Biomass-Derived Liquid Fuels Via Fischer-Tropsch Process As a Potential Replacement for Marine Fuels

Eric C.D. Tan, Ph.D., LCACP

National Renewable Energy Laboratory (NREL), Golden, CO

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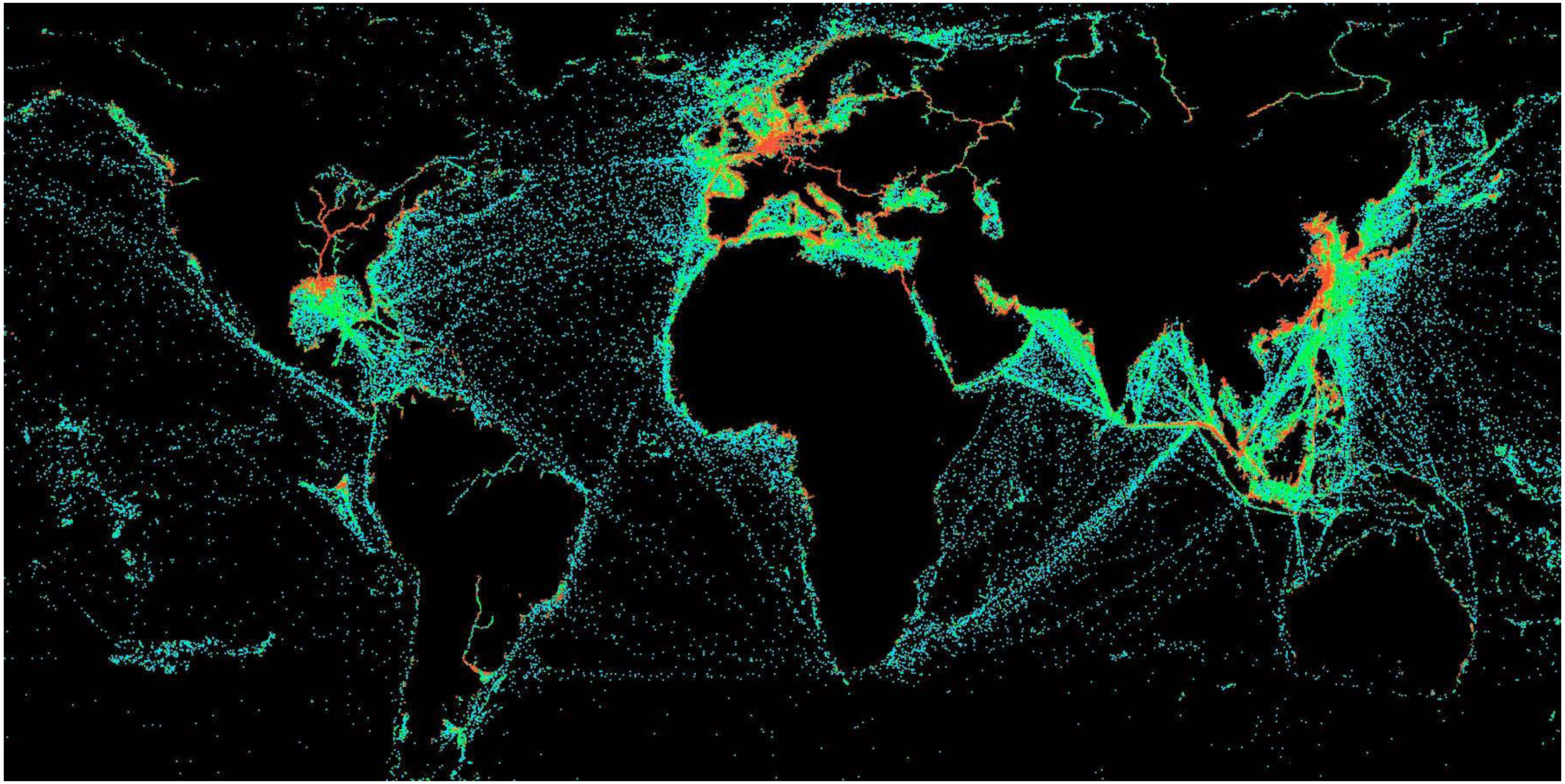
Disclaimer

Source: https://www.wired.com/story/new-satellites-will-use-radio-waves-to-spy-on-ships-and-planes/



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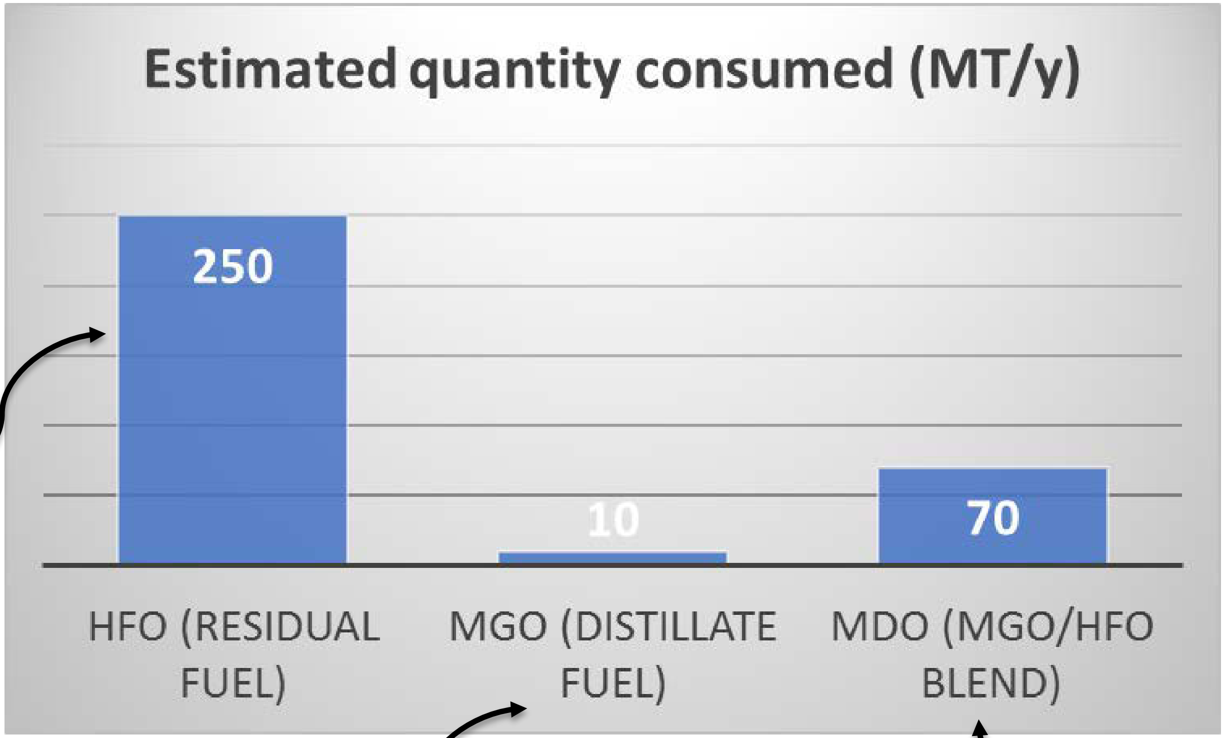
Marine shipping sector

Source: https://www.traveller.com.au/cruising-on-cargo-ships-how-to-be-a-passenger-on-a-cargo-ship-gl9muk

- One of the largest consumers of petroleum fuels, i.e., = one of the largest emitters of air pollutants
- Annual consumption: ~330 million metric tons (87 billion gal)
- > 90% world's shipped goods by marine vessels

Current marine fuels

Created with data obtained from https://info.ornl.gov/sites/publications/Files/pub120597.pdf



- Left over
- Account for ~76%
- Inexpensive
- Hi conc H2O & impurities
- Required heating
- $1.72/gal

- Lighter distillates
- Similar to diesel but > 100x sulfur
- $2.62/gal

- MGO-HFO blend
- Predominantly MGO, thus ~$2.62/gal

Challenges related to emission regulations

- Marine fuel – a significant contributor to air emissions of SOx, NOx, and PM.

http://mfame.guru/ship-emissions-monitoring-enforcement-human-health/

- The IMO has issued new rules that steeply cut the global limit on the sulfur content of marine fuel **from 3.5% to 0.5%** starting January 1, 2020.

- CARB and other state agencies have established regulations limiting the sulfur content of fuel used in coastal regions (known as emission control areas or ECAs) to **0.1%**.

- Beyond 2025, IMO has established a framework for reducing CO2 emissions per tonne-mile by 30%, and at least by 50% by 2050 compared with 2008 levels.

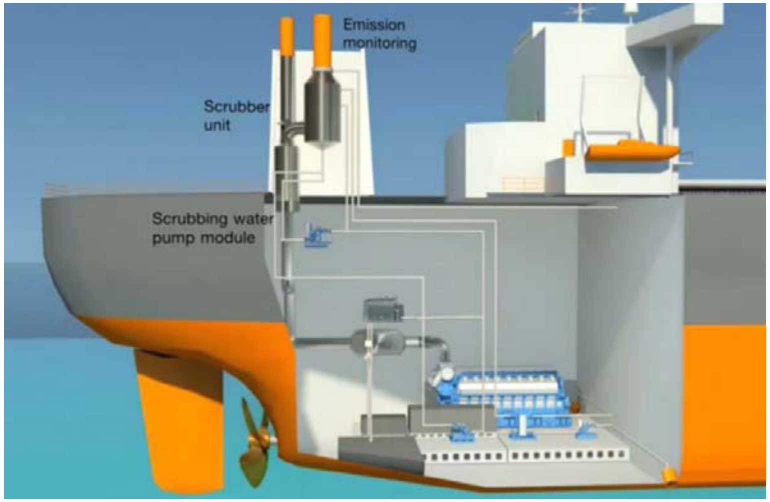
The reduced S content has required ship operators to shift their engines from lower cost bunker C heavy fuel oil to much costlier distillate fuels, such as diesel.

Options to comply with low-S regulations

❖ Ship owners and operators have two foreseeable alternatives to consider:

- Install **sulfur scrubber** on ships to reduce SOx emissions

- Switch to **low-sulfur content fuels**



Source: http://www.ikwangsung.com/dnv-gl-adds-scrubber-ready-class-notation/

Properties	Biodiesel	Diesel
Density at 20 °C (g/L)	0.874	0.836
Kinematic viscosity at 40 °C (mm^2/s)	5.19	2.73
Lower heating value (MJ/kg)	38.81	42.50
Flash point (°C)	160	64
Cloud point (°C)	1	7
Cetane index	49	53
Acid value (mg KOH/g)	1.762	0.032
Distillation range (90% °C)	354	338
Cold filter plugging point (°C)	0	3
Sulfur content (% mass)	0.014	0.048

Source: DOI: 10.1016/j.jtice.2013.06.021

Low-S fuel options

1. ***Low-S HFO***
   - ✓ Low-S price increase,
   - ✓ High-S price decrease due to lower demand --> favor the adoption of sulfur scrubbers

2. ***Low-S distillates (MGO, MDO)***
   - ✓ cost of MGO and MDO > HFO (2.62/gal vs. $1.72/gal)
   - ✓ with limited supply of distillate fuels, increased MGO demand --> increased diesel fuel prices worldwide

Low-S fuel options (continue)

3. ***LNG***
   - ✓ added costs of LNG storage infrastructure
   - ✓ low LNG prices help improve the economic challenges
   - ✓ limited range due to the lower energy content
   - ✓ currently limited infrastructure for LNG supply and distribution for use in marine vessels

Source: https://info.ornl.gov/sites/publications/Files/pub120597.pdf

4. ***Marine biofuels***
   - ✓ Biofuel candidates include:
   - ✓ (1) oxygenated biofuels, e.g., straight vegetable oil (SVO), biodiesel, fast pyrolysis bio-oil, and hydrothermal liquefaction (HTL) biocrude.
   - ✓ (2) hydrocarbon biofuels, e.g., renewable diesel, Fischer-Tropsch diesel, and fully upgraded (deoxygenated) bio-oil, and biocrude.
   - ✓ Significant uncertainty in quality requirements, scalability, properties, and blending issues.

https://www.nrel.gov/bioenergy/biomass-deconstruction-pretreatment.html

Low-S fuel options (continue)

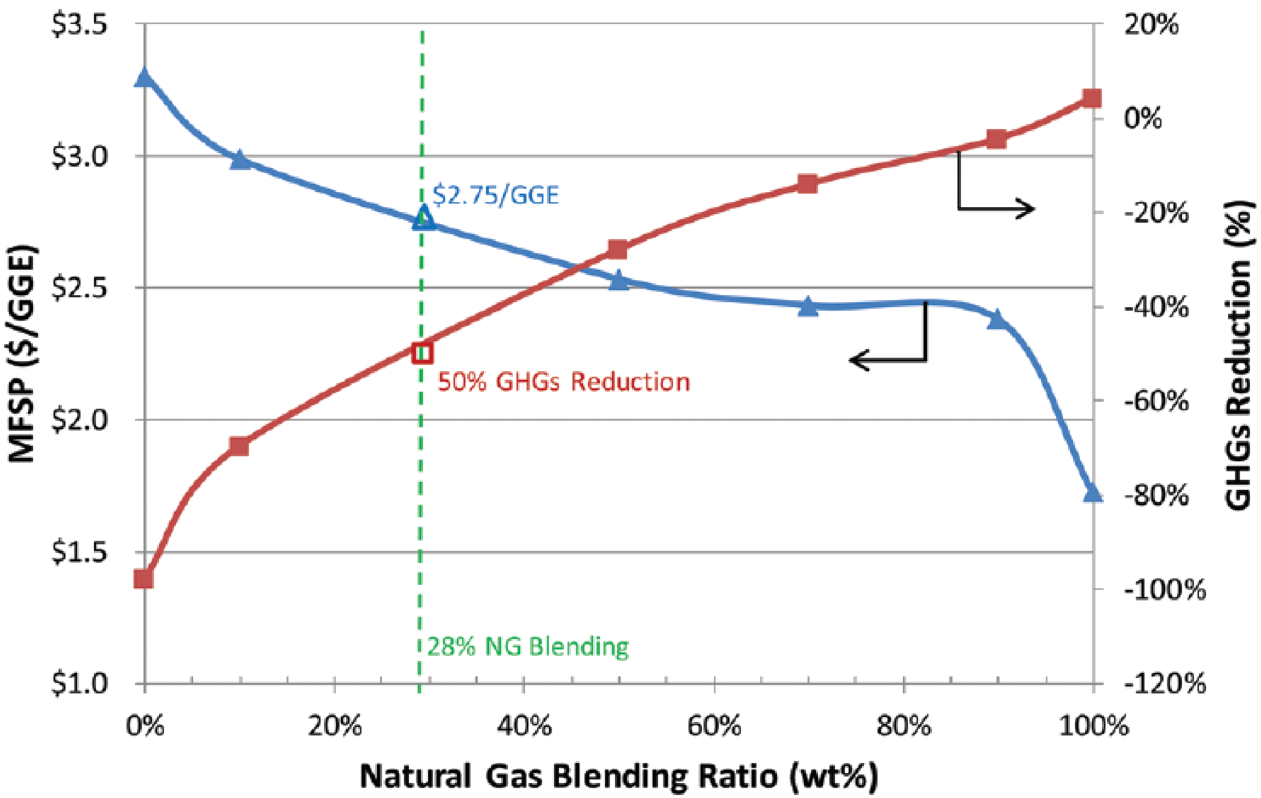
4. ***Marine biofuels***

- ✓ Significant uncertainty in quality requirements, scalability, properties, and blending issues
- ✓ Example, per ISO 8217:2010—FAME has **good ignition and lubricity** properties, but there is currently little experience with respect to storage, handling, treatment in a marine environment where potentially complications can arise such as:
  - Tendency to oxidation and long-term storage issues
  - Affinity to water and thereto linked risk of microbial growth
  - Degraded low-temperature flow properties
  - Deposition of FAME related material on filter elements and other exposed surfaces.
- ✓ Therefore, the ISO 8217:2010 standard has taken precautionary approach and limits the FAME content in marine fuels to a de minimis level (i.e., **0.1 vol%).**

Source: Chevron (2012), Everything You Need To Know About Marine Fuels

Biofuels offer potential synergistic benefits when blended with fossil fuels

Source: Zhang et al. Green Chem. 20, 5358-5373 (2018).



Co-feeding biomass with the fossil feedstock can be an effective synergistic approach to improve $ and GHGs

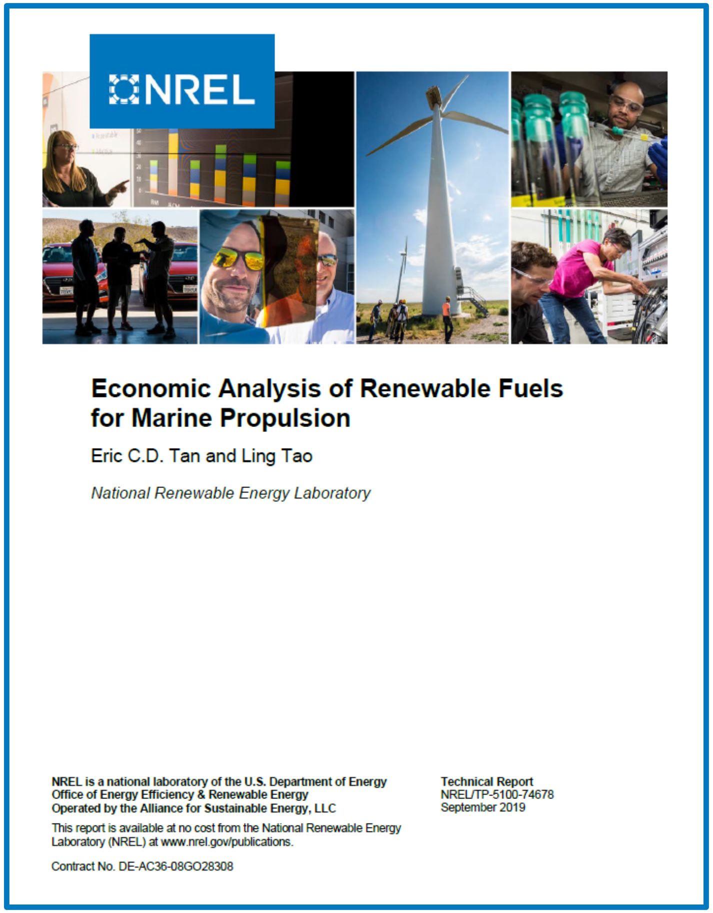
Economic assessment of selected biomass conversion pathways

Pathway 1: Syngas conversion via Fischer-Tropsch synthesis with a range of feedstock scenarios:

- **biomass only (BTL)**
- **natural gas only (GTL)**
- **biomass and coal co-feed (CBTL)**
- **biomass and natural gas co-feed (GBTL)**

Pathway 2: Conversion of extracted oils to marine fuels via hydrotreating. The feedstock options are:

- **yellow grease only (YG)**
- **yellow grease and heavy oil co-feed (YG+HO)**



NREL

Economic Analysis of Renewable Fuels for Marine Propulsion

Eric C.D. Tan and Ling Tao

National Renewable Energy Laboratory

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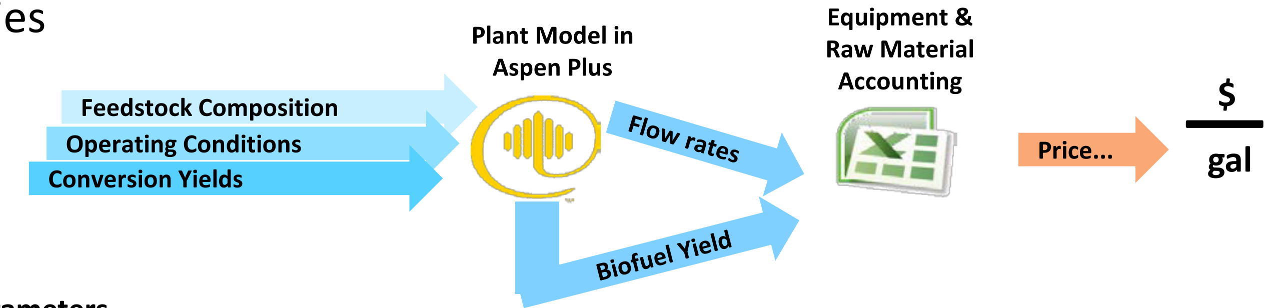
Technical Report
NREL/TP-5100-74678
September 2019

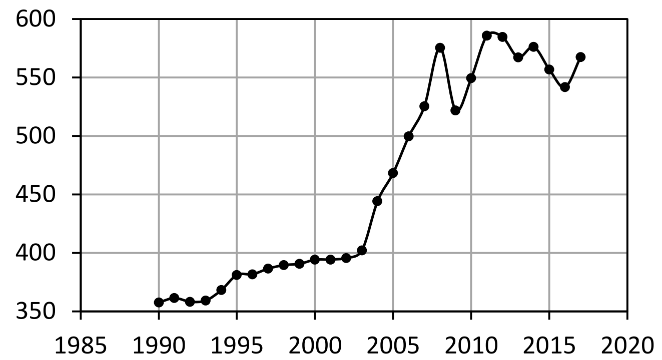
TEA Methodology & Assumptions

- Techno-economic analysis (TEA)
  - Assess the technical and economic viability of new processes and technologies



Discounted Cash Flow Analysis Parameters

Description of Assumption	Assumed Value
Cost year	2016 US dollars
Internal rate of return (IRR) on equity	10%
Plant financing by equity/debt	40%/60% of total capital investment
Plant life	30 years
Income tax rate	21%
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 purchase cost)
Depreciation schedule	7-year MACRS schedule[1]
Construction period (spending schedule)	3 years (8% Y1, 60% Y2, 32% Y3)
Plant salvage value	No value
Start-up time	6 months
Revenue and costs during startup	Revenue = 50% of normal Variable costs = 75% of normal Fixed costs = 100% of normal
On-stream percentage after startup	90% (7,884 operating hours per year)



$$Cost\ in\ 2016\$ = Base\ Cost\left(\frac{2016\ Cost\ Index\ Value}{Base\ Year\ Cost\ Index\ Value}\right)$$

$$Scaled\ Equip\ Cost = Base\ Equip\ Cost\ \left(\frac{Scaled\ Capacity}{Base\ Capacity}\right)^n$$

$$Total\ Installed\ Cost = f_{installation} * Total\ Purchased\ Equip\ Cost$$

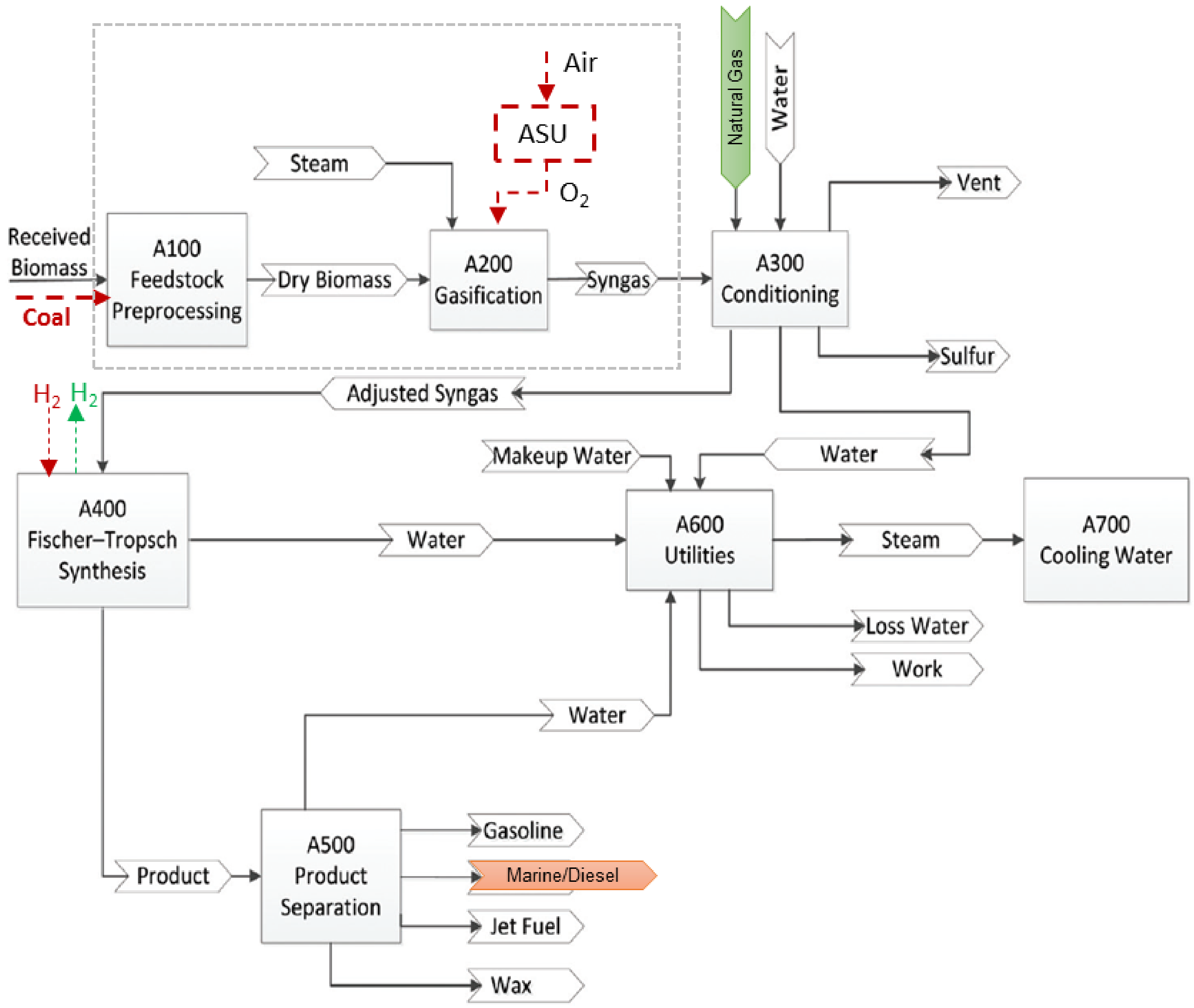
Economic assessment of selected biomass conversion pathways

Feedstock	Cost (2016$)	Unit
Woody biomass	60.58	$/dry ton
Bituminous coal	29.52	$/ton
Natural gas	0.13	$/lb
Yellow grease	0.28	$/lb
Heavy oil	0.26	$/lb

Feedstock		**Woody Biomass**	**Bituminous Coal**
Component		***Weight % (Dry Basis)***	
Carbon		49.81	74.55
Hydrogen		5.91	4.96
Nitrogen		0.17	1.59
Sulfur		0.09	2.44
Oxygen		41.02	6.84
Ash		3.00	9.66
Heating Value (Btu/lb)	HHV	8,449	13,326
	LHV	7,856	12,812

HHV: Higher Heating Value LHV: Lower Heating Value

Pathway 1: Syngas conversion via FT synthesis (BTL, GTL, CBTL, GBTL)



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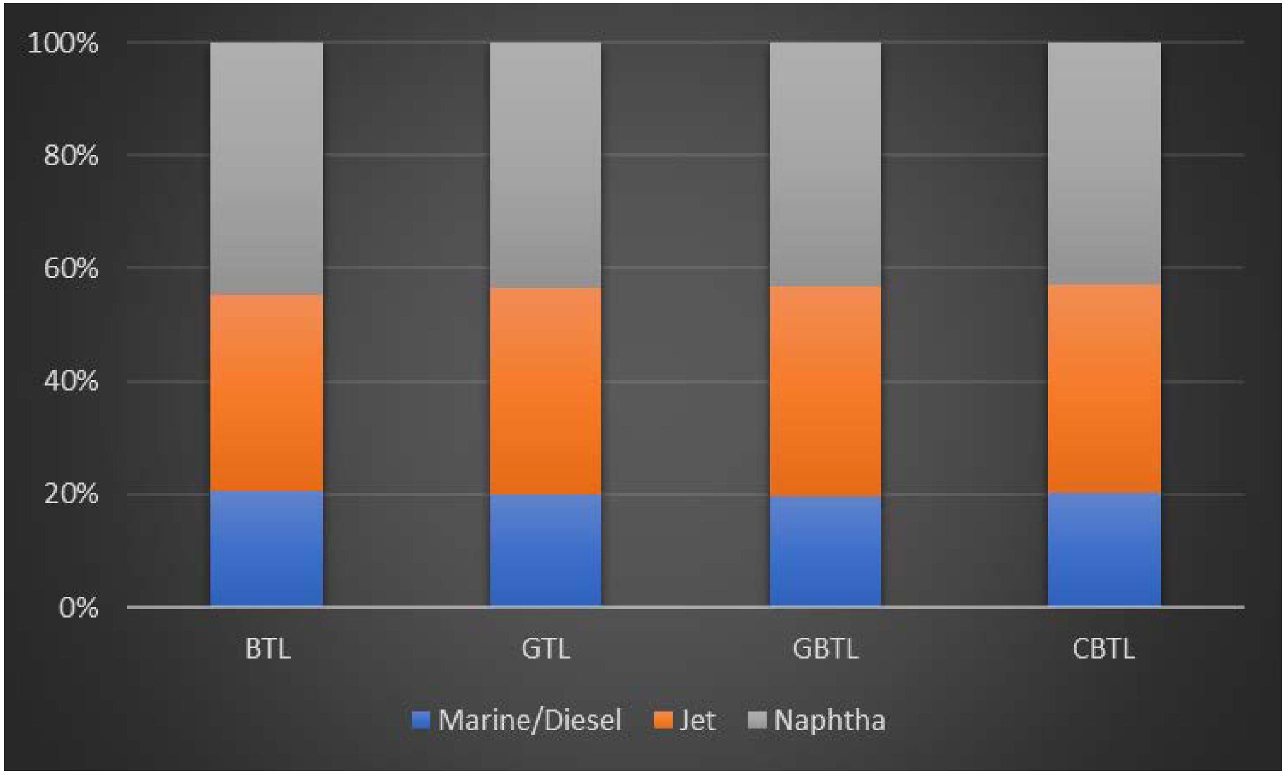
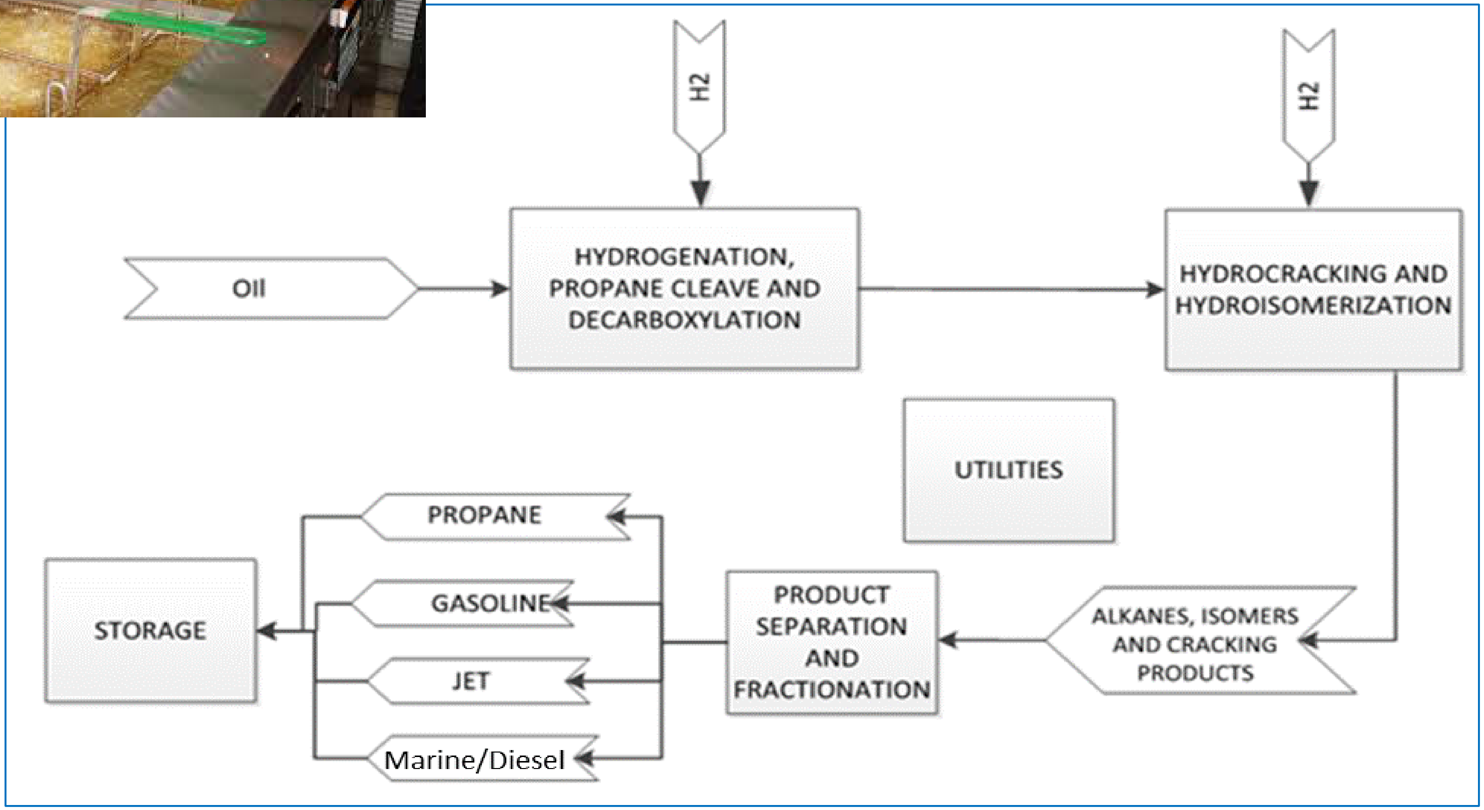


50 MM GGE/yr

Pathway 2: Conversion of extracted oils to marine fuels via hydrotreating (aka hydroprocessed esters and fatty acids or HEFA)

Source: https://mobile-cuisine.com/culinary-lessons/how-to-discard-your-food-trucks-used-cooking-oil/



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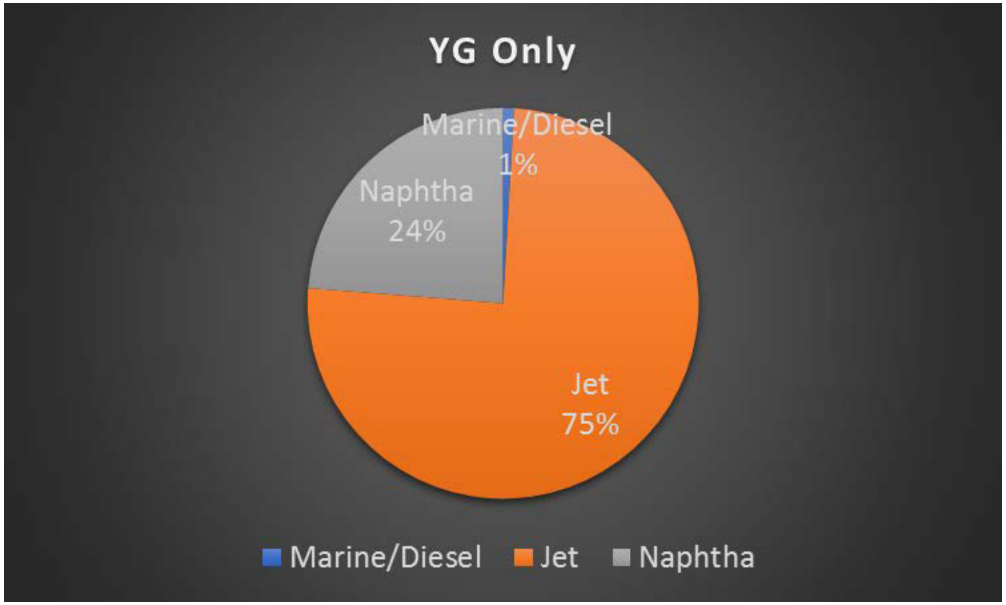

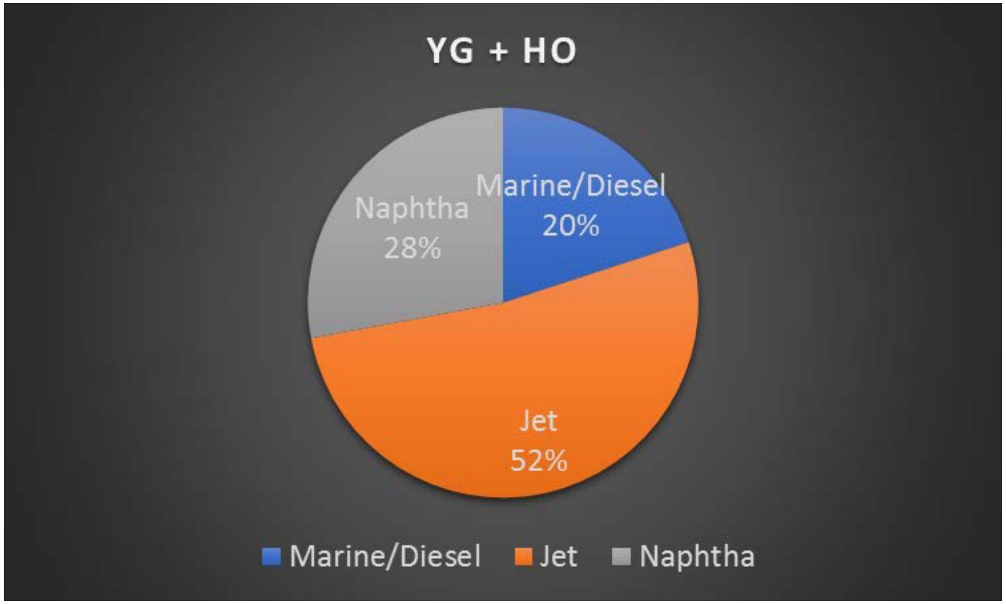

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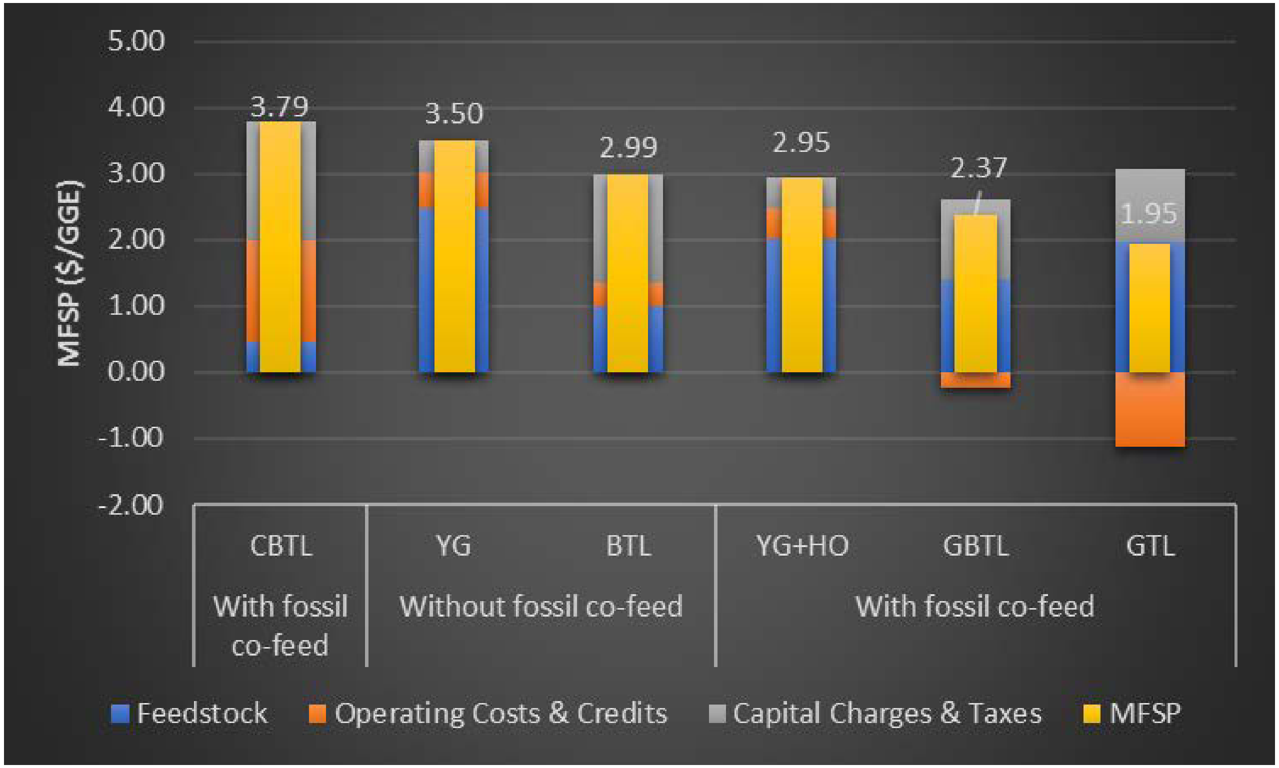
TEA Result Highlights



- GTL exhibits the lowest MFSP due to a combination of **favorable yields** and **lower operating costs**.
- CBTL has the highest MFSP, attributing to the higher capital expenditure associated with the **air separation unit** and the high-temperature **slagging gasifier**, as well as **hydrogen cost**.
- Cofeeding biomass with fossil feedstock (except coal) is an effective synergistic approach to improve liquid fuel yields while simultaneously lowering greenhouse gas (GHG) emissions.
- The current TEA evaluations will provide an important baseline analysis for the bio-economy and marine fuel industry.

Acknowledgements

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Speaker information:
Eric.Tan@nrel.gov
(303) 384-7933
http://www.nrel.gov/biomass

DOE's Bioenergy Technologies Office (BETO)
http://www.eere.energy.gov/biomass

DOT's Maritime Administration (MARAD)
https://maritime.dot.gov/