TECHNO-ECONOMIC EVALUATION OF STRATEGIES TO APPROACH NET-ZERO CARBON SUSTAINABLE AVIATION FUEL VIA WOODY BIOMASS GASIFICATION AND FISCHER-TROPSCH SYNTHESIS

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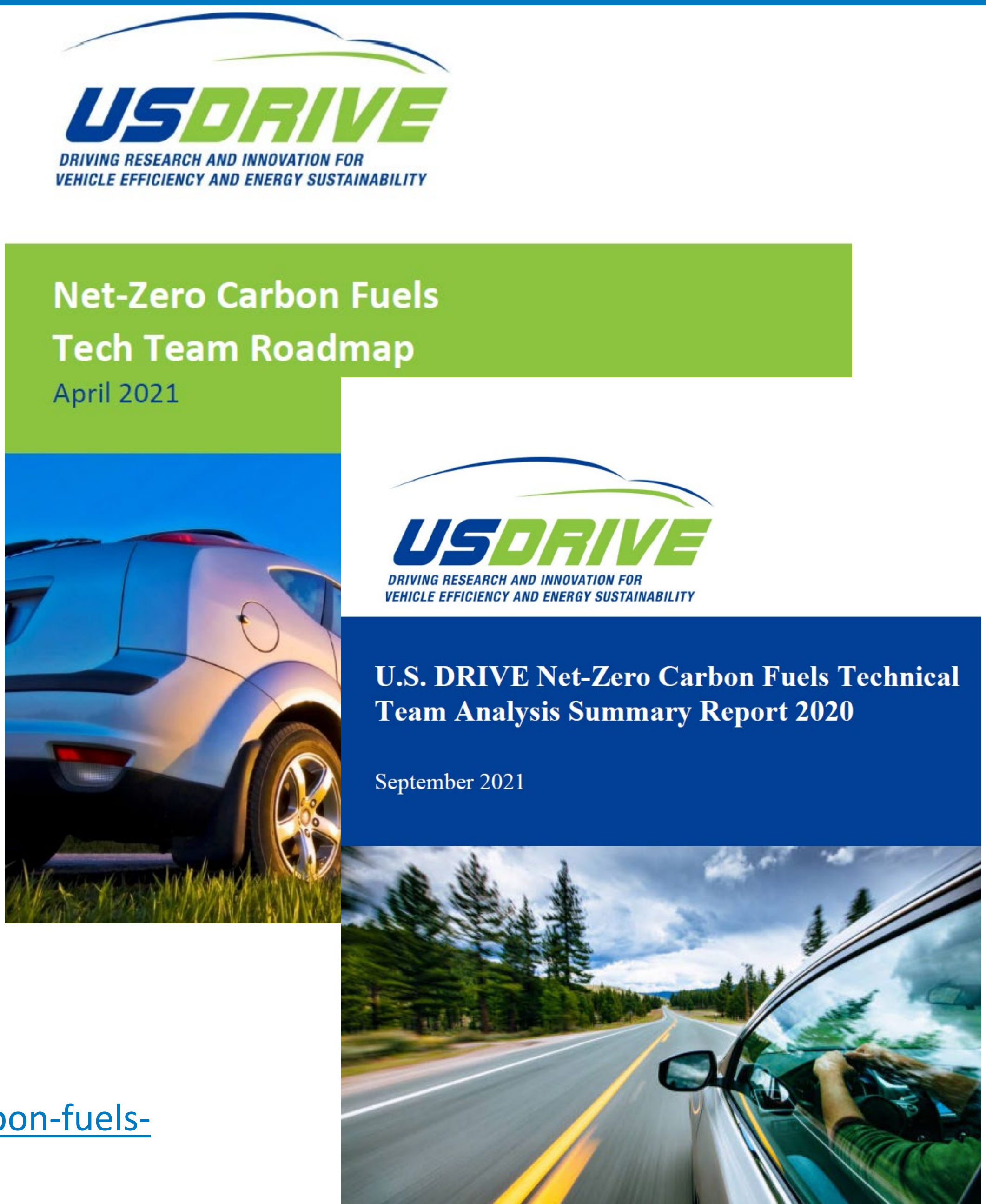
USDRIVE Net Zero Carbon Fuel Tech Team (NZTT)

MISSION: *Drive research, development, and demonstration of renewable energy solutions for the transportation sector through an assessment of the carbon intensity, technoeconomic readiness, and challenges for volume implementation of net-zero carbon fuel pathways.*

USDRIVE NZTT: Fuels Industry, US Department of Energy, Electric Utilities, Automotive Industry, Associate members, Analysis task by the four participating National Labs (NREL, PNNL, ANL, and LLNL)

OUTCOME: Completed initial techno-economic analysis and life cycle assessment (TEA/LCA) to understand the potential of near-term pathways for generating net-zero carbon fuels.

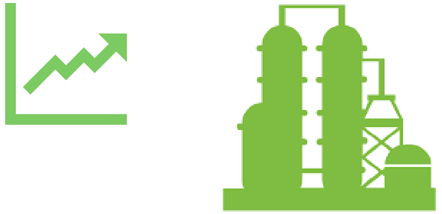


Roadmap Report: https://www.energy.gov/sites/default/files/2021-04/NZTT_Roadmap_v202010401_FINAL.pdf

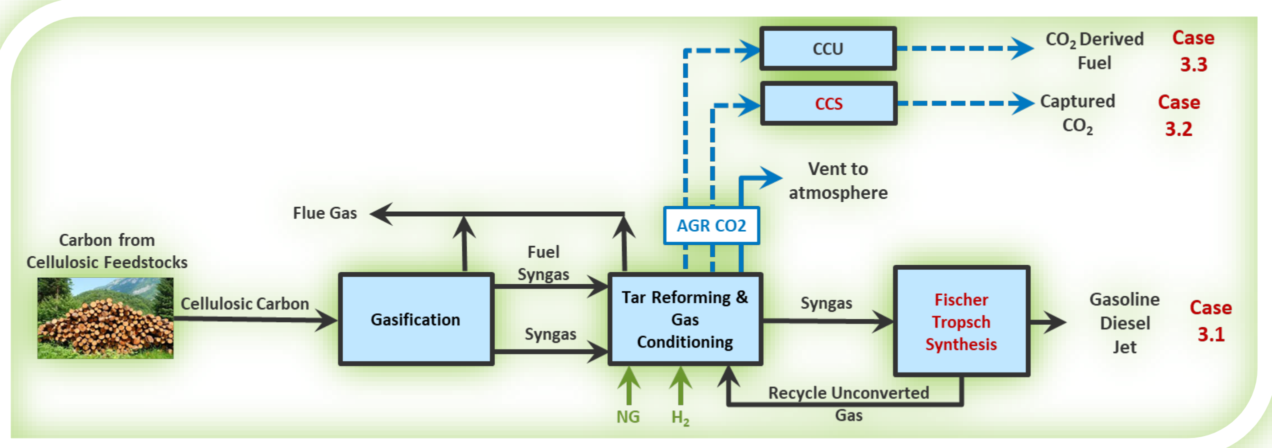
FY20 Report : https://www.energy.gov/eere/vehicles/articles/us-drive-net-zero-carbon-fuels-technical-team-analysis-summary-report-2020

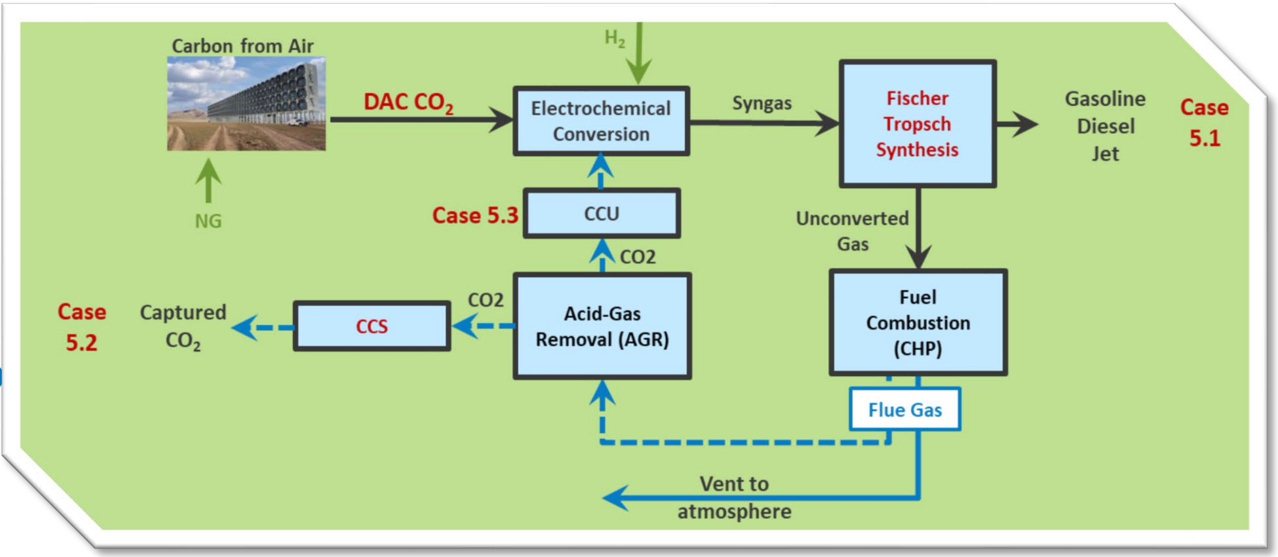
Background: Sustainable Aviation Fuel (SAF)

Reducing the carbon dioxide (CO_2) emissions from the transportation industry is a key target for achieving global net-zero carbon goals.



Numerous options exist for decarbonization strategies, what are the tradeoffs between TEA/LCA?





Approach: Techno-Economic Analysis (TEA)

aspentech

Process models developed in Aspen Plus

Discounted cash-flow rate of return (DCFROR) analysis and sustainability assessment conducted

Key metrics identified and leveraged to generate comparative analysis

Metric	Definition	Unit
Cost	Minimum methanol selling price	\$/kg
Carbon efficiency	$\frac{Carbon\ in\ product\ (methanol)}{Total\ carbon\ in\ (biomass\ \frac{and}{or}\ CO2)}$	%
Energy efficiency	$\frac{Product\ LHV\ (methanol)}{Total\ energy\ in\ (biomass, H_2, process\ electricity\ and\ heat)}$	%
Life-cycle GHG emissions	equivalent grams of CO_2 per MJ of FT fuel produced and used	gCO_2e/MJ_{FT}
Technology Readiness Level (TRL)	U.S. Department of Energy (DOE) TRL Guide 2011	Scale 1-9

Key Metrics

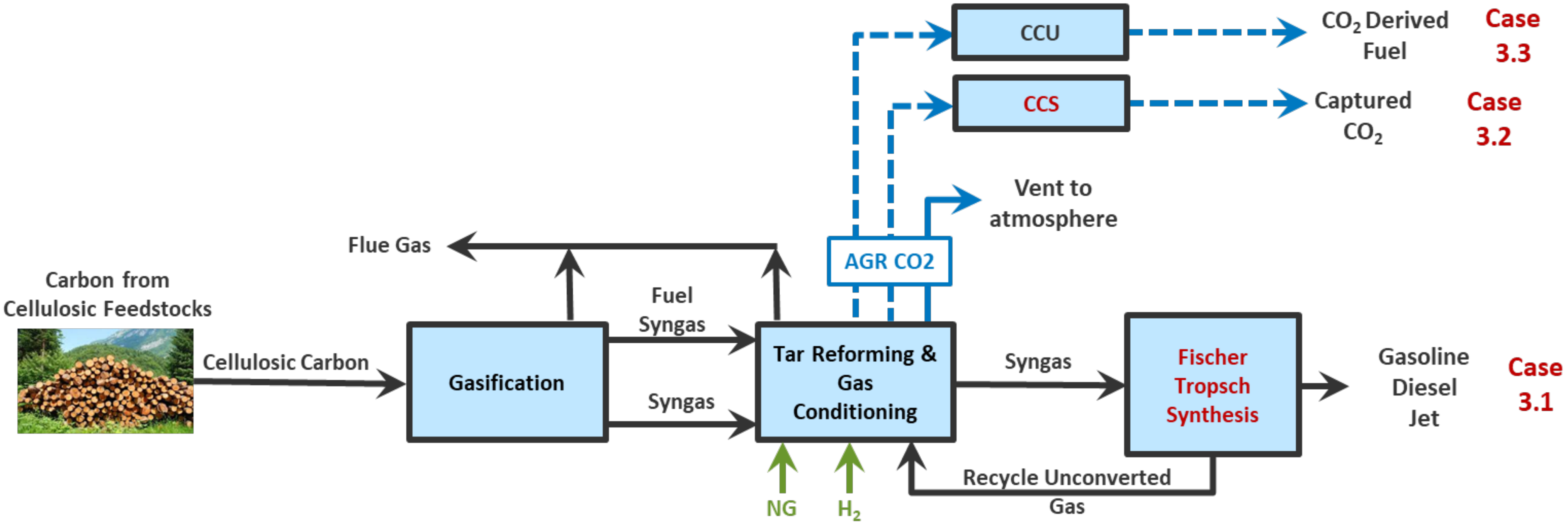
- Derived from TEA to produce cross-comparison
- Selected to harmonize economic and environmental factors
- Considers “time-to-deployment” as a key indicator

Baseline Assumptions

PROPOSED COSTS:		SOURCE
Fossil H2 ($/kg)	$1.57	NREL SOT models
Renewable H2 ($/kg)	$1.38-$6.35 (baseline $4.50)	H2A Report 2020
Grid Electricity ($/kWh)	$0.068	FY20 USDRIVE Report
Renewable Electricity ($/kWh)	$0.02-$0.10	FY20 USDRIVE Report
Natural Gas ($/MMBTU)	$3.39	FY20 USDRIVE Report
Renewable Natural Gas ($/MMBTU)	$7.48-$29.44 (baseline $12.00)	FY20 USDRIVE Report

NREL SOT: https://www.nrel.gov/docs/fy21osti/79986.pdf
H2A Report 2020: https://www.nrel.gov/docs/fy21osti/77610.pdf
FY20 USDRIVE Report: https://www.energy.gov/eere/vehicles/articles/us-drive-net-zero-carbon-fuels-technical-team-analysis-summary-report-2020

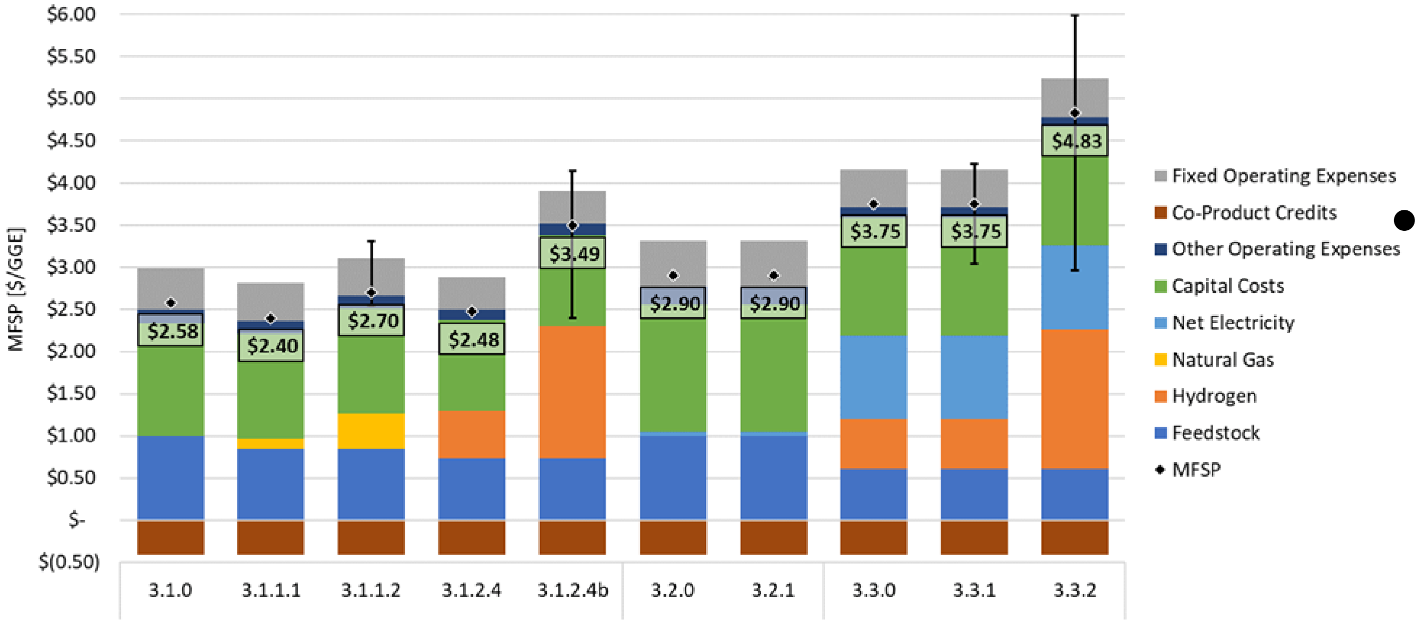
Biomass Gasification to Fuels

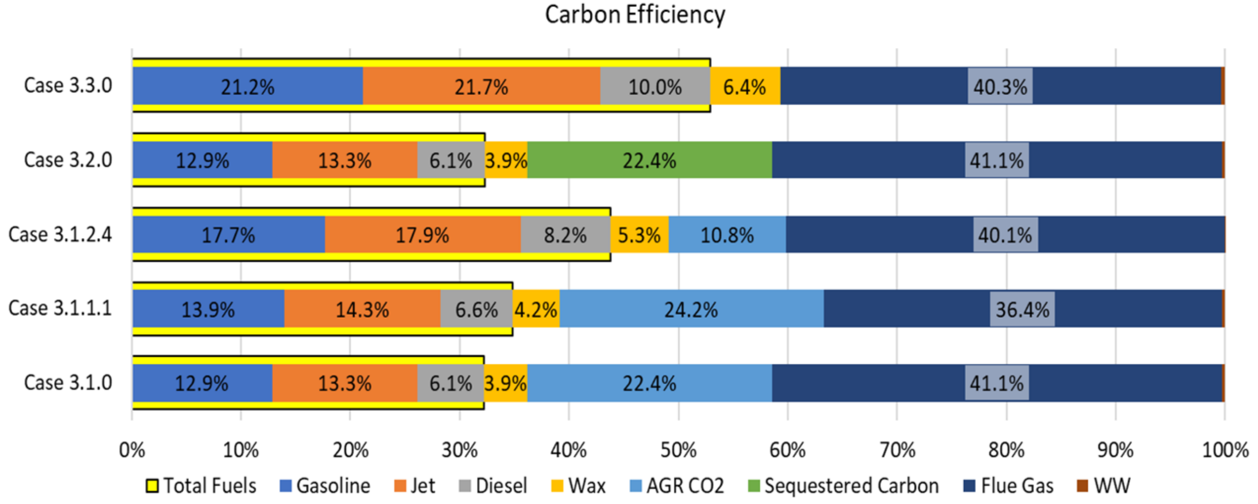


Case	CO_2 capture	Electricity	Heat	H_2
3.1.0	-	Biomass (internal)	Biomass (internal)	-
3.1.1.2	-	Biomass (internal)	Import RNG	-
3.1.2.4b	-	Biomass (internal)	Biomass (internal)	Renewable
3.2.1	With CCS	Renewable (for CCS)	Biomass (internal)	-
3.3.2	With CCU	Renewable (for CCU)	Biomass (internal)	Renewable

- CCS is carbon capture and storage
- CCU is carbon capture and utilization
- RNG is renewable natural gas

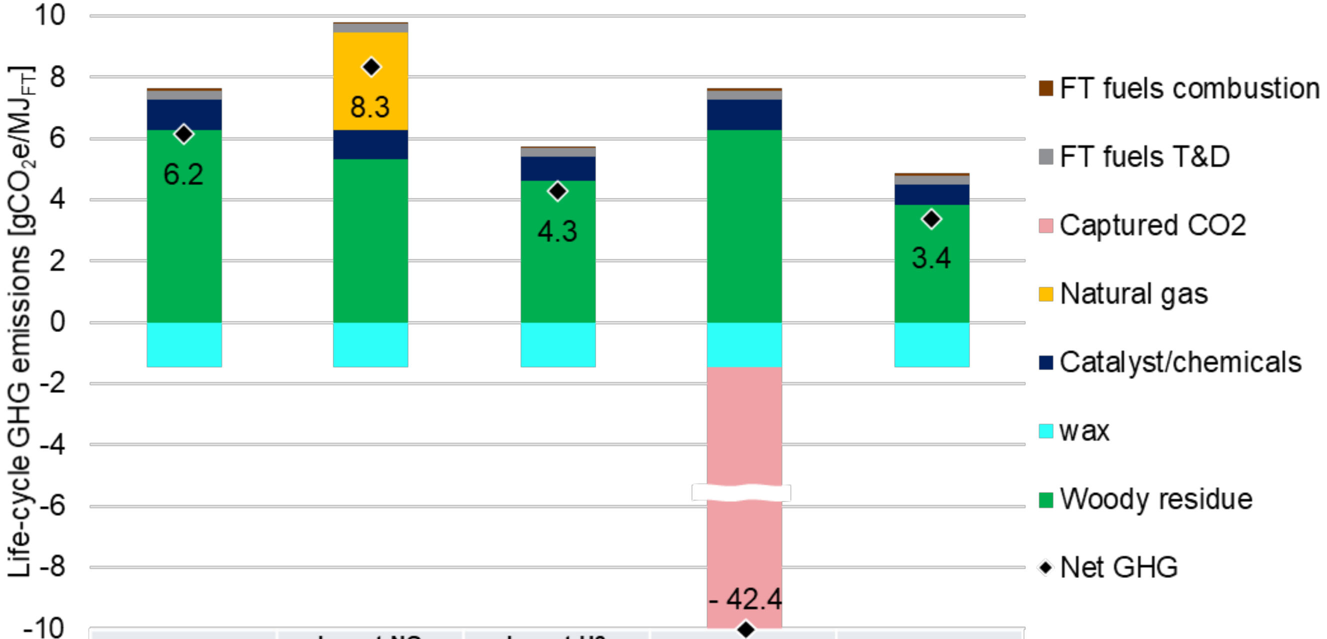
Biomass Gasification Preliminary TEA Results





- Gasification and Fischer Tropsch (FT) synthesis technologies present a near-term viable pathway for biomass-derived fuel production.
- CCS is another near-term carbon mitigation strategy with a high TRL which could readily be implemented and remove a large fraction of CO_2 emissions, with a low-cost burden.
- CCU technologies present a strategy for reincorporating CO_2 to fuels. Implementing a CCU system results in the largest increase in carbon efficiency, up to 52.9%, but should be viewed as a long-term strategy for carbon mitigation and utilization in the biomass-to-fuels via FT pathway.

Biomass Gasification Preliminary LCA Results

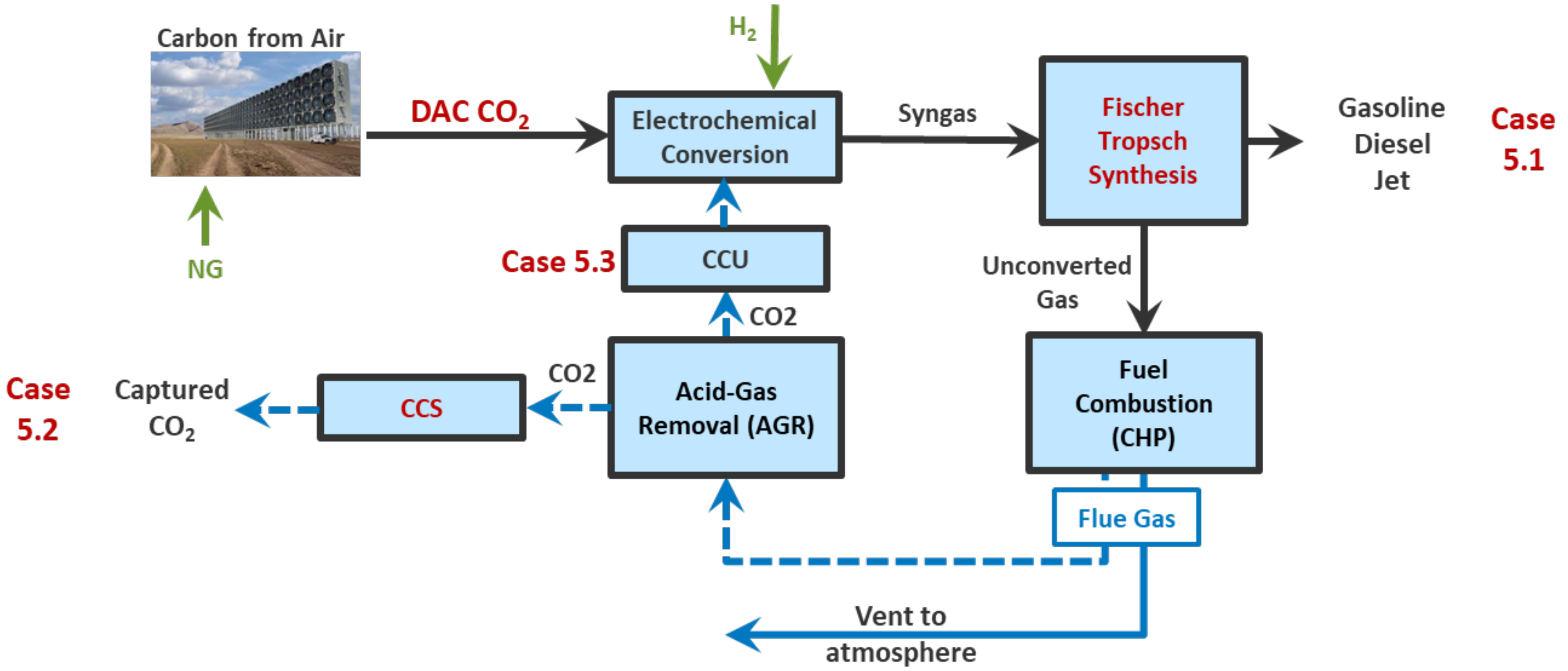


Base case	Import NG as a process fuel	Import H2 for tar reforming	With CCS	With CCU	
Case 3.1.0	Case 3.1.1.2	Case 3.1.2.4b	Case 3.2.1	Case 3.3.2	
117	99	86	117	72	**Biomass input [dry g/MJ_{FT}]**
-	0.3 (RNG)	0.34 (H_2)	0.02 (electricity)	0.36 (H_2) 0.43 (electricity)	**Renewable energy consumption [MJ/MJ_{FT}]**

* CI of petroleum jet: 84.5 gCO_2e/MJ

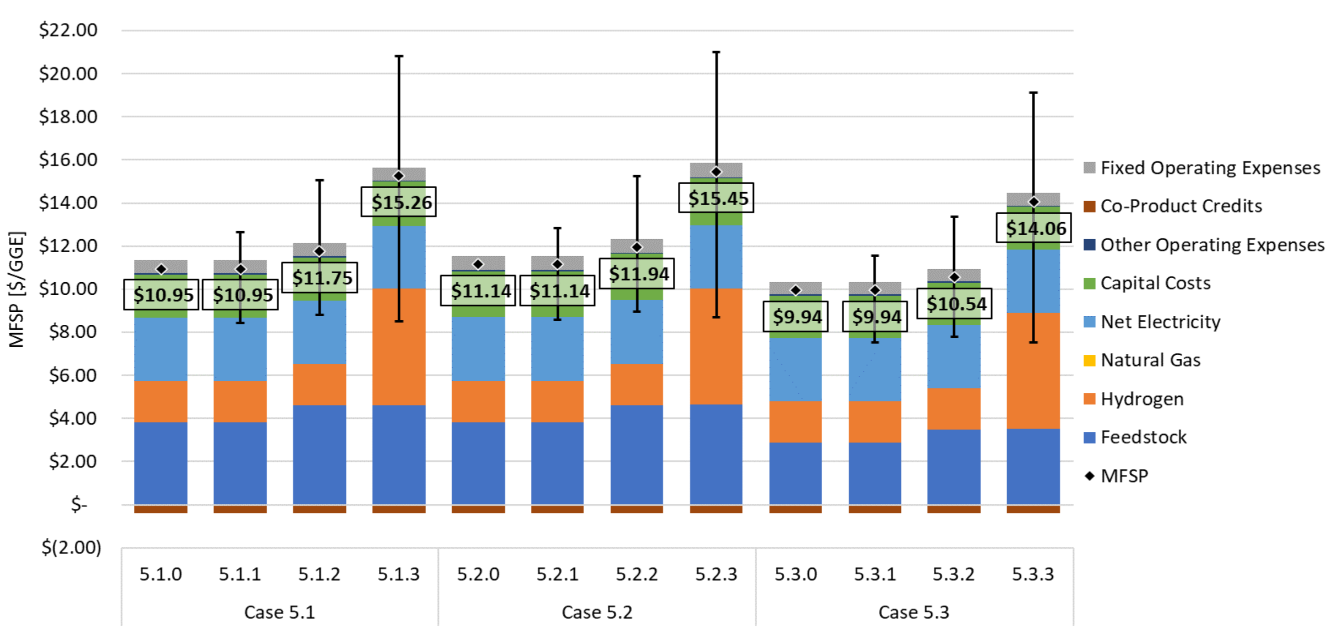
- The CI of SAF from base case is 93% lower than the CI of petroleum jet mainly by using biomass for utility
- External RNG input as a process fuel reduces the biomass inputs but increases the net CI of FT fuel. Imports 0.34 MJ of additional renewable H_2 can reduce the CI of SAF to 4.3 gCO_2e/MJ, while generating 0.64 MJ of additional FT fuels compared to the base case
- With CCS case reduces the CI of FT fuel to -42.4 gCO_2e/MJ with only 0.02 MJ of additional renewable electricity.
- CCU technology needs significant amounts of renewable H_2(0.36 MJ) and electricity (0.43 MJ) to reduce the CI to 3.4 gCO_2e/MJ while saving 39% of biomass input

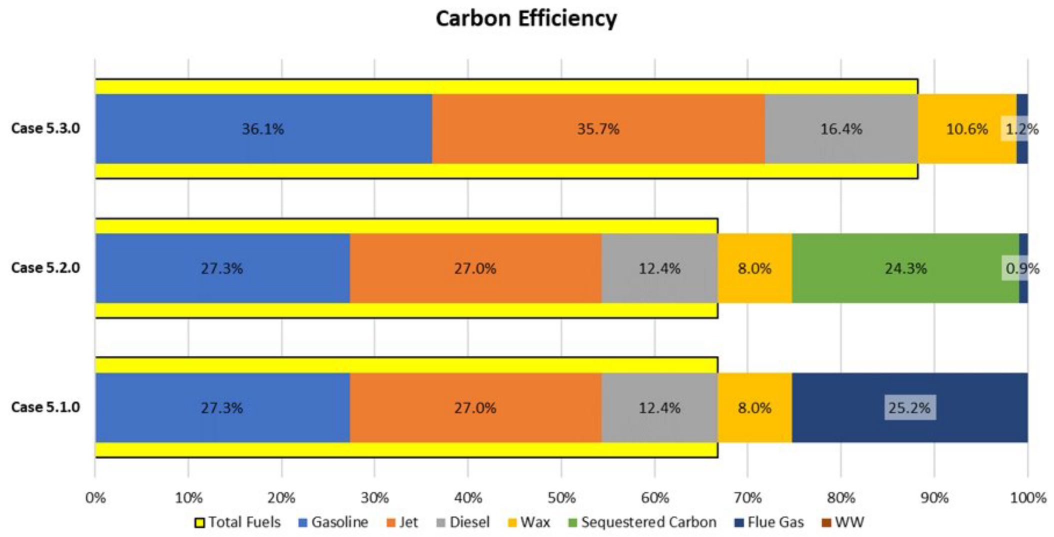
Direct Air Capture CO_2 and CO_2 to SAF



Case	Electricity	NG	H_2
5.X.0	US mix	fossil	SMR
5.X.1	renewable	fossil	SMR
5.X.2	renewable	landfill	SMR
5.X.3	renewable	landfill	Renewable

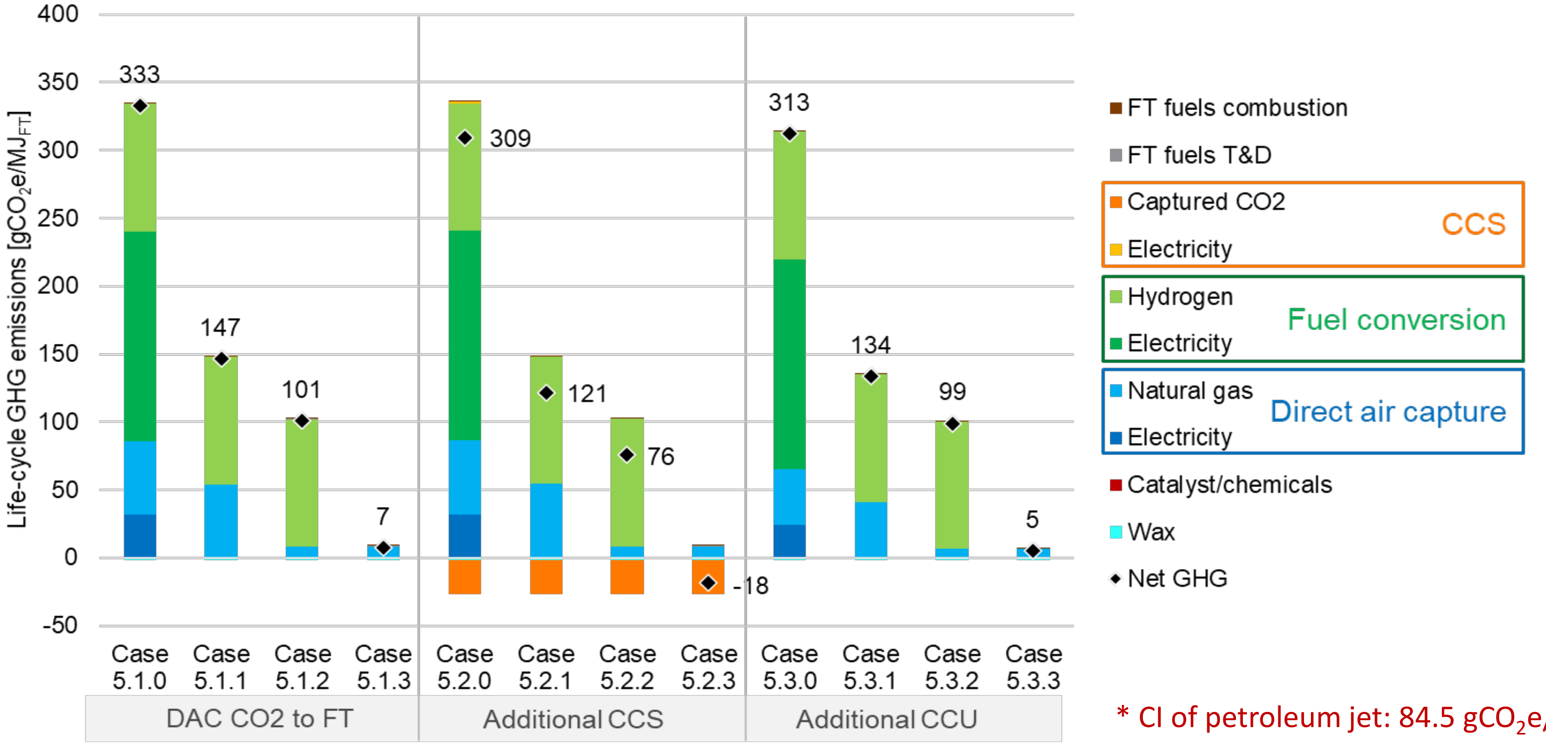
DAC CO_2 to SAF Preliminary TEA Results





- Both DAC and CO_2-to-CO electrolysis are low TRL technologies, require significant R&D efforts. Coupling with the established FT technology shows potential for the development of a novel pathway with high carbon efficiency in the baseline design (66.8%).
- CCS technologies has key environmental benefits, but this strategy does not recover the costs of expensive DAC CO_2 and does not improve carbon or energy efficiency to fuels.
- CCU strategy requires only the addition of an amine flue-gas scrubbing system and can utilize the existing CO_2-to-CO framework to improve both carbon and energy efficiency to fuels.
- Due to low TRL and high near-term costs, the DAC CO_2-to-SAF pathway should be considered a long-term option for fuels.

DAC CO_2 to SAF Preliminary LCA Results



* CI of petroleum jet: 84.5 gCO_2e/MJ

- DAC CO_2 to fuel is energy intensive, requiring 1.2 MJ of H_2, 0.4 MJ of NG, and 0.5 MJ of electricity.
- Without using renewable energy, the DAC CO_2 FT process does not provide CI reduction benefits, but shifting to renewable energy sources significantly reduces the CIs of FT fuels.
- CCS decreases CI by 25.5 gCO_2e/MJ.
- CCU decreases CI by 2–20 gCO_2e/MJ compared to baseline.
- If using renewable energy sources, the CIs of CCS and CCU become -18 and 5 gCO_2e/MJ, respectively.

Conclusion and Key Takeaways

- Biomass gasification is capable of meeting market competitive costs and displays a high TRL, and a promising technology for the near-term commercialization.
- The direct CO_2 pathway is comparatively much lower in TRL and requires the substantial R&D efforts pushing technology feasibility and economic viability.
- Future analyses should consider process designs that are optimized across a variety of economic and environmental metrics.
- To produce net-zero carbon fuel:
  - ➢ Using renewable energy inputs (electricity, H_2, and NG)
  - ➢ Applying CCS option provides significant emission reductions with a slight increase in electricity consumption for CO_2 capture and compression
  - ➢ CCU coupled with renewable energy can reduce the CIs while providing additional fuel outputs to maximize carbon yields from carbon-based feedstocks

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Thank you

www.nrel.gov

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