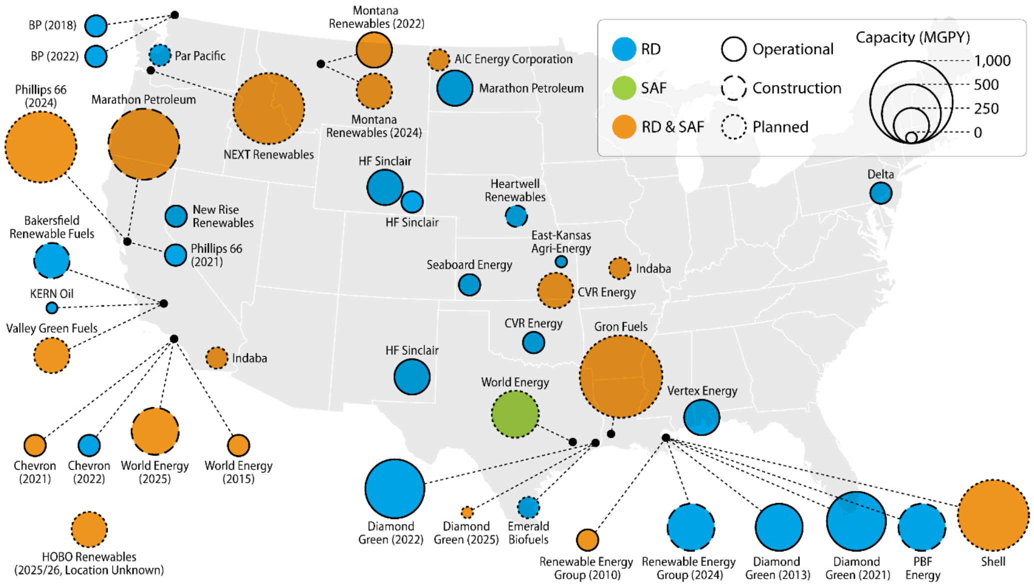
NESTE MY
Sustainable Aviation Fuel



Most New HEFA Facilities Are Being Planned For Both Renewable Diesel and SAF

- Process for producing SAF and RD are similar, however, **SAF production requires more severe isomerization and hydrocracking, fractionation adjustments, and higher hydrogen consumption. SAF yields are lower than RD yields.**

- Most of operating HEFA facilities are not optimized for SAF production.



Location and capacity of HEFA SAF and RD facilities in operation, under construction, and planned

Additional feedstocks needed with new SAF conversion routes

- U.S. biomass and waste carbon availability has embedded energy content on par with current jet fuel consumption of 26 BGPY

- SAF provides links to agriculture, food security, and waste management with opportunities for cross-sector benefits at the intersection of energy and environment

Lignocellulosic Biomass (23 BGPY jet potential)

- Agricultural residues*	9.0 BGPY jet
- Forestry trimmings and residues*	7.1 BGPY jet
- Bioenergy crops by 2030*	7.4 BGPY jet

Assumes 34 gal of SAF range hydrocarbons per dry tonne of biomass, excluding other fuel cuts

Other Waste C Sources (10 BGPY jet potential)

- Inedible animal fats**	1.8 BGPY jet
- Animal manure**	4.7 BGPY jet
- Wastewater sludge**	2.0 BGPY jet
- Food waste**	2.7 BGPY jet
- MSW (paper, wood, yard)***	0.9 BGPY jet
- Industrial waste gas***	1.3 BGPY jet

BGPY = billion gallons per year; estimates of jet potential will vary based on conversion technology and feedstock composition

Sources: *2030 estimate from DOE 2016 Billion-Ton Report; **Bhatt et al. (2020) iScience, 23, 101221; ***CAAFI U.S. Jet Fuel production potential from wastes

Near-Term Goal Is To Deploy and Longer-Term Goal is to Deeply Decarbonize While Achieving Grand Challenge

Near Term → Longer Term

Near Term Focus on Deployment

Broaden feedstock
- MSW, wet waste, CO2, flue gases

Feedstock Conversion interface
- Reliable feeding of biomass into reactors is still a challenge!

Tech support to BETO-SDI Projects

Refinery integration to accelerate deployment

Gen 1 EtOH refineries
- Decarbonize
- ATJ Pathways

Longer Term Focus on Deep Decarbonization

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

Carbon & energy efficient conversion
- Carbon efficiency ~35%

Electro-fuels
- Increase CI
- Use CO$_2$ & waste gases

Negative Carbon flights

Zero Carbon shipping

Production of organic acid via arrested anerobic digestion, and via sugar fermentation

Lignin conversion to SAF

Pathways for complementary biochemicals

Organic acids ketonization and upgrading via the HEFA pathway

Syngas upgrading via olefins to produce SAF

Electro-fuels to convert CO$_2$ to SAF

Production of cellulosic sugars via DMR & upgrading via ATJ or APR

Algae conversion to lipids & acids to produce SAF

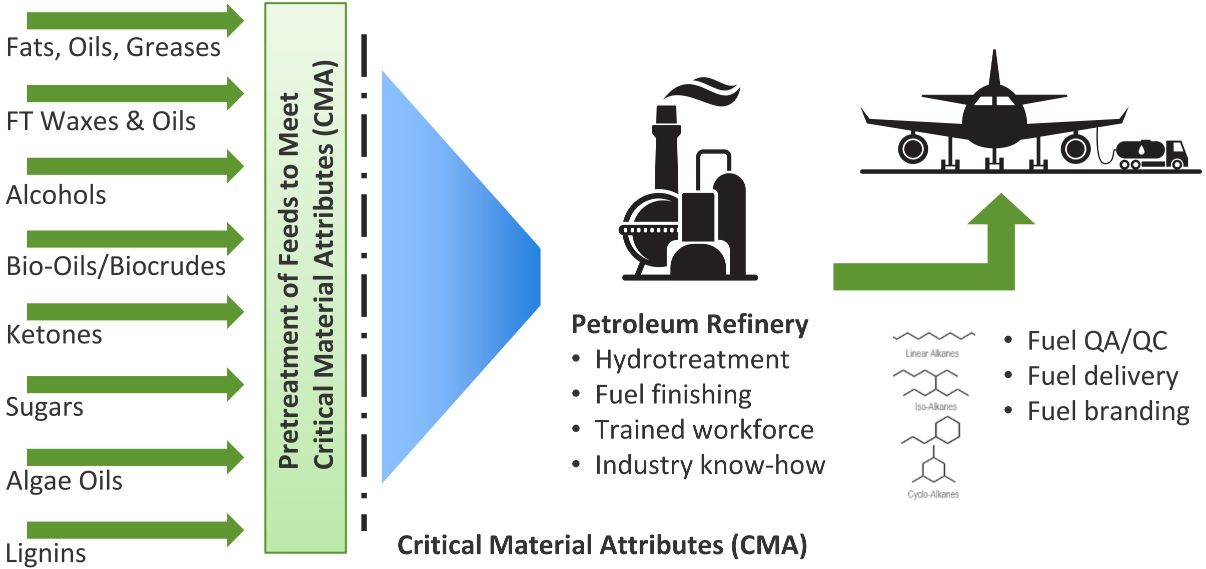
Leveraging Petroleum Industry’s $10B Investment in Hydrotreating Will Lower Costs and Accelerate Deployment

Opportunities to Use Existing Petroleum Refineries

- US has ~6.6M BBPD (97 BGPY) distillate hydrotreatment and finishing capacity
- Much of this capability is already depreciated
- This capability may become idled with electrification of ground transportation

Opportunity

Leverage ~$10B of depreciated capital equipment by pretreating renewable streams so that they can be processed by refinery hydrotreatment equipment



Petroleum Refinery

- Hydrotreatment
- Fuel finishing
- Trained workforce
- Industry know-how

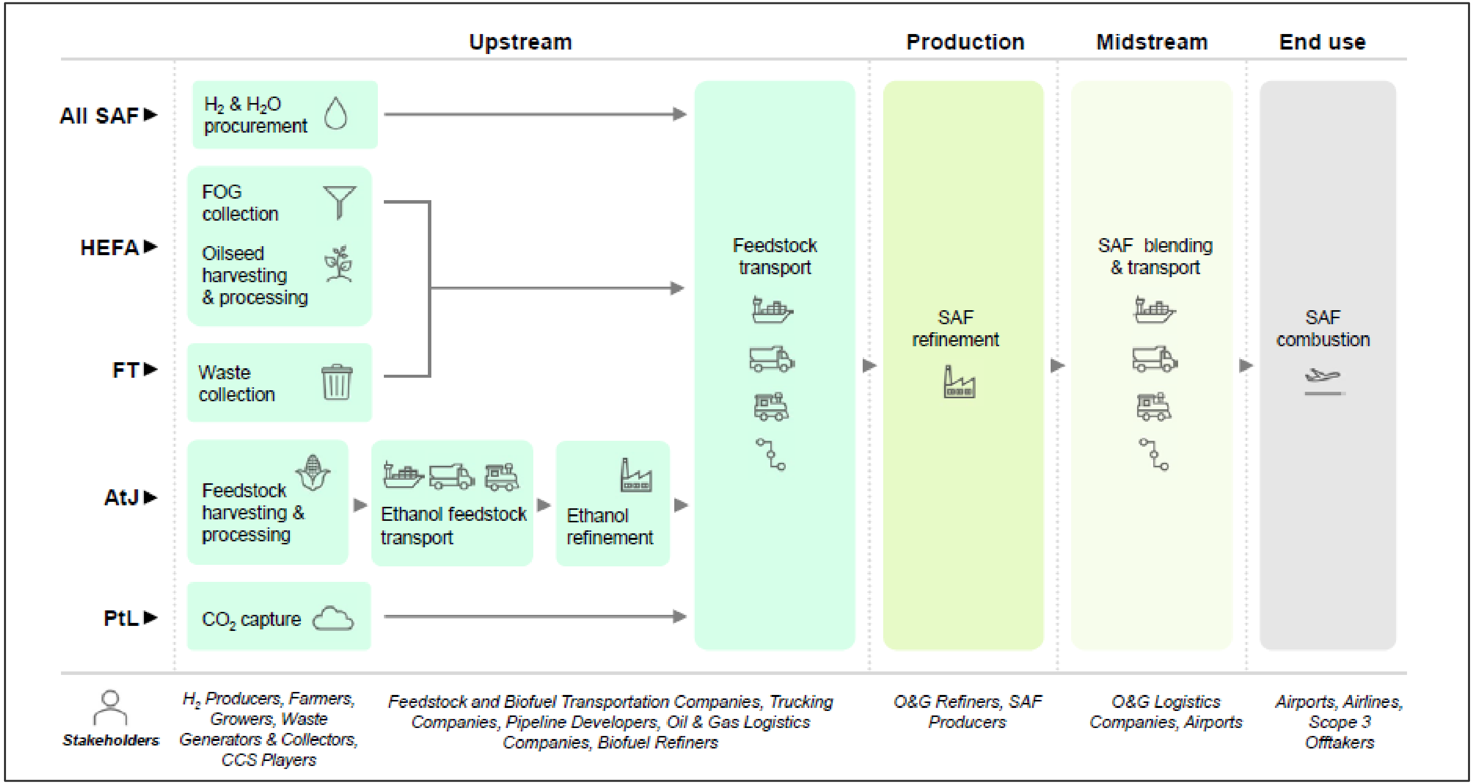
- Fuel QA/QC
- Fuel delivery
- Fuel branding

Critical Material Attributes (CMA)

- These are physical and chemical properties of pretreated renewable streams which can be processed by refineries with no or minor modifications

https://www.eia.gov/dnav/pet/PET_PNP_CAP1_A_(NA)_8CDHD0_BPSD_A.htm

Pathways to Commercial Liftoff: Sustainable Aviation Fuel (DOE Report: November 2024)



Upstream

Production

Midstream

End use

All SAF ▶ H_2 & H_2O procurement

HEFA ▶ FOG collection

Oilseed harvesting & processing

FT ▶ Waste collection

AtJ ▶ Feedstock harvesting & processing ▶ Ethanol feedstock transport ▶ Ethanol refinement ▶

PtL ▶ CO_2 capture

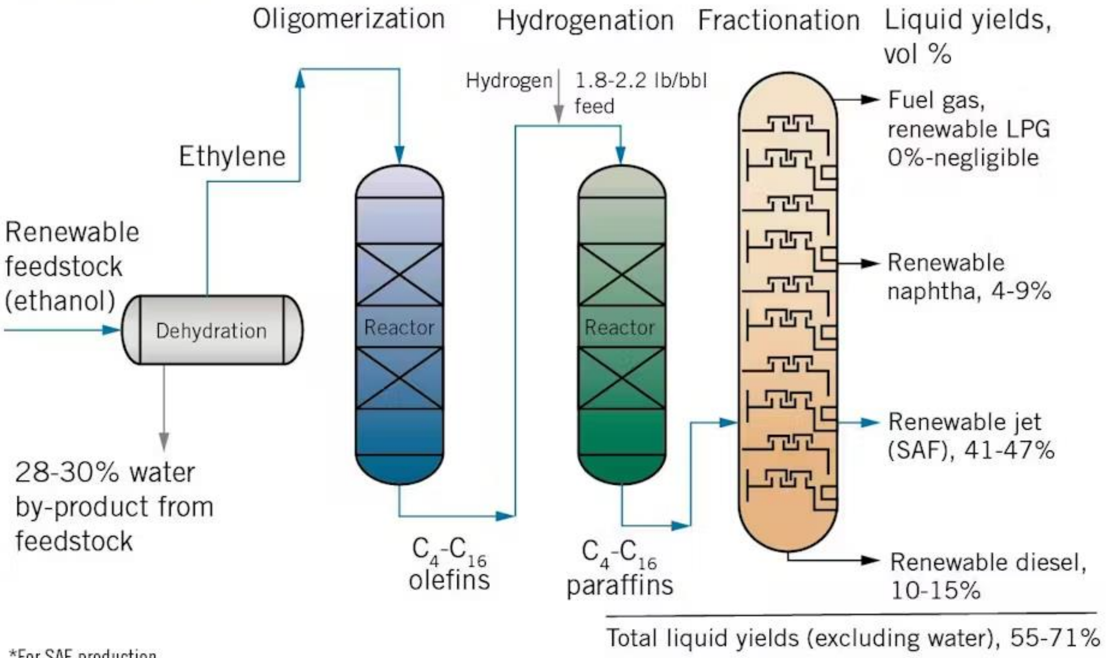
Feedstock transport ▶ SAF refinement ▶ SAF blending & transport ▶ SAF combustion

Stakeholders	H_2 Producers, Farmers, Growers, Waste Generators & Collectors, CCS Players	Feedstock and Biofuel Transportation Companies, Trucking Companies, Pipeline Developers, Oil & Gas Logistics Companies, Biofuel Refiners	O&G Refiners, SAF Producers	O&G Logistics Companies, Airports	Airports, Airlines, Scope 3 Offtakers

Alcohol (Ethanol) to Jet Technology

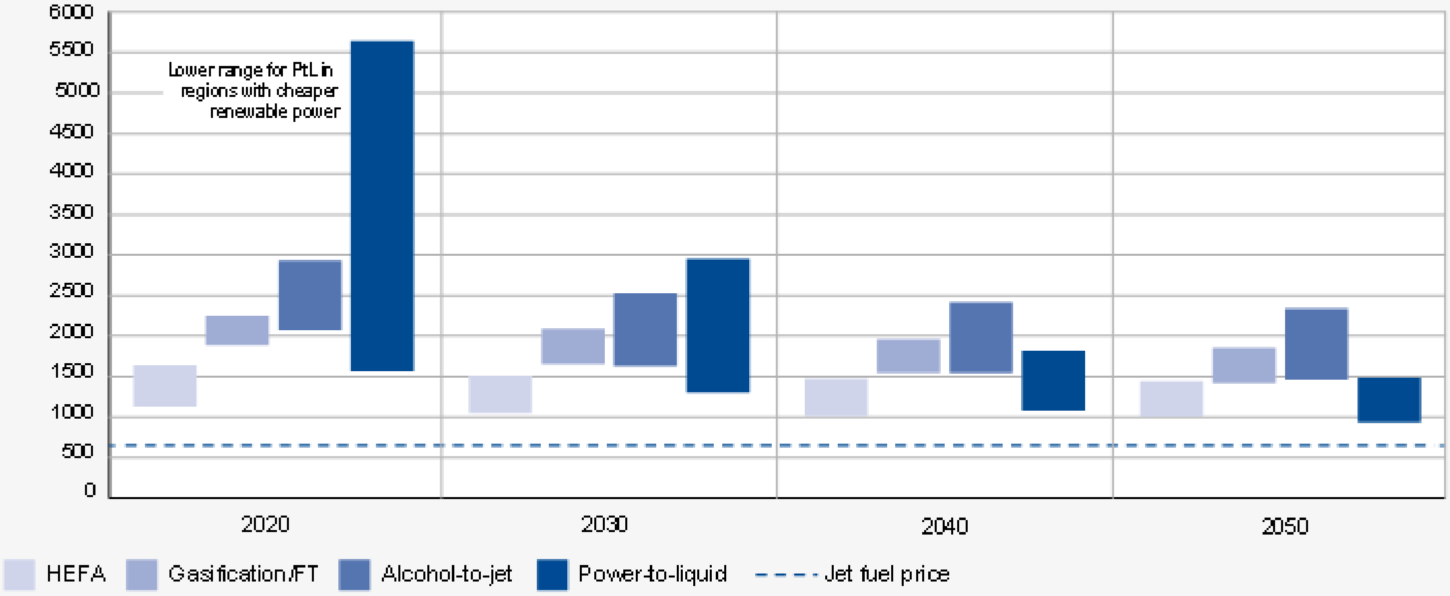
SIMPLIFIED ATJ PROCESS-FLOW DIAGRAM*

FIG. 2



*For SAF production.
Source: Baker & O'Brien

Transition of Sources of SAF



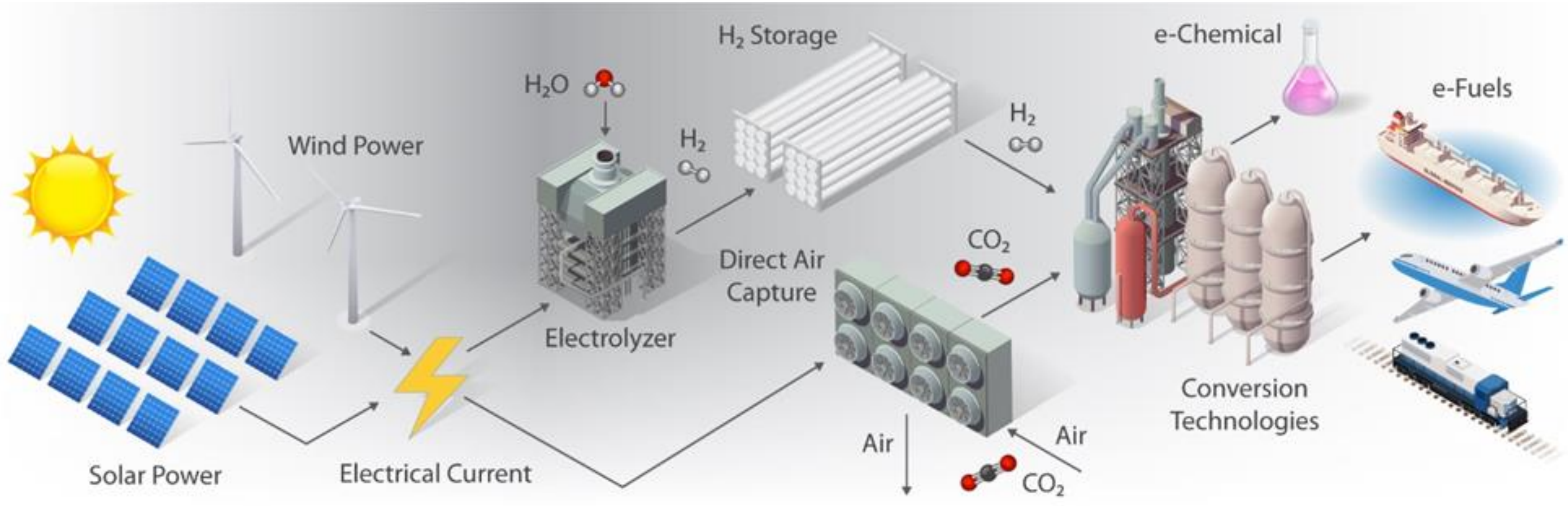
Global SAF production cost for selected feedstocks *Indicative*

Source: Expert interviews

World Economic Forum in Collaboration with McKinsey & Company
Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net Zero Aviation
November 2020

e-fuels and e-Chemicals
Generation of net zero/net negative e-Products

- E-fuels and e-chemicals require the integration of renewable electricity, electrolytic hydrogen generation, CO_2 capture, renewable heat generation, with existing and next generation conversion technologies.



Thank you

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www.nrel.gov

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