Decarbonization of Hydrothermal Liquefaction (HTL) of Wet Waste to Transportation Fuels and Its Techno-Economic Analysis and Life Cycle Analysis

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tcbiomass

U.S. DEPARTMENT OF ENERGY BATTELLE

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Net-Zero Carbon Fuels Technical Team (NZTT) Analysis

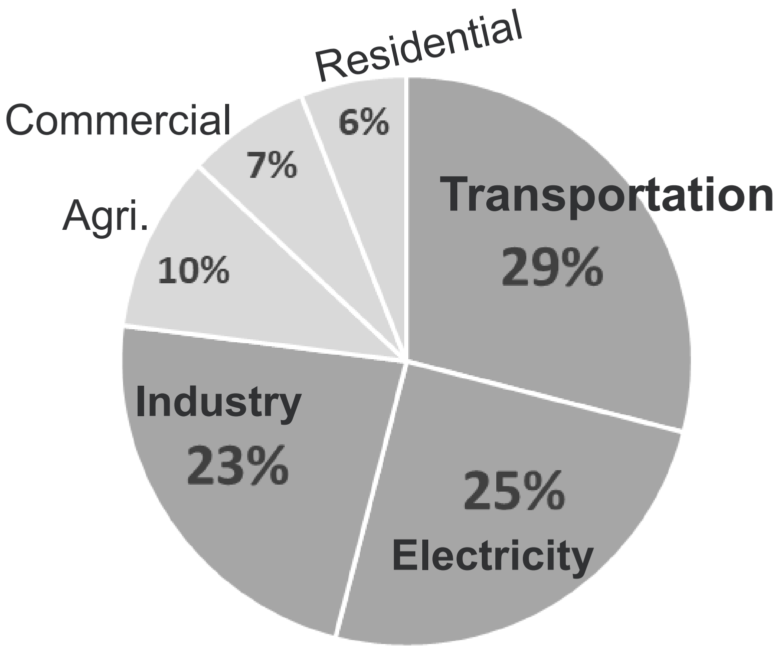
Investigating the potential to generate carbon-based fuels with much lower carbon intensities (CIs) compared to those of conventional fuels, approaching or exceeding net zero greenhouse gas (GHG) emissions.

Year 2 analysis work – Life Cycle Analysis and Techno-Economic Analysis of:

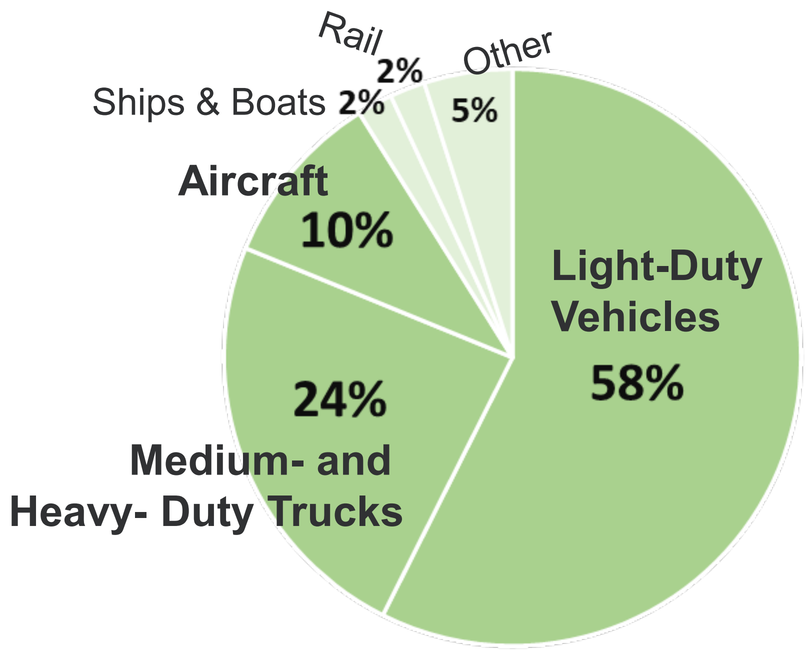
Lawrence Livermore National Laboratory, NREL, Argonne National Laboratory	Case 1. Conventional corn ethanol production with upgrading to sustainable aviation fuel (SAF), incorporating renewable process inputs and carbon capture and sequestration (CCS) or carbon capture and utilization (CCU).
Lawrence Livermore National Laboratory, NREL, Argonne National Laboratory	Case 2. Advanced cellulosic ethanol production using corn stover biomass feedstock and ethanol upgrading to sustainable aviation fuel (SAF).
NREL, Argonne National Laboratory	Case 3. Production of gasoline, jet, and diesel fuel from woody biomass gasification followed by Fischer Tropsch (FT) synthesis.
Pacific Northwest National Laboratory, Argonne National Laboratory	**Case 4.** Production of gasoline, jet, and diesel fuel from the hydrothermal liquefaction (HTL) of wet wastes (sludge from wastewater treatment plants) and subsequent hydrotreating and fractionation.
NREL, Argonne National Laboratory	Case 5. Direct air capture (DAC) of CO_2 and water/CO_2 electrolysis to syngas followed by FT synthesis to produce gasoline, SAF and diesel.

Why Decarbonizing Transportation Sector

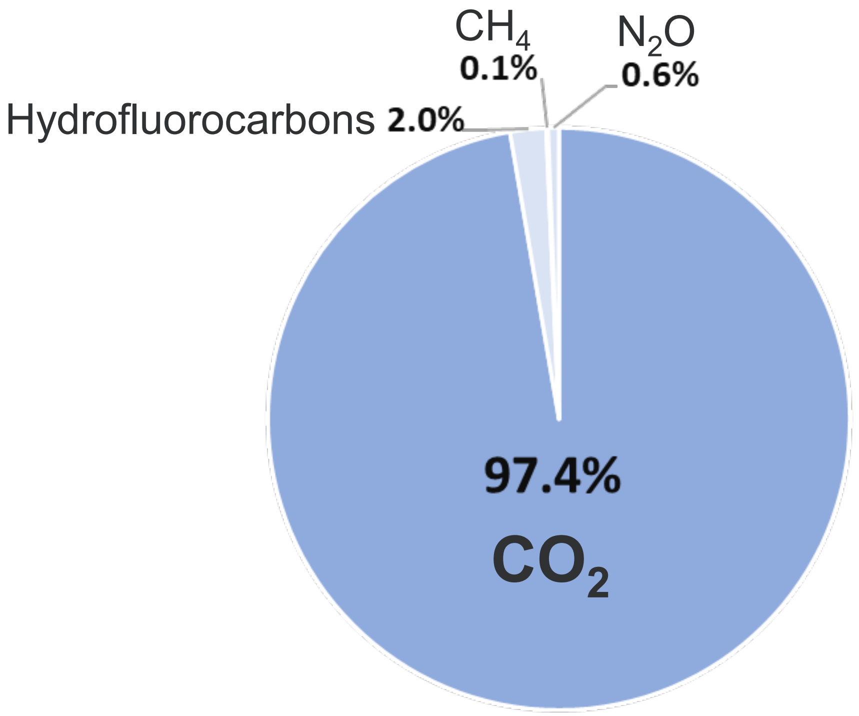
Data published by EPA (2021)



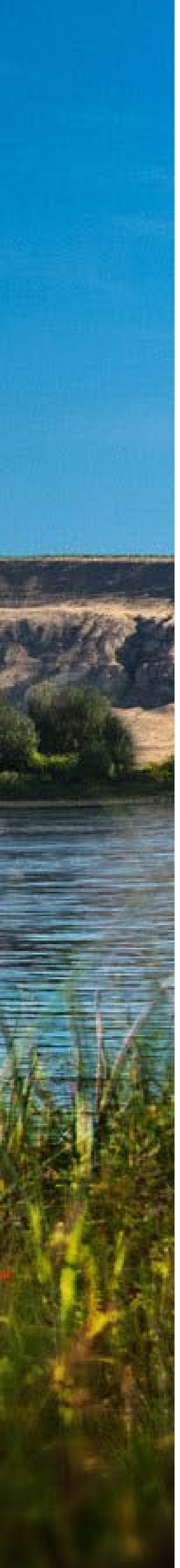
Share of U.S. GHG Emissions by **Sector**



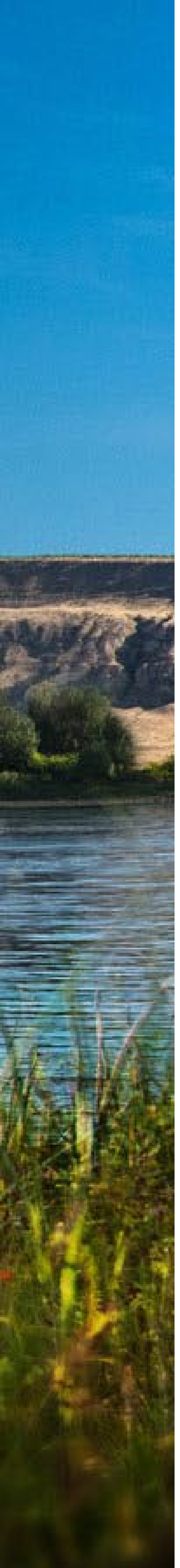
Share of U.S. Transportation GHG Emissions by **Source**



Share of U.S. Transportation GHG Emissions by **Gas**



- Transportation sector is one of the largest contributors to greenhouse gas (GHG) emissions.
- Light-duty vehicles were the largest category contributing 58% of GHG emissions
- CO2 from transportation sector is the most significant greenhouse gas (GHG) emissions.



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What and Why

Hydrothermal Liquefaction (HTL)

Hydrothermal liquefaction (HTL) is

the conversion of solid biomass in hot, pressurized water to predominantly liquid components

HTL is

- conceptually simple (i.e., heated pipe), scalable, versatile, and robust
- can accept high-moisture feedstocks (no drying!)
- results in high carbon yields to biocrude oil (up to 60%)
- produces a gravity-separable biocrude with low oxygen content (5–15 %) that can be upgraded in a single stage hydrotreater to diesel-range fuel blendstocks

Feedstock
Wet biomass material
(sludge, manure, algae)

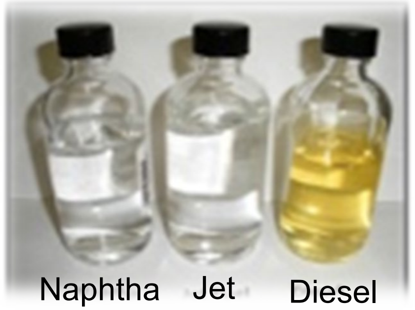
330-350°C
2900 psig
10-30 min

HTL →

Intermediate
Stable biocrude oil
(up to 60% C yield)

400°C
1500 psig H_2
Sulfided NiMo on Al

Hydrotreating →



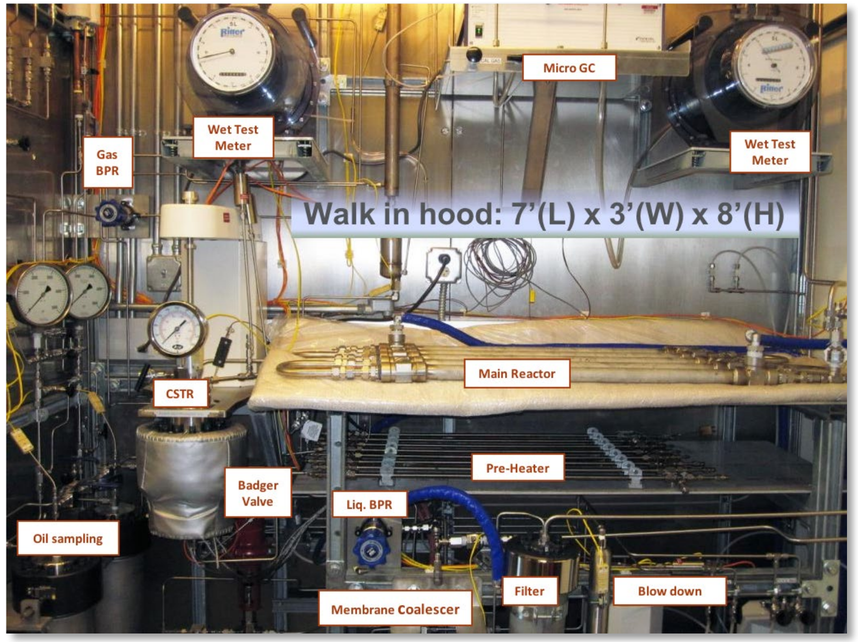
Final product
Fuel Blendstocks
(95%+ C yield)

Hydrothermal Liquefaction (HTL) System at PNNL

Program Support

- Capability funded by DOE/BioEnergy Technologies Office (BETO)
- Based on PNNL's extensive experience in hydrothermal liquefaction

Bench-scale continuous HTL system



Modular Hydrothermal Liquefaction System (MHLS)

MHLS Design Features

- ~5X scale-up of bench scale
- Modular/relocatable
- Feed prep for feedstocks
- HTL modes - PFR or CSTR/PFR hybrid
- Heat recovery (product to feed)
- Capacity 12-16 L/hour feed
- Ash solid separations
- Flexible product separations unit ops

Wet Waste Feedstock – Low Cost and Abundant

Wastewater Solids

Fats/Oils/Grease

Food Waste

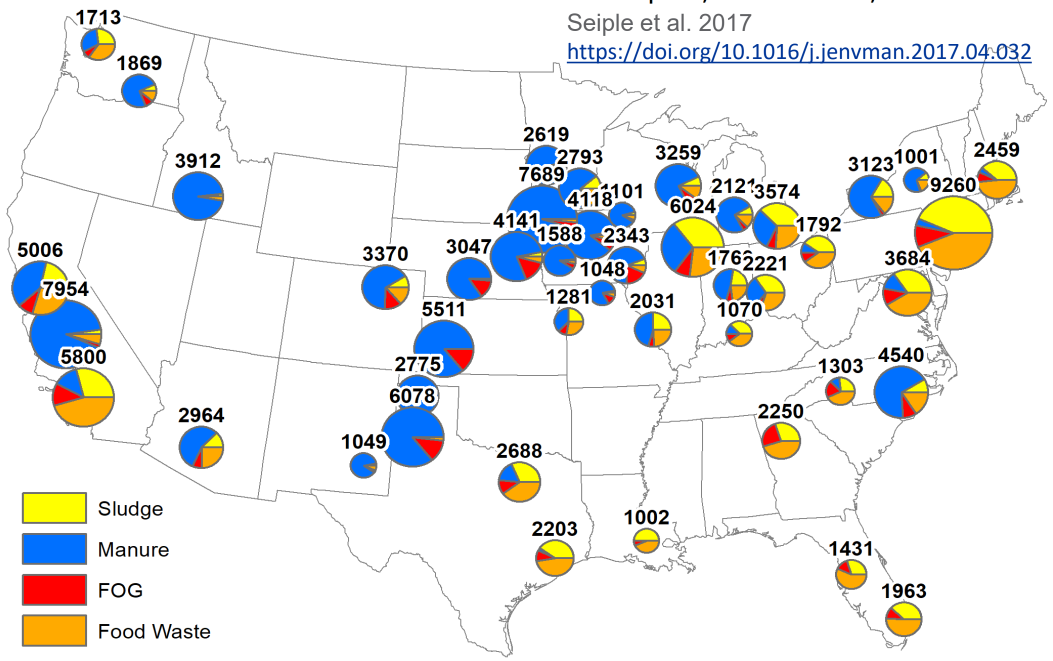
Manures

Annual Wet Waste Availability in 2016

Resource	Million Dry Tons	Energy Content (Trillion Btu)
Wastewater Solids	15	238
Animal Waste	41	547
Food Waste	15	318
Fats, Oils, and Greases (FOG)	6	214
Total:	**77**	**1317**

45 Service Areas ≥1000 dry Mg/d account for 51.3 dry Tg/y (82% of total inventory)
Scenario: Compete; USD 50 max; 250-km max

Seiple et al. 2017
https://doi.org/10.1016/j.jenvman.2017.04.032



Potentials

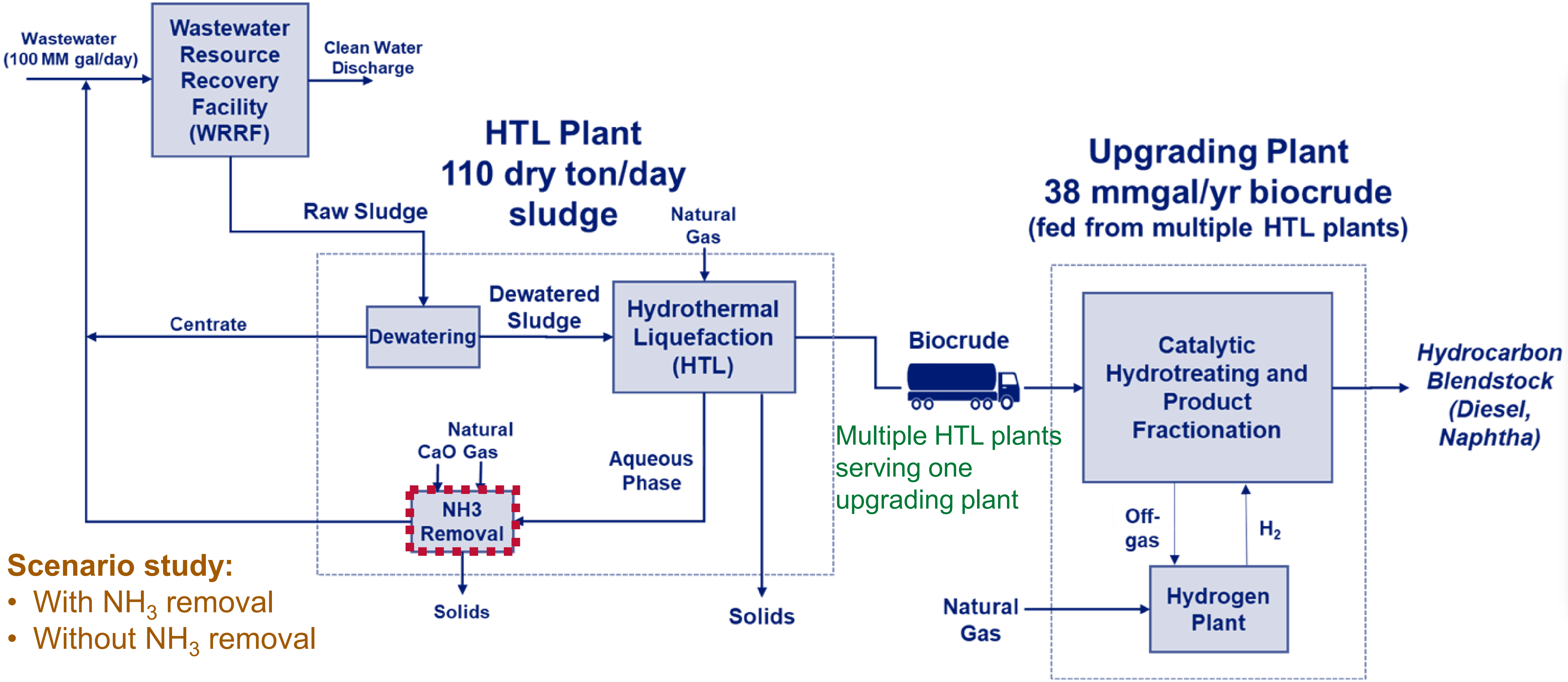
5.5 billion gallons biocrude from wet waste feedstocks is:

- twice the amount of bio-based diesel made today
- 20X the amount of cellulosic biofuels made today
- 12% of petroleum diesel consumption

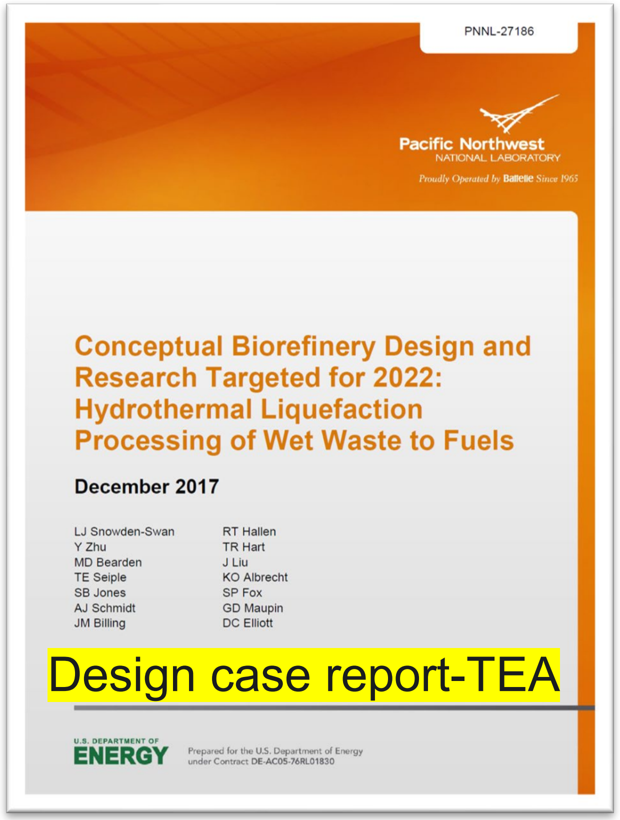
Base Case Study of Wet Waste HTL Applying TEA and LCA to Guide Research

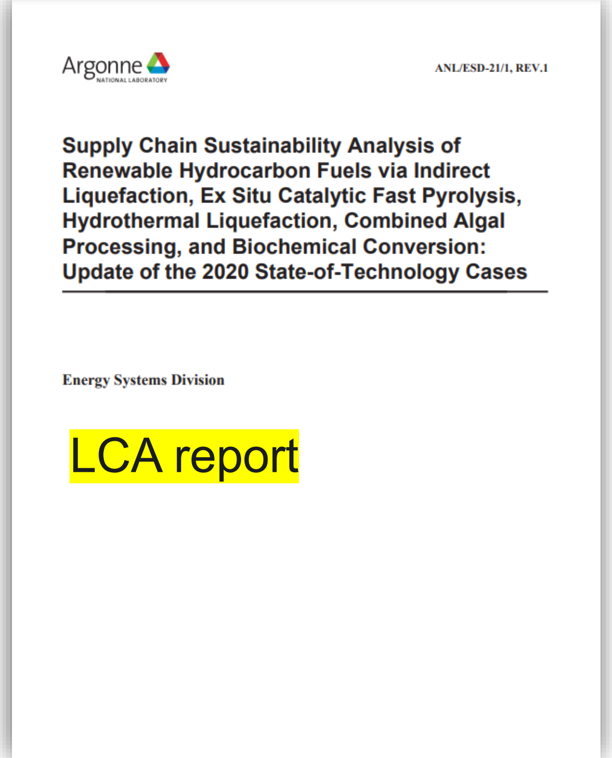
Wet Waste HTL Design Case

- Process model and simulation is developed.
- Identify process parameters driving costs and GHG emissions.
- Enables focused HTL and biocrude upgrading research to improve process cost and GHG emissions.



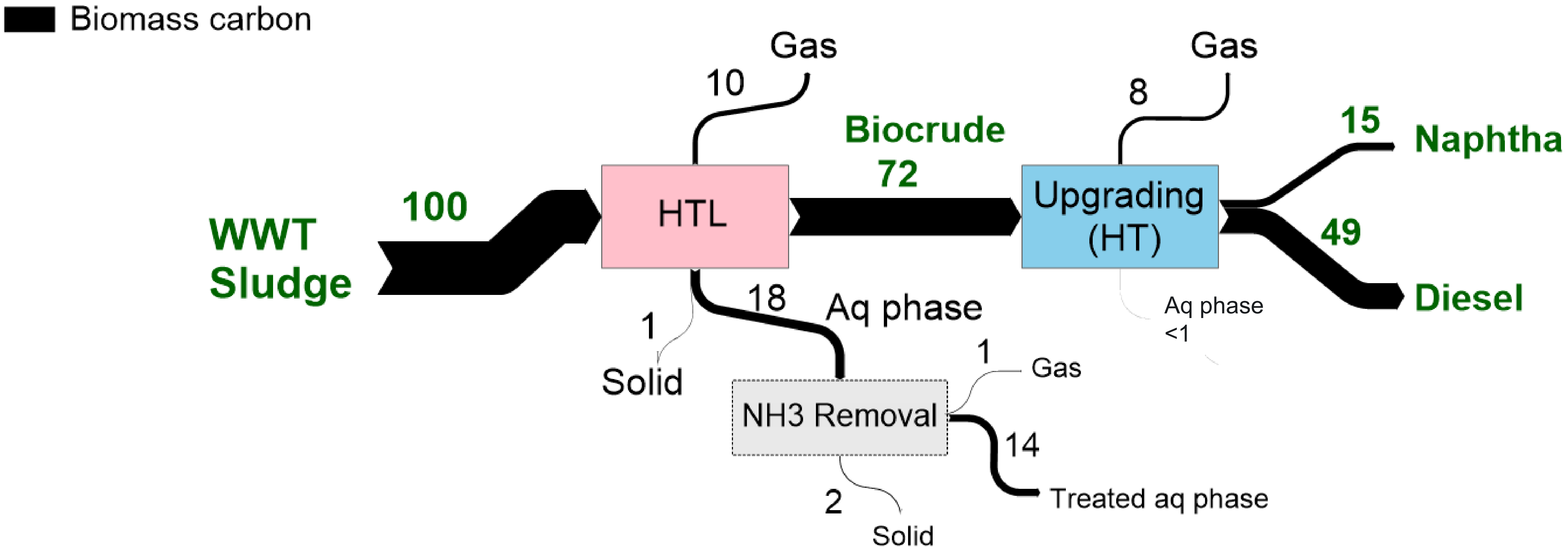
Scenario study:
- With NH_3 removal
- Without NH_3 removal





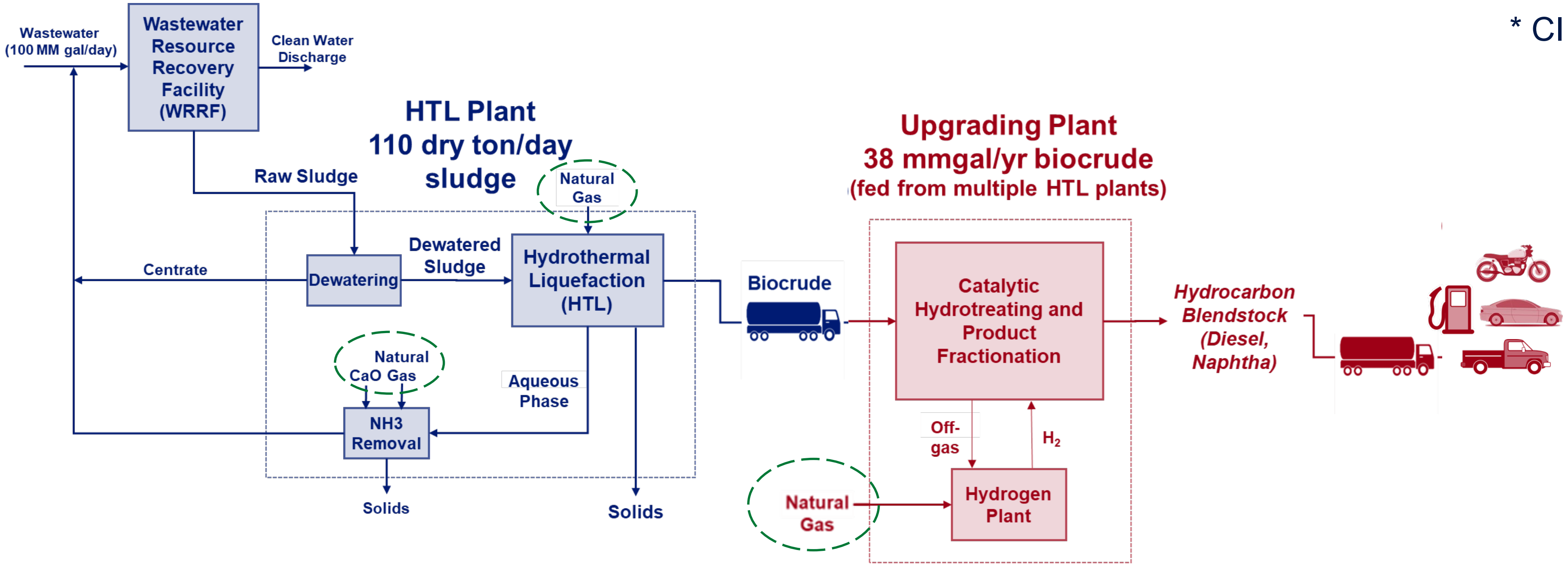
Carbon Balance and Efficiency of Wet Waste HTL and Biocrude Upgrading

Carbon flow: Wet Waste HTL and Upgrading



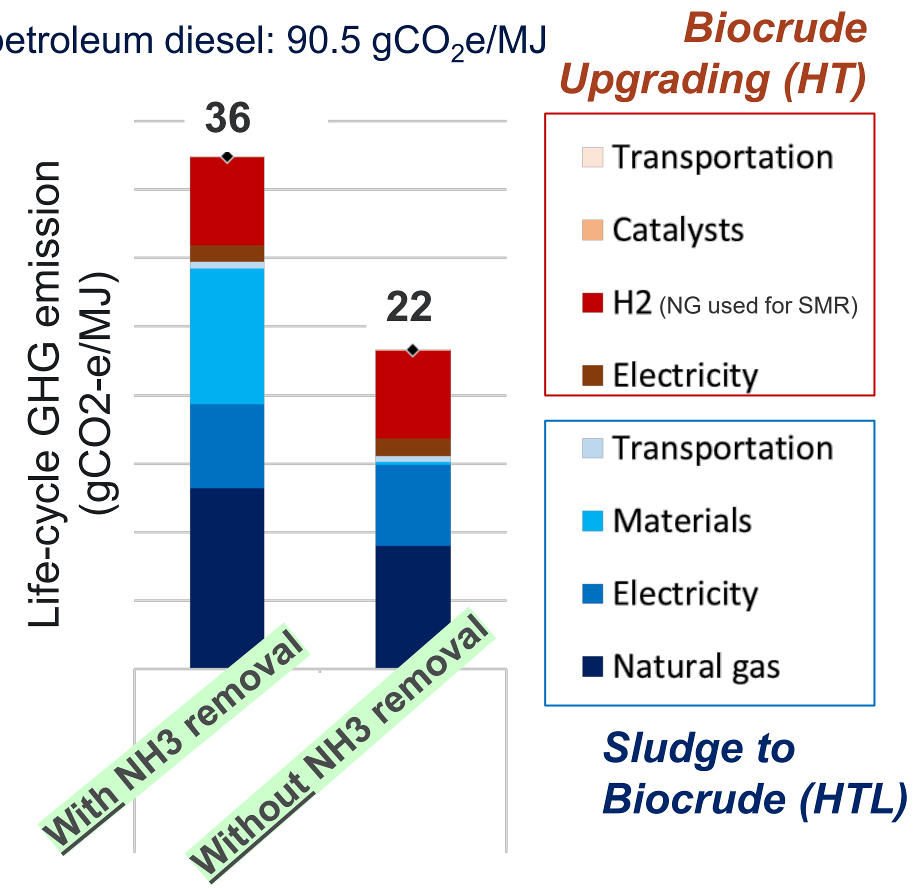
Aqueous Phase Upgrading	Wet Waste HTL		Biocrude upgrading	
	Carbon Efficiency	Thermal Efficiency	Carbon Efficiency	Thermal Efficiency
With NH3 Removal	65.5%	68.8%	83.2%	85.9%
Without NH3 Removal	67.5%	72.0%		

Natural Gas and Lime Drive GHG emissions for the HTL process



Preliminary LCA results for conversion steps only
(without avoided GHG emissions credits for sludge)

* CI of petroleum diesel: 90.5 gCO_2e/MJ



Process parameters significantly drive GHG emissions for the baseline case

HTL process to produce biocrude	**HT process** to upgrade biocrude
➢ NG for heat ➢ CaO and NG for NH3 removal step ➢ Electricity	➢ NG for H2 generation (via on-site SMR) ➢ Electricity

Decarbonization Strategies:

- Cut energy consumption
- Maximize product yield
- Replace fossil fuels with cleaner alternatives

Primary TEA Assumptions for Wet Waste HTL (2016$)

n^{th} Plant assumptions

The technology is well established. Several plants have already been built and are operating.

Financial Assumptions	Assumed Value
Internal rate of return	10%
Plant financing debt	60% of total capital investment
Plant financing equity	40% of total capital investment
Plant life	30 years
Income tax rate	35%
Interest rate for debt financing	8.0% annually
Term for debt financing	10 years
Working capital cost	5.0% of fixed capital investment (excluding land)
Depreciation schedule	7-years Modified Accelerated Cost Recovery System schedule
Construction period	3 years (32% 1st year, 60% 2nd year, 8% 3rd year)
Plant salvage value	No value
Startup time	6 months
Revenue and costs during startup	Revenue = 50% of normal Variable costs = 75% of normal Fixed costs = 100% of normal
On-stream factor	90% (330 operating days per year)

Fixed Operating Costs

Salaries	
Annual salaries	MM$ 1.63 (HTL), MM$ 4.39 (HTL)
Other Fixed Costs	Factor
Benefits and general overhead	90% of total annual salaries
Maintenance	3% of fixed capital investment
Insurance and taxes	0.7% of fixed capital investment

Feedstock Cost

No cost for WWT sludge (HTL plant is located on WWT site)

Natural Gas Price

	Feedstock	Cost Range ($/MM Btu)		
		min	**baseline**	max
RNG	Landfill Gas	$7.10	$13.05	$19.00
NG	Fossil		$3.22	

Electricity and Hydrogen Prices

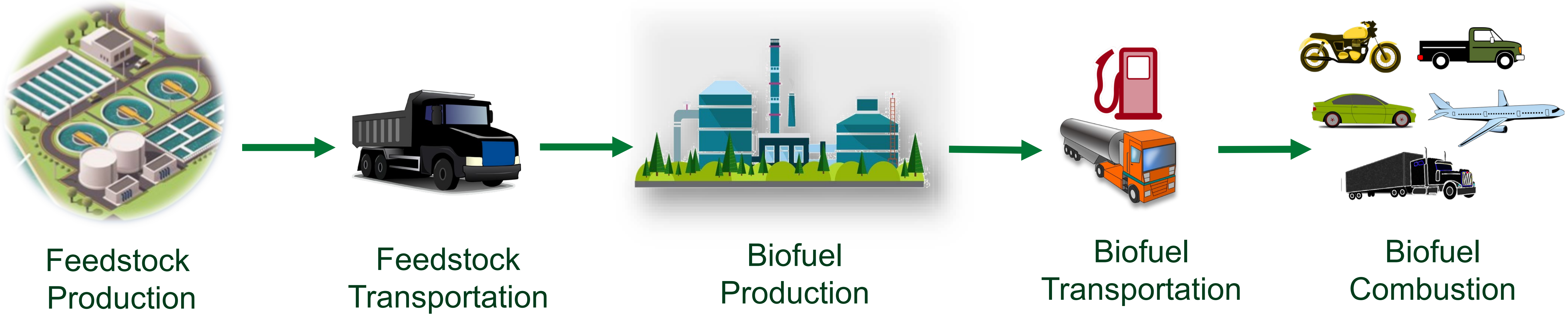
Resource	Min.	Baseline	Max.
Renewable Electricity ($/kWh)	$0.02	$0.068	$0.10
Grid Electricity ($/kWh)		$0.068	
Renewable H_2 ($/kg)	$1.38	$4.50	$6.35
Fossil H_2 ($/kg)		$1.57	

Life Cycle Analysis (LCA) of Biofuel

- Life cycle analysis (LCA) has been conducted to estimate “well-to-wheels” (WTW) GHG emissions.
- Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model developed by Argonne National Laboratory is used.
- GHG emission analysis results are presented in grams of CO_2-equivalent (CO_2-e) per MJ of fuel produced.

GREET LIFE-CYCLE MODEL

System boundary for biofuel LCA



Primary LCA Assumptions for Wet Waste HTL

LCA system boundary and key assumptions for fuel from HTL and HT processes

1,100 dry ton/day sludge
multiple WWT+HTL plants

38 MM gal/yr
biocrude

36.8 MM gal/yr (25% gasoline; 75% diesel)

Multiple WWT and HTL plants to produce biocrude via HTL

Biocrude Transportation

Biocrude Upgrading via HT

Renewable fuel Transportation and Distribution

Renewable fuel Combustion

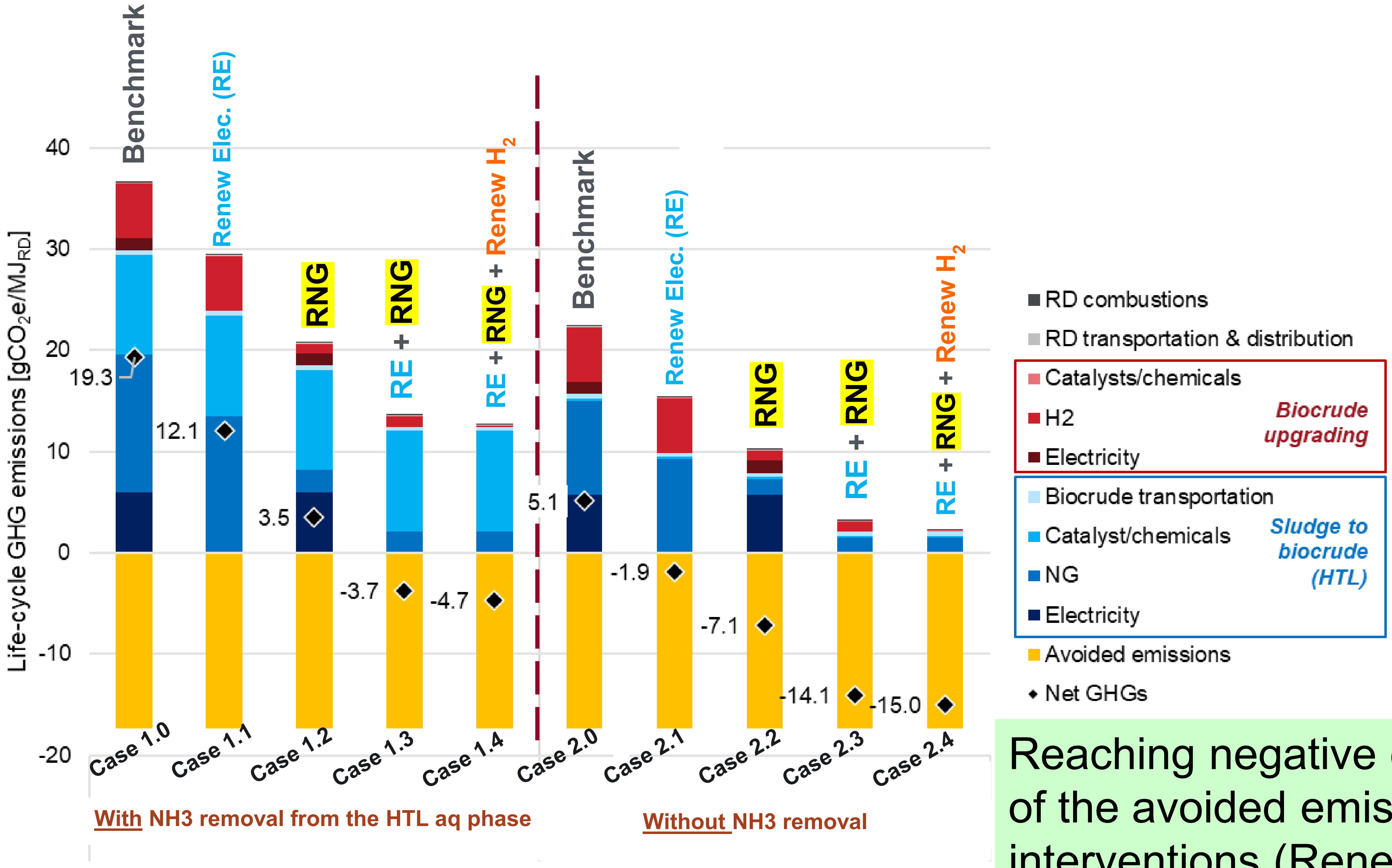
LCA key assumptions

- Emissions are accounted starting from collection/recovery not including upstream emissions for feedstock production.
- Using sludge leads to avoiding GHG emissions (-17 gCO_2e/MJ) from conventional sludge management practices

LCA key assumptions

	Conventional scenario	Renewable scenario
Electricity	U.S. grid mix (2020) 440 gCO_2e/kWh	Renewable electricity 0 gCO_2e/kWh
H_2	NG SMR (off-site, 50 miles) 79 gCO_2e/MJ	Electrolysis with renewable electricity 13 gCO_2e/MJ (off-site, 50 miles)
NG	Fossil NG 69 gCO_2e/MJ	Renewable natural gas from landfill gas 11 gCO_2e/MJ

LCA Results – Net negative carbon fuel achieved by renewable resources

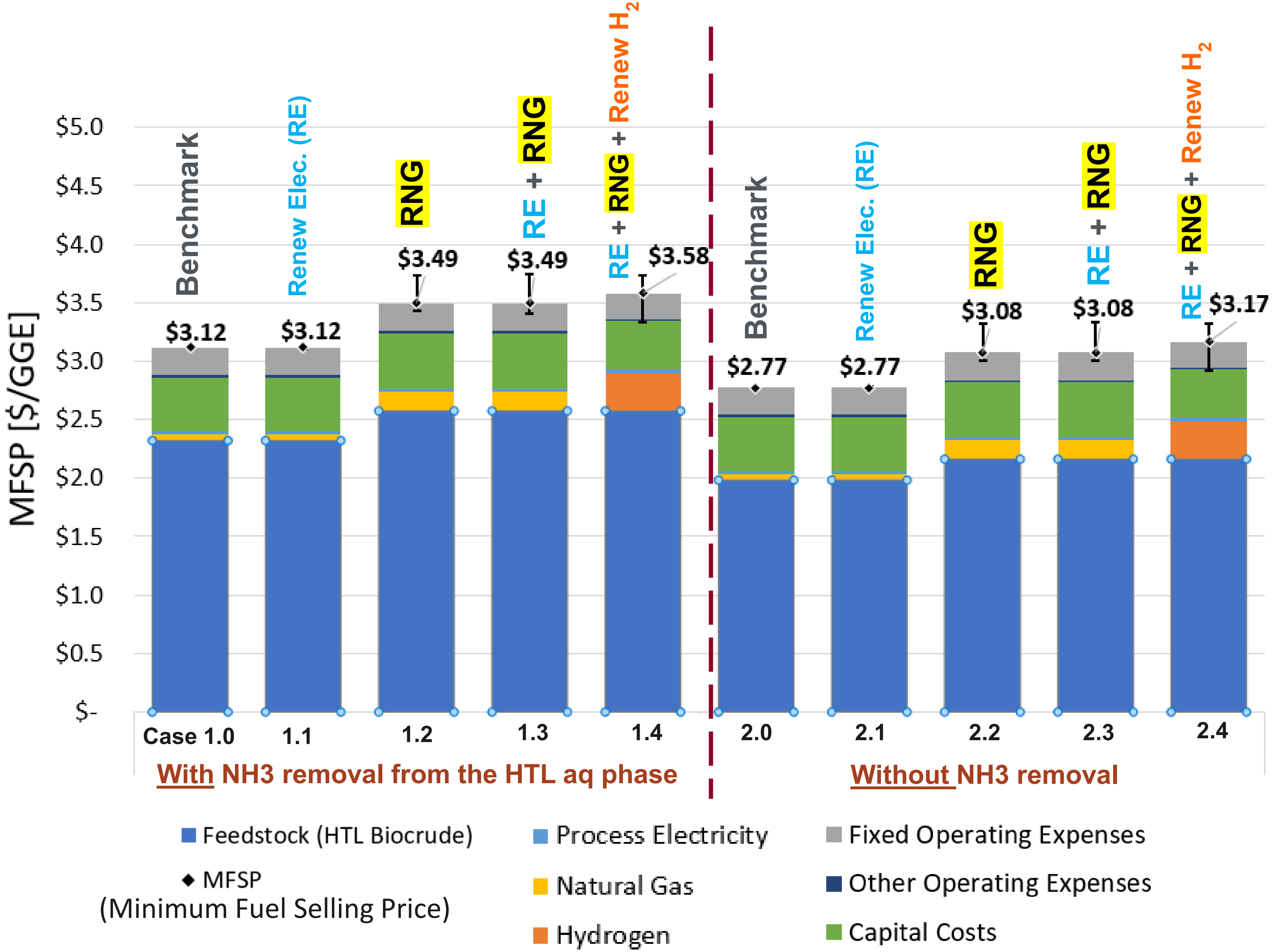


* CI of petroleum diesel: 90.5 gCO_2e/MJ

- LCA Benefits from using wastewater sludge biogenic carbon emissions are carbon neutral,
  - ➢ The biogenic carbon in sludge is carbon neutral when released into atmosphere as CO_2 emissions.
  - ➢ Avoiding GHG emissions (-17 gCO_2e/MJ) from conventional sludge management practices.
- The base case CI (Case 1.0) is 79% lower than conventional diesel

Reaching negative carbon fuels with the help of the avoided emission credit and renewable interventions (Renew Elec. RNG, Renew H2)

TEA Results – Renewable resource can be expensive



- Process economics are not significantly impacted by electricity cost.
- Natural gas cost is one of the largest operating costs in the wet waste HTL and biocrude upgrading pathway.
- RNG could increase the fuel production cost by 40 cents per gge.
- Renewable hydrogen could increase MFSP by 10 cents per gge.

Key Findings

Key findings - LCA

- Two advantages from an LCA perspective.

1. The biogenic carbon in sludge is carbon neutral when released into atmosphere as CO_2 emissions.
2. Using sludge leads to avoiding GHG emissions from conventional sludge management practices.

- Reaching negative carbon fuels with the help of avoided emissions and renewable resources (renewable electricity, RNG, renewable H2)

Key findings - TEA

- Process economics are not significantly impacted by renewable electricity
- RNG could increase the MFSP by at least 40 cents per gge.
- Renewable H2 could increase the MFSP by 10 cents per gge.

Step Forward – Year 3 analysis

Regional analysis and alternative renewable heat source (RNG can be fuel and is to valuable)

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Thank you

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